

# POWER PLANT ENGINEERING

Dipendra Kumar  
Manjunath H R



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**BOOKS ARCADE**

KRISHNA NAGAR, DELHI

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## CHAPTER 1

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### AN INTRODUCTION TO POWER PLANT

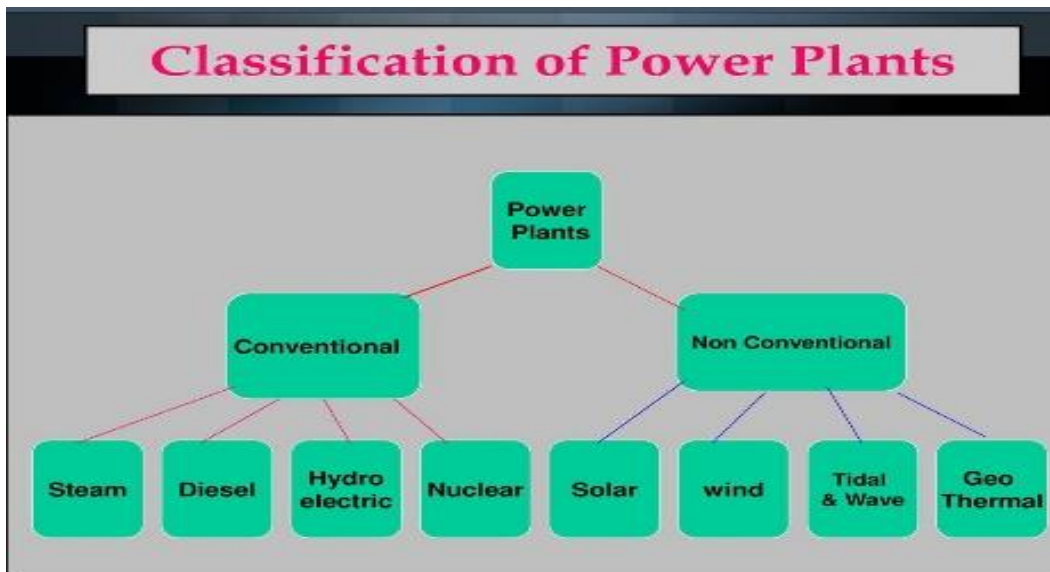
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The energy crisis that has gripped the whole globe is being exacerbated by pollution, which is presenting itself in rising energy prices, discomfort from pollution growth, and the depletion of traditional energy sources. One strategy for addressing these issues is to restrain the rise in energy consumption, but doing so would slow economic expansion in the first place. The second strategy is to create non-polluting energy conversion systems. It is widely acknowledged that as per capita energy consumption rises, so does the standard of life. Any analysis of the demand for and supply of energy must take increased conservation measures into account. It is important to emphasize how much work is being done to continuously cut energy usage in the industrial sector. Without having an impact on the economy as a whole, fundamental improvements to processes, products, and services may result in significant energy savings. It is unnecessary to underscore how much room there is for energy savings in household, commercial, and industrial usage. Due to the development of R-134a (and non-pollutant refrigerant) and the burgeoning field of environmental management, attempts to comprehend the integrated link between the environment and energy have taken form. Our exploration or commercialization of these are reflected in soil erosion, salutation, floods, but also rapid destruction of our forest, floral, and wild life resources. The government of India has established the policy that "it is imperative that designers carefully utilize with us renewal (i.e., non-decaying) resources of ground water, plant, and animal currently reside to sustain our economic development." Given that the majority of our population relies on these natural resources, the degradation of these resources frequently tends to be irreversible. Depletion of the natural resources, including those for shelter, food, and fuel.

#### Concept of Power Plant

A power plant is a collection of systems or subsystems that work together to create energy, or power that meets needs and is economical. The power plant itself has to benefit society economically and be environmentally sustainable. Both conventional and unconventional energy production are the focus of the current book. While conventional power systems place a lot of emphasis on energy efficiency, specifically increasing system conversion efficiency, the ultimate objective is to develop, design, and manufacture non-conventional power generating systems in the coming decades, preferably after 2050 AD, that are beneficial to society as well as having workable energy conversion efficiency and are not pollutant-friendly, keeping in mind the pollution act in Figure 1.1. The topic as a whole may alternatively be referred to as modern power plants for energy production in the twenty-first century. Modern refers to a period of time. Due to the current energy crisis, the first objective is to conserve energy for the future, and the second is to develop alternative energy systems, including immediate energy conversion devices, with a commitment, dedication, and determination, keeping in mind the adage "Delve and Delve Again until wade.





**Figure 1.1: Illustrates the classification of power plant.**

A machine or group of machines that produces and distributes a flow of mechanical or electrical energy may be referred to as a power plant. The generator is the primary piece of machinery used to produce electricity. The generator generates electricity when it is connected to a primary mover. The kind of power plants depends on the kind of primary move. The significant power plants covered in this book include:

- A. Plant that burns steam
- B. A diesel engine
- C. Turbine powered by gas
- D. Atomic power plant
- E. Water-based energy source

Because they transform heat into electric energy, the steam power plant, diesel power plant, gas turbine power plant, but also nuclear power plant are referred to as thermal power plants.

## Energy

The ability to produce labor, heat, and light is referred to as energy. The mass multiplied by gravity over the distance is the force in the equation for work. Heat has the power to alter an object's or a substance's phase's temperature. Heat may convert a solid into a liquid or even a liquid into a vapor, for instance. Energy includes heat in its definition. Radiation, which is defined as light and energy released in the form of waves moving at the speed of light, is another aspect of the concept of energy. Calorie, quadrillion, and joule units are used to quantify energy. The energy or heat needed to elevate 1 kilogram of water from 14.5°C to 15.5°C is measured in kilocalories. The quad unit is used to quantify the amount of energy required by large nations. Joules are the ultimate unit of energy measurement. Energy is a crucial component for advancing economic growth and enhancing quality of life. The amount of commercial energy used per person in India (coal, petroleum, and electricity) is just one-eighth of the global average, and this amount will rise as GDP and living standards rise. The majority of the energy used in the nation comes from commercial sources, with the remaining percentage coming from non-commercial sources such cow dung, fuel wood, and agricultural waste. Even while these non-commercial sources have a decreasing percentage of the market, since 1953, consumption has climbed by nearly twice as



much. These non-profit, renewable resources have been used for hundreds of years, albeit in a crude and ineffectual manner. Rural communities are experiencing an energy crisis as a result of the careless usage of non-commercial energy sources. The development and expedited use of renewable energy sources in urban and rural regions was emphasized in the Seventh Plan. In order to lessen reliance on oil, which is rapidly becoming limited, the government has made growing the use of coal in homes and electricity in the transportation sector one of its top priorities. The government has developed an energy strategy with the goals of guaranteeing enough energy supply at the lowest possible cost, attaining self-sufficiency in energy supplies, and safeguarding the environment from the negative effects of using energy resources carelessly. Accelerated domestic conventional energy resource exploitation of oil, coal, hydro, and nuclear power; Intensified exploration to boost domestic oil and gas production; Management of demand for oil as well as other forms of energy; Energy management and conservation; Optimum utilization of available capacity in the nation; Development and exploitation of renewable energy sources to meet the energy needs of rural communities. The government, namely the Department of Power, Coal, and Petroleum and Natural Gas, is in charge of developing conventional kinds of energy to fulfill the society's expanding energy demands at a fair cost. The Department of Non-Conventional Energy Sources, established in September 1982, is also giving consistent attention to the development and promotion of non-conventional/alternative/new and renewable sources of energy, including solar, wind, and bioenergy. The Department of Atomic Energy is preparing nuclear energy development to make a substantial contribution to the nation's total energy supply. The greatest attention is being placed on energy conservation, which is being utilized as a strategy to close the gap between supply and demand for energy. On April 10th, 1989, an independent organization called the Energy Management Center was established as the nodal agency for energy saving programs.

### **Types of Energy**

Energy may be classified into a number of different categories, including nuclear, electrical, thermal, chemical, and radiant energy. Additionally, kinetic energy and gravitational potential energy combine to create mechanical energy. Heat is produced by heat engines when nuclear energy creates heat via fission on nuclei. The greatest source of emission-free energy in the world is nuclear energy. Nuclear energy is produced via the fission and fusion processes. Atomic nuclei of uranium or plutonium separate during fission, releasing energy. When tiny nuclei join together or fuse, energy is produced in fusion. All currently operating nuclear power facilities employ the fission process since fusion can never be regulated. Steam engines are heated by nuclear energy. A nuclear power plant uses uranium as its fuel in a steam engine, and as a result, it has a poor efficiency. In modern world, the majority of households and industries run on electricity. Some items, such as flashlights and Game Boys, require power that is chemically stored in batteries. Other gadgets make use of power that comes from a wall socket or an electrical plug. Energy is conducted or transferred from one location to another through electricity.

The movement of energy is what creates electricity. Electrons are orbiting in atoms, some of which are just weakly connected. An electrical current is produced when electrons flow between the atoms of matter. Although it is kinetic and potential energy, thermal energy is linked to the arbitrary motion of atoms in an item. Thermal energy is the kinetic and potential energy related to this random microscopic motion. The seas of the planet contain a substantial quantity of thermal energy (heat). The seas take up as much heat from the sun each day as there is in 250 billion barrels of oil (Ocean Thermal Energy Conversion Systems). Chemical processes may provide energy in the form of chemical energy, which is produced via the oxidation process. Chemical energy is the potential energy that is released whenever a chemical reaction takes place. An excellent example is a car battery, as the chemical reaction creates the voltage and current needed to start the vehicle. During the photosynthesis process, a plant produces more chemical energy than it does water and

carbon dioxide. In scientific laboratories, chemical energy is employed to create electricity from gas and generate medicines.

There are many different wavelengths of radiant energy, ranging from radio waves with lengths of thousands of meters to gamma rays with lengths as small as a million-millionth (10<sup>-12</sup>) of a meter. Through the process of photosynthesis, radiant energy is transformed into chemical energy. Kinetic and potential energy are the next two forms of energy, and they work in tandem. The idea behind the word "energy" is that mechanical energy, which includes both potential and kinetic energy, is a single entity.

Every time a mass-containing item is in a force field, potential energy is present.  $PE = mgh$ , where PE is energy throughout joules, m is the object's mass, g is the gravitational acceleration, while h is the object's height, gives the potential energy of the object in this situation.

Motion is created by kinetic energy. A moving item possesses kinetic energy, whether it is moving vertically or horizontally. Vibrational kinetic energy the energy resulting from vibrational motion rotational kinetic energy the energy resulting from rotational motion and transnational kinetic energy the energy resulting from mobility from one site to another are three distinct types of kinetic energy. Kinetic energy's equation is  $\frac{1}{2}mv^2$ , where m stands for mass and v for velocity. This formula demonstrates how an object's kinetic energy is directly related to the square of its own speed.

### **Introduction to the Different Energy Sources**

There are primarily two categories of energy sources.

1. Traditional Energy Sources (Non-Renewable Sources of Energy)
2. Non-Traditional Energy Sources (Renewable Sources of Energy).

### **Conventional energy sources**

These supplies are limited and eventually run out. These sources cannot be refilled after they have been consumed. Coal, wood, oil, lignite, natural gas, fossil fuels, nuclear fuels, etc. are a few examples.

Examples include fossil fuels, nuclear power, and hydropower.

A priceless source of energy, fossil fuel is created when plants and animals that have been buried deep in the earth's crust for millions of years undergo chemical transformations without oxygen. This process results in the formation of fossil fuels including coal, petroleum, and natural gas. These energy sources are traditional ones. Energy sources including petroleum, natural gas, coal, and nuclear power are a few examples.

### **Radiant Power**

About 70% of India's electricity is produced by thermal means. Coal, furnace oil, and natural gas are the primary fuels used to generate thermal energy. Energy may be produced via the steam cycle, rankin cycle, or sterling cycle. Now, commercial-scale thermal power plants are using clean coal technology (with 10% ash content).

### **Thermal Power National Corporation (NTPC)**

It was established in November 1975 as a public sector enterprise with the primary goals of organizing, developing, and planning integrated thermal power development. NTPC projects have an installed capacity of 16000 MW.

## Non-Conventional Energy Sources

These resources are endless and are continually created by nature. Examples include wood, solar energy, biomass, geothermal energy, wind, tidal energy, nuclear fusion, gobar gas, and so on. Energy sources include solar energy, wind energy, geothermal energy, water from the ocean (such as tide and wave energy), and biomass (such as gobar gas). It is obvious that all fossil fuel-based energy sources have their supply limits and will eventually run out. Therefore, the only choice for long-term energy supply is non-conventional energy sources. For the foreseeable future of many hundreds of thousands of years, these resources remain inexhaustible. Non-conventional energy sources are those that are evergreen, continually provide energy, and do not exhaust with usage. Energy sources including sun, bio, wind, geothermal, wave, tidal, and OTE are a few example.

### Introduction to Various Non-Conventional(Renewable) Sources of Energy

The development of renewable energy is progressing in India. It has become a practical means of achieving the objective of sustainable development. The Indian renewable energy program, however, needs greater momentum right now. India now boasts the biggest program in the world for the deployment of renewable energy systems and goods, and the country's adoption of diverse renewable energy technologies has been aided by a number of legislative changes and financial incentives. In light of the risks to the environment presented by the over use of conventional fossil fuels, power production from non-conventional renewable sources has gained relevance. Renewable energy technologies have made electricity generating practical, but not so much as a replacement as a supplement to traditional power generation. At the moment, the installed generating capacity of renewables is over 3500 MW, or about 3.5 percent of the overall installed generating capacity of 1 lakh MW from all sources. A total of 1617 MW of this comes from wind energy alone, while 450 MW comes from biomass energy and 1438 MW from minor hydroelectric plants. During the Tenth Five Year Plan (2002-07) era, an additional 4000 MW of electricity from renewable sources is to be added, mostly via wind, biomass, small hydros, waste energy, and solar energy systems. India has also set a target to increase the proportion of renewable energy sources in power production to 10% of new capacity expansion, or 10,000 MW, by 2012.

The world's biggest decentralized solar energy program, second-largest biogas and improved stove programs, and fifth-largest wind energy program are all now being implemented in India. The development of a sizable manufacturing base in a number of renewable energy technologies has put India in a position to not only export innovations but also to provide technical assistance to other nations (Table 1.1).

**Table 1.1: Illustrates the non-conventional energy potential of power plants.**

Non-Conventional Energy Potential And Achievements		
Source/system	Potential	Achievements (as on 31-03-2002)
Biogas Plants	120 lakh	33 lakh
Improved Chulhas	1,200 lakh	350 lakh
Wind	45,000 MW	1,617 MW
Small hydro	15,000 MW	1,438 MW
Biomass Power	19,500 MW	391 MW

Biomass Gasifieres		51 MW
Solar PV	20 MW/Sq Km	85 MW
Waste-to-energy	1,700 MW	22 MW
Solar Water Heating	1,400 lakh sqm collector area	6 lakh sqm collector area

### Bio-Gas

The fuel biogas is excellent. In a biogas plant, biomass such as animal waste, vegetable waste, and weeds decompose without oxygen to produce a combination of gases. The biogas is this combination. Methane is the major component in it. This serves as fuel for lighting and cooking.

Process of Aerobic and Anaerobic Bioconversion for biomass energy applications, there are primarily three aerobic and anaerobic bio-conversion processes: the following

**Bio products:** The chemical transformation of biomass for the production of goods generally manufactured from petroleum.

Utilizing biomass to create liquid fuels for transportation.

**Bio power:** The direct burning of biomass or its transformation into an oil or gas fuel for the production of energy.

**Bio-based goods.** Biomass may be used to create any items that can be produced using fossil fuels. These bio products, also known as bio-based products, are produced from renewable resources and often use less energy than goods generated from petroleum. Researchers have found that the method for producing biofuels, which involves releasing the sugars found in plants' starch and cellulose, may also be utilized to produce antifreeze, plastics, glues, fake sweeteners, and toothpaste gel.

Carbon monoxide and hydrogen are additional crucial components for bioproducts. These two gases are created in large quantities during the heating of biomass when a modest quantity of oxygen is present. This combination is known scientifically as biosynthetic gas. Biosynthesis gas may be used to create polymers and acids, which can then be utilized to create synthetic fibers, photographic films, and textiles. Pyrolysis oil is created when biomass is cooked without oxygen. Pyrolysis oil may be used to extract the chemical phenol. Foam insulation, molded plastic, and wood adhesives are all produced using phenol.

**Biofuels.** Biomass, in contrast to other renewable energy sources, may be turned straight into liquid fuels, or biofuels. Regarding the necessity for transportation (cars, trucks, buses, airplanes, and trains). Ethanol and biodiesel are the two most widely used kinds of biofuels. A kind of alcohol, ethanol is also present in wine and beer. It is produced using a method akin to beer brewing in which any biomass rich in carbs (starches, sugars, or celluloses) is fermented. The main application of ethanol is as a gasoline additive to reduce carbon monoxide and other smog-producing emissions from vehicles. However, there are now flexible fuel cars on the market that operate on blends of gasoline and up to 85% ethanol. Alcohol (often methanol) with vegetable oil, animal fat, or used cooking greases are combined to create biodiesel. It may be used as a pure renewable alternative fuel for diesel engines or as an additive to lower car emissions (usually 20%).

Methanol and modified gasoline components are examples of additional biofuels. Methanol, often known as wood alcohol, is presently made from natural gas, although biomass might potentially be used. There are many methods for converting biomass to methanol, but gasification is the most

probable one. By first vaporizing the biomass at high temperatures, contaminants are removed, and the hot gas is then passed through a catalyst to be converted to methanol. The majority of biomass-derived components in reformulated gasoline are fuel additives that reduce pollutants, such as methyl tertiary butyl ether (MTBE) and ethyl tertiary butyl ether (ETBE). "Bio power." The utilization of biomass to produce energy is known as bio power or biomass power. Direct fired, co-firing, gasification, anaerobic digestion, pyrolysis, and compact, modular systems are the six main categories of bio power systems. Direct fired systems are used by the majority of biopower facilities worldwide. To generate steam, they directly burn bioenergy feedstocks. Typically, a turbine collects this steam, which a generator subsequently transforms into energy. The steam from the power plant is also utilized in certain businesses to heat buildings or run industrial operations. Combined heat and electricity facilities are what they are. For instance, paper mills often utilize wood waste to generate both steam and power.

Cofiring systems may be used by many coal-fired power stations to drastically cut emissions, especially sulfur dioxide emissions. High efficiency boilers that burn coal use bioenergy feedstocks as a supplemental energy source. High temperatures and an oxygen-starved atmosphere are used in gasification systems to turn biomass into gas (a mixture of hydrogen, carbon monoxide, and methane). The gas powers a device known as a gas turbine, which functions very similarly to a jet engine except that it spins an electric generator as opposed to propulsion for a jet. Methane, a gas that may be utilized as an energy source, is produced as biomass decomposes. Wells may be dug in landfills to release the methane produced by the decomposing organic material. The gas is then brought by pipelines from each well to a central location where it is cleaned and filtered before being burned. Anaerobic digestion is a method that may also create methane from biomass. In anaerobic digestion, microorganisms are used to break down organic material without oxygen. There are several methods to utilize methane as an energy source. To create steam for energy generation or industrial activities, most facilities burn it in a boiler. Fuel cells and microturbines are two brand-new methods. The output of a microturbine ranges from 25 to 500 kilowatts. They are space-efficient power generators that are about the size of a refrigerator and may be employed in tight spaces. A fuel cell may also utilize methane as its "fuel." As long as there is fuel available, fuel cells may produce power similarly to batteries but without the requirement for charging. Through a process known as pyrolysis, liquid fuels may also be created from biomass in addition to gas. When biomass is heated without oxygen, pyrolysis happens. The biomass is subsequently transformed into pyrolysis oil, a liquid that may be burnt like gasoline to produce energy. Pyrolysis oil-based bio-power technology is now being commercialized. The application of many bio-power technologies in compact, modular systems is possible. 5 megawatts or less of power are produced through a compact, modular system. This method is intended for usage at the consumer level or even at the level of small towns. For instance, some farmers generate power for their farms using the manure from their cattle. These devices not only provide renewable energy but also assist farmers and ranchers in adhering to environmental rules. The use of compact, modular systems as distributed energy resources is also a possibility. In order to enhance the performance of the electricity distribution system, a number of tiny, modular power producing technologies are referred to as distributed energy resources.

## **Utilization of Non-Conventional Energy Resources**

### **Graphic Files**

Anaerobic digestion in a biogas plant may produce biogas from any sort of organic waste that can solidify into a slurry. Incineration may be favored since producing wood and sugar biogases using this method is challenging and time-consuming. The availability of the trash determines the choice of source material (in feed). The biogas plant is designed to work with a certain kind of in feed.



## CONSTITUTION OF BIO GAS

- Biogas's primary characteristics are:
- Quite easy to make, and relatively straightforward.
- Burns cleanly, producing no smoke or ash as byproducts.
- It is possible to dispose of biowaste and household waste in a beneficial and healthy way.
- Lessens the need for wood and, to some measure, halts deforestation.
- Excellent manure may be made from the biogas plant's slurry.

## Technology of Bio Gas Plant

- The key components of a biogas plant are
- the tank where breakdown of biomass takes place (digester)
- the vessel where water and biomass are combined (mixing tank)
- the container used to collect biomass slurry (out flow tank)

Biogas is created in the plant as a result of the activity of bacteria when oxygen is not present. The tank holds the accumulated debris. As the gas fills the tank and the storage capacity grows in the gasholder type of plant, the cylinder rises higher. Dome type gas storage will be less than gasholder type gas storage. Slurry, a biomass residue, makes excellent manure. Small (0.5 m<sup>3</sup>/day) to extremely big (2500 m<sup>3</sup>/day) biogas plants may be created. The configurations range from basic too sophisticated as a result. Following are the primary categories under which biogas plants fall. Batch type vs continuous type

Both dome and drum types.

These kinds come in a variety of configurations.

### Constant Type

A continuous type biogas plant is supplied with biomass on a regular basis and continuously produces biogas. There are two kinds of continuous type biogas plants.

#### 1. Just one stage constant-flow biogas plant

Phase I (acid production) and Phase II (methanation) are carried out in the same chamber in such a plant without the need of a barrier. Such plants are basic, affordable, simple to run, and simple to regulate. In general, these plants are chosen for small and medium-sized biogas plants. Compared to two stage plants, single stage plants produce gas at a lower rate.

#### 2. States Biogas Plant of the Continuous Type

Phase-I (acid production) and Phase-II (methane formation) in such a plant happen in different chambers. Compared to the single stage plant, the plant generates more biogas in the allotted period. However, the procedure is intricate, and the facility is more expensive, labor-intensive, and difficult to maintain. For bigger biogas plant systems, a two stage plant is preferable.

### Type of Batch Biogas Plan

Batches of the infeed biomass are supplied, with a long gap between each successive batch. A single batch of biomass infeed is given enough digester retention time (30 to 50 days). The residue

is evacuated and the new charge is supplied when the digestion is finished. After feeding, the new biomass charge may be aerated or nitrogenated before the digester covers are shut to begin the digestion process. Following that, the digester produces biogas after 10 to 15 days. 30 to 50 days pass throughout the fermentation process.

**Important Features:** A batch type biogas plant may contain numerous digesters (reactors) that are fed in a sequential way and discharged in a sequential manner to acquire the output biogas constantly; it distributes gas sporadically and seldom; it may have these features. Batch type biogas plants require initial seeding to start the anaerobic fermentation and larger volume of the digester to accommodate large volume of a batch because they have longer digestion times and are therefore better suited for materials that are difficult for anaerobic digestion (such as harder, fibrous biomass). Because of the greater initial cost and relative complexity of operation and maintenance. Batch-type biomass plants require feeding that is well-organized and scheduled. Farmers in Europe like these plants. In India, these plants are not yet widely used.

### **Fixed-Type Digester with Dome**

The digester and gas-collector (gas dome) are contained in the same chamber in a fixed dome type digester biogas system. This design is appropriate for batch-style biogas plants. In a somewhat colder area, the digester is easily constructed at or below ground level. Bricks and terra-cotta, which are readily accessible locally, are used to build the digester. As the biogas is released, the pressure within the digester rises. In a hollow with a dome shape, the biogas is gathered in the digester's top section. The fixed dome's top has an outflow pipe available. The gas collector (also known as the gas holder) may also be a separate chamber that is fitted. A water seal tank separates the gas collecting chamber from the digester tank.

It is preferable to set up a separate gas collector since tapping gas from the gas holder has no negative effects on the pressure or digestion in the main digester. The water seal tank stops the gas from the gas collector from returning to the digester chamber. Due to gas pressure in the top dome of the fixed type digester, an extra displacement chamber may be built to accommodate the displacement slurry in the digester. Small amounts of the slurry may be fed to the fixed dome type digester each day. The displacement chamber serves as a storage space for the extra slurry in the digester. The volume and pressure of the biogas in the fixed kind of dome may affect the level of the slurry in the main digester and the displacement collector. Due to their connection to the main digester's exit, the fixed dome's and displacement gas collector's pressures are almost equal.

### **Wind energy**

Another possible energy source is wind energy. The uneven heating of the earth's surface by the sun and the earth's rotation are what generate winds, which are the movement of air. It develops as a result of a variety of global events, such as the "air-temperature difference" linked to varied rates of solar heating.

The surface of the planet absorbs the sun's energy differently according to its composition, which includes land, desert, water, and forest regions. Locally, the stark temperature differential between the land and the water is what causes the high winds. India has a wealth of wind resources. They are often found close to the seashores. According to estimates, it has a potential in India of 25 103 mW. According to a press release from the American Wind Energy Association, India had installed wind capacity of 1167 mW and produced 2.33 106 mWh of wind energy in 2000. 0.6 percent of all power is produced in this way.

Air over land warms up during the daytime more fast than air above water. Local winds are produced when the heavier, cooler air above a body of water rushes in to replace the expanding,



rising hot air over land. Due to the fact that air cools more quickly over land than it does over sea, the winds change at night. Similar to this, the earth's enormous air winds are caused by land around the equator being heated by the sun more than territory near the North and South Poles.

Today, power may be generated using wind energy. Since humans will always have access to wind, it is referred to as a renewable energy source. There are two main sources for winds, which are a natural phenomenon in the atmosphere. The daily rotation of the globe around its polar axis and the temperature disparity between the polar and equatorial regions are what create planetary winds. Local winds are brought on by uneven heating and cooling of lake and ocean ground surfaces during the day and night.

### **Fundamentals of Wind Machines**

Throughout time, humans have used wind power. Ancient Egyptians sailed their ships down the Nile River using wind power more than 5,000 years ago. Windmills were constructed later to grind grain. Persia has the oldest windmills that were recorded (the area now occupied by Iran). The first windmills resembled enormous paddle wheels. After many centuries, the Dutch developed the windmill. They made it able to be rotated to face the wind and gave it blades that resembled propellers. They have been used to mill grain or pump water. By the 17th century, Holland was among the most industrialized nations in the world because to windmills. A wind turbine, today's version of the windmill, can harness the power of the wind to produce electricity. Windmills were utilized by colonists in America to pump water, process grain, and chop lumber for sawmills. In the 20th century, residents in rural regions without electric service utilized windmills to produce power. Electric windmills were utilized less and less when power lines were installed in rural regions in the 1930s. Then, as a result of oil shortages in the early 1970s, there was a renewed interest in alternative energy sources, which helped bring back electric windmills to the American landscape. The wind turbine of today is considerably different from the windmill of the past. The usage and technology of the windmill have changed in tandem with the name change. Today's wind turbines are used largely to produce electricity, as opposed to yesterday's devices, which were used to grind grain or pump water by converting the kinetic energy of the wind into mechanical power. Today's wind machines still employ blades to capture the kinetic energy of the wind, much as traditional windmills did. Because they slow down the wind, windmills are effective. The airfoil-shaped blades are lifted by the wind as it passes over them, much as how aircraft wings are affected, which makes them revolve. The driving shaft, which the blades are a part of, rotates an electric generator to provide power. What to do when there is no wind is still a challenge for contemporary wind turbines. Large turbines are linked to the utility power grid; in the absence of wind, another form of generator takes over. Small turbines often contain batteries or connections to electric or diesel engines to store the additional energy they capture when the wind is blowing strongly.

### **Design of an aerofoil**

A wind turbine converts the wind's kinetic energy into rotational motion (or torque), which may be used to generate power. It could operate a generator or a water pump.

Because of the sun's uneven heating of an earth's surface and the earth's rotation, winds are the movement of air. The swept area of a turbine blades and the power output of both the turbine are directly correlated (see above). About  $1e15$  W is the estimated overall power capacity of a winds passing across the land. However, the total amount of usable wind energy is just  $2e13$  W.

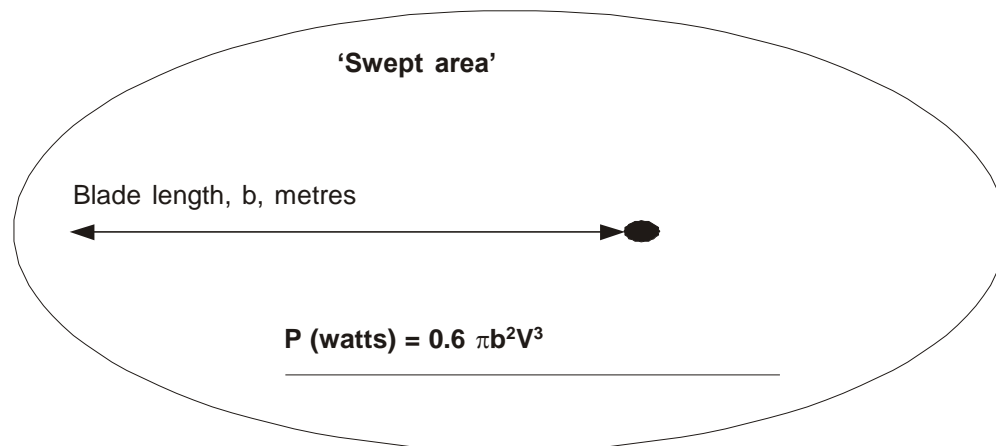
The theoretical wind power can be estimated as:

$$\text{Power density} = 0.6 k \cdot v^3 = 0.6 b^2 v^3$$

Where,  $k$  = Energy pattern factor (depends on type of wind)

$W$  = Wind density

$v$  = the average wind velocity



Large commercial wind turbines are unlikely to harvest more than 25% of the potential amount of energy that can be generated from the wind. Designs that are small and low-tech may only get 15%. However, the result of this equation is that the power output multiplies eight-fold as the wind speed doubles. Therefore, even slight changes in wind speed may result in significant increases in power production. Most wind turbines have a pre-designed maximum power output because extremely high wind speeds create significant quantities of energy and the equipment might otherwise tear itself apart. Large wind turbines with a rating of 150 kW or more are extremely sophisticated devices. To stop the turbine from escaping as the wind speed rises, all wind turbines must "feather" their blades, rotating them slightly out of the wind. The centripetal force may pull the blades off if this didn't take place. Large turbines, however, also use intricate automated gears that maintain the generator's rotation at the speed necessary for power production. The wind seldom blows nonstop. This indicates that the turbine's rated power will never be attained as a continuous output. About 30% of a turbine's rated capacity is typically produced continuously. As a result, in order to compare wind turbines to continuous power sources, you must multiply the continuous capacity by 3.33 in order to determine how much wind turbine capacity is needed to provide the same amount of electricity. For instance, 3,333 mW of wind power would be needed to provide the same amount of electricity on average as a 1,000 mW coal-fired power plant. There is currently no effective method of large-scale power storage that would enable the varying output of wind turbines to be balanced out over time. The usage of reversible hydrogen fuel cells, which can create hydrogen to store energy and then utilize it to generate electricity at other times when the production of wind turbines is low, may become a possibility in the future. The tower that holds up the wind turbine's blades has to be taller as the wind turbine becomes bigger. The purpose of this is more than just to keep the blades off the ground. The wind becomes quicker and more even as you ascend from the earth, giving you additional strength. Thus, the size of turbines rises along with their power production. The strength of the materials used to construct a wind turbine is the sole limitation on its size. This is a challenging technical challenge since the turbine must be light enough to spin in a gentle breeze but the building must be sturdy enough to withstand heavy gusts.

### Forces affecting the Blades

A propeller-type wind turbine's blades are under the control of two different kinds of forces. The torque is produced by circumferential forces acting in the direction of wheel rotation, and the axial

forces acting in the direction of the wind stream produce an axial thrust that has to be balanced by appropriate mechanical design.

### **Systems for Wind Power**

To appreciate the wind, you often stand in a wide open area. You are aware of the source of wind. Wind is moving air. The wind possesses kinetic energy because it moves with velocity. This is the wind's energy. We'll examine the potential for generating electricity using the kinetic energy of the wind. We can utilize windmills for it. Wind-powered machinery includes windmills. We'll investigate how windmills use the kinetic energy of the wind. We'll investigate how a windmill operates. The crucial component of a windmill is a big leafy structure connected to the top of a tall tower. Just as efficient as coal-fired power plants are wind turbines. Wind farms produce electricity by converting 30% of the kinetic energy of the wind. About 30-35 percent of the thermal energy in coal is converted into electricity in coal-fired power plants. Wind power plants lag behind other power plants due to their capacity factor. The capacity of a facility to create energy is referred to as the capacity factor. A facility that could operate at full capacity would do so 24 hours a day, seven days a week. No maintenance or refueling would be required, which is an impossibility for any facility. Because wind turbines only operate when the wind is blowing at least nine miles per hour, wind farms only operate at around a quarter of their theoretical capacity. In contrast, since coal plants can operate day or night, all year round, they generally have a 75 percent capacity rating. 275–500 thousand kilowatt-hours (kWh) of power may be generated annually by a single wind turbine. About 50 households might use that much power each year. About three billion kWh of electricity are produced annually in this nation by wind turbines. A negligible 0.12% of the country's power is produced from wind energy.

However, there is still enough energy to power almost 300,000 homes, which is equivalent to the population of San Francisco or Washington, D.C. More wind energy is generated in California than in any other state in the USA. In the US, 98 percent of the wind-generated power is produced there. In California, 16,000 wind turbines provide more than 1% of the state's power. (This generates roughly half the amount of energy that one nuclear power plant does.) Five percent of California's power might be generated by wind turbines in the next fifteen years. The world's largest generator of wind energy is the United States. About half of the world's wind energy comes from the United States. Denmark, Japan, Germany, Sweden, The Netherlands, United Kingdom, and Italy are more nations that have made significant investments in the study of wind energy. Within the next 30 years, according to the American Wind Energy Association (AWEA), wind energy might provide more than 10% of the country's power. Wind power may therefore play a significant role in alternative energy sources in the future, but it won't be the only solution to our energy issues. To fulfill the rising demand for power, we will still need alternative energy sources.

### **Economic Concerns**

There is a lot of positive news for wind energy on the economic front. First off, building a wind farm is far less costly than building a traditional electricity plant. As the need for power grows, wind farms can easily install more wind turbines. Second, during the last 20 years, the cost of generating power from wind has significantly decreased.

In 1975, the cost of a kWh of wind-generated electricity was 30 cents; now, the cost is less than 5 cents. New coal-fired power plants, in contrast, cost four cents per kWh to generate energy. Oil shocks and shortages in the 1970s and 1980s drove the creation of alternate energy sources. The drive in the 1990s can originate from something else, such a resurgence of environmental awareness. Efficiency and capacity factor will be used to discuss how wind energy is produced. Efficiency is the amount of useable energy (such as electricity) that may be obtained from a given energy source. A machine that was 100 percent energy efficient would convert all of the energy

used to power it into usable energy. There wouldn't be any energy wastage. (You should be aware that there is no machine that is completely energy efficient. When one source of energy is used, some energy is always "lost" or "wasted.")

### **Recently occurring events**

For the low wind speed locations of the plains, current windmill technology is insufficient. In order to utilise wind energy in the low wind speed zones, special development initiatives must be undertaken in the following areas.

**Synthetic Winds.** It is theoretically possible to create fake winds to power windmills by heating vast surfaces with advantageous thermodynamic qualities. To heat a sizable area, a project report has been created, and the current that results (artificial wind) may power turbines. The project will need a significant amount of time, money, and labor to complete.

**Aero electric Power Plant** The usage of diffusers at wind turbine intakes may increase the low wind velocity in the plains. There have been many other wind turbine designs throughout the years in addition to the propellers, Madaras, and Darrieus. The aero electric plant, a fascinating power plant concept, employs the flow up a tower that resembles a cooling tower, as seen in Fig. Solar heat is used to warm its walls.

The sun's rays do not need to be followed as it moves around the sky during the day since the walls are circular. In turn, the heated walls heat the inside air, creating a flow up the tower. A number of air turbines are positioned close to the top of the tower and are driven by this air flow. The well-known chimney effect provides the propelling pressure that causes air movement. In a somewhat modified version, Carlson of California has suggested cooling the inside air of a very tall tower by pumping water to the top. There is a downward flow of cooled air as a result of the water evaporating in the low pressure environment. Calculating the driving pressure is equivalent to doing so for wet cooling towers. Such a plant's proposed design planned for a 300 m in diameter, 2.4 km high tower in a scorching desert, with 10 wind turbines at the foot of the tower generating 2500 MW.

### **Solar Energy**

The great majority of the energy we consume on earth comes from the sun. While most of the energy we consume has undergone many changes before being used, it is also feasible to capture solar energy as it enters the earth's atmosphere. The direct use of solar thermal energy has several uses, including crop drying, room heating and cooling, water heating, and solar cooking. It is a technique that is well-known and extensively used in a variety of nations throughout the globe. The majority of solar thermal technologies have a well-established industrial base in the majority of sun-rich developed nations and have been there in one form or another for millennia. Domestic water heating is the most typical use for solar thermal technology. Worldwide, there are hundreds of thousands of household hot water systems in operation, particularly in regions with high solar insulation, like the Mediterranean and Australia (the total energy per unit area received from the sun). It is a technology that is quickly gaining recognition as an energy-saving strategy in both home and commercial water heating applications due to fluctuations in the price of oil throughout the globe. At this time, domestic water heaters are mostly exclusively seen in emerging nations' affluent neighborhoods. There are other technologies that make use of the solar energy that is available for free. Technologies that actively use solar energy to heat water are known as active solar technologies, whereas those that passively use solar energy to cool or heat spaces while having no moving parts are known as passive solar technologies. There are more advanced solar technologies available for generating energy. Later on in this information sheet, we shall take a quick look at them.

### **Solar radiation that is both direct and diffuse**

We may get energy in many different sources thanks to the sun. Do you know how the sun generates energy? Hydrogen is the element that the sun has the most of. The condition of it is plasma. When this hydrogen undergoes nuclear fusion at a high temperature, high pressure, and high density, a large quantity of energy is released. This energy radiates out throughout the electromagnetic spectrum in a variety of ways. Gamma rays and the majority of UV rays from these X-rays do not penetrate through the earth's atmosphere. However, the primary radiations that reach the planet are heat and light energy.

The existence of life on earth depends on this energy. With a diameter of  $1.39 \times 10^9$  meters and a distance from earth of  $1.5 \times 10^{11}$  meters, the sun is a sphere of very hot gaseous substance. Sun has a temperature range of  $8 \times 10^6$  K to  $40 \times 10^6$  K with an effective black body temperature of 5762 K. Helium is created by the constant fusion of hydrogen (4 protons) in the sun (one He nucleus). Since mass was lost in the reaction and turned into energy, the mass of the He nucleus is less than that of the four protons. The solar constant, which has a value of  $1353 \text{ Wm}^{-2}$ , is the energy received from the sun on a unit area perpendicular to the direction of radiation propagation outside the atmosphere. When it hits the planet, this radiation has a fluctuating average value of  $1100 \text{ Wm}^{-2}$ . 0.29 to 2.5 micrometers is the wavelength range. Through both natural and artificial processes, this energy is often transformed into the conventional energy type. Wind and biomass are examples of natural processes. Heat and electricity conversion are examples of man-made processes.

### **Solar Radio Fields**

Diffuse radiation is the result of the sun's radiation entering the earth's atmosphere being dispersed by air gas molecules and dust particles and reaching the planet from all directions. Beam or direct radiation is the part of solar energy that reaches the earth without altering its original quality. With the sun slightly off-center of the circle, the earth circles around it in a roughly round course. At the time of the winter solstice, when the North Pole is inclined 23.5 degrees away from the sun, the earth's axis of rotation is slanted 23.5 degrees with regard to its axis of revolution around the sun. North of 66.5 N latitude, the whole surface of the planet is completely dark, but south of 23.5 N latitude, all areas are continuously lit by the sun.

The scenario is inverted on the summer solstice. Somewhere at time of the two equinoxes, the sun is equally far from both poles, and there are 12 hours of daylight and 12 hours total darkness everywhere on the surface of the globe. At the time of equinoxes, the sun's beam that passes through the center of the earth is on the equatorial plane. The rays are north of the equatorial line from the spring equinox towards the autumnal equinox.

The rays are south of the equatorial plane from the fall equinox to the vernal equinox. The equatorial plane is where the sun's rays generally point throughout the year. A solar collector in the northern hemisphere should be angled and facing straight south in order to capture the most solar energy possible throughout the year.

The types and sources of solar radiation. At its peak power density, solar radiation strikes the surface of the planet at a rate of around 1 kilowatt per square meter ( $\text{kWm}^{-2}$ ). The amount of useful radiation varies based on factors including geographic location, cloud cover, daily sunshine hours, etc. The solar flux density (also known as power density) ranges in reality between 250 and 2500 kilowatt hours per square meter per year ( $\text{kWhm}^{-2}$  per year).

The equator, particularly in bright, arid regions, experiences the greatest levels of total solar radiation, as could be predicted. A straight beam of solar energy enters the outer atmosphere of the planet. After then, clouds, smog, dust, or other atmospheric phenomena partly disperse this light.



Therefore, depending on the air conditions, we may get solar energy as direct radiation, scattered radiation, or diffuse radiation. The main difference between the direct and diffuse constituents of radiation would be that diffuse radiation cannot be focused for utilization. Short wave radiation from the sun's rays reaches the surface of the planet. The sun's energy is ultimately reflected back into deep space; otherwise, the earth's temperature would be perpetually rising. Long-wave radiation is used to disperse this heat away from the planet. The technique of catching the short wave radiation and preventing it from being reradiated straight to the atmosphere is the foundation of the art of drawing energy from the solar energy source. To do this, glass and other picky surfaces are employed. Glass has the capacity to transmit short wave radiation while blocking the long wave radiation that would otherwise emit heat. A liquid or solid with such a high thermal mass is used to store the trapped heat. This is the fluid that passes through the collector in a water heating system, while in a building, the thermal mass is represented by the walls. Sometimes people store heat for the winter in lakes or pools.

### **Thermal Solar Power Plant**

Solar energy is utilized in the solar power plant to produce electricity. Concave reflectors are used to direct sunlight onto copper tubes that are filled with water but also painted black outside. The tubes' water subsequently boils and turns into steam. The generator operates as a result of the steam being utilized to power the steam turbine. In Gurgaon, Haryana, a plant using this idea is operating on an experimental basis. It has a 500 kilowatt capacity. In Rajasthan's Jodhpur, a second facility of a comparable sort is now being built.

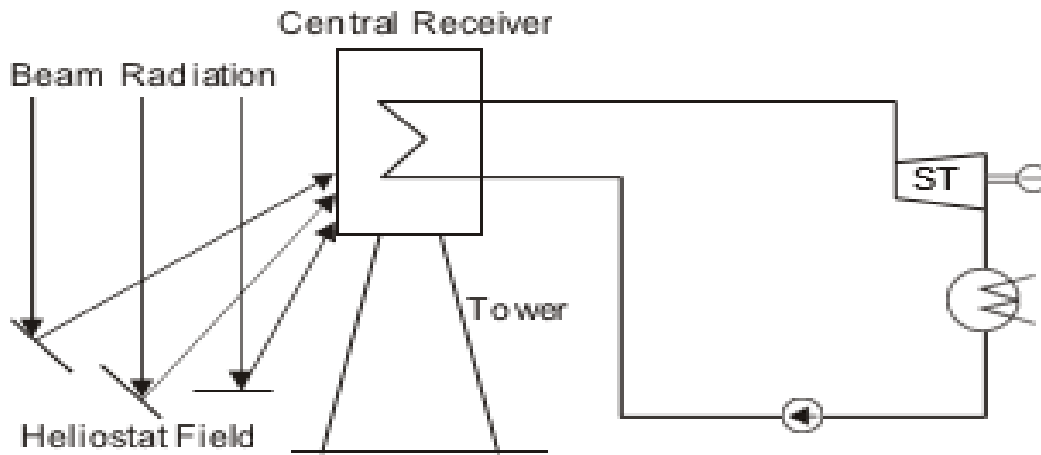
Fossil fuels are a common heat source used by power plants nowadays to boil water. A sizable turbine is turned by the steam from the boiling water, and this turbine then drives a generator to generate power. A new generation of power plants, however, employs the sun as a heat source and has concentrating solar power systems. Concentrating solar power systems come in three primary varieties: parabolic-trough, dish/engine, and power tower.

The sun's energy is concentrated by long, rectangular, curved (U-shaped) mirrors in parabolic-trough systems. A pipe that runs through the middle of the trough is illuminated by sunlight because the mirrors are oriented toward the sun. Through the pipe, the oil is heated as a result. The water is then brought to a boil in a typical steam generator using the heated oil, which generates power.

A mirrored dish is used in a dish/engine system (similar to a very large satellite dish). The sun's heat is concentrated and collected by the dish-shaped surface onto a receiver, which then absorbs it and transmits it to fluid within the engine. To generate mechanical power, the fluid expands in response to pressure from a piston or turbine due to heat. A generator or alternator is then powered by the mechanical energy to generate electricity.

In a power tower system, sunlight is focused onto a receiver at the top of a tower using a vast field of mirrors. As molten salt passes through the receiver, this warms it. A normal steam generator is then utilized to produce power using the heat from the salt. Since molten salt effectively holds onto heat, it may be kept for days before being used to generate power. This implies that power may be generated even on overcast days or many hours after sunset.

**Power Plant with a Solar Power Tower** The first is the "Solar Power Tower" concept, which focuses and directs solar energy onto a boiler at the top of a tower using thousands of heliostats or sun-tracking reflectors Figure 1.2. The boiler's interior temperature increases to between 500 and 7000 °C, and the steam produced may be utilized to power a turbine that generates energy. Also known as central receiver solar power facilities.



**Figure 1.2: Illustrates the Solar Power Tower.**

### Solar power plant for central receiver

A heliostat field is made up of a lot of flat mirrors that range in size from 25 to 150 m<sup>2</sup> and reflect beam radiation onto such a central receiver that is situated on a tower. On two axes, each mirror is tracked. The temperature of the absorber surface ranges from 400 to 1000 °C. The entire mirror area divided by that of the receiver area yields a concentration ratio of up to 1500. As a working fluid, you may utilize steam, air, or liquid metal. For the traditional steam power plant, steam is raised.

### Power Plant for Distributed (Parabolic) Collector Systems.

The distributed collector system is the second kind. Due to the interconnection of many solar modules made up of parabolic trough solar collectors, it is also known as a solar farm power plant. This system makes use of a number of uniquely created "Trough" collectors that have an absorber tube along the length of them.

These collectors are connected in large arrays to supply high temperature water for a steam turbine's drive. Such power plants are limited to locations with enough solar insulation while having the capacity to generate several megawatts (mW) of energy.

Solar-powered chimney. The clear cover and sun radiation that is absorbed by the ground heat the air stream. Due to the pressure drop brought on by the chimney effect, the hot air flow through our chimney causes the air to move at a certain velocity. To produce electricity, the heated air passes through an air turbine.

### Storage of Solar Energy

It is commonly known that from ancient times, people have used solar energy for a variety of purposes. Find instances of these applications and add them to the list below. Obtaining salt from seawater to dry leather, damp clothing, firewood, grains, fish, and other foods. Many of the items we use now utilize solar energy. Solar radiation is absorbed and transformed into heat by appliances like solar cookers and solar heaters.

Solar energy is transformed into electrical energy, which may either be utilized immediately or saved in a battery. There are eight ways that solar radiation may be converted into useable energy. Utilizing solar flat collectors, the solar thermal conversion process transforms photons into heat. Solar thermochemical conversion uses a pump or turbine to convert radiation into heat, steam, and



ultimately kinetic energy. The solar thermal electric conversion technique transforms radiation into steam, kinetic energy, and electrical energy via the use of a turbine and generator. Chemical energy is produced using the aforementioned procedure and further electrolysis (H<sub>2</sub> fuel). Chemical energy (H<sub>2</sub> fuel) is directly produced by a high temperature catalytic conversion process. Solar radiation is converted by photovoltaic technology into direct electrical energy. Direct chemical energy is generated during photosynthesis from photons. With the help of the electricity generated by the photovoltaic technology, chemical energy (H<sub>2</sub> fuel) is directly created from solar radiation. A couple of these techniques are discussed in further depth.

The same solar technologies—photovoltaic, passive heating, day lighting, and water heating—that are utilized in residential buildings may also be employed in commercial and industrial structures. A residence would not be able to employ solar energy technology, however these nonresidential structures can. These technologies include solar process heating, solar cooling, and ventilation air preheating.

To preserve the purity of the air within many huge structures, ventilation is required. Heating this air may be quite energy-intensive in cold climes. The air may be preheated using a solar ventilation system, which conserves electricity and money. A thin, black metal panel installed on a south-facing wall serves as the standard transpired collector in this kind of system to capture solar energy. The panel's many tiny holes allow air to move through. The air streams from the perforations might mix in a place beyond the perforated wall. The hot air is then drawn into the ventilation system from the top of the chamber.

Large amounts of hot water or space heating may be provided by solar process heating systems for non-residential buildings. Solar collectors, a pump, a heat exchanger, and/or one or more sizable storage tanks are common components of a typical system. The two most common solar collector forms, evacuated tubes and parabolic troughs, are both very efficient when operating at high temperatures. A shallow box filled with several glass, double-walled tubes and reflectors to heat the fluid within the tubes is an evacuated-tube collector. The inner tube keeps the heat in by being insulated by a vacuum between its two sides.

Long, rectangular, curved (U-shaped) mirrors that are slanted to direct sunlight onto a tube that runs through the middle of the trough are called parabolic troughs. The fluid within in the tube warms as a result. Building cooling may also be accomplished by using the heat from a solar collector. It may seem difficult to utilize heat to chill a house, but if you merely consider solar heat as an energy source, it makes more sense. Electricity is the energy source that your accustomed house air conditioner utilizes to produce cool air. Similar methods are used by solar absorption coolers, along with some quite sophisticated chemical techniques, to produce cold air using sun energy. Desiccant cooling is a chemical method that may be utilized with evaporative coolers (also known as "swamp coolers") to increase their effectiveness in humid conditions.

### **Space Heating**

Space heating is often needed throughout the winter in colder parts of the globe (including high altitude places inside the tropics). To do this, enormous amounts of energy may be utilized. Most of the heating needs may be satisfied by solar gain alone if buildings are correctly planned to make the most of the solar insolation that they get. A new home may be built to be both energy-efficient and livable by implementing a few basic design ideas. The majority of these technologies are passive in nature and dependent on design. Large glazed sections, adequate insulation, and building materials with a high thermal mass (which stores heat) may all help a structure's ability to absorb and store solar heat. While there are several solutions to help with daytime heating requirements, seasonal storage is more challenging and expensive.

**Certain rules must be adhered to for passive solar design to be effective:**

To optimize solar gain, a structure should have significant amounts of windows towards the sun. A structure should include features to control heat input to avoid overheating and should have enough mass to store heat for the appropriate amount of time.

**Include elements that encourage the uniform diffusion of heat throughout the structure.**

The Trombe wall is one example of a straightforward passive room heating method. To keep the heat that has been trapped within from escaping, a gigantic black painted wall has a double glazed covering. Warm air may enter the room at a high level via the wall's vents while cold air can enter the space between the wall and the glass. The heat that was accumulated in the wall during the day is released into the space at night. In places where the days are nice and sunny but the nights are chilly, this kind of technology is helpful.

**Room Cooling**

However, the bulk of the emerging nations in the globe are located in tropical regions and have no need for space heating. However, there is a need for space cooling. The majority of warm-climate societies across the globe have once again evolved conventional, basic, and beautiful methods for cooling their homes, often using benefits encouraged by passive solar phenomena. There are several ways to reduce heat gain. These include placing a building in a shaded area or next to water, employing landscaping or plants to funnel wind into the structure, and smart town planning to take use of the prevailing winds and available cover. Domed roofs and thermally substantial buildings may be created for hot, dry conditions; shuttered and shaded windows can be used to reduce heat gain; and open-frame bamboo houses can be used in hot, humid climates. In certain nations, homes are built underground to take advantage of the ground's generally constant and low temperature. As many alternatives are available as there are individuals.

**Recent Advances in Solar Power Facilities**

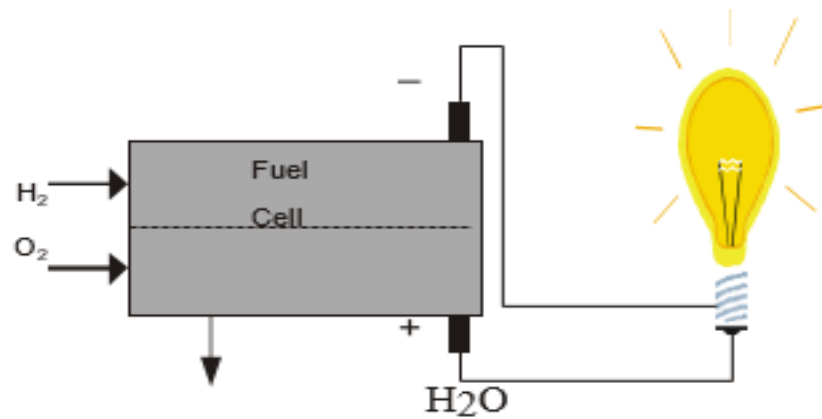
Application of solar thermal energy. The applications include space heating and drying, solar distillation, solar cooling via absorption & adsorption cycles, solar water pumping, and solar power production. They also include water heating for household, commercial, and industrial usage.

PV solar technology. The generation of electricity from light is referred to as photovoltaic (PV) or solar cells. A converter, a solar cell transforms light energy into electrical energy. Since a cell doesn't contain any energy, it has no electrical current whenever the source of light, which is usually the sun, is no longer there. A battery must be added to the circuit if power is required at night. Solar cells may be made from a variety of materials, although silicon is the most used. A common solar cell has a diameter of 3 to 6 inches and is currently made in a number of designs, including round, square, and others. Whenever light strikes a cell's surface, the conversion process begins immediately. Additionally, the cell's output is proportional to its light input.

**Effects of Electrochemistry and Fuel Cells**

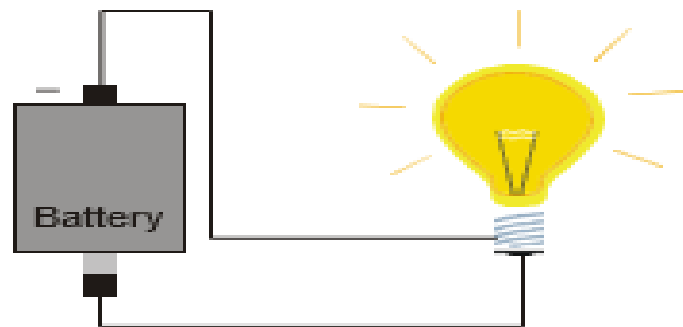
An electrochemical reaction between hydrogen and oxygen powers fuel cells. For the generation of electricity, fuel cells are dependable, efficient, and safe for the environment. Fuel cells have been used successfully in several applications, including the production of fixed and portable electricity.

A fuel cell is an apparatus that directly transforms the chemical energy contained in a fuel into electrical energy. Fuel cell is an open system in Figure 1.3.



**Figure 1.3: Illustrates the Fuel cell is an open system.**

Some similarity to a battery except that energy must be stored or built into a battery. Batteries are closed systems in Figure 1.4.



**Figure 1.4: Illustrates the Batteries are closed systems.**

The fuel cell operates on two principles. Chemistry must take place before energy can flow, the F/C system functions like a full chemical plant, the energy source should be matched to the application, and sometimes the F/Cs won't function.

### Transparent Cells

In order to complete the process in a fuel cell, two things must take place as oxidation and reduction are physically distinct: Ions move through the electrolyte, moving from the cathode in an acidic solution to the anode in an alkaline solution. Electrons go from anode to cathode along a "potential gradient" and carry out work in this way.

**Cathode:** the electrode where cations move. Anode: Mnemonic for electrode to which anions move, Oxidation takes place at the anode, whereas reduction happens at the cathode (redcats).

Potential of a cell: The difference between both the cathode potential  $E_c$  and the anode potential  $E_a$  is indeed the cell potential  $E$  or  $E_o$ .

$$E = E_c - E_a \text{ or } E^o = E_c^o - E_a^o$$

In Fuel cells: Cathode (+); Anode (-);  $E, E_o > 0$

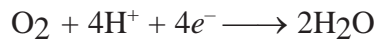
In Electrochemical cells: Cathode (-); Anode (+);  $E, E^{\circ} < 0$

By definition, the hydrogen reaction is defined to be 0.000 V at standard conditions,  $S_{he}$  = standard hydrogen electrode; hydrogen electrode in equilibrium at standard conditions (298 K, unit activity of species)

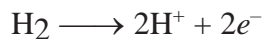
### In Reversible Cell

For  $H_2/O_2$  fuel cell:

Cathode (reduction):



Anode (oxidation):



Reversible cell potential

$$E^{\circ} = E_c^{\circ} - E_a^{\circ}$$

### Ideal Fuel Cells

Ahead of Potentials the electrodes cannot function at their equilibrium potentials in a practical process because non-idealities cause efficiency losses or process resistances. To compensate for efficiency losses, electrodes must move to potentials that are more conducive to oxidation or reduction. Over potentials are the name given to these shifted potentials.

The fuel's chemical energy powers the over-potential in a fuel cell, which powers the reaction.

### Ideal Potentials for Fuel Cells

Fuel cell potentials are constantly decreased by over-potentials, which results in less supplied voltage per electron transported. The system no longer has to store significant amounts of extremely explosive hydrogen, however this lowers the efficiency of the energy generating process to 30% or 40%. It is still more efficient to do this than to burn the methanol directly since combustion engines are only around 20% effective at converting fuel energy into motion on the ground. Creating the hydrogen needed to power hydrogen fuel cells is an issue. The four electrons must be added at the time hydrogen is created in order to remove them when two hydrogen molecules combine with an oxygen molecule. Four common procedures are as follows:

Hydrocarbon reformation. Any fossil fuel, including coal or oil, may be used to create hydrogen by heating it and then "reforming" it with steam.

Natural gas reformation using steam. Similar to the last example, but without the requirement to convert the solid hydrocarbons first into hydrocarbon gases.

Organic biomass may be gasified or paralyzed to create hydrogen-rich gases that can subsequently be converted into hydrogen using steam.

Electrolysis. Directly generating hydrogen from water with the use of electricity.

In comparison to other fuels, the utilization of fuel cells in mobile applications is often limited. They could be useful for adjusting the variances from certain renewable energy sources like wind or tidal power.

Cellular Efficiency

Current density at the electrode surface (100 to 400 mA/cm<sup>2</sup>) at a specific temperature, chemical partial pressures, and voltage are used to evaluate the performance of fuel cells.

Let,

$V_o$  = No load voltage of cell, Volts,  $DCV_c$  = Cell voltage on load

$I_c$  = Cell current on load, Ampere  $P_c$ , = Cell power, Watts

$V_p$  = Polarization voltage = Voltage drop in the cell

= No load voltage  $V_o$  – On load voltage  $V$ ,  $A$  = Surface area of on face of an electrode,  $mI_d$  = Current density of cell, =  $I_c/A$ .... A/m....

$E$ = Efficiency

The cell voltage is highest when there is no current (no load or open circuit), and is referred to as no load voltage ( $V_o$ ).

The real  $V_c$  vs.  $I_d$  curve serves as an example of the performance. A rise in operating temperature but also partial pressure enhances the efficiency of fuel cells (increase in  $V_c$  and  $P_c$ ). A trade-off exists between increased performance and more expensive costs (for high temperature, pressure design).

Current density vs. voltage characteristic (polarization curve)

The cell voltage  $V_c$  vs. electrode current density  $I_d$  curve is used to assess the efficiency of a fuel cel. Due to polarization inside the cell, the voltage of the cell,  $V_c$ , decreases as current density increases (Figure 1.5). As a result, the curve is also known as the fuel cell's polarization curve. Polarization is a fuel cell's internal biochemical, electrical, and thermal impact that causes inefficiencies. The polarization phenomenon, which results in internal energy loss, is quantified by the polarization voltage  $V_p$  (Figure 1.6).

$$V_p = v_o - v_c$$

$V_p$  = Polarization voltage of the cell = Voltage Drop

= No load voltage  $V_o$  – On load voltage  $V_o$ .

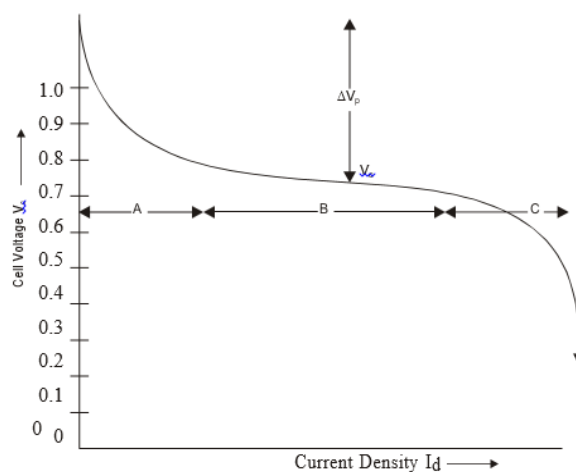
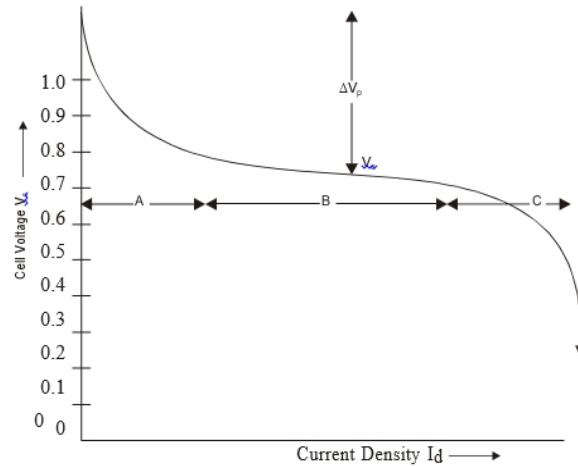


Figure 1.5 electrode current density  $I_d$  curve



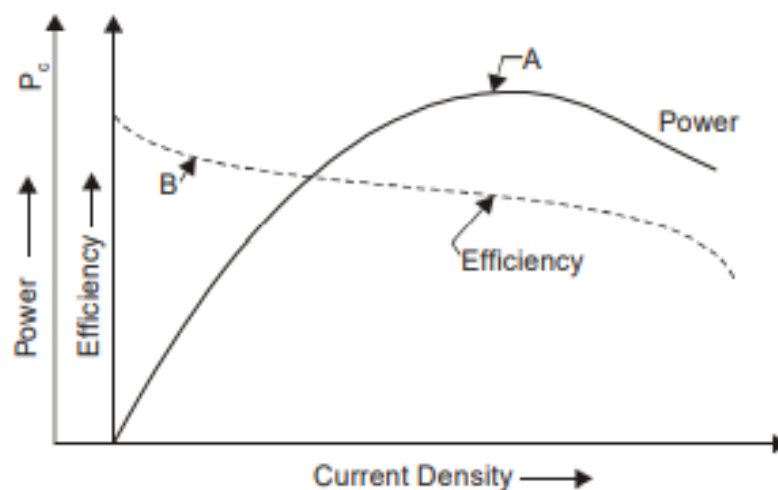
**Figure 1.6 polarization curve**

The internal electro-chemical processes attempting to counter the cause likewise grow as the load on the cell ( $I_s A = I$ ) rises. The terminal voltage  $V_c$  decreases as internal losses rise. Polarization is the term used to describe these inherent losses and inefficiencies that grow with current. Polarization Voltage  $V_p$  is the name given to the voltage drop  $V_p$ .

Power per Cell ( $P_c$ ), defined as Power = Voltage Current ( $P_c = V_c I$ ),

With an increase in the current density, a cell's power rises until it achieves saturation from polarization effects.

Output power equals input power minus polarization losses, and Output power divided by input power equals efficiency ( $\eta$ ); cells' efficiency. With the exception of electrolysis, which may be up to 80% efficient, all methods are only 40% to 60% effective in terms of the ultimate energy production. Fuel cell proponents contend that this cycle still constitutes a development for automobiles. When using fuel, total efficiency is about 40% as opposed to an internal combustion engine's 20% (Figure 1.7).

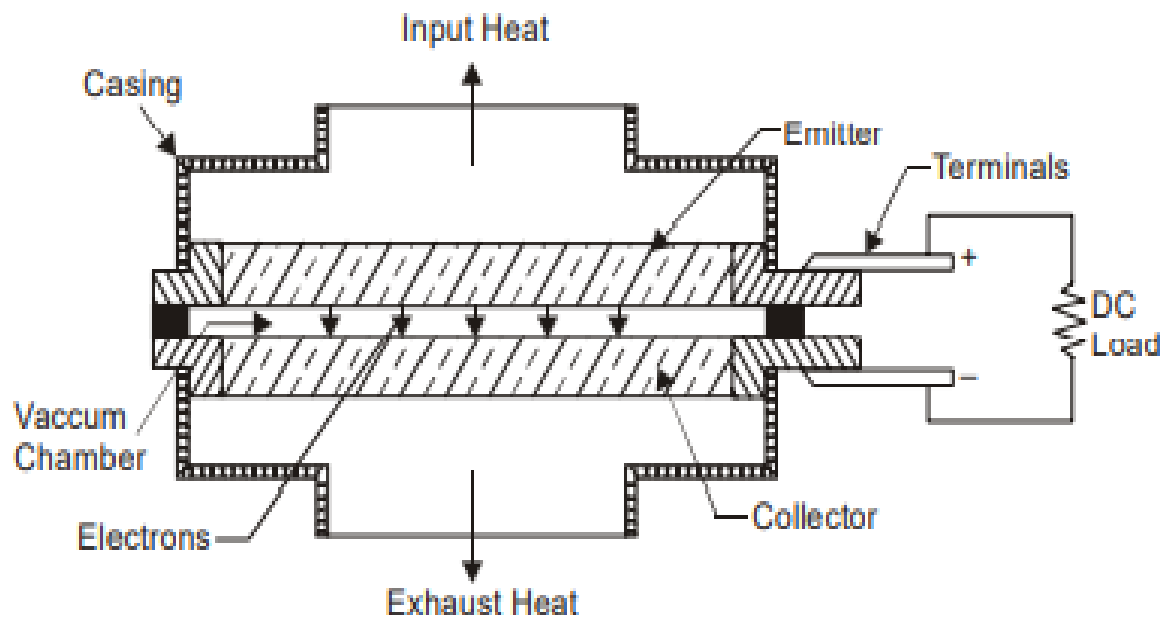


**Figure 1.7 Output power equals input power minus polarization losses**

After reaching saturation level, then and power per cell starts decreasing. The losses increase and are converted to waste heat.

### Thermionic Systems and Thermionic Emission

A thermionic converter uses thermionic emission to convert heat directly into electricity. The free electrons in all metals and certain oxides were released when they are heated. These electrons may go across a space and gather on a metal that has been cooled. Through an external load, these electrons may return to the heated metal and generate electricity. The two electrodes of a VA thermionic converter are encased in a tube in Figure 1.6. The cathode is referred to as an emitter and is sufficiently heated for its surface to release electrons. The electrons pass through a narrow gap and accumulate on the collector, a cooled metal anode. To reduce energy losses, the space between the electrodes is either kept at a high vacuum or filled with such a highly conducting plasma, such as ionized cesium vapour. Anode and cathode are used to link the external load  $R$ . Through the external load, the electrons return to the cathode, producing electrical power.



**Figure 1.8: Illustrates the Thermionic Systems and Thermionic Emission.**

A sealed and evacuated device called a thermionic converter consists of a heated cathode (electron emitter), an anode (electron collector), as well as a vacuum gap between one and two (with ionised vapour to neutralise space charge). There is merely an mm-sized gap. The anode and cathode are linked via an external electrical circuit (Figure 1.8). The thermionic converter uses the movement of electrons via the vacuum gap to transform thermal energy directly into electrical energy. To the emitter is provided heat. When an emitter releases electrons, they pass through a tiny vacuum gap that is seeded with an ionizing material. Heat from the collector is discarded. The terminals are used to tap electrical energy.

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## CHAPTER 2

### THERMIONIC CONVERSION

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A potential barrier equal to the energy difference between an electron's energy outside and within the metal opposes the emission of an electron from a metal surface. The electron must thus be released from the surface with a specific amount of energy. The term surface work function refers to this energy. According to the Richardson Dushman equation, the maximum electron current per unit area radiated from the surface is as follows:

$$J = A_1 T^2 e^{\left(-\frac{\phi}{kT}\right)}$$

where

$J$  = current density, [A/m<sup>2</sup>]

$T$  = Temperature, [K]

$\phi$  = work function, [eV]

$K = 1.38 \times 10^{-23}$  J/molecule K  
= Boltzmann constant

$A_1 = 120$  A/cm<sup>2</sup>-K<sup>2</sup>) = Emission constant.

Some electrons may well have energy greater than the Fermi level above absolute zero. The work function, is the amount of energy required to overcome the weak attractive force acting on the outermost orbital electrons such that the electron exiting the emitter has an energy level +  $\phi$ . Some high energy free electrons just at Fermi level gain energy equal to the emitter work function  $\phi$  when the emitter is heated, and they then leave the emitter surface. They cross the opening and collide with the collector. This energy is rejected as heat from of the low temperature collector together with the K.E. ( $\phi$ ) plus the amount of energy equal to the collector work function ( $\phi_c$ ).

The electron energy is lowered to the anode's Fermi energy level. The electron's energy state at the cathode's Fermi energy level,  $\phi_c$ , is lower than this one. As a result, the electron may go from the anode to the cathode via the external load. Compared to anode materials, which must have greater Fermi levels, cathode materials are chosen with lower Fermi levels.

#### Realistic and Ideal Efficiency

Similar to a cyclic heat engine, a thermionic generator's maximum efficiency is limited by Carnot's law. It is a low-voltage, high-current device that has produced current densities of 20–50 A/cm<sup>2</sup> at voltages between 1 and 2V. 10–20% thermal efficiency have been attained. Future values might be higher.

Thermionic generator development is ongoing. Building useful functioning prototypes and demonstrating feasibility (1980s). A power output density of around 6 W/m may be reached using an anode of low work functionality material (barium oxide, strontium oxide), and a cathode of high work function material (tungsten impregnated barium compound). About 35% of the time.

The released electrons tend to be drawn back by the positively charged cathode. The electrons attempting to bridge the gap are slowed down by the electrons already present in the gas. A

space charge barrier is created. A thermionic generator with just an interspace retarding potential equal to  $S$  volts just above anode work function its characteristic curve.

### System Thermoelectric

When the loop's two connections are maintained at various temperatures, an e.m.f forms in a loop made of two distinct metals. It's known as the Seebeck effect. A thermocouple uses this phenomenon to measure temperature. The Seebeck thermoelectric effect is used by thermoelectric generators to directly transform heat energy into electrical energy. Although the gadget is relatively straightforward, its thermal efficiency is just around 3%. The temperature of the hot and cold junctions as well as the characteristics of the material affect the thermoelectric generator's efficiency. The features of semiconductor materials are more advantageous since they can provide good efficiency while withstanding high temperatures. Peak load power plants in the order of 100 mW that operate at 20% thermal efficiency are likely to be developed. The development of thermoelectric generators for base load and backup power production is also possible in areas with inexpensive fuel sources. The use of radioactive decay heat to produce electricity in space and other far-off places is another significant use. If high efficiency materials can be created, using solar energy to generate heat for electricity might be an appealing use for thermoelectric devices (Figure 2.1).

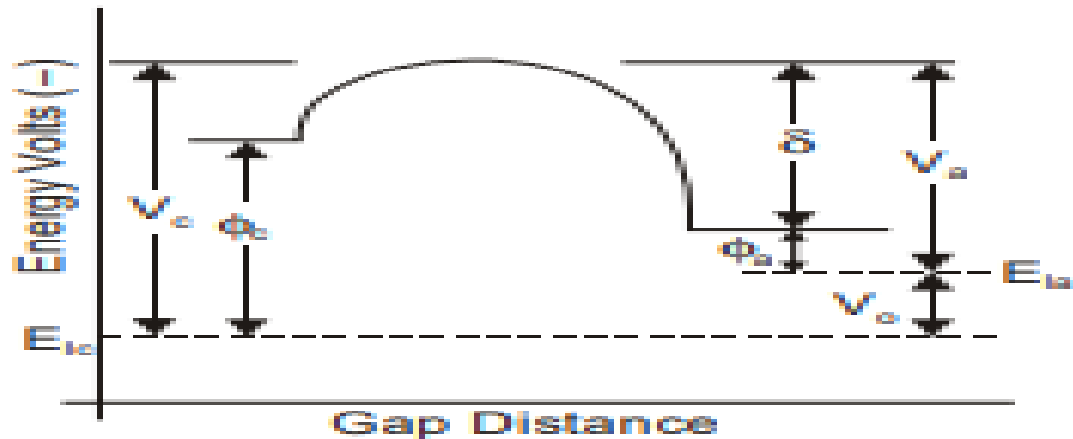


Figure 2.1: Illustrates to calculate thermoelectric.

Potential barrier,

$$V_c > \Phi_c \text{ and } V_c > \Phi_a$$

The current densities are :

$$J_c = A_1 T_c^2 e^{\left(-\frac{V_c}{kT_c}\right)} \text{ [A/cm}^2\text{]}$$

$$J_a = A_1 T_c^2 e^{\left(-\frac{V_c}{kT_2}\right)} \text{ [A/cm}^2\text{]}$$

The output voltage across the electrical resistance  $R$ ,

$$V_o = V_c - V_a = \phi_c - \phi_a = \frac{1}{e} (\epsilon_{fa} - \epsilon_{fc})$$

Each electron has to overcome the interspace potential  $(V_c - \Phi_c)$  and work function  $\Phi_c$  when it leaves the cathode. The net energy carried,

$$Q_{tc} = J_c (V_c - \phi_c + \phi_c) = J_c V_c \text{ [W/cm}^2\text{]}$$

## Thermoelectric Systems

When the loop's two connections are maintained at various temperatures, an e.m.f forms in a loop made of two distinct metals. It's known as the Seebeck effect. A thermocouple uses this phenomenon to measure temperature. The Seebeck thermoelectric effect is used by thermoelectric generators to directly transform heat energy into electrical energy. Although the gadget is relatively straightforward, its thermal efficiency is just around 3%. The temperature of the hot and cold junctions and the characteristics of the material affect the thermoelectric generator's efficiency. The features of semiconductor materials are more advantageous since they can provide good efficiency while withstanding high temperatures. Peak load power plants in the order of 100 mW operating at 20% thermal efficiency are likely to be developed. The development of thermoelectric generators for base load and backup power production is also possible in areas with inexpensive fuel sources. The use of radioactive decay heat to produce electricity in space and other far-off places is another significant use. If high efficiency materials can be found, using solar energy to generate heat for electricity might be an appealing use for thermoelectric devices.

## Geo Thermal Energy

The sun in the sky and the heated rocks under the earth's surface are two powerful energy sources that surround us. Our forefathers used hot springs for cooking and bathing because they understood the importance of geothermal energy. They now understand that there is considerably more potential for this resource's use. The words "geothermal" and "thermal" both refer to heat and the earth, respectively. Drilling water or steam wells, which is a procedure akin to drilling for oil, is one way to get geothermal energy, which is also known as heat from the Earth. It is feasible to utilise the geothermal energy that is produced by the earth's very heated interior (in Greek it means heat from the earth). These are regions with volcanoes, hot springs, geysers, and underwater methane reservoirs in the oceans and seas. In other nations, like the USA, residents heat their homes by pumping hot water out of subterranean reservoirs. Geothermal energy is a massive, underutilized source of heat and electricity that is safe (emits little to no greenhouse emissions), dependable (has a 95% average system availability), and domestic (making us less dependent on foreign oil). William Bell Elliot, an explorer and surveyor who was climbing in the mountains between Cloverdale and Calistoga, California, in pursuit of grizzly bears, made the initial discovery of the geothermal fields in 1847. In close proximity to Colb Mountain, an extinct volcano now known as the Geysers, he observed steam oozing out of the earth for a quarter of a mile here on steep slope of a canyon. Geothermal energy was first used for cooking, heating, and therapeutic reasons. The disintegration of radioactive isotopes is thought to cause the earth's core to reach temperatures of up to 10,000 K. The entire continuous flow of geothermal energy to the surface of the earth is  $4.2 \times 10^{10}$  kW. The flow energy, however, is just 0.063 W/m<sup>2</sup> on average. Since the very beginning of the 20th century, geothermal energy has been used to generate power. The production of power from geothermal energy was restricted to Italy for 50 years, and interest in this technology only slowly extended to other countries. Iceland was the first country to employ geothermal hot water in 1943.

The development of geothermal energy has the following broad goals: reducing reliance on nonrenewable energy sources and boosting the state's economy. Mitigation of geothermal development's negative social, economic, and environmental effects, the maintenance of the productivity of renewable resources by the investment of the revenues from these resources. Financial support to counties to cover the expenses of providing public services and infrastructure required by the development of geothermal resources within their jurisdictions.

## Hot Springs

Early Cenozoic earth earthquakes brought magma in certain areas quite near to the earth's surface and opened crust fractures. Active volcanoes, hot springs, and geysers are therefore caused by the heated magma close to the surface where there is water. Additionally, it leads to steam venting via the crevices. Igneous rock is formed when hot magma close to the surface hardens. This igneous rock receives heat from the magma by being exposed to it upward. Through cracks in the rock, any ground water that descends to it will be warmed by the heat of the rock or by interacting with steam and hot gases coming from the magma. Following this, the hot water will convectively ascend higher and collect in a reservoir that is porous and permeable above the igneous rock. This reservoir is covered by an impenetrable layer of solid rock that keeps the hot water within the reservoir trapped. However, the solid granite features cracks that serve as vents for the enormous subterranean boiler. Geysers, fumaroles, and hot springs are the surface manifestations of the vents. Hot springs have been a manifestation of the earth's inherent heat for thousands of years. Steam from the fissure is drawn from a well and used in a geothermal power plant. Many locations throughout the globe with access to geothermal steam have geothermal power plants erected. In the year 2000, 0.3% of the total power produced worldwide was generated by geothermal sources. There are more than 300 hot springs in India.

## Steam Ejection

Geothermal energy reserves with hot water may be found all over the planet. Heat is absorbed by underground water from nearby hot rocks. Such hot water reservoirs have a low steam content. Rainwater that has accumulated across many hundred square kilometers of land percolates through the soil to depths of 1 to 6 km, in which it is heated by thermal conduction from the nearby hot rocks. The confined sections of the rocks' flaws allow the hot water to flow upward. The rock's fissures and extremely porous regions constitute the "defects." With minimal to no storage in between, the hot water rises to the surface. The energy deposits will, however, be kept underground and will be easily accessible for extraction if a zone of geothermal energy deposits was covered by an impervious rock with a few fissures or faults. Production wells that are bored through the impermeable rocks may be used to extract the energy that is present in such deposits. The geothermal fluids in hydro-geothermal energy deposits take the forms of geothermal brine, hot mineral water, and steam.

There are extremely few steam deposits. However, the biggest petro-geothermal energy deposit is of the Hot Dry Rock type, which is devoid of subterranean water. The world's highest geothermal energy potential is found in HDR deposits. In order to harvest geothermal energy from these hot, dry rocks, water must be injected into holes in the rocks that have been intentionally cracked, and then hot water and steam must be extracted using production wells. Through the use of injection wells, cold water is injected to the well, while production wells are used to extract hot water and steam. As a heat-collecting and heat-transporting medium, water pumped into the well serves these functions. A heated, dry rock cavity generates steam like a boiler. After injecting cold water, hot water or steam is produced.

## Section of a Site

There are around 150 geothermal locations in India with fluid that is moderately and low-temperature (160°C). Hot water springs (40 to 98°C) and shallow water reservoirs with temperatures under 160°C make up India's geothermal fields.

The Puga Hydro-Geothermal Field in Jammu and Kashmir is a significant hydro-geothermal resource area. Gujarat, Gujarat's West-Coast Hydro-Geothermal Field, Maharashtra Madhya

Pradesh's Tattapani Hydro-Geothermal Field. India's chances of developing geothermal electric generating plants are quite slim because of the moderate and low temperatures of geothermal fluids. The temperature range of 30°C to 190°C, however, is anticipated to have a number of uses for geothermal hydrothermal energy. The following considerations may be taken into account while choosing a geothermal energy location.

There are deposits of borax

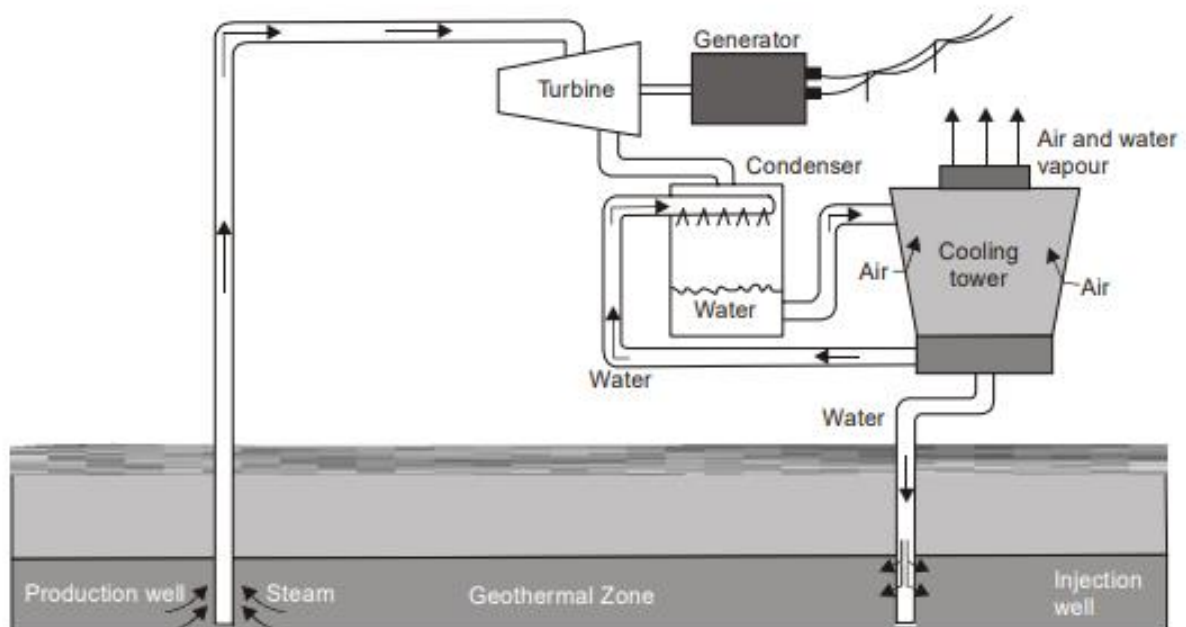
Several spots have water that is 120°C and 200–500 m deep.

Na-Ca-Cl-SO<sub>4</sub> composition

A shallow depth reservoir with water between 80 and 110 degrees Celsius.

### Plantations of Geothermal Power

The first mechanical conversion occurred in 1897 in Larderello, Italy, when field steam was utilized to heat a boiler, which then produced steam that powered a small steam engine. Larderello also made the first effort to create electricity in 1904 using a generator that ran four light bulbs. The first effort to develop the geysers field in the United States was conducted in 1922. Although steam was successfully tapped, the corrosive and abrasive steam was too much for the pipelines and turbines of the time. It wasn't until 1956 that the project was restarted when two businesses, Magma Power and Thermal Power, bought steam from the region and sold it to Pacific Gas and Electric Company. By that point, corrosion-resistant stainless steel alloys had been created, and in 1960 the first electric-generating unit with a capacity of 11 mW went into service. Since then, the system has received 13 typically becoming bigger units. The most recent unit, a 109 mW one, went into service in September 1982 and increased the Geysers' overall capacity to 909 mW. By the late 1980s, the total capacity will reach 1514 mW thanks to the four more units that are now being built and two more that are currently under development.

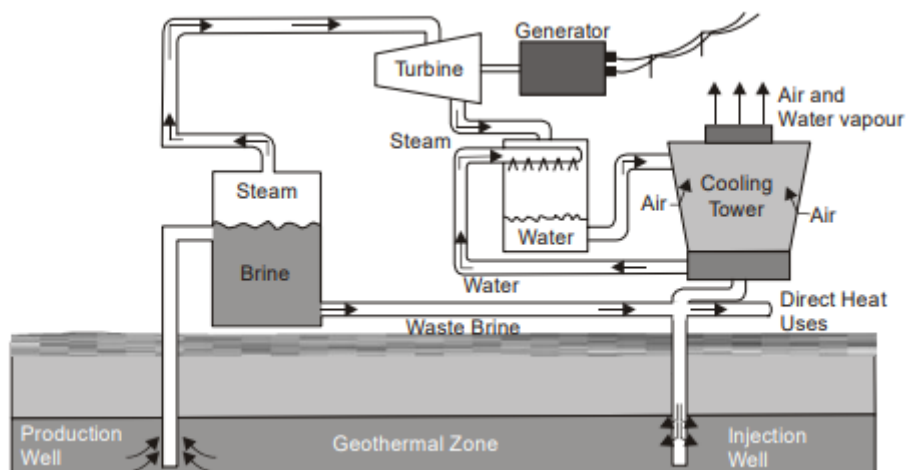


**Figure 2.2:** Illustrates the working procedure of dry steam power plant.



Other notable locations for electric-generating fields include Japan, the Philippines, the Soviet Union, Mexico (at Cerro Prieto), New Zealand (where the major activity at Wairakei goes back to 1958), and Iceland (a large space-heating program). Based on the decade of the 1970s, future global geothermal electric generation is expected to grow by 7 percent annually. However, the growth rate in the latter four years of that decade was 19% annually. Through the 1980s, growth in the United States is predicted to range between 13.5 and 22% annually, which is 2.5 to 4 times the 5.3 percent annual growth rate of the entire electric-generating capacity. This comprises additional fields of various kinds as well as the steam field at the Geysers. According to the U.S. Geological Survey, the United States has the potential to generate 23,000 mW of electric power and 42 10 SkJ of space and process heat for 30 years with current technology, as well as 72,000 to 127,000 mW of power and 144 to 294 1015 Btu of heat from sources that are currently unknown. Geysers Region in Northern California, Imperial Valley in Southern California, and Yellowstone Region throughout Idaho, Montana, and Wyoming are examples of geothermal potential areas in North America. To produce electricity, the majority of power plants use steam. Steam causes a turbine to spin, which ignites a generator and generates power. For the purpose of producing steam, many power plants still utilize fossil fuels. However, geothermal power plants employ steam generated from hot water reservoirs located many miles or more underneath the Earth's surface. Dry steam, flash steam, and binary cycle geothermal power plants are the three different kinds (Figure 2.2).

**Steam Power Plant in a Flash (Liquid Domain System).** The most prevalent are flash steam power plants in Figure 2.3. They make use of geothermal reservoirs with water that is hotter than  $182^{\circ}\text{C}$ . Under its own pressure, this very hot water rises via wells drilled into the earth. Some of the heated water boils becoming steam as it rises due to a drop in pressure. After being separated from the water, the steam is utilized to drive a turbine/generator. This resource is sustainable since any remaining water and concentrated steam are fed back into the reservoir.



**Figure 2.3: Illustrates the Schematic of the Flash Steam Power Plant.**

The 1980s saw the construction of flash-steam power facilities that used water reservoirs with temperatures over  $182^{\circ}\text{C}$ . Under its own pressure, the hot water rises via underground wells. The pressure drops as the water rises, and part of the hot water "flashes" into steam. The greatest single source of geothermal energy in the whole globe is produced by The Geysers in northern California, which utilizes steam pumped straight from wells. The most prevalent kind of geothermal power producing facility now in use is a flash steam plant. They employ water that is pushed at high pressure to the surface generation equipment at temperatures more than 182

°C. When the pressure reaches the generation apparatus, it is abruptly dropped, causing part of the hot water to transform or "flash" into steam. The turbine/generator units are then driven by this steam to generate energy. The hot water that hasn't been flashed into steam and the steam's condensed water are often pushed back into the reservoir. The Cal Energy Navy I flash geothermal power station in the Coso geothermal field is an instance of a location that uses the flash steam operation.

**Power Plant with a Binary Cycle (Liquid Dominated Systems).** Water is used in binary cycle power plants to run at lower temperatures of 107°–182°C. In these facilities, a working fluid, often an organic chemical with a low boiling point, is boiled using the heat generated by the hot water. In a heat exchanger, the working fluid is converted to vapor and utilized to drive a turbine. After that, the water is pumped back into the earth to warm. There are very little or no air emissions since the water and the working fluid are maintained separate during the whole operation.

At lower temperatures, between 107 and 182 degrees Celsius, binary cycle power plants run on water. These facilities boil a fluid, often an organic chemical with a low boiling point, using the heat from the hot water.

In contrast to Dry Steam and Flash Steam systems, binary cycle geothermal power production facilities never make contact with the turbine or generator units with water or steam from of the geothermal reservoir. In the Binary system, heat from either the geothermal reservoir's water is utilized to evaporate a second "working fluid" and operate turbine/generator units. The "working fluid" and the geothermal water are kept separate in closed loops or circulation systems and never come into touch. With the use of working fluids that have a boiling point even lower than water, the binary cycle plant has the benefit of being able to function in the 225°F to 360°F temperature range. They don't even create any air.

Fossil system and hybrid geothermal power plant. The idea of hybrid geothermal-fossil fuel systems makes use of the comparatively low-temperature heat from geothermal sources inside the low end of a conventional cycle and indeed the high-temperature heat from the combustion of fossil fuels inside the high end of that cycle. Thus, the idea reduces the use of the pricey and finite fossil fuel by combining the high efficiency of a high-temperature cycle with such a natural supply of heat for a portion of the heat addition. For hybrid plants, there are two configurations that are feasible. These are fossil superheat, suited for vapor-dominated and high-temperature liquid-dominated systems, and geothermal preheat, ideal for low-temperature liquid-dominated systems.

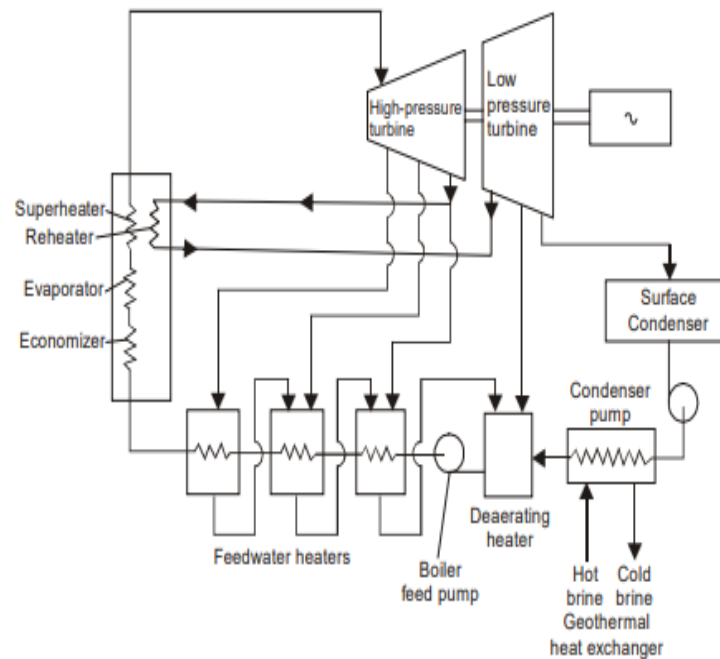
### Hydride Geothermal-Preheat Systems

In these systems, a typical fossil-fueled steam plant uses low-temperature geothermal energy to heat its feed water. Depending upon the temperature, geothermal heat may replace some or perhaps all of the feed water heaters. Figure 2.4 shows a cycle that applies this theory. As shown, a low-temperature end of the feed water is heated using geothermal energy before an open-type reerating heater. The DA is followed by three closed-type feed water heaters with cascading backward drains and a boiler feed pump. Steam that has been lost from the turbine's higher-pressure stages is used to heat these. Geothermal brine performs this role, therefore no steam is leaked from the lower-pressure stages (Figure 2.4).

Hybrid systems for fossil-superheat. In these systems, a fossil-fired super heater is used to further heat the vapor-dominated steam or the vapor produced by a flash separator inside a high-temperature liquid-dominated system in Figure 2.5. It has a geothermal steam system with two flashes. Steam exhaust from the high-pressure turbine at 7 preheats steam generated at 4

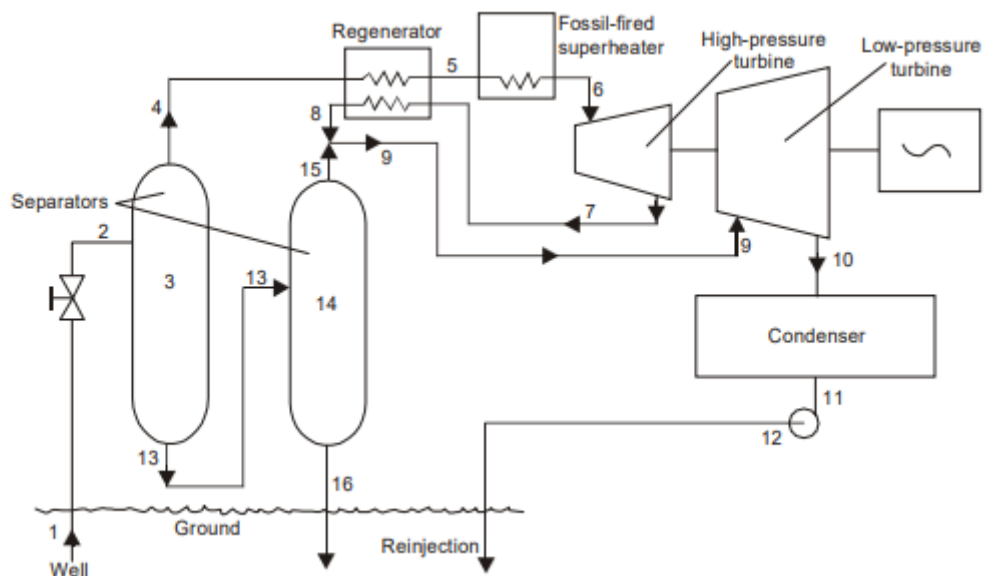


in the first-stage flash separator between 4 to 5 in a regenerator. It is then expanded to 7 at a pressure that is similar to that found in the second stage steam separator inside the high pressure turbine after being superheated to 6 by a fossil fuel fueled super heater.



**Figure 2.4: Illustrates the Hybrid Geothermal-Preheat Systems.**

After entering the regenerator, it exits at 8, combines with the lower pressure steam produced in the second stage flash separator at 15, and then creates steam at 9. This steam then expands in the lower pressure turbine to produce 10 at 9. At 12, the condensate from step 11 is pumped back into the earth. Additionally, the second stage evaporator's waste brine is reinjected into the earth at 16.



**Figure 2.5: Illustrates the Hybrid systems model for fossil-superheating.**

### **Advanced Ideas**

Geothermal energy systems use the heat of the ground to generate electricity, heat pumps, and direct-use applications. The usage of geothermal energy is growing and becoming more affordable thanks to research in all related fields. Modern technology will help develop new resources including hot dry rock, geopressured brines, and magma as well as manage geothermal resources for optimal power production. The discovery of nearly 340 hot springs in the nation inspired a systematic collaborative research, development, and demonstration program with a variety of organizations, including IIT, Delhi, National Aeronautic Limited, Bangalore, Geological Survey of India, National Geophysical Research Institute (NGRI), Hyderabad, Oil & Natural Gas Corporation, etc. The use of geothermal energy was demonstrated in the nation for small scale power generation and the heating of homes.

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## CHAPTER 3

### AQUATIC ENERGY

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The Ministry intends to develop these geothermal fields for the purpose of producing electricity after NGRI, Hyderabad's magneto-telluric studies confirmed the presence of prospective reservoirs in the Tattpani and Puga geothermal fields in Chhattisgarh and Jammu & Kashmir, respectively. Some other potential locations for electricity production are Surajkund in Jharkhand, Bcas and Parbati valley in Himachal Pradesh, Badrinath-Tapovan in Uttarakhand, and Sutluj-Spiti in Himachal Pradesh. Through NGRI, Hyderabad, and NHPC, the Ministry is planning a program to determine the presence and potential of the reservoir at these places. Some demonstration projects with direct heat use are scheduled to be undertaken at various locations around the nation since the majority of geothermal sites in the country are in the low to moderate temperature range. There are now operating or in development 1400–3600 Mwe plants. 6000 MWt of non-electric applications are used globally. This energy boils and converts to steam. This steam's pressure rises as a result of being trapped between rocks. Electricity may be generated by finding such locations and putting pipes there to release the steam needed to power a turbine.

Direct-Use Piped hot water melts snow off sidewalks and warms greenhouses. The majority of the geothermal reservoirs in the United States are found in Alaska, Hawaii, and the western states. To heat structures, cultivate plants in greenhouses, dry onions and garlic, heat water for fish aquaculture, and pasteurize milk, hot water near Earth's surface may be pumped straight into facilities. In certain areas, hot water is piped beneath sidewalks and roadways to melt snow. Applications for district heating heat buildings across whole towns using networks of hot water pipes. for further details on using geothermal energy directly.

Buildings may be heated and cooled using geothermal heat pumps. The top 10 feet of Earth's surface often maintain a temperature between 50 and 60 degrees Fahrenheit (10 and 16 degrees C). A heat exchanger, ducting into the structure, and pipes buried in the nearby shallow ground make up a geothermal heat pump system. The heat exchanger transfers heat from the somewhat warmer earth into the home during the winter. Summertime involves pulling hot air from the home through the heat exchanger and into the ground, which is often cooler. Heat lost during the summer may be utilized to heat water at no additional expense.

Geothermal Energy's Future. The three systems mentioned above only use a very small portion of the available geothermal energy. Hot, dry rock that lies many miles below Earth's surface is being heated by the molten lava below it. The ability to drill into this rock, inject cold water down one well, circulate it through the hot, cracked rock, and extract the heated water from another well is now being developed technologically. We could even be able to extract heat straight from the lava in the future.

#### **Aquatic Energy**

The ocean may generate two different forms of energy: mechanical energy from the tides and waves and thermal energy from the sun's heat. Oceans are the greatest solar collectors in the world since they make up more than 70% of the Earth's surface. Thermal energy is produced as a result of the sun's heat warming surface water much more than deep ocean water. The

globe might be powered by only a tiny percentage of the heat trapped in the ocean. Ocean thermal energy and ocean mechanical energy are quite different. Although the sun has an impact on all ocean activities, the moon's gravitational pull mostly determines tides, and winds primarily determine waves. As a consequence, ocean thermal energy is more consistent than tides and waves, which are sporadic sources of energy. Additionally, unlike the conversion of thermal energy, both tidal and wave energy often need the use of mechanical equipment. Tidal energy is often converted into electricity using a barrage (dam), which works by pushing water through turbines to start a generator. In order to convert wave energy, there are three main systems:

System types that employ waves to compress air within containers include oscillating water column systems, channel systems that direct waves into reservoirs, and float systems that power hydraulic pumps.

These systems either directly activate a generator or transfer mechanical energy to water or air, a working fluid, which powers a turbine/generator.

Let,  $E_t$  = Total Terrestrial Ocean Thermal Energy Incidence may be used to determine the amount of ocean thermal energy present on Earth.

$E_r = 5.457 \times 10^{18}$  MJ/year = total alien solar energy that the earth receives

$C_r$  = Average Clearness Index,  $F_A$  = Fraction of Ocean Area, and  $E_t = E_r C_r F_A = 5.457 \times 10^{18} \times 0.5 \times 0.7$ , and  $1.9 \times 10^{18}$  MJ/year, respectively

This is equivalent to a typical terrestrial incidence of the solar constant  $S = 1353 \text{ W/m}^2 \times 0.5 = 676 \text{ W/m}^2$  on the oceans.

Because part of this energy is reflected back to the sky, it is not entirely absorbed by the water.

The yearly evaporation of water provides a decent approximation of the quantity absorbed: Annual evaporation ( $EV$ ) = 1.20 m

(20°C) is the typical water surface temperature. Latent Heat of Vaporization = 2454 kJ/kg ( $C$ )  
The density of seawater is 1000 kg/m<sup>3</sup>.

The annual energy absorbed ( $E_{ab}$ ) is calculated as follows:  $E_{ab} = EV C = 1.20 \times 1000 \times 2454 = 3 \times 10^6 \text{ kJ/m}^2 = 95 \text{ W/m}^2$ .

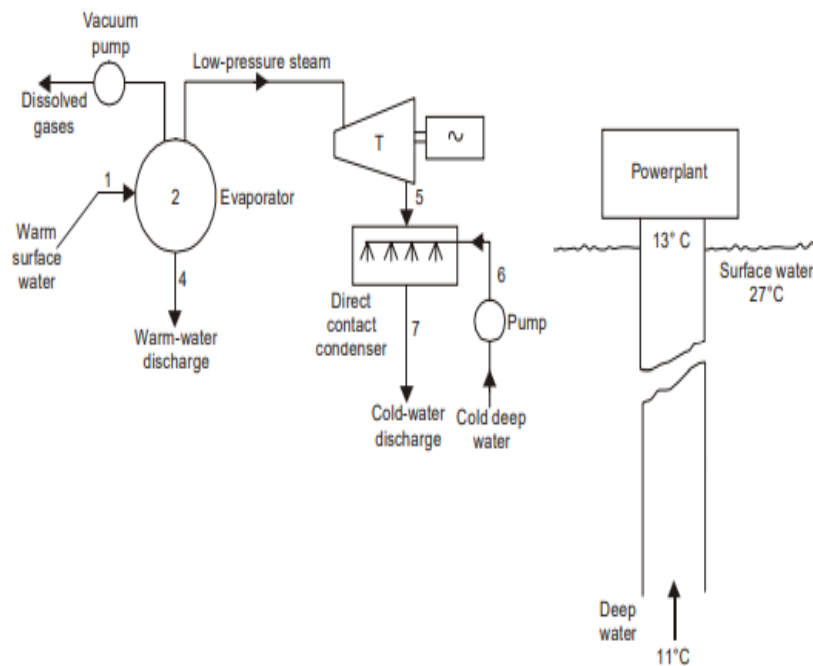
Naturally, rainfall that falls back onto the lake and drainage from the land both replenish this quantity. Absorbed energy as a percentage of incoming energy is equal to  $E_{ab}/S = (95/676) \times 100$ , or 14%.

### **Ocean Energy-Based Power Plant**

Many uses of ocean thermal energy exist, including the production of electricity. Closed-cycle systems, which employ the warm surface water of the ocean to evaporate a working fluid with a low boiling point, such ammonia, are the most common form of power conversion system. By expanding, the vapor drives a turbine. The generator is then started by the turbine to generate power. Open-cycle systems operate at low pressures to actually boil the saltwater. As a result, steam is generated, which powers a generator or turbine. Closed-cycle and open-cycle systems are combined in hybrid systems. Depending these energy conversion methods allow for a general division of the Ocean power plant into two categories.

OTEC Cycle Power Plant, Open or Claude

The first OTEC facility was built in 1929 in Cuba's Mantanzas Bay by the Frenchman Georges Claude. In the open cycle used by the Claude plant, saltwater it serves as a heat source, working fluid, coolant, and heat sink in Figure 3.1.



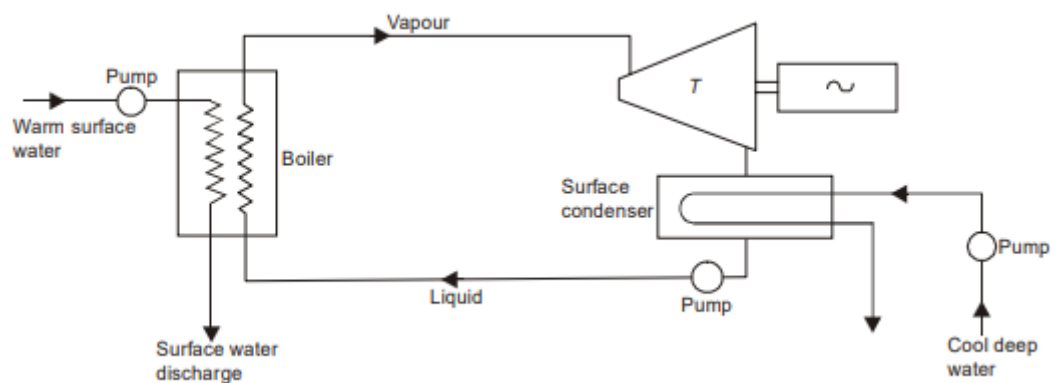
**Figure 3.1: Illustrates the OTEC Cycle Power Plant**

In the cycle, warm surface water with a temperature of 27°C is introduced into an evaporator with pressure that is kept at a level just below the saturation pressure for that water temperature. When water first enters the evaporator, it is "superheated" by the increased pressure. Volume boiling occurs on this momentarily superheated water, which causes it to partly flash to steam and then reach an equilibrium two-phase state at the new pressure and temperature. A vacuum pump that additionally removes the dissolved non-condensable gases from of the evaporator maintains the evaporator's low pressure. A very poor quality combination of water and steam at 2 is now present in the evaporator. At 3, the saturated vaporized steam is separated from the water. At 4, the remaining water becomes saturated and is returned to the ocean as brine. Even by standards of traditional power plants, the steam at 3 is a very high specific volume, extremely low pressure working fluid (0.0317 bar, 43.40 m<sup>3</sup>/kg, against around 160 bar, 0.021 m<sup>3</sup>/kg for contemporary fossil power plants). It increases to five in a turbine that was created especially to handle such circumstances. The usage of a direct-contact condenser, in which the exhaust at 5 is combined with cold water from the deep cold-water pipe at 6, creates a near-saturated water at 7, is necessary since the turbine exhaust system will be released back into the ocean during the open cycle. Now, that water is released into the ocean.

Deep water at 11°C (51.8°F) is used to produce the cooling water that enters the condenser at 13°C. The reason for this temperature increase is heat transfer from the outside water, which is becoming steadily warmer, to the cooling water within the pipe as it moves up the cold water pipe. Thus, there are three temperature differential, each of which is around 2 degrees Celsius: one between warm groundwater and working steam, one between exhaust steam and cooling water, and a third between deep water and cooling water that will eventually reach the condenser. ' These are examples of external irreversibilities that decrease the total temperature difference between the heat source and sink from 27 - 11 = 16°C (28.8°F) to 25 - 15 = 10°C

(18°F) as the temperature difference available during cycle work. It goes without saying that in order to achieve the highest efficiency feasible, the external differences must be reduced to an absolute minimum since the available temperature differences are so limited. Unfortunately, such an essential technique also produces extremely huge warm and cold water flows, and as a consequence, pumping power, as well as massive, heavy cold water pipelines.

The Closed or Anderson, OTEC Cycle Power Plant in Figure 3.2. In 1881, d'Arsonval proposed a closed cycle that also made use of the warm surface and cool deep waters of the oceans as heat sources and sinks, respectively, but called for a different working fluid that transferred heat to and away from the source and sink through heat exchangers (boiler and surface condenser). The operating fluid might be Freon, propane, or ammonia. Such fluids have operational (saturation) pressures at the boiler with condenser temperatures that are much greater than those of water (10 bar at the boiler), and specific volumes that are far lower than steam in traditional power plants.



**Figure 3.2: Illustrates the Closed OTEC Cycle Power Plant.**

In comparison to turbines that utilize the low-pressure steam of the open cycle, those that employ these pressures and particular volumes are substantially smaller and hence less expensive. The issues with the evaporator are also avoided by the closed cycle. However, since the volumes of heat added and rejected are 50 times the plant's output for an efficiency of roughly 2 percent, it necessitates the use of extremely large heat exchangers (boiler and condenser). Additionally, due to the enormous surfaces of these units and the need to allow for the greatest possible temperature differential across the turbine, the temperature variations between the boiler and condenser must be maintained as low as feasible. The closed-cycle technique was initially put out by Barjot in 1926, while Anderson and Anderson's idea from the 1960s is the most current. The Anderson cycle is another name for the closed cycle. With a 20°C difference between heated surface water and chilly water, the latter 600 m below the surface, the Andersons decided to use propane as the working fluid. At 10 bars or greater, propane is vaporized in the boiler and expelled at around 5 bars in the condenser. The Anderson OTEC system uses thin plate-type heat exchangers rather of the customary heavier and more costly shell-and-tube heat exchangers in order to decrease the bulk and quantity of material (and hence expense) necessary to produce the very large heat exchangers. The heat exchangers are positioned at depths where the static pressure of the water in either exchanger about equates to the pressure of the working fluid to assist minimize the thickness of the plates. Therefore, if propane is the boiler's working fluid at 26.7 °C and 9.9 bar,



## Additional technologies

### Fluid fuel

The current tariff disputes involving active IPPs have brought the choice of fuel into sharp focus. In retrospect, several experts have also said that using liquid fuel for initiatives like the DPC was a mistake. However, this logic misinterprets liquid fuels and is excessively constrained. Naphtha is unquestionably the least popular and most expensive fuel in the world, however it does fall within the criteria and description of a liquid fuel. There are also eminently feasible alternative liquid fuels, such as furnace oil, LSHS, etc., where liquid fuel power plants are commercially viable. Furnace oil is the least expensively volatile liquid fuel, making it the clear choice for many liquid fuels-based IPPs. There are several great benefits to using furnace oil. Furnace oil is a powerful low grade fuel for energy production with an average gross calorific value of 10,200 Kcal/Kg. Furnace oil has no further commercial use outside being burned to produce energy, in contrast to more basic and refined fuels like naphtha and natural gas. At the present international oil pool, the price of crude oil has fluctuated between \$55 and \$65 a barrel (Sept.—2005). It has great promise for cheap power generating costs. Furnace oil will in fact be the preferable substitute for liquid fuel IPPs because to its efficient and tried-and-true technology of power production with heavy fuel-operated diesel engine-based power plants. In addition, developing captive power plants and IPPs based on DG technology has a far shorter gestation time than building combined cycle power plants using gas turbines or steam turbines. High sulphur concentration may be used as a scare tactic by opponents of DG technology and heavy fuel use. However, because the government has cleared IPPs to utilize furnace oil as fuel with sulphur at 2% by weight, this is not a very problematic issue.

In addition, LSHS or its Indian equivalent, LSWR, if utilized, will account for an even lower sulphur content of between 0.5% and 0.8%. By building chimneys tall enough for exhaust gases to leave, the pollution control standards for burning both of the aforementioned heavy fuels in diesel engine power plants may be satisfied. Both the furnace oil and LSHS are always available. Fuel handling, transportation, and storage are much easier to set up. Additionally, it is anticipated that over time, furnace oil will have the most consistent and predictable pricing levels. Additionally, it offers the chance to use furnace oil while paying less in import fees for fuel. All of these will aid the government in reducing future fuel import costs, which is desired. All medium and small IPPs may begin their projects if they want to convert to DG power plants based on furnace oil under the given conditions. This path has already been taken by several IPP proponents. It is encouraging that at least some, if not all, have come to the conclusion that using the most technically and financially feasible fuel for liquid fuel-based power generation is more judicious and time-saving. Additionally, IPPs may independently source their liquid fuel needs; no fuel connection is required for project approval.

Naphtha was the most disputed subject. This fuel was largely imported to use as feedstock for the petrochemical and fertilizer industries. It is still unclear why it was ever considered for energy production. Government specialists believed that the extra naphtha generated locally might meet the demands of the power plants that used liquid fuels. However, since it contains HAN (High Aromatic Naphtha), the grade generated locally could not be utilized for gas turbine combustion (Low Aromatic Naphtha). This revealed a terrible ignorance of the technology behind gas turbines, which are used to generate electricity, and their fuel application process. This strategy persisted till it came to an end.

After the government finally permitted alternative fuels, diesel engines powered by heavy fuels for medium- and small-scale liquid fuel-based power plants gained popularity. The best fuel to utilize in diesel power plants is heavy fuel, particularly furnace oil grades. The most dependable sort of

power generating system is one that burns furnace oil utilizing four-stroke engines. Given that furnace oil is used as fuel, the idea of extending the use of diesel engines to IPPs makes logical. For a 35 MW power plant, the gestation period for such projects might be as short as 14 months. As residual fuels, furnace oil and LSHS have no additional commercial use except burning to provide energy. Both naphtha and natural gas are used as raw materials for the fertilizer and petrochemical industries. As a result, the idea of residual fuels is exclusive to the power production sector and maritime propulsion. A modest estimate of roughly Rs. 3.50 per KWhr of energy might be used to estimate the generation cost from fuel oil power plants. These generating costs take into account all relevant factors, including the price of furnace oil, lubricating oil, operation and maintenance expenses, interest on capital and borrowings, depreciation, etc. Over the last two years, crude oil prices have fallen to their lowest troughs in a decade. The somewhat less unpredictable cost of heavy fuels like furnace oil, LSHS, and residual fuels during the last ten years was one of the primary factors that led India's liquid fuel captive power plants to switch to diesel engine technology. The OPEC nations have largely been responsible for the weakening of the crude oil cartel over the last couple of years, which has eliminated the monopolistic character of the oil pool or cartel of the chosen countries that has control of 80% of the world's oil reserves. The price of Brent, the global standard, is between \$27 and \$28 a barrel. For nations like India, using heavy fuel diesel engine technology for power production for the medium capacity (up to 150MW range) of the power plants would be strategically worthwhile. To achieve the optimum operating economics in terms of lower generating costs, all small and medium-sized IPPs should preferably seek to this option.

Extraneous manipulations cannot accomplish supply and demand mechanisms. They are really a result of market forces operating freely. A better plan would be to boost cash inflow via improved sales and a larger market share in order to shift the oil market in a favorable direction. Crude oil producers that pursue such a strategy will eventually benefit and be able to meet the demands of their own populations in terms of increased GDP, per capita income, technological advancement, etc. Lack of agreement on oil price and stock mobilization leads to parallel, monopolistic, and borderline opportunistic coalitions of oil exporters. This unofficial alliance's goal was to crush OPEC and cut down on production of crude oil so that it would sell for more money. This market price structure may be explained by a variety of factors. Among these are the global crude oil market's stock excess, the low level of industrial outputs everywhere, and the impact of the world economic downturn on the energy markets, which is followed by a decline in demand.

From this vantage point, India's bilateral negotiations with Iraq for a part-barter agreement for the delivery of petroleum at \$7 a barrel should be seen as a step forward. To make up for differences in crude oil prices around the globe, the remaining payment will be made via the counter-trading of wheat of equal value. Such pricing mechanisms should be welcomed in India in order to curb the rising oil pool deficit and develop useful technologies and fuel alternatives.

### **Fuel Cell Engineering**

An electrochemical reaction between hydrogen and oxygen powers fuel cells. For the generation of electricity, fuel cells are dependable, efficient, and safe for the environment. Fuel cells have been used successfully in several applications, including the production of fixed and portable electricity. Projects on several fuel cell types have been undertaken by the Ministry of Non-Conventional Energy Sources (MNES) via a number of institutions. These initiatives have produced fuel cell prototypes, fuel cell system components, and fuel cell materials and catalysts. For the generation of decentralized electricity, phosphoric acid fuel cell (PAFC) stacks have been created and proven. A 50 kW (2 25 kW) PAFC power plant has been created and tested by BHEL, Hyderabad, for the distribution of electricity as part of a project sponsored by MNES. The SPIC Science Foundation, Chennai, has created a better 5 kW Proton Exchange Membrane (PERM) fuel cell module as part of a government-funded R&D initiative and successfully demonstrated its usage for on-site power

production and vehicle propulsion. The development of robust ion-exchange membranes as well as the performance and dependability of systems were under way.

A compact Molten Carbonate Fuel Cell (MCFC) stack has been constructed by the Central Electrochemical Research Institute (CECRI), Karaikudi. A 1 kW solid oxide fuel cell (SOFC) power pack is being developed by the Central Glass and Ceramic Research Institute (CGCRI), Kolkatta. The Indian Institute of Science (IISc), Bangalore, will build a 100-watt liquid-feed solid polymer electrolyte direct methanol fuel cell as part of an R&D initiative supported by MNES (DMFC). Another project involving chemical technology is being worked on by the Indian Institute of Technology (IIT), Madras and Chennai in association with SPIC Science Foundation. For the reformation of methanol into hydrogen for fuel cells, BHEL and the Indian Institute of Chemical Technology (IICT), Hyderabad, have developed catalysts and reformers. The SPIC Science Foundation in Chennai has created and tested a PEMFC-based uninterrupted power supply (UPS) system to give single-phase AC power at 220 volts, 50 Hertz. Indian Institute of Technology, Madras, Chennai has received this system for testing and demonstration. In an R&D initiative, the SPIC Science Foundation discovered a variety of polymers and investigated their feasibility as fuel cell electrolytes. For use in applications requiring high temperatures, modified nation membranes have indeed been created. The mechanical strength of films made of block polymers of polystyrene has been increased by adding an appropriate reinforcing agent. Up to 100 sq cm of area in membranes have been created.

In order to conduct a literature review on the different kinds of polymeric membranes used in PEMFCs, the National Chemical Laboratory (NCL), Pune, obtained significant patents and reprints of pertinent works. Based on the expected proton transport characteristics, they chose the appropriate monomers and synthesis methods. Additionally, NCL has used surface fictionalization to create a variety of proton conducting polymers, including polyamides, polybenzimidazoles, and surface fictionalized polymers. For the fuel cell stack, memory electrode assemblies (MEAs) have been created. A prototype is currently being created utilizing MEAs. An initiative to optimize the design of a proton exchange membrane fuel cell stack using cutting-edge computational methods is being collaboratively carried out by the Indian Institute of Technology, Madras, Chennai, and SPIC Science Foundation, Chennai. The first modeling work has started. The use of fuel cells for electric car operation and small-scale power production has previously been proven. It is suggested to start undertaking initiatives and tasks pertaining to the field testing and demonstration of fuel cell devices. The performance of systems and components may be improved for increased dependability by using the information, data, and experience acquired on the operation of fuel cells under real-world settings. During the Tenth Plan, MNES wants to start a Technology Mission of Fuel Cells.

### **Hydrogen as a Fuel**

The simplest element is hydrogen. Just one proton and one electron make up a hydrogen atom. The universe's most abundant element is also this one. Despite its ease of use and availability, hydrogen never exists on Earth as a gas by itself; instead, it is always coupled with other elements. For instance, water is made of hydrogen and oxygen (H<sub>2</sub>O). Numerous organic substances, particularly the hydrocarbons which make up many of our fuels like gasoline, natural gas, formaldehyde, and propane, include hydrogen.

Reforming is the process of applying heat to hydrocarbons to remove the hydrogen from them. The majority of hydrogen produced today is done so using natural gas. Water may also be broken down into its oxygen and hydrogen components using an electrical current. Electrolysis is the name given to this process. Under certain circumstances, some bacteria and algae that use sunlight as their energy source may even produce hydrogen. Despite having a lot of energy, pure hydrogen creates practically minimal pollution when it is used in an engine. Since the 1970s, NASA has utilized liquid

hydrogen to launch the space shuttle and other rockets into orbit. The electrical systems of the shuttle are powered by hydrogen fuel cells, which also produce pure water, which is used by the crew.

Hydrogen and oxygen are combined in a fuel cell to generate electricity, heat, and water. Batteries and fuel cells are often contrasted. Both transform the chemical reaction's energy into useful electric power. However, the fuel cell never runs out of power and will continue to generate energy as long as fuel (hydrogen) is available. A potential idea is the use of fuel cells to power electric motors that drive cars as well as provide buildings with heat and energy. Pure hydrogen is the ideal fuel for fuel cells. However, it is possible to reform fuels like natural gas, methanol, or even gasoline to create the hydrogen needed for fuel cells. Methanol may even be used to fuel certain fuel cells directly, without the need for a reformer. Hydrogen may eventually join electricity as a significant energy transporter. An energy carrier transports energy and provides it to users in a form they can use. The sun and wind are examples of renewable energy sources that cannot continuously provide electricity. However, they might, for instance, generate electricity.

**Hydrogen Energy Technology (As a Fuel)** In chemistry, you learned that hydrogen is a flammable gas. There is a lot of heat released when burning. Only water vapour is created. Burning hydrogen produces no harmful gas. Explosion is a real possibility while burning hydrogen. Furthermore, it is challenging to securely store hydrogen. In an effort to lower the risk of an accident, modest amounts of hydrogen are being burned. Future predictions indicate that everyone will be able to utilize hydrogen as a fuel. Even now, hydrogen is employed as a rocket fuel. Fuel cells and other devices may use hydrogen as an effective energy source since it is a clean fuel. From water, unconventional energy sources, and other fuels, hydrogen may be created. A wide variety of uses for hydrogen might be utilized to environmentally friendly complement or replace the usage of hydrocarbon fuels and fossil fuels. The widespread use of hydrogen as a fuel would decrease the need for fossil fuels and maintain clean, pollution-free air. At several research, scientific, and educational institutions, labs, universities, and companies, this Ministry is funding research, development, and demonstration projects on different elements of hydrogen energy, including generation, storage, and usage of hydrogen as fuel.

Different processes may be used to manufacture hydrogen from unconventional energy sources. Technologies for producing hydrogen using electrolysis, photolysis/photobiolysis, photo-electrolysis, and thermos-chemical reactions are actively being developed and used. The availability of resources, knowledge, infrastructure, and economic considerations will all influence the choice of manufacturing techniques and technologies. Studies on semiconductor-septum solar cells for pilot-scale hydrogen generation by photocatalytic breakdown of water were conducted by the research group at Banaras Hindu University (BHU), Varanasi. The Chettiar Research Center (MCRC), Chennai, initiative will produce hydrogen from organic effluents at a pre-commercial level and optimize a number of parameters for hydrogen production. At Nillikuppam, photo bioreactors measuring 0.125 m and 1.25 m have been constructed. The MCRC is currently building a 12.5 m capacity reactor. Twelve heterotopy bacteria and two phototropic bacteria were identified for the production of hydrogen from various sources. The project aims to show sustained biological hydrogen generation at a pre-commercial level, investigate and optimize different parameters, and provide documentation for commercial exploitation of the technology for treating industrial biological effluents. A laboratory size bio-hydrogen production unit is also being developed by the research team at BHU, Varanasi, to produce hydrogen from bagasse.

The Indian Institute of Technology (IIT), Madras (Chennai), is working to create an indigenous Mischmetal-based alloy-based hydrogen storage system. A hydrogen storage device made of 100 g of AB alloy, 100 unique SS tubes, and a filter has been built, and its operational



performance has been examined. It has been investigated how to design a bigger hydrogen storage system that makes use of specific SS tubes, a heat exchanger, and an alloyed flow meter. The hydrogen storage system uses four Mischmetal-based AB and Ab alloys, which have a respectable plateau pressure at ambient temperature. An additional research team at IIT Madras in Chennai has investigated the design features of innovative metal hydride reactors for green energy conversion technologies. Metal hydrides have been preliminarily screened and chosen using a concept for use in certain energy conversion devices. Analyses are being conducted on a variety of energy conversion systems using appropriate metal hydrides, such as carbon nanotubes and Zr-based hydrides. Analysis of transient heat and mass transport is being carried out. The reactor bed's design elements are also being researched.

The MNES-funded project proposes to field test and showcase 5 hydrogen-powered two-wheelers at BHU in Varanasi. To go up to 100 kilometres, each vehicle will need roughly 20–25 kg of hydrogen storage material. As part of this initiative, BHU has created novel composite materials for storing hydrogen. 5 motorbikes are among the materials and equipment for which purchase orders have already been made. A compressor-driven metal hydride system for cooling and heating purposes is being developed at IIT Kharagpur. The design optimization of a functioning prototype for a 1 kW metal hydride compressor-driven space cooling system that uses hydrogen as the working fluid is now complete. Compressors are among the several components that have been chosen. The development of a low-polluting hydrogen-diesel dual-fuel engine is supported by MNES. The hydrogen-diesel dual fuel engine (125 KVA) has been successfully run by IIT Delhi. The features of this system's exhaust emission and engine performance are only two of the many aspects that have been researched. During the Tenth Plan, MNES proposes to launch a technology mission on hydrogen energy.

### **Battery-Powered Automobiles**

The Government of India's Ministry of Non-Conventional Energy Sources (MNES) is implementing a program on Alternative Fuel for Surface Transportation that focuses on the creation and introduction of battery-powered cars (BOVs). BOVs don't use any oil, don't make any noise, and are ecologically friendly. For use in vehicle traction, the Central Electrochemical Research Institute (CECRI), Karaikudi is creating high-energy lithium polymer batteries with a 1 ah capacity and 350 life cycles. LiCoO cathode active material has previously been created and characterized by CECRI, and fundamental cell research as well as the optimization of polymer electrolyte sheets have been completed. According to experiments on charge-discharge, cells have efficiencies of greater than 60%.

**The Center for Materials for Electronics Technology (C-MET)** in Pune has approved a project that calls for the creation of innovative syntheses, characterizations, and electrochemical investigations on high-grade cathode materials for rechargeable lithium batteries used in electric vehicle applications. One of the cathode materials for lithium batteries is lithium manganese oxide. With the use of several characterisation methods, C-MET has produced cathode materials. The development of prototype lithium cells and the optimization of different parameters for the cathode materials created so far in this research are ongoing tasks. Laboratory size lithium ion secondary cells with aluminum as the negative electrode and lithium manganese oxide as the positive electrode have been put together and characterized by the Indian Institute of Science (IISc), Bangalore. For the separation of negative electrodes and electrochemical characterization, many carbon samples are employed. For the preparation of positive electrodes and electrochemical characterization, commercial lithium cobalt oxide is employed. Over a lengthy cycle life, a discharge capacity of 60–80 mAh/g has been attained.

Using a variety of activation techniques, NCL, Pune has created carbonaceous materials based on coconut shell carbon for super capacitor electrodes. Activated carbon has been made in the lab using several processing techniques using KOH, ZnCl<sub>2</sub>, LiOH, and CsOH, among others. After gas phase activation, the BET surface area is in the range of 800–1000 m<sup>2</sup>/g. Using Ru and Ir metal oxides, the study team also created carbon composite electrodes. Development of solid electrolyte materials for electrochemical double layer super capacitors is a project being carried out at the IISc in Bangalore. For use in ultra-capacitor applications, the Institute has created solid polymer electrolytes of silicate-salt composites based on the sol-gel technique. The developed material exhibits a 300–400 Farad per gram capacitance. Solid electrolytes based on polyacrylonitrile have been created, and capacitances on the order of a few hundred Farads have been attained. Applications using super capacitors would involve the investigation of various solid electrolyte systems. A project to create super capacitors based on conducting polymers is being carried out by the CECRI in Karaikudi. N-type and p-type conducting polymer composite electrodes have been made and examined by the Institute for usage in super capacitors. In order to attain better performance, it is now manufacturing and studying a model super capacitor. Under a different project, the Nimbkar Agricultural Research Institute (NARI) in Phaltan developed and tested 20 battery-assisted cycle rickshaws in Maharashtra. Encouraged by the results, NARI intends to create and use more of these passenger rickshaws. The Ministry approved a pilot project for 300 battery-operated three-wheelers (BOTWs) to be shown in Agra and other cities by M/s Scooters India Limited (SIL), Lucknow, and M/s Mahindra Eco Mobiles Limited, Mumbai. 250 BOTWs are already in use in Agra, Allahabad, Ahmedabad, Delhi, Kolkata, Lucknow, and Pune for demonstration, awareness-raising, and advertising purposes as well as to collect performance data on the vehicles under real-world driving circumstances. In addition to battery-operated buses and minibuses, the Ministry expanded the demonstration program's focus on BOVs in the years 2002 and 2003 to include battery-operated passenger three-wheelers and passenger vehicles. Through the Nodal Agencies and Departments of the States and Union Territories, this program offered subsidies for the purchase of certain kinds of locally produced automobiles. During the Tenth Plan, MNES proposes to launch a technology mission on battery-operated electric vehicles.

### **Technology Using Biofuel**

The two main concerns in the nation right now are environmental contamination and the conservation of imported petroleum products. Therefore, it is necessary to look for alternatives to gasoline and diesel for usage in cars and diesel engines. Ethanol, which is now mostly utilized as a raw ingredient for the chemical industry, in pharmaceuticals, and for drinking water, is increasingly being considered as a viable fuel for cars. Ethanol improves gasoline combustion when combined with gasoline since it contains oxygen molecules, leading to a cleaner burn and fewer pollutants. Edible and non-edible oils like *Jatropha curcas*, Karanje, honge, etc. are possible additional biofuels. Recent global developments have made the usage of biodiesel and ethanol gasoline blends intriguing new choices for traditional, unaltered diesel cars.

The Ministry is attempting to reduce the use of imported petroleum products in automobiles by developing technology for the production of ethanol via various routes, converting various non-edible oils to bio-diesel, and developing kits and modified engines capable of using biofuels with 10% and more blends. The Ministry recently conducted a research on policy analysis in preparation for formulating a long-term biofuels strategy. For the makers of adapted engines and kits that allow the use of biofuels, as well as producers of ethanol and other biofuels, a special loan program based on interest subsidies has been created for the current fiscal year. Andhra University has been granted funding for a research and development initiative to create



an aqua-porthole and establish the engine requirements needed to utilise the new fuel. In partnership with several oil companies and diesel vehicle manufacturers, efforts are being made to start a demonstration project on the use of biodiesel in diesel cars. This will be followed by the initiation of a Technology Mission on Biofuels.

### **Hyaluronic Power**

Water flow produces energy that may be harnessed and converted into power. This is referred to as hydropower or hydroelectric power. The most popular kind of hydroelectric power plant stores water in a reservoir using a dam on a river. When a reservoir is drained, water passes through a turbine, spinning it and turning on a generator to generate electricity. However, a huge dam is not always necessary to generate hydroelectric power. Some hydroelectric power stations simply direct river water through a turbine using a small canal. Even electricity may be stored in a different kind of hydroelectric power station known as a pumped storage facility. The electric generators get the electricity from a power grid. The turbines then move water from a river or lower reservoir to a higher reservoir, where the electricity is stored, while the generators spin them backward. Water is discharged from the higher reservoir back into the river or lower reservoir to generate electricity. In turn, this propels the turbines ahead and starts the generators, which generate energy. For a house, farm, or ranch, a tiny or microhydroelectric power plant may provide adequate energy.

### **Heat Exchanger Innovation to Save Energy**

Saving energy Producing energy is not only a cliché; it is also in the majority of global enterprises. One such device that minimizes the consumption of energy sources like coal, oil, and gas is the heat exchanger. It has the ability to put India's fertilizer sector on level with the most productive ones worldwide. The Department of Chemical Engineering at IIT Delhi, the pilot plant site for the Innovative Heat Exchanger, produced state-of-the-art manufacturing. The pilot project has a cost of Rs. 2.46 crore and was developed after three years of planning and study.

About 25% of the equipment deployed in the fertilizer sector uses heat exchangers. The process industries now use shell and tube heat exchangers, plate type exchangers, and helical pipe exchangers. The cost of energy alone accounts for 70–80% of the overall cost of producing fertilizer in fertilizer plants. In 1996–1997, the fertilizer industry produced a record 11.20 million tons, including 2.82 million tons of phosphate fertilizer and around 8.38 million tons of nitrogen fertilizer. The sector now has an influence on the national economy in addition to being a crucial link in the food chain. Ammonia plants are still being designed and built with less energy use. As a consequence, energy consumption for naphtha-based plants has decreased from previous levels of 16–18 Giga Calories/Metric Tonnes to the current values of 7.5–8.0 G Cal/MT of ammonia. The significance of energy conservation measures in the fertilizer industry has increased recently, and all new facilities are built using the most contemporary low energy consumption concepts. Although all processes will lose some energy from the system, there is a significant opportunity to cut energy consumption. The theoretical thermodynamic heat demand for ammonia synthesis is around 4.47 GCal/MT, as opposed to the present average usage of 8 GCal/MT.

Its performance is enhanced, residence time is decreased, and thermal time distributions may be achieved by enhancing mixing between fluid components of various ages and temperatures. The novel heat exchanger has flatter velocity profiles and reduced temperature gradients. Due to the cross-sectional mixing that centrifugal force causes, innovative heat exchanger is also widely used. Any heat exchanger's performance will be greatly enhanced by a uniform temperature environment. The unique heat exchanger's design is based on the principle of

centrifugal force. An innovative approach has been used in the current technology to effectively take use of centrifugal force. The flow created in this device is constrained by the curvature of a fixed surface, and as a result, the flow's direction varies continually, deflecting the velocity vector locally. One of the key characteristics of fluid flow in this device is the creation of complicated secondary flows as a consequence of this. By rotating the plane of vortex generation at any angle, the new flow geometry takes use of centrifugal force. This phenomenon makes it easier for fluid components of various ages and temperatures to mix together. The heat transfer coefficient increases significantly as a result.

Following a technical conversation with the management and technical team in the fertilizer sector, many possible applications for this cutting-edge heat exchanger to take the place of the current heat exchangers were found. among them are: Lean solution/BFW exchanger, CO<sub>2</sub> ejector steam generator, CO<sub>2</sub> ejector steam reboiler, NH<sub>3</sub> refrigeration condenser, methanator feed preheater, CO<sub>2</sub> strip reboil/shift effluent coolers feed gas, CO<sub>2</sub> stripper overhead trim cooler, CO<sub>2</sub> strip club condenser air cooler, lean-solution cooler (air cooler), CO<sub>2</sub> stripper condenser air cooler, and distillation pre- In comparison to a pipe heat exchanger, there is a 15-20% increase in heat transmission and a 60-70% decrease in the exchanger area. The use of this device has the dual benefits of intensifying convective transfer processes (i.e., increasing heat and mass transfer coefficients) and increasing the transfer area per unit volume of space. It provides a greater film-coefficient, or the rate during which heat is transmitted from one fluid to another through a wall, and makes better use of the pressure drop that is already there, resulting in more effective and less costly designs. High-induced stresses or expensive expansion joints are not necessary when using the Innovative Heat Exchanger shape to handle high temperatures and large temperature differentials. Compact size has clear advantages for manufacturing convenience and performance that is much closer to plug flow systems. It may function as a heat exchanger, an inline mixer, a separator, and in chemical reactors, among other things. It has many uses, including in blood oxygenators with coiled membranes, kidney dialysis machines because they are effective at reducing concentration polarization, chemical reactors because of their longer residence times and reduced axial dispersion, heat exchangers, cryogenic systems, biosensors, clean steam generators, natural gas heaters, freeze condensers, chromatographic columns, sample coolers, and room heaters.

### **A Range Of Energy**

Energy may be classified into a number of different categories, including nuclear, electrical, thermal, chemical, and radiant energy. Additionally, kinetic energy and gravitational potential energy combine to create mechanical energy. Heat is produced by heat engines when nuclear energy creates heat via fission on nuclei. The greatest source of emission-free energy in the world is nuclear energy. Nuclear energy is produced via the fission and fusion processes. Atomic nuclei of uranium or plutonium separate during fission, releasing energy. When tiny nuclei join together or fuse, energy is produced in fusion. All currently operating nuclear power facilities employ the fission process since fusion can never be regulated. Steam engines are heated by nuclear energy. A nuclear power plant uses uranium as its fuel in a steam engine, and as a result, it has a poor efficiency.

In modern world, the majority of households and industries run on electricity. Some items, such flashlights and Game Boys, require power that is chemically stored in batteries. Other gadgets make use of power that comes from a wall socket or an electrical plug. Energy is conducted or transferred from one location to another through electricity. The movement of energy is what creates electricity. Electrons are orbiting in atoms, some of which are just weakly connected. An electrical current is produced when electrons flow between the atoms of matter. Although it is kinetic and potential energy, thermal energy is linked to the arbitrary

motion of atoms in an item. Thermal energy is the kinetic and potential energy related to this random microscopic motion. The seas of the planet contain a substantial quantity of thermal energy (heat). The seas take up as much heat from the sun each day as there is in 250 billion barrels of oil (Ocean Thermal Energy Conversion Systems). Chemical processes may provide energy in the form of chemical energy, which is produced via the oxidation process. Chemical energy is the potential energy that is released when a chemical reaction takes place. An excellent example is a car battery, as the chemical reaction creates the voltage and current needed to start the vehicle. During the photosynthesis process, a plant produces more chemical energy than it does water and carbon dioxide. In scientific laboratories, chemical energy is employed to create electricity from gas and generate medicines.

There are many different wavelengths of radiant energy, ranging from radio waves with lengths of thousands of meters to gamma rays with lengths as small as a million-millionth ( $10^{-12}$ ) of a meter. Through the process of photosynthesis, radiant energy is transformed into chemical energy. Gravitational potential energy and kinetic energy are the next two forms of energy, and they work in tandem. Potential energy and kinetic energy are two separate characteristics of mechanical energy, which is the source of the word "energy."

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## CHAPTER 4

### ESSENTIALS OF A POWER PLANT

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Every time a mass-containing item is in a force field, potential energy is present.  $PE = mgh$ , where PE is energy in joules, m is the object's mass, g is the gravitational acceleration, and h is the object's height, gives the potential energy of an object in this situation. Motion is created by kinetic energy. A moving item possesses kinetic energy, whether it is moving vertically or horizontally. Vibrational kinetic energy the energy resulting from vibrational motion rotational kinetic energy the energy resulting from rotational motion and transnational kinetic energy the energy resulting from mobility from one site to another are three distinct types of kinetic energy. Kinetic energy's equation is  $\frac{1}{2}mv^2$ , where m stands for mass and v for velocity. This formula demonstrates how an object's kinetic energy is directly related to the square of its speed.

#### **Power**

Energy per time is equivalent to power, which is the pace at which work is done. Thus, in order to create electricity, energy is needed. To operate power plants and produce electricity, we require energy. To operate our appliances and heat our houses, we need electricity. Electricity would not exist without energy.

Watts, joules per second, and horsepower are the different types of power, with 1 Watt equal to 1 joule per second.

Kilowatts equal 1,000 Watts.

A megawatt is equal to 1,000 kilowatts and a horsepower.

The most practical and adaptable kind of energy is electricity. As a result, it has been in more demand than other sources of energy. Over the last several decades, the power sector has also seen extraordinary expansion in terms of both its volume and technical complexity. Electricity consumption in a nation is a measure of productivity and development since it is essential to both the industrial and agricultural sectors. Power development has so been accorded top emphasis in the development agenda.

#### **Indian Power Development**

India's history of electricity development began in 1897 with the commissioning of a 200 kW hydro-station in Darjeeling. In Calcutta, the first steam station was built in 1899. The entire capacity by the year 1920 was 130 mW, which included. Diesel 6 mW, thermal 50 mW, and hydro 74 mW. The overall capacity increases to 1208 mW in 1940. Due to the Second World War, progress was very sluggish from 1935 until 1945. By the end of 1951, the overall generation capacity was 1710 mW. The first five-year plan's introduction in 1951 marked the official beginning of development.

Construction of many major river valley projects, including Bhakra-Nangal, Damodar Valley, Hira Kund, and Chambal Valley, was undertaken under the First Plan. The electricity generation increased as a consequence of these developments. The first plan's finish saw a

generating capacity of 34.2 lakh kW. The Second Plan (1956–1961) placed a strong emphasis on the growth of light and heavy industries as well as the associated requirement to increase electricity production. At the conclusion of the Second Plan, installed capacity was 57 lakh kW, made up of 3800 mW thermal and 1900 MW hydropower. The Third Plan's focus on expanding electricity access to rural regions (1961–1966). The creation of the Inter-state Grid System was a notable breakthrough during this time. To encourage electricity growth on a regional basis, the nation was split into five regions. an area electricity. In order to enhance the integrated functioning of the component power system, boards were constituted in each area. The Third Plan was followed by three annual plans with the goal of bringing together the Third Plan's programs.

The Fourth Plan foresaw the need of central involvement in the construction of power production programs at key sites to support state sector operations. With installed capacity increasing to 313.07 lakh kW compression at the end of the Fifth Plan, with 113.86 lakh kW from hydroelectric projects, 192.81 lakh kW from thermal power projects, and the remaining 6.4 lakh kW from nuclear projects, there was significant progress made during the period spanning the Third Plan, three Annual Plans, and Fourth Plan. Total capacity expansion of 196.66 lakh kW, made up of hydro 47.68 lakh kW, thermal 142.08 lakh kW, and nuclear 6.90 lakh kW, was projected under the Sixth Plan. However, 142.26 lakh kW, or 72.3% of the objective, had been achieved (28.73 lakh kW hydro, 108.98 lakh kW thermal, and 4.55 lakh kW nuclear). In utilities, the Seventh Plan's power program called for a total generating capacity of 22,245 mW. This made up 15,999 mW of the planned 22,245 mW of extra capacity in thermal, 5,541 mW in hydro, and 705 mW in nuclear. 9320 mW of additional capacity (7,950 mW thermal, 665 mW hydro, and 705 mW nuclear) was planned to be added under the Central Sector Program throughout the course of the Plan Period. 21401.48 mW total, made up of 17104.1 mW thermal, 3,827.38 mW hydro, and 470 mW nuclear, have been added during the Seventh Plan. The year-by-year commissioning of the additional hydro, thermal, and nuclear capacity from 1985–1986 to 1989–1990 is provided. A capacity addition program of 38,369 mW has been recommended for the Eighth Plan period by the Working Group on Power, which was specifically established by the Planning Commission inside the context of formulation of the power program. Of this, it is anticipated that the Central Sector Projects will add a capacity of 17,402 mW. The Eighth Plan's first year's program (1990–1991) calls for the production of 4,371.5 mW extra capacity, made up of 1,022 mW of hydropower, 3,114.5 mW of thermal power, and 235 mW of nuclear power.

The Concurrent List of the Constitution contains the topic "Power," and as a result, both the federal government and the state governments are responsible for its growth. The Ministry of Energy's Department of Power is in charge of developing electric energy at the national level. The department is responsible for creating policies, long-term planning, selecting projects for investments, overseeing projects, developing staffing and training programs, and administering and enacting laws related to the production, transmission, and distribution of electricity. The department is also in charge of carrying out any revisions to the Indian Electricity Act of 1911 and the Electricity (Supply) Act of 1948. The foundation of the administrative framework for the electrical sector is the Electricity (Supply) Act of 1948. The Act calls for the creation of a Central Electricity Authority (CEA), which will be tasked with, among other things, creating a national power policy and coordinating the efforts of several organizations and State Electricity Boards. In order to expand CEA's authority and functionality and make it possible to establish enterprises that produce energy, the legislation was revised in 1976.

The Department of Power seeks advice from the Central Electricity Authority on technical, financial, and economic issues. The National Thermal Power Corporation (NTPC), National



Hydro-Electric Power Corporation (NHPC), and North-Eastern Electric Power Corporation (NEEPCU), all Central Power Corporations under the administrative control of the Department of Power, are responsible for the construction as well as operation of generation and transmission projects inside the Central Sector. The Department of Power also has administrative responsibility over the Bhitkara Beas Management Board (BBMB), which was established under the Punjab Reorganization Act of 1966, and the Damodar Valley Corporation (DVC), which was established under the DVC Act of 1948. Additionally, the department oversees the Central Power Research Institute (CPRI), Beas Construction Board (BCB), and Power Engineers Training Society, which are training and research organizations and construction agencies, respectively (PETS). The Rural Electrification Corporation (REC), a funding organization, is in charge of programs for rural electrification. “ The Nathpa Jhakri Power Corporation and Tehri Hydro Development Corporation are two joint venture power corporations that fall under the administrative supervision of the Department of Power and are in charge of carrying out the Nathpa Jhakri Power Project and the Projects of the Tehri Hydro Power Complex, respectively. The European Economic Community and other organizations collaborated to create the Energy Management Centre, an independent organization in charge of training, research, and information sharing among energy experts. It is also in charge of the Department of Power's energy saving programs and initiatives.

The development of transmission and distribution infrastructure across the nation has advanced significantly. Transmission lines with a voltage of 66 kV or higher had an overall length rise from 10,000 circuit kilometers in December 1950 to 2.02 lakh circuit kilometers in March 1990. The country's current highest transmission voltage is 400 kV, and as of March 1990, more over 80,000 ckt km of 400 kV lines had been built, with roughly 18,000 ckt km of them actually in use. Since producing stations were predominantly constructed in the State Sector prior to the Fourth Plan, the Transmission Systems in the Country were created more or less as state systems. A possibility of linked operation of individual state systems with other surrounding systems within the area (northern, western, southern, eastern, and north-eastern) was considered after State Transmission Systems had matured to a respectable level in the Third Plan. There are now systems at a voltage of 220 kV with a gradual overlay of 400 kV in all parts of the country with the exception of the north-eastern region. The Center began taking on a bigger role in the design of grid systems with the founding of Two Generation Corporations, notably National Thermal Power Corporation and National Hydro-Electric Power Corporation in 1975.

The National Power Grid would be made up of the 400 kV transmission systems that these organizations are building as part of their generation projects as well as 400 kV interstate and interregional transmission lines. The National Electricity Grid will encourage coordinated operation and the transfer of power from one system to another with the ultimate goal of ensuring the country's resources are used as effectively as possible. India now has highly linked regional power networks, and frequent power transfers between many different state systems considerably enable greater use of available capacity.

### **Resources for the Production of Power**

Due to its unconventional nature and longevity as a source of energy, the hydel power source is essential to the production of electricity. Because of this, it is known in French as "huile blanche" or "white oil-the force of flowing water." It is a non-conventional energy source, as opposed to black oil. a portion of the never-ending cycle in which the sun raises water, creates clouds, and then releases it back to the ground to feed rivers whose flow may be used to generate hydroelectric power. A key demand of the modern power business is non-pollution, and water is a non-polluting energy source. The potential for waterpower worldwide is



estimated to be 1500 million kW at mean flow. Accordingly, 6.5 million kW-hr of energy would be produced at a load factor of 50%, which is equivalent to 3750 million tonnes of coal burned at a 20% efficiency. Only 65 million kW, or 4.3% of the mean flow, of installed hydropower capacity was estimated for the whole globe in 1963.

India has enormous waterpower potential. The average annual river flow in India is around 1675 million cubic meters, of which 555 million cubic meters are available for human use. The Himalayan Rivers provide 60% of overall river flows (Ganga, Indus and Brahmaputra). 16 percent comes from rivers in central India (Narmada, Tapi, and Mahanadi), and the remainder rivers that drain the Deccan plateau (Godavari, Krishna and Cauvery). According to a recent study, India has a potential for 41500 mW of hydropower, but its actual hydropower capacity is just 32000 mW. India still has plenty of room for hydroelectric development to fulfill the growing demand for electricity in the country. Its growth in India was facilitated by the abundance of water resources, their generally uniform distribution, and the country's overall economic climate. Other elements contributing to its quick growth include locally available resources, inexpensive labor, and technical expertise. Given the significance of this supply, the government has included a number of hydro-projects in the IX five-year plan. The main challenge in creating hydroelectric projects is how long it takes to do the hydrological, topographical, and geological research. Lack of appropriate site is an additional issue while implementing hydro-projects. In the past, hydropower dominated the world's electrical energy supply, and it still does in Canada, Norway, and Switzerland. However, since the 1950s, its usage has diminished in other nations as readily accessible, substantially less costly fuel. Only 10% of the electricity produced in the USA is produced using water. The role of hydropower is now again being reviewed in light of fuel shortages and its rising costs, and greater emphasis is being placed on waterpower development. According to Mr. Hays (Manager of Hydro Projects in the USA), Building a single 1000 mW thermal plant was less expensive per mW than constructing 20 small hydro-plants. However, interest in hydro is growing again as a result of rising fuel prices and the expensive expense of achieving environmental standards for new thermal plants. The feasibility of small hydro-projects with a power output of 10 to 1500 kW is increasing as the cost of standardized key equipment falls. One significant option to address the current power crisis is via the development of micro-hydro projects, which India has yet to do.

Hydropower projects provide electricity at a cheap cost, are unconventional, simple to administer, pollution-free, and do not place unreasonably high demands on the transportation system. The main disadvantage is that it is dependent on the weather. The risks of relying too much on hydropower have been highlighted by many instances of poor rainfall. Riches sang an old prayer that is still said today: "Let rivers flow and let showers shower the world with wealth." There are several advantages to developing hydropower systems as a backup for thermal systems. The adaptability of hydraulic turbines' functioning makes them appropriate for operating under peak demand. Thus, the growth of hydropower not only makes financial sense but also addresses the main issue of peak demand. The current Indian power development strategy accords the development of hydrogen power enough priority. Fuel in the form of coal, oil, or gas is the next crucial source for the creation of electricity. Unfortunately, India has relatively little access to oil and gas resources. Oil and gas are seldom used as energy sources in power plants. It is not advisable to utilize oil for power production in India since the country imports the majority of the oil it needs. The estimated 121,000 million tonnes of coal resources in India are concentrated in West Bengal, Bihar, Madhya Pradesh, and Andhra Pradesh. Nearly 140 million tonnes of coal are produced annually at the current pace, of which 40 million tonnes are utilized to produce electricity. The majority of the coal used to generate electricity is low-grade coal with a high ash percentage (20–40%). Since current steam power plants were built

for low ash coals, one of the reasons for their poor performance and frequent outages is the high ash percentage of Indian coal (40–50%). Enough focus has been placed on thermal power plants throughout the IX plan era due to the substantial coal resources that are accessible in the nation. The placement of thermal plants is influenced by the supply of fuel or the availability of transportation infrastructure if the power station is to be built distant from coalmines. The site of hydropower plants is mostly governed by the natural terrain that is available. Any location may be chosen for a nuclear power plant while giving proper regard to load and safety. India must take into account nuclear power production in locations far from coal mines and water power plants. States with limited natural resources and those with few untapped conventional resources for future growth must take the construction of nuclear facilities into consideration.

Uranium is the nuclear fuel that is most often utilized in nuclear power reactors. Uranium deposits have been discovered in Rajasthan and Bihar. According to estimates, the country's current uranium stocks may provide 10,000 mW power plants for its thorium throughout the nuclear Indian lifespan. The abundance of thorium in this nation, which is believed to be 500,000 tonnes, makes it another potential source of nuclear energy. However, the commercial use of this nuclear fuel is dependent on the advancement of fast breeder reactors, which transform energy into profitable methods. These methods must be developed by the end of the twentieth century.

Lack of technical infrastructure and foreign currency needed to buy the primary nuclear power plant component is the biggest obstacle to the development of nuclear power in this nation. By 1980–1981, Dr. Bhabha predicted 8000 mW of nuclear power from reactors, which Dr. Sarabhai later reduced down to a more achievable amount of 2700 mW. Of this, only 1040 MW less than 1.5% of the nation's installed power capacity have realized. Additionally, compared to thermal plants, the performance of nuclear reactors has been good.

### **India's Current Power Position**

The current electricity situation in India is concerning since there are severe power shortages in practically all of the states, which cripples industry and results in the loss of hundreds of thousands of jobs and significant productivity. The nation's overall electricity situation reveals severe deficits in almost every state. The problem will worsen in the next years as a result of the power industry's inability to keep up with the growing demand. In India, a lot of the states rely heavily on hydropower for their energy needs.

The construction of new plants has not kept up with the growth in demand. Furthermore, there isn't a central grid to transfer extra energy from one area to another. The knowledge about how to operate thermal plants is insufficient. All of these have caused serious shortages and human suffering. To resolve the electricity crisis in our nation, a very thorough understanding of the issue, good planning, and effective implementation are required. the right hydrothermal mixture, the optimum phasing of new plant construction, and staff training for thermal plant maintenance.

### **Future Power Generation Planning**

Power industry has been given great priority in the country's development plans because of its significance to the overall growth of the nation. About 29% of investments made under the sixth plan are in the energy industry alone. The entire investment in the energy industry will make up around 40% of the projected investments when transportation investments for coal and oil as well as other infrastructures are included. The fact alone is sufficient to demonstrate the significance of the power sector for the development of the nation. The expenditure for

electricity during the sixth plan period has climbed to Rs. 15750 crores from only Rs. 149 crores during the First Plan. Between 1951 and 1978, the installed generating capacity increased ten-fold, from 2300 mW to 25900 mW. This was broken down into 11000 mW for hydro, 14000 mW for thermal, and less than 1000 mW for nuclear power plants. At the end of March 1978, there were 127 power plants with capacity of 20 mW or more, of which 65 were hydroelectric, 60 were thermal, and 2 were nuclear. From 1950–1951 to 1978–1979, power production increased by 103754 million kWh, or about 15 times, or 7514 million kWh. The number of people who used electricity in total increased from 15 lakhs in 1950 to 2641 lakhs in 1978–79. Electricity use per person increased from 18 kWh in 1950–51 to 121 kWh in 1978–79.

This industry is unable to fulfill demand despite these steps. Power shortages are becoming a common occurrence throughout the nation. The actual availability in 1978–1979 was just 97588 million kWh, which was less than the predicted need of 108656 million kWh, representing a shortfall of around 11070 million kWh or 10.2%. The demand for electricity in the nation is rising quickly as a result of the large-scale industrialisation program and growing agricultural activities. If the current pattern holds, there will be a 125–150 million kW demand for electricity by the end of the year 2000. The required overall producing capacity by the year 2000 would be between 175 and 200 million kW, taking into account the necessary reserve margins for planned maintenance.

This would result in an 8–10 times increase in current capacity. To accomplish the necessary expansion, the nation's hydro, thermal, and nuclear resources must be properly developed. Only 16% of the available hydel-potential (41,000 mW) has been exploited, therefore there is still room to expand this source of energy in the future. The northern area has the most hydel potential. Even if all of the hydel potential is realized, the rising demand cannot be satisfied. As a result, thermal potentials must be added to hydel potentials. Although India only has around 176 tonnes of coal per person, compared to nations like China with 1170 tonnes, the United States with 13500 tonnes, and the former Soviet Union with 22000 tonnes, India is undoubtedly underdeveloped in terms of coal reserves. The country's distribution of coal is likewise unequal (60°C coal is only accessible in Bihar and Bengal). The construction of transportation infrastructure is further required by this.

As a result, relying only on the growth of thermal power is also not viable. Future consideration of the use of nuclear fuel for the generation of electricity is also crucial, especially in areas with limited access to coal resources and low hydropower potential. Future planning for power development should focus on maximizing the use of existing resources to reach a power mix of hydro, thermal, and nuclear.

The establishment of central sector super-thermal power plants around the nation is a further step to be made in the power development business. The Farakka, Ramagundam, Korba, and Singrauli super-thermal power plants have been providing electricity for the last 20 years. At the moment, all of them are providing deficit states with electricity through the national grid. Even 20 mW hydro potentials have not been produced in our nation, despite the fact that it would seem beneficial to construct even 20 kW units. The stress on already-existing plants has been significantly lessened by the development of minor hydro potentials, such as those in China. The growth of biogas may reduce the pressure on household consumers' access to oil, which would otherwise be redirected to power production.

### **Cycles of Thermodynamics Related To Power Plant**

The study of several processes involved in converting one kind of energy into another is known as thermodynamics. It is a collection of accounting rules that enables us to comprehend and

track energy when it changed into different forms or states. After the first law, the zeroth law of thermodynamics was established. It asserts that two bodies must be in thermal equilibrium with one another if they are both in thermal equilibrium with a third body. Equilibrium presumes the presence of a state in which there is no net charge change in the system and no net heat transfer between the bodies.

According to the first rule of thermodynamics, energy cannot be generated or destroyed. The overall quantity of energy stays constant when one kind of energy is changed into another. A gasoline engine is an illustration of this rule. Chemical energy in fuel is transformed into kinetic energy, potential energy, chemical energy in carbon dioxide, and water in exhaust gas, among other kinds of energy.

The entropy law, which states that all physical processes progress in a manner that makes the available energy involved less available, is the second law of thermodynamics. In other words, no conversion of an energy source can ever be 100% efficient. According to the second law, the resources that support the material economy must and will inevitably deteriorate. Entropy is a metric for chaos or disorder; as entropy rises, so does disorder.

The third law of thermodynamics states that a perfect crystal has zero entropy at absolute zero Kelvin, which is in accordance with the rule of unattainability of absolute zero temperature. It is impossible to achieve since it is the coldest temperature that might ever exist and can only be approached.

This equation serves as a reminder that there are absolute boundaries in physics, similar to the efficiency of an ideal engine, even if it is not required for the majority of thermodynamic work. When it comes to steam engines, the steam power plants use a modified Rankine cycle, and when it comes to impulse and reaction steam turbines, they use an isentropic cycle. I.C. Engines (Diesel Power Plants) operate on the Otto cycle, diesel cycle, or dual cycle; gas turbines operate on the Brayton cycle; nuclear power plants operate on the Einstein equation as well as the fundamentals of fission or fusion. But when it comes to unconventional energy production, it may be complicated and relies on whether the system uses thermoelectric or thermionic fundamental theories.

### **Power Plant Cycle Classification**

Generally speaking, power plants cycle into the following categories: Vapour Power Cycle 1 (Carnot cycle, Rankine cycle, Regenerative cycle, Reheat cycle, Binary vapour cycle) Gas power cycles (2) (Otto cycle, Diesel cycle, Dual combustion cycle, Gas turbine cycle.)

#### **Does Not Cycle**

Despite the fact that it has not been able to build a real plant using this cycle, it is of significant significance to the theory of heat power. It has a high efficiency in thermodynamics. It serves as a benchmark for all subsequent cycles.

The Carnot cycle's thermal efficiency is as follows:  $T_1$  is the temperature of the heat source, thus  $\eta = (T_1 - T_2)/T_1$   $T_2$  is the receiver's temperature.

#### **Circle of Rankine**

The Rankine cycle is employed in steam engines and steam turbines that use steam as their working medium in Figure 4.1. Four pieces of equipment connected by pipes for the conveyance of the working media may perform this cycle as depicted. The cycle is shown on the Pressure Volume P-V and S-T graphs.

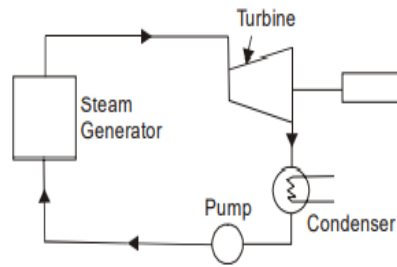


Fig. 1.1

Efficiency of Rankine cycle  

$$= (H_1 - H_2) / (H_1 - H_{w2})$$

where,

- $H_1$  = Total heat of steam at entry pressure
- $H_2$  = Total heat of steam at condenser pressure (exhaust pressure)
- $H_{w2}$  = Total heat of water at exhaust pressure

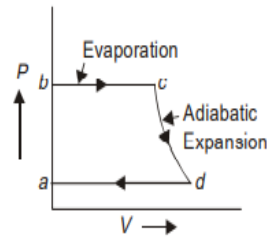


Fig. 1.2

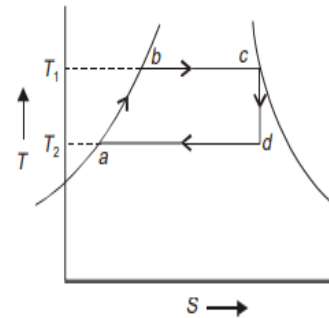


Figure 4.1: Illustrates the circle of Rankine cycle.

### Reheat Cycle

In this cycle, steam is taken out of the turbine at an appropriate location and normally warmed to its original temperature by flue gases. When the pressure is high, say over 100 kg/cm<sup>2</sup>, rewarming is often performed in Figure 4.2. The following are some of the many benefits of reheating: I It raises the dryness percentage of steam at the exhaust to lessen blade attrition brought on by the impact of water particles. It improves thermal effectiveness (ii). (iii) It reduces the size of the boiler by increasing the amount of work done per kilogram of steam. Reheating has the following drawbacks: I the reheater and its lengthy connections raise the cost of the plant. (ii) The increasing dryness percentage boosts condenser capacity.

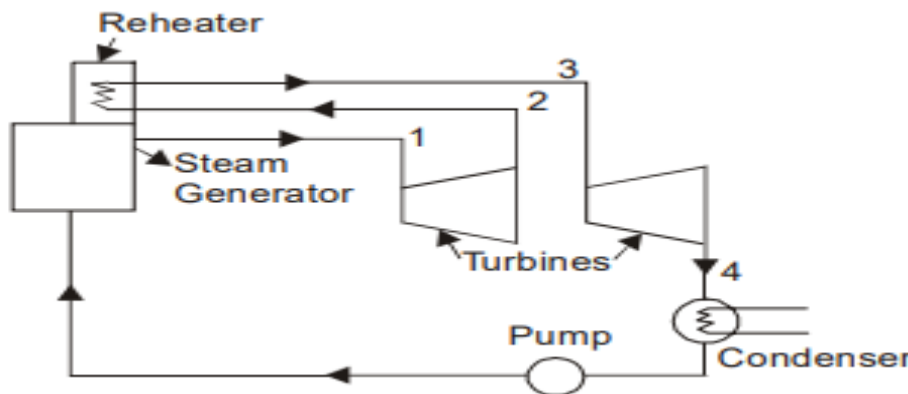


Figure 4.2: Illustrates the schematic diagram of reheat cycle.

### Regenerative Cycle (Feed Water Heating)

Regeneration or bleeding of steam is indeed the process of removing steam from the turbines at certain periods during its expansion and utilizing it to heat feed water setup for steam bleeding in two phase in Figure 4.3.

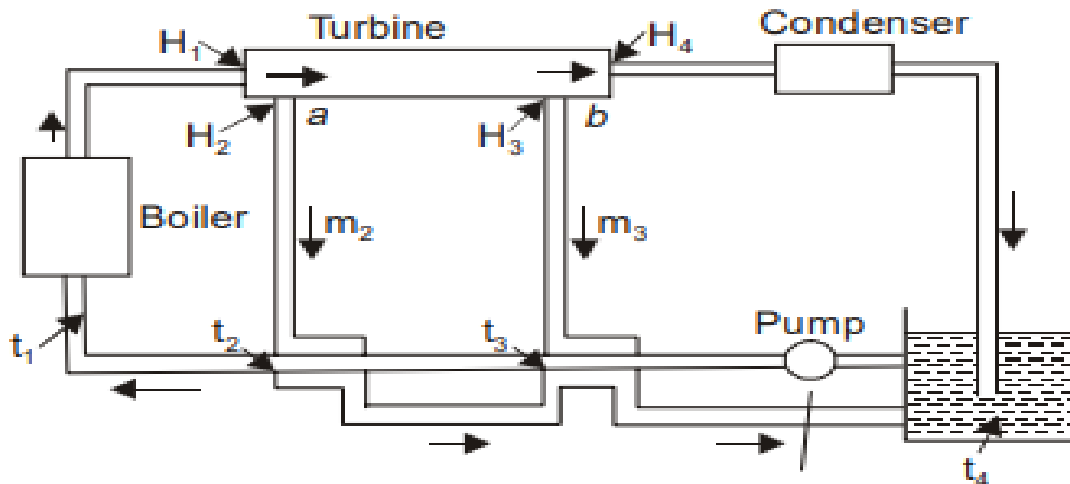


Figure 4.3: Illustrates the schematic diagram of Regenerative Cycle.

### Binary Vapour Cycle

Two working fluids from a binary vapour power plant are employed in this cycle. The mercury is heated in a dry, saturated condition to produce mercury vapours in the mercury boiler in Figure 4.4.

Those mercury vapours increase in size in the mercury turbine before passing through a heat exchanger that heat the input water and turn it into steam. In the steam super heater, the steam is heated to a much higher temperature by the hot flue gases. In the steam turbine, the steam then expands.

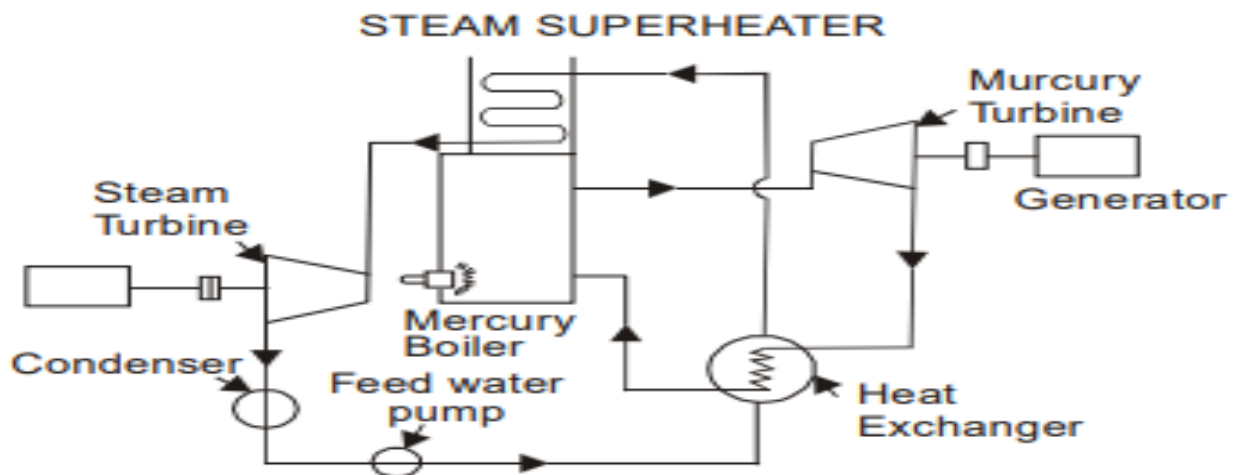


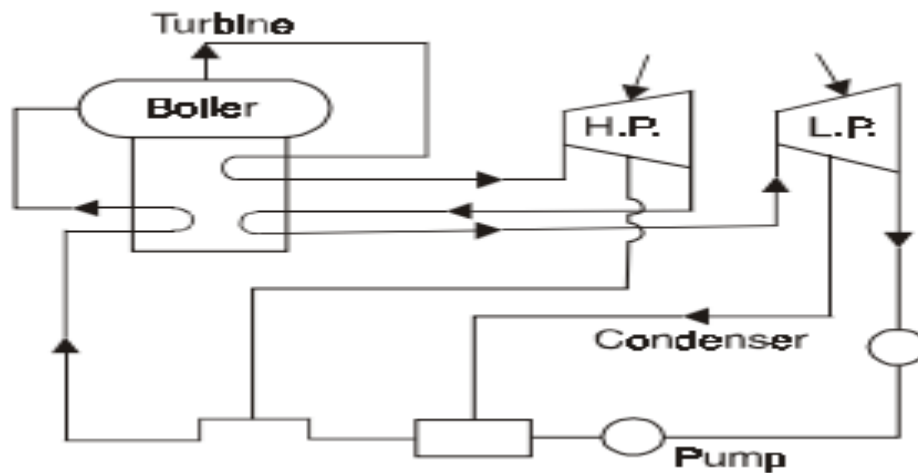
Figure 4.4: Illustrates the schematic diagram of Binary Vapour Cycle.

### Reheat-Regenerative Cycle

Reheat regeneration cycle is utilized in steam power plants that employ high steam pressure. This cycle has a better thermal efficiency than only the reheat or regeneration cycles in Figure 4.5. The reheat regenerative election cycle flowchart.

To boost the cycle's performance, high pressure steam (90 kg/cm<sup>2</sup>) is often produced using this cycle.





**Figure 4.5: Illustrates the schematic diagram of Reheat-Regenerative Cycle.**

### Combustion and Fuel

The primary component of an energy conversion device, or prime mover, known as fuel, transforms natural energy sources into electricity or power. In the case of steam power plants, internal combustion engines, gas turbines, and hydroelectric power plants, the much more common fuel is fossil fuel, such as coal, gasoline, diesel, or water gas. In the case of nuclear power plant fission reactors, uranium 235 ( $^{235}\text{U}$ ) as a fissionable fuel and  $^{238}\text{U}$  as fertile fuel, and hydrogen as gasoline in the case of nuclear power plant fusion reactors. Due because of its uncontrolled reaction rate, fusion reactor is thought to be non-conventional whereas fission reactors are conventional. It is also claimed that Russians have built it while keeping the rest of the world in the dark. According to their properties, the fuels used in non-conventional power plants include thermionic materials (Na, K, Cs, W, etc.), thermoelectric materials ( $\text{Bi}_2\text{Te}_3$ , bismuth telluride, lead telluride, etc.), hydrogen or hydrocarbons or coal for fuel-cells, and more recently, water and methane. Any energy conversion gadget must burn the fuel in order to function. It is described as a chemical process that is accelerating quickly and releasing heat and light. This phenomena first appeared in gas turbines and I.C. engines used in thermal power plants. But in the case of a fuel cell, it takes the form of a chemical reaction, namely the transfer of ions. In a similar way, a thermoelectric generator conducts electrons and holes, and an MHD power plant drifts positive and negative ions, among other examples.

### Generators of steam

Power generating, industrial process heating, and space heating all need steam. When compared to other boilers, the capacity of the boilers used to generate electricity is notably big. Because of the need for great efficiency, steam is generated for power generation at high pressures and in massive amounts. They are very huge in size and have unique designs depending on the fuel type that will be utilized. In general, process heating boilers are smaller in size and produce steam at a significantly lower pressure. They have a simpler design and are consistently built following the same plan. Although the majority of these boilers are used to generate heat, some, like locomotive boilers, are also used to generate electricity. Several simple boiler types will be discussed in this chapter. A closed vessel built of premium steel in which steam is produced from water by that of the application of heat is referred to as a boiler or steam generator. Through the heating surfaces of the boiler, the hot gases heat the water. Fuel, which might be

coal, oil, or gas, is burned to produce the hot gases. The boiler's heating surface is the area that is exposed to hot gases solely on a single side and water or steam on the other. The boiler's super heater and appropriate pipes are used to remove the steam that has accumulated on the water's surface, which is subsequently used to power turbines or motors or to heat an industrial facility. A boiler includes a steam generator as well as a number of other components that contribute to the system's safe and effective functioning. Accessories and mountings are the names of these components.

### **Prime Movers in Steam**

The primary mover transforms energy from natural sources into electricity or power. Diesel engines, steam engines, steam turbines, gas turbines, and water turbines might be the main generators of power. We know that a power plant used generators to produce a flow of mechanical or electrical energy. The generator is a primary mover when coupled to an engine. The prime mover of a steam power plant is either a steam engine or steam turbine, and they are both referred to as steam prime movers. At this time, steam turbines completely replace steam engines. A boiler produces the steam, which is enlarged in the turbine. The generator is powered by the steam turbine's output. Coal or oil is the fuel utilized in the boiler.

### **Condensers for Steam**

The thermal efficiency of a closed-loop, Carnot-cycle power generation system that uses steam as the working fluid is provided by the formula  $(T_1 - T_2)/T_1$ . This efficiency formula demonstrates that efficiency rises with rising  $T_1$  temperature and falls with rising  $T_2$  temperature. Material considerations provide a cap on the maximum temperature  $T_1$  of the steam delivered to a steam prime mover. If the steam is exhausted below atmospheric pressure, the temperature  $T_2$  (the temperature during which heat is rejected) may be brought down to that level. Heat rejection is at  $100^\circ\text{C}$  if the exhaust is at atmospheric pressure.

To achieve low exhaust temperature, low exhaust pressure is required. However, if the steam is expanded inside the engine or turbine to a pressure lower than that of the atmospheric pressure, it cannot be discharged to the atmosphere. In this scenario, steam is expelled into a container known as a condenser, in which the pressure is continually kept below atmospheric pressure by condensing the steam using continuously flowing cold water heated to atmospheric pressure. A condenser is a closed vessel where steam is condensed by absorbing heat and where the pressure is kept below atmospheric pressure. The use of a condenser significantly boosts the steam plant's efficiency. Condensate recovery is crucial in big turbine plants and is also made feasible by the use of condensers.

One of the crucial elements of all contemporary steam power plants is the steam condenser. There are two different kinds of steam condensers: surface and jet.

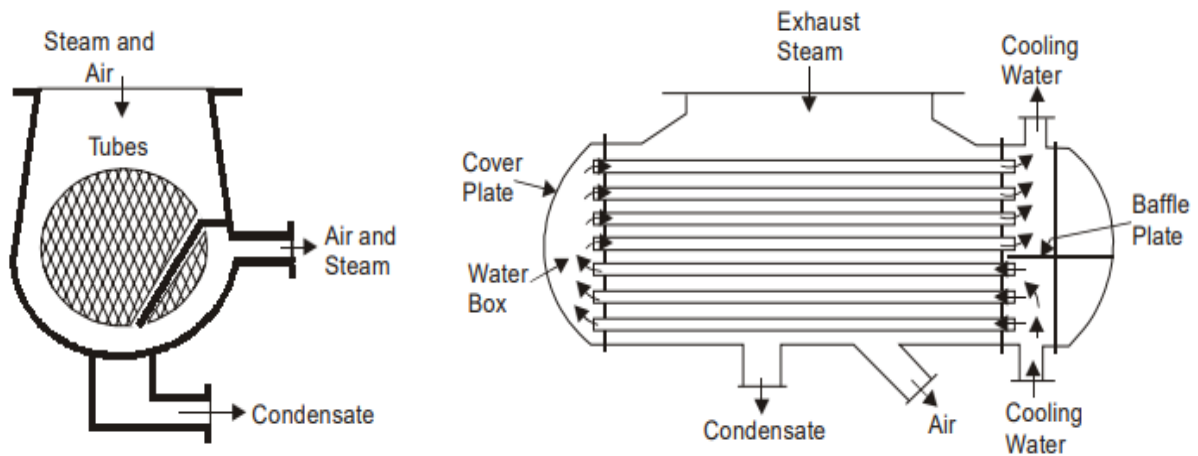
### **Roof Condensers**

Surface condensers allow the condensate to be recycled in the boiler because there is no direct contact between both the steam and cooling water there: While cooling water in jet condensers must be clean, it is possible to utilize dirty water in this kind of condenser in Figure 4.6. Surface condensers have a higher initial investment and need more area, but they are compensated by the plant's increased efficiency and reduced operating costs.

The surface condensers may be categorized as follows depending on the location of the condensate extraction pump, the condensate flow, and the arrangement of tubes:

Flow-down style view of the dawn flow condenser from a portion. Steam enters at the top and

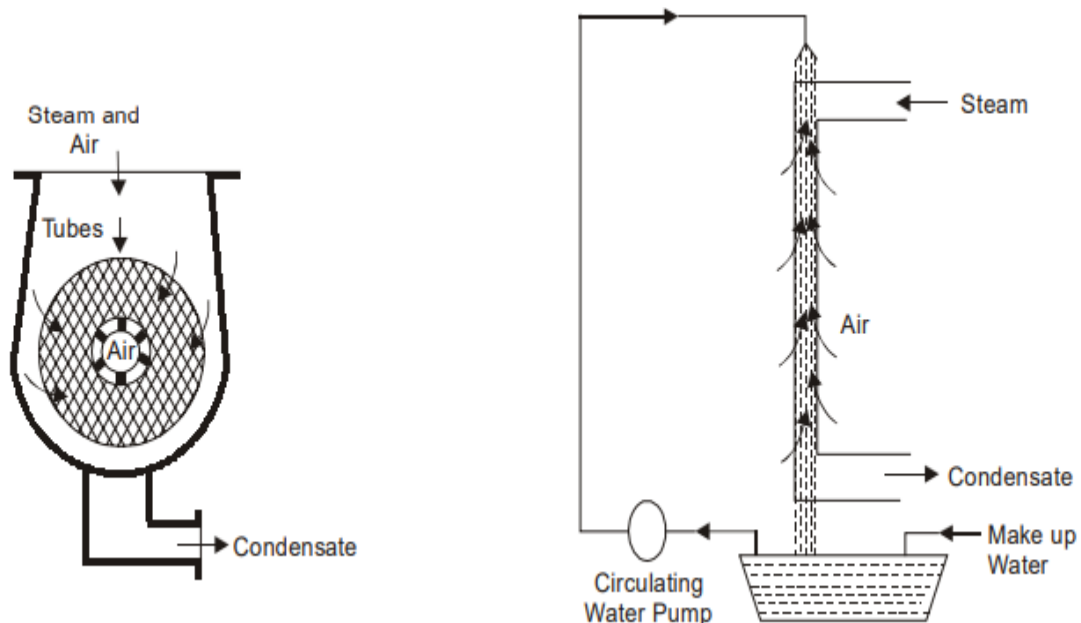
exits at the bottom. Water enters the tubes in the bottom half and exits the top half of the tubes in the opposite manner. A two pass down-flow condenser's longitudinal section is shown.



**Figure 4.6: Illustrates the schematic diagram of Roof Condensers.**

#### Central flow condenser.

A condenser with center flow, the steam tubes of this condenser wrap around the outside of the shell. Air is pushed out of the condenser's center. Condensate travels radially in the direction of the tube nest's center. While traveling towards the center, some of the exhaust steams collide with the undercooled condensate but also pre-heat it, minimizing undercooling in Figure 4.7. Steam that has to be condensed is fed through a network of tubes in an evaporation condenser, while cooling water falls as spray over the tubes. To accelerate the evaporation of cooling water, air is steaming over the tubes. This raises the condensation of steam.



**Figure 4.7: Illustrates the schematic diagram of Central flow condenser.**

#### A Surface Condenser's Perks and Contrains

The following are some of the many benefits of a surface condenser:

- Boiler feed water may be made from condensate.
- Since the cooling water does not come into direct contact with the steam, even water of low quality may be utilized.

In the surface condenser, a high vacuum may be attained (about 73.5 cm of Hg). The plant's thermal efficiency is boosted as a result. The following list includes the surface condenser's several drawbacks:

- There is a higher capital cost.
- This condenser has significant operating and maintenance costs.
- It takes up more room and is cumbersome.

#### **A Modern Surface Condenser's Requirements**

The following are the specifications for the optimum surface condenser used in power plants:

With the least amount of pressure loss, the steam entering the condenser should be spread uniformly throughout the whole cooling surface of the condenser vessel.

The volume of cooling water circulating in the condenser should indeed be controlled in such a way that the temperature of the water exiting the condenser is comparable to the steam saturation temperature for the condenser's steam pressure. This will aid in avoiding condensate undercooling.

It is important to avoid letting dirt collect on the outside surface of tubes. This is accomplished by running cooling water through the tubes and allowing steam to pass over them.

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## CHAPTER 5

### CONDENSERS JET

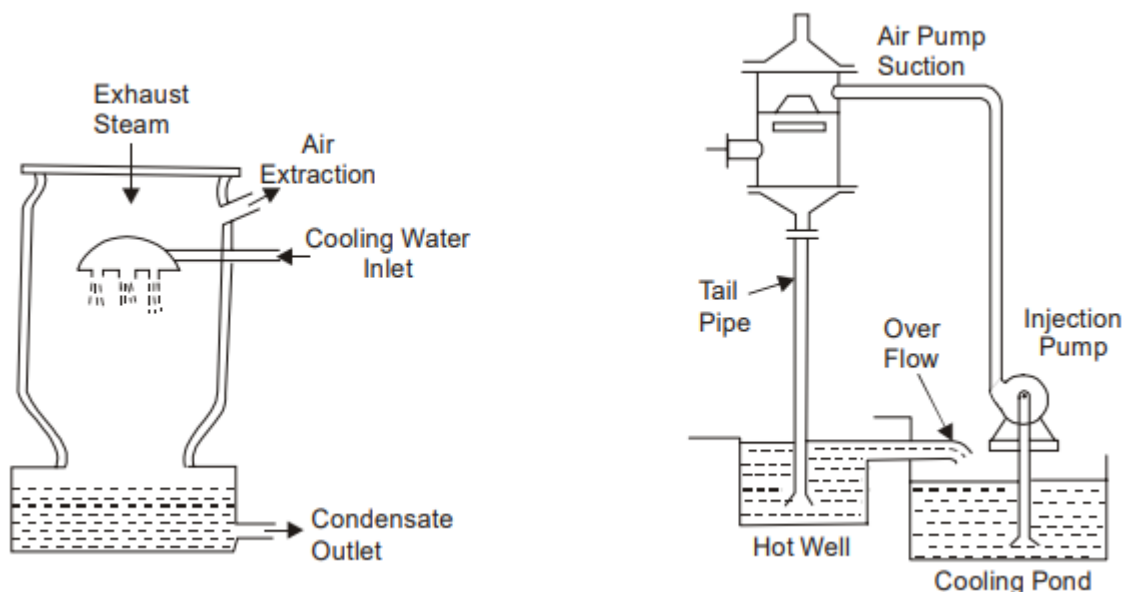
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In jet condensers, the cooling steam and water from the exhaust are in direct touch. When exiting the condensers, the condensate and cooling water are both at the same temperature. The following are the components of the jet condenser: 1. Distributors or nozzles again for condensing water 2. A steam intake. 3. Depending on whether the steam and water flow in the same direction before condensation or if the flows are opposite, mixing chambers may be either (a) parallel flow type or (b) counter flow type. 4. Warm well condensing water is referred to as injection water in jet condensers.

#### Jet Condensers: Types

Condensers for low-level jets (Parallel flow type).

Water and steam are mixed in the condenser by jets that spray water. An air pump at the top removes the air in Figure 5.1. In a condenser with a counterblow design, the steam that has to be condensed travels uphill while the cooling water goes downhill.



**Figure 5.1:** Illustrates the schematic diagram of Condensers for low-level jets.

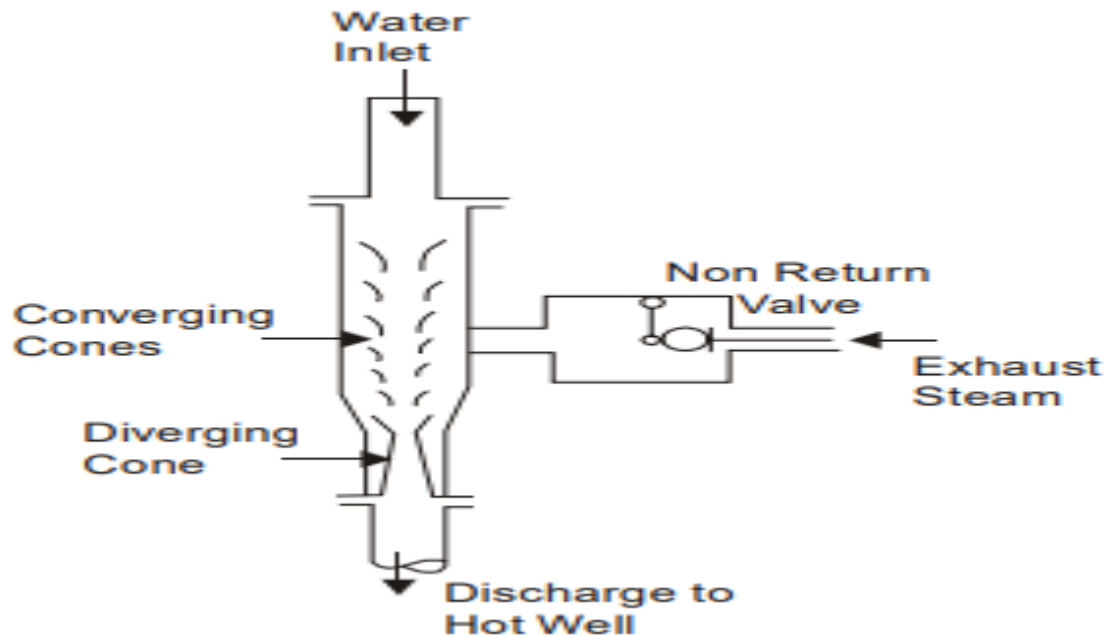
#### Barometric or high level condenser

The hot well is above the condenser shell at a barometric height of 10.33 m. vs a low level jet condenser. If indeed the water extraction pump fails, this condenser does not cause the engine to flood. To get rid of the air, a different air pump is used.

#### Compensator Ejector.

Through a series of convergent nozzles, cold water is ejected from this condenser at a head of around 5 to 6 meters. Through a non-return valve, the steam and air are introduced to the

condenser in Figure 5.2. Steam condenses when combined with water. At the convergent cones, pressure energy is partially converted to kinetic energy. To discharge liquid condensate into the hot well, the diverging cone achieves a pressure greater than air pressure by partially converting kinetic energy into pressure energy.



**Figure 5.2: Illustrates the schematic diagram of Compensator Ejector.**

### Hydraulic Water Turbines

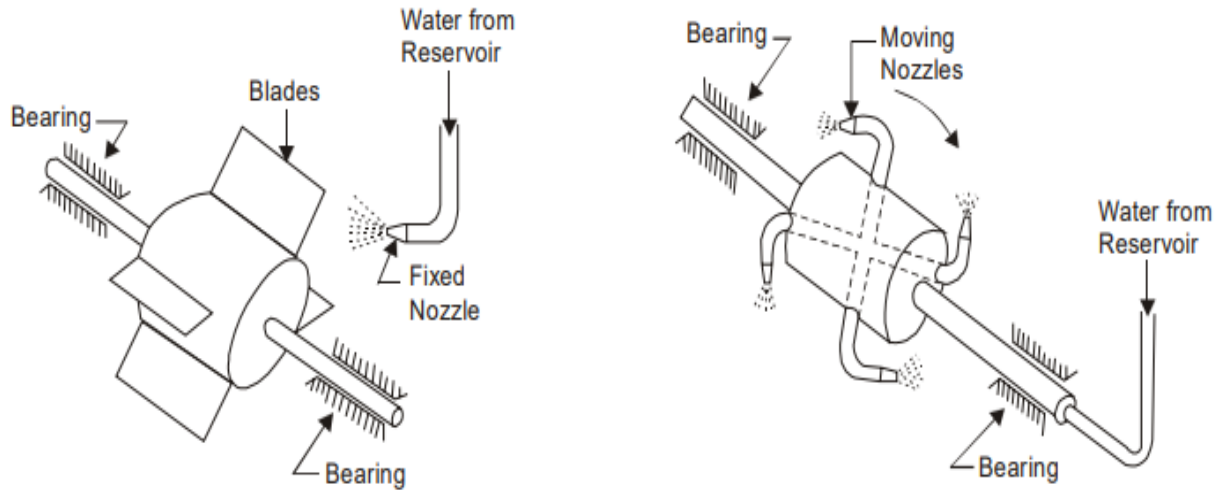
In a turbine, the high-velocity fluid jet that emerges from a nozzle changes direction, creating centrifugal forces that cause the machine to rotate. A primary mover known as a water turbine utilizes water as its working ingredient to produce electricity. A water turbine transforms water's potential and kinetic energy into useful mechanical energy. The fluid energy may be found in either natural or man-made high-level water reservoirs, which are made by building dams at strategic locations along rivers' flow paths. Energy is transferred in the turbine's blade channels when water from the reservoir is pumped there. Since ancient times, hydraulic turbines inside the form of water wheels have been employed; nowadays, their main usage is in the production of electricity. An electric generator that is directly linked to the turbine shaft is powered by the mechanical energy made available just at turbine shaft. High efficiency, operational flexibility, minimal wear and tear, and simplicity of maintenance are all benefits of the electricity produced by exploiting the potential and kinetic energy of water. Different nations have attempted to use all of their available waterpower resources, despite the high capital costs associated with building dams and reservoirs, constructing pipelines, and installing turbines (as compared to an equal thermal power plant). For the best use, the right kinds of water turbines have been built. Amid order to exploit the abundant waterpower in the current dilemma of quickly idle energy supplies, a number of hydroelectric power plants have been established and are being built in India as well. A major portion of the world's energy sources come from hydroelectricity.

### Turbines with Impulse and Reaction

To convert fluid energy into useful mechanical energy as effectively as feasible, hydraulic turbines are necessary. The quantum of potential and kinetic energy of the fluid energy may



also differ depending on the location. As a result, an appropriate turbine type must be chosen to carry out the necessary task. Water turbines are divided into impulse as well as reaction turbines based on the main working principle, depending on whether the available pressure head is totally or partly transformed into kinetic energy in the nozzle in Figure 5.3.



**Figure 5.3: Illustrates the schematic diagram of Water turbines.**

### Impulse Generator

Whereby an effective nozzle first transforms the available hydraulic energy into kinetic energy. The high-velocity jet next impacts a number of appropriately designed buckets that are fastened around the rim of a wheel after leaving the nozzle. The jet's pressure remains constant while its direction is changed by the buckets. The momentum shift that follows causes the buckets and wheels to start rotating, releasing mechanical energy at the turbine shaft. The runner has less energy after the fluid jet. An impulse turbine, also known as a free jet turbine, runs at air pressure with no change in the static pressure across the turbine runner. Important impulse turbines include the Turgo-impulse wheel, Girard turbine, Banki turbine, and Jonval turbine, among others. At the moment, Pelton wheel is most often employed.

Before the water is sent to the turbine runner, a portion of the total hydraulic energy is converted into kinetic energy in a reaction turbine. Still there is a significant portion of pressure energy. Water then moves along the turbine runner as pressure and velocity change concurrently. Because of the pressure created by the flow from the turbine's intake to its exit, the reaction turbine's blades are closed tunnels that are shut off from the atmosphere. The disc contains four radial apertures that are accessed by nozzle-shaped tubes. The water's pressure energy falls and its kinetic energy increases in relation to the revolving disc as it exits via these tubes. The disc starts to rotate as a consequence of the reaction force. In the opposite direction from the water jet's direction, the disc and shaft revolve. Fourneryon, Thomson, Francis, Kaplan, and Propellor turbines are significant reaction turbines. At the moment, Francis and Kaplan turbines are often employed.

### Utilization of Non-Conventional Energy Resources

In addition to human and animal power, the main sources of energy include petroleum resources, natural gas, coal, hydropower, biomass, geothermal, nuclear, wind, and solar energy. These resources may theoretically be used in place of one another to complete a certain goal. Technical and financial restrictions that place restrictions on the use of such energy resources

for certain purposes at specific places and at specific times would prevent replacement in reality. Few energy resources are utilized and consumed at the same place that they are discovered; instead, the majority of them need to be transported and converted via typically complex infrastructure before they can be used for the intended job. The availability of energy supplies as well as the production, processing, and distribution facilities should thus be included in the analysis.

### Science of Energy

A systematic body of knowledge concerning any aspect of nature, whether it be internal or exterior to man, is known as science. Energy science is the branch of science that studies the numerous types of energy and how it is transformed. It deals with these concepts, features, regulations, rules, units/dimensions, measurements, processes, etc. Experiments, measurements, mathematical computations, rules, observations, etc. are all part of science. Every other science interacts with energy science. Physics, thermodynamics, electromagnetics, nuclear science, mechanical science, chemical science, biosciences, etc. are all branches of energy science. Each science focuses on a certain "action." Activities are based on energy. The management of energy is a national priority. With regard to the National Economy and Civilization, energy science focuses on the "energy" and "energy transformations" that are engaged in the different other areas of science.

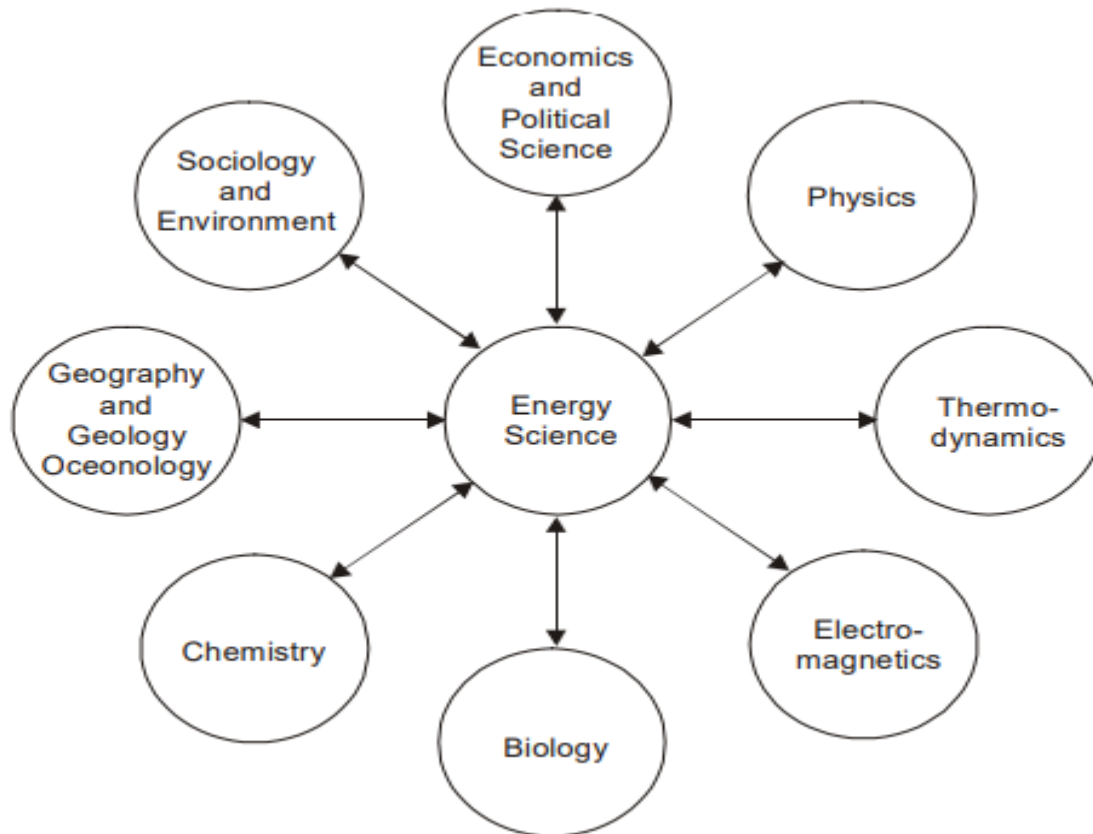
**Different Energy Science Physics:** This area of natural science studies the characteristics and transformations of matter and energy. Physics, which covers mechanics, electromagnetics, heat, optics, nuclear energy, etc., and the principles regulating energy transformations, deals with ongoing changes in matter and energy. Energy science has been created by physicists.

**Thermodynamics:** This field of physics studies the rules controlling the conversion of thermal energy into other types of energy, particularly mechanical energy. Energy Technologies heavily rely on thermodynamics.

**Biological Sciences:** It deals with biological processes and biomass. Biosciences study the physical traits, physiological functions, and decomposition of living plants, animals, and microorganisms on land and in water. The term "biomass" refers to material obtained from plants and animals. A natural non-conventional energy source, biomass has received top focus in recent years. (1980s and after) The crucial non-conventional energy source for the twenty-first century is biomass.

**Chemistry:** This branch of science studies how compounds interact with one another to produce new substances. Chemical Reactions are intermediary energy conversion processes that include the release of thermal energy (exothermic reactions) or the absorption of thermal energy (endothermic reactions). Chemical processes provide a wide variety of usable energy types (for instance, gasoline, artificial gases, and liquids). The two most significant energy sources in the globe throughout the 20th and 21st centuries are natural gas and petroleum products.

Electromagnetic fields with electrical power are produced when electrons and electrical charges move across a circuit. A subfield of physics known as electromagnetic studies electricity, magnetism, and the conversion of mechanical, thermal, chemical, and other kinds of energy into electrical energy and back again in Figure 5.4. The most superior, effective, and practical kind of energy that can be produced, transported, distributed, controlled, and used is electrical energy. Electrical energy is a secondary and intermediate source of energy that is utilized extensively across the globe the different "energy"-related scientific and technological fields.



**Figure 5.4: Illustrates the various types of energy science.**

#### **Technology (technologies in Greek):**

It is a systematic study of practical or industrial arts, applied sciences, and human and social activities, etc., that results in technological advancement via the use of equipment, plants, and automation in industry, agriculture, transportation, and other fields. Technology is indeed an applied science that deals with particular technological issues; it is concerned with meeting the immediate, long-term, and future demands of society and its people.

#### **Theoretical Energy**

Energy technology refers to the applied portion of energy sciences for tasks and procedures beneficial to human civilization, countries, and people. Different basic energies, processing, useable energies, and related plants and processes are all covered by energy technology. Exploration, transportation, conversion, and usage are all included. Energy technology is concerned with the "demand" for different secondary energy sources (usable energy) as well as the "supply" strategies. Energy-technology encompasses a variety of aspects that influence "demand" and "supply." There are several alternate ways to provide energy. For instance, to generate heat, we may utilize electricity, natural gas, or wood. Energy technology covers a range of options. To make the best decision, the energy chains (routes) between different raw energies (primary energy resources) and ultimate energy consumption are analyzed and contrasted. Energy technologies deal with the facilities and procedures that convert energy and analyze both usable energy (exergy) and useless energy (anergy). The study of diverse processes' environmental effects and efficacy is a part of energy technology. Energy technology is concerned with the whole energy pathway and its phases, including: 1. Investigating available energy sources and finding new ones 2. Non-conventional resource extraction, exploitation, or biofarming 3. The process 4. Storage in between 5. Transit/Transportation

Reprocessing, 6. 7. Middle-level storage Distribution 8. 9. Provide 10. Recycling, conservation, and use. Every phase involves measurements in terms of standard units. The long-term policies, short- and mid-term plans, economic planning, and social and environmental elements of different energy pathways are all included in the energy strategies. These are examined from the viewpoints of the globe, area, region, country, states, sub-regions, different economic sectors, communities, and people. With reference to the past, present, and future, energy science and technology provide a systematized, qualitative, and quantitative approach to energy studies for the whole of human society, for a person, and for the environment. The economy, ecology, and current and future standards of life are all influenced by energy technologies. 36 Engineering for power plants Energy science and technology is a topic that planners, economists, scientists, engineers, professionals and industrialists, societies and individuals, etc. are all very interested in.

### **Energy sciences and technology**

Energy Science and Technology" covers a variety of practical man-made and natural energy systems. The main goals are to extract, transform, change, transport, distribute, and reconvert various forms of energy with the least amount of pollution and greatest economic efficiency. Energy technology is the systematic study of different energy flow branches and how they relate to human civilization from a scientific, economic, social, technical, and industrial perspective for the benefit of both people and the environment. The science of energy is concerned with the natural laws and properties of energy, energy resources, energy conversion processes, and various phenomena related directly or indirectly to the extraction, conversion, and use of energy resources crucial to the economy and prosperity. The science of energy deals with the phenomena related with energy conversion factories and processes for generating secondary energy (electricity, heat, steam, fuel, gas, etc.) by converting primary energy sources. The field of energy science examines several elements of usable energy, including losses and other types of wasteful energy. Numerous disciplines and technologies are linked by energy technology.

Theoretically, a variety of physical, technical, and social sciences—which are often considered as different areas of study—are connected to energy technology. Each field of engineering and social science has unique coverage and goals that are mostly unrelated to those of other fields. For instance, electrical power engineering only considers energy in terms of kW, MW, voltage, and current, ignoring the many energy sources, the energy cycle, and ecological considerations. Thermodynamics deals with heat and work, but it doesn't address how to operate an electrical energy system that uses thermal power plants for its source. Social sciences may not be concerned with chemical equations and reactions, but they are focused on the environment and pollution, energy supply and demand, and the economy. Energy science and technology gives a broad picture of the energy landscape and delves into the specific interactions between diverse scientific, technological, and managerial fields. Energy technology has an impact on economic and societal planning at the national level. Energy technology affects industrial project planning and a plant's process economics. Due to the abundance of natural resources, the issues with energy technology were completely disregarded earlier in history. Energy resources and energy management were not taken into consideration throughout the development of each scientific and technological field. This strategy was made possible in part by the cheap and plentiful supply of fossil fuels (such as firewood) and the very low demand for useable energy. The use of energy rose sharply in the 20th century. Following significant developments have developed since the 1973 increase in oil prices and worldwide pollution brought on by energy conversion processes: 1. Individual, societal, and national life and the economy are being impacted by the rising cost of energy supplies. 2. An energy crisis has resulted from the

depletion of fossil fuel energy reserves (coal, petroleum products, oil, and gas). 3. Global energy resources are being depleted and energy consumption rates are rising, which is causing inflation to persist. The term for this is energy crisis. Without emission control mechanisms, large fossil power plants release fly ash, SO<sub>x</sub>, NO<sub>x</sub>, CO, and other gases into the sky, causing pollution, ecological catastrophes, global warming, acid rains, and other problems. Power plants, the environment, and energy are all interconnected. Although there are plenty of non-conventional resources in nature, the conversion technologies are still in the early stages of research and have not yet shown to be as effective economically as conventional. However, unconventional are worldwide on a modest upward trend. A man, society, country, and the whole planet face energy challenges that cannot be solved by the independent study of a single discipline of science and technology. The Integrated Energy Technology has come to the attention of planners, economists, sociologists, engineers, technologists, environmentalists, etc. due to the shortcomings of individual research. Energy technology combines the energy facets of several scientific disciplines and provides a comprehensive overview of numerous energy issues. In the context of the existing scientific, technical, and energy resources, energy technology provides different alternatives. There are specific theories, principles, equations, units, and dimensions for each discipline of engineering science. Energy science connects the equations and analyses of several engineering science fields. Energy technology examines the complete process of converting energy, from the initial input of raw energy through the supply of secondary energy. This includes engineering sciences from the fields of chemical, thermal, mechanical, electrical, biological, and nuclear.

### **Law of Energy Conservation**

Energy cannot be produced in new ways. Energy is indestructible. The overall mass and energy stay constant in a closed system. An enclosed system conserves energy. The distinction between productive and wasteful energy is not made by the law. The legislation disregards "losses" that occur outside of the closed system. Energy is transferred from one or more forms to another form or forms during an energy conservation process, which causes some work, heat transfer, and energy loss. Numerous energy conversions from one form to another may occur in a closed system that has a certain amount of both matter and energy. The closed system's overall mass and energy stay constant.

### **Global and India Resources for Energy**

We do many kinds of labor every day. It need energy to do it. Cooking and other uses of heat energy from the combustion of fuels including wood, coal, gasoline, and cooking gas are quite common. Electrical energy is created by converting other types of energy. The resulting electrical energy is utilized in industries to power heavy machinery, cars, and lights as well as radios, televisions, and radio-operated lighting. Imagine a circumstance in which energy is lacking. Our lives will come to an end, along with our everyday routines. As a result, energy is an essential component of life. This subject covers several energy sources and their properties. Energy sources are those that can provide a sufficient quantity of energy in the right form over an extended period of time. In addition to human and animal power, the main sources of energy include petroleum resources, natural gas, coal, hydropower, biomass, geothermal, nuclear, wind, and solar energy. These resources may theoretically be used in place of one another to complete a certain goal. Technical and financial restrictions that place restrictions on the use of such energy resources for certain purposes at specific places and at specific times would prevent replacement in reality. Few energy resources are utilized and consumed at the same place that they are discovered; instead, the majority of them need to be transported and converted via typically complex infrastructure before they can be used for the purpose at hand.



The availability of energy supplies as well as the production, processing, and distribution facilities should thus be included in the analysis. Several of the energy sources include:

### Sun

We may get energy in many different sources thanks to the sun. Hydrogen is the element that the sun has the most of. The condition of it is plasma. When this hydrogen is subjected to nuclear fusion under conditions of high temperature, high pressure, and high density, a tremendous quantity of energy is released. This energy radiates out throughout the electromagnetic spectrum in a variety of ways. Gamma rays and the majority of UV rays from these X-rays do not penetrate through the earth's atmosphere. However, the primary radiations that reach the planet are heat and light energy. The existence of life on earth depends on this energy. With a diameter of  $1.39 \times 10^9$  meters and a distance from earth of  $1.5 \times 10^{11}$  meters, the sun is a sphere of very hot gaseous substance. Sun has a temperature range of  $8 \times 10^6$  K to  $40 \times 10^6$  K with an effective black body temperature of 5762 K. Helium is created by the constant fusion of hydrogen (4 protons) in the sun (one He nucleus). Since mass was lost in the reaction and turned into energy, the mass of the He nucleus is smaller than that of the four protons. The solar constant, which has a value of  $1353 \text{ Wm}^{-2}$ , is the energy that the sun provides on a unit area perpendicular to the direction of radiation propagation outside the atmosphere. When it hits the planet, this radiation has a fluctuating average value of  $1100 \text{ Wm}^{-2}$ .

### Utilisation of Non-Conventional Energy Resources

39 There is a 0.29 to 2.5 micrometer wavelength range. Through both natural and artificial processes, this energy is often transformed into the conventional energy type. Wind and biomass are examples of natural processes. Heat and electricity conversion are examples of man-made processes.

### Petroleum

The most adaptable and practical energy sources currently accessible are petroleum products. Petroleum products were the most practical and cost-effective commercial energy resources because of their cheap prices up until 1973, simplicity of transportation, and unlimited divisibility. Currently, petroleum products provide between 50 and 95 percent of the commercial energy supply and practically all of the demands of the transportation sector and mobile equipment. There are just a small number of possible replacements, too. In areas where they are accessible, coal, natural gas, and hydro resources are utilised, but they also serve as the primary fuel for electric power plants. In places without electricity, kerosene is the main source of illumination while LPG and kerosene are the preferred cooking fuels. It is interesting to learn a little about the history of oil and its economic and political ramifications before continuing. Rock oil, or petroleum, may be found deep inside the earth's crust. Petroleum is drilled for in order to estimate the reserve's size and to extract oil at a regulated pace. Petroleum recovery involves three phases. The main recovery stage is when oil flows under its own pressure or by straightforward pumping. Typically, 30% of the oil in the well is the maximum recovery. The process of forcing oil out of a well using water or gas is known as secondary recovery, and it comes after primary recovery. This increases the amount that can be retrieved by 10–20%. In the third process, known as tertiary recovery, hot gases and chemicals are injected into the well to reduce the viscosity of the oil and facilitate pumping. According to its viscosity and sulfur concentration, petroleum is categorized. Crude oil from Pennsylvania has a low sulfur content and viscosity. 40 POWER Engineer plants Middle East crude oil typically has less sulfur than Venezuelan crude oil and is viscous. By separating the various components of petroleum, petroleum is refined. To create suitable fuels and chemicals, it modifies the chemical makeup of petroleum components. There are 3 main steps in the refinement of



petroleum. Distillation is a physical procedure used in the initial step to separate components based on their boiling points. The second process, cracking, involves dismantling lengthy chains in order to produce additional jet fuel, diesel fuel, and gasoline. It is a chemical reaction that uses a catalyst. The reforming process, which is the third step, turns straight chains into branched chains for improved performance in gasoline engines. Super tankers that go overseas and pipelines that traverse continents are used to deliver petroleum across enormous distances. Petroleum is moved over short distances via barges, trucks, and rail carriages. In internal combustion engines, where the fuel is directly injected into the cylinder with the piston, petroleum products are employed. Diesel engines are started by compression, whereas spark plugs start gasoline engines.

### **Evolution of Oil**

Despite the fact that oil has been known for countless generations, it is generally accepted that the first modern commercial drilling for and production of oil began in the US in 1859 when Col. Edwin L. Drake dug a well in Pennsylvania near a natural oil seepage. Within a few years, oil was widely used across the US. Overproduction had undermined the producers, who were eventually replaced by Rockefeller's Standard Oil Trust-led refineries and distributors. Prior to being required by anti-trust law to sell off all of its subsidiaries in 1911, Standard Oil controlled the US oil market. Three of the 38 businesses in the group—Exxon, Mobil, and Socal—played a significant influence in the global oil market. The "Seven sisters"—a group of seven big corporations that includes Gulf, Texaco, Shell, and BP—ruled the global oil market throughout the first part of this century. Intense rivalry existed in the 1920s and 1930s, and the potential of overproduction was made worse by recent finds in Mexico, Venezuela, Sumatra, and Iran, as well as a decline in demand during the Great Depression. Exxon, Shell, and BP, three of the main worldwide oil firms, made a covert agreement in 1928 to accept their present levels of business and to collectively determine the shares in future growth in output. The cartel that resulted from this persisted until it was dismantled by antitrust in the US in the 1940s. During this time, negotiations between oil firms and the governments of the nations that produced the oil controlled the prices paid for crude oil. This process continued throughout the 1960s, but by then the Middle East's ongoing discovery and development of substantial low-cost oil supplies had caused the price paid to producing nations to fall after the end of the conflict. A collection of oil-producing nations, including Iran, Iraq, Kuwait, Saudi Arabia, and Venezuela, who's GNP was heavily reliant on oil money, established OPEC, the Organization of Oil Exporting Countries, in an effort to stop this drop. Following a unilateral decrease by Exxon of the listed price they would pay for the supply of Middle Eastern crude oil, which was copied by other major oil firms, the producers saw the establishment of OPEC in 1960 as a defensive move. At the time, 80 percent of the crude oil sold worldwide came from the five founding members of OPEC. When all operating businesses in Mexico were nationalized in 1938, government intervention in the operations of oil corporations in their nations took a drastic turn. Churchill took control of BP (formerly Anglo Persian) far earlier, in 1913, to guarantee oil supplies for the UK Navy, although the UK was seldom ever engaged in the business administration. Venezuela, a significant exporter at the time, forced the big corporations (Exxon, Shell, and Gulf) to double their royalty payments in 1938 under fear of nationalization. Ten years later, in 1948, it successfully adopted a legislation guaranteeing the Venezuelan government a 50% share of all revenues. The majority of oil-producing nations embraced this profit-sharing structure in the 1950s and 1960s after it was quickly required elsewhere. an embargo placed by the Arab OPEC members on nations they suspected were aiding Israel during the 1973 October conflict between Israel and her neighbors, the outlook for the world's oil drastically shifted in 1973. By coincidence, the decision to increase the price of oil from \$3 to \$5.12 was made by OPEC ministers at the same moment. The Arab members of OPEC

(who made this declaration in October 1973) decided to immediately cut oil output by 5% the next day. By December 1973, the price of oil on the world market had increased to \$20 a barrel. Soon after, OPEC raised oil prices to \$11.65 a barrel, a five-fold rise over the previous price of the commodity two years before. Following this, the price steadily decreased in real terms due to inflation until the end of 1978, when the spot market once again increased in reaction to local scarcities brought on by the suspension of Iran's oil output. Following the spot market's example, OPEC started to raise posted prices once again.

### History of Oil

Numerous hydrocarbons that are discovered in sedimentary basins on or below the earth's surface are referred to as oil and gas. In general, oil or petroleum is a complex combination of the heavier (non-gaseous) hydrocarbons, with an average of two hydrogen atoms for every carbon atom. The composition of the oil varies across reservoirs and often even within a single reservoir. Its characteristics range from a light fluid to a heavy oil that is viscous and grades to asphalt. Beginning between tens of millions and hundreds of millions of years ago, when marine creatures mixed with sand and salt to produce sedimentary deposits, the process of oil creation began. As more material was deposited, it was buried, which caused an increase in warmth and pressure that compacted the sediment into sedimentary rock, or "source rock," and transformed the organic material into hydrocarbons (oil) that were imbedded in the source rock. Small oil globules moved into the highly permeable environment of reservoir rocks as a consequence of increasing pressure from ongoing burial and water flow, which saturated rock below the water table. These oil-bearing reservoir rocks are the sources out of which oil is now extracted. In certain cases, the oil got trapped in the reservoir rocks by a nearby layer of impermeable rock. There are many different kinds of geological structures that might result in oil traps. The first kind of trap, known as an antline trap, is shaped like a dome and holds gas, oil, and water under reservoir rock that is covered by an impermeable rock layer that prevents the gas and oil, which are more buoyant than the water beneath, from rising to the surface. The second kind is referred to as a "fault trap," and it may happen when impermeable rock near a fracture in the layers of reservoir rocks prevents oil from rising. POWER PLANT ENGINEERING, the fourth

Oil may now travel farther through the reservoir rock's pores because of a change in the rock's permeability. In summarizing: The remnants of marine organisms that have been deposited and buried in source rocks produce hydrocarbons. Surface tension, gravity, and pressure forces carry them into reservoir rocks, where, if there are appropriate traps, they concentrate in the rock's pores and create the reservoirs of oil and gas that are there today. For the pressure and temperature to be high enough for oil to form inside the source rocks, they must have been buried for at least a million years at depths over 1 km, but rarely more than about 4 km because the higher temperature at those depths would typically decompose the oil, leaving methane gas and petroleum coke.

The first oil wells were just a few to a few hundred meters deep, while the majority of today's producing accumulations are 500 to 3000 meters deep. The deepest producing wells are 6500 meters for oil and 7500 meters for gas. Although the pressure typically rises by 100 to 150 atm per kilometre of depth—corresponding to the depth of the underlying column of rock pore water—variations in pressure between atmosphere and 1000 atm have been observed. Although temperatures in oil reservoirs are typically below 110°C, temperatures also rise with depth at a pace determined by the geothermal gradient, typically in the range of 15 to 40°C per kilometer in oil producing regions. Seismic surveying, geomagnetic and gravitational surveys, geochemical tests, geothermal, radiation, and electrical conductivity surveys, among other techniques, have supplemented earlier exploration techniques like geological surveys,

measuring the angles of tilt of the rock strata that emerged at the surface, and correlating nearby drilling data. These exploration techniques enable the detection of potential trap structures, but they seldom reveal the existence of oil, which can only be confirmed by drilling. The differential in pressure causes oil to be forced into the borehole from the reservoir rocks. As a result, the pace of oil well output is constrained. The reserves to production ratio (R/P), expressed in years, is a gauge of a reservoir's rate of output. R/P is high in the early years, but between the ages of 5 and around 15 years, it tends to stabilize. Information on the quantity of oil present in the reservoir as well as an estimate of the recovery factor are needed to determine the potential amount of oil that might be retrieved from it. The conditions in the reservoir, the makeup of the oil, and the extraction technique all affect how much can be extracted. The current global average recovery factor is between 25 and 30 percent. The pressure-driven flow of reservoir fluids into the borehole from the reservoir rock is essential for the production of conventional oil. Typically, oil recovery procedures are divided into three groups: Primary Recovery: The oil recovered by the natural deformation processes that take place as oil is produced from a reservoir; Secondary Recovery: The additional oil recovered as a result of water/gas injection into the reservoir to support the naturally occurring drive processes; Enhanced Recovery/Tertiary Recovery: Oil recovery by processes aimed at higher displacement efficiencies than those obtained through the natural processes of water and gas drive, like us; and Tertiary Recovery: The additional oil recovered as a result of artificial processes. Reserves of oil. The amount of oil that can be produced on a commercial scale with the available technologies is referred to as the proved reserves. Currently, the world's proven reserves comprise roughly 1047 barrels (1047 bbl), 77% of which are found in OPEC nations (1996 estimate). In 1996, 71.7 million barrels of crude oil were used daily on a global scale. According to OPEC, by the year 2020, global oil consumption might increase from the 70 million barrels per day it was in 1995 to somewhere near 100 million barrels per day. The greatest known reserves of crude oil are included in Table 2.1, along with production data. According to projections, oil's share of the global energy market will decrease from almost 40% in 1995 to less than 37% in 2020. However, oil will continue to be the primary source of energy in the globe. Oil may someday run out since it is a finite resource, but this won't happen for many years. At the present pace of production, OPEC's oil reserves will last another 80 years, but non-OPEC oil producers' reserves may only last 20 years. The need for oil is increasing globally, but if we manage our resources wisely, utilize the oil effectively, and create new fields, our oil reserves should continue to grow for many more generations.

### **Native Gas**

The natural gas, abbreviated as CNG, is utilized in Delhi in buses, Lorries, and other vehicles. It is a fossil fuel, natural gas. Typically, this forms in the Earth with petroleum. Methane is the major component in it. Small amounts of ethane and propane are also present. CNG is natural gas that has been liquefied under high pressure (Compressed Natural Gas). CNG is utilized as a fuel in residences, industries, and cars. Additionally, it serves as a source of the hydrogen needed to make fertilizers. Methane (CH<sub>4</sub>) predominates in natural gas (CNG), which is often a combination of lighter hydrocarbons with different amounts of nitrogen and contaminants such as hydrogen sulfide. Nearly 20% of the world's energy demands are met by natural gas. During this century, the growth of NG supplies has been virtually as significant as the growth in oil supplies. The growth of the NG business has, however, been restricted to regions where a pipeline could economically link such regions to the natural gas deposits. Only in cases where there are substantial reserves and a certain demand might the cost of building expensive pipeline networks be justified. The globe relies heavily on massive gas reserves and resources in regions farthest from major markets, and the role of NG will be primarily defined by transit costs. Around 394 billion boe (1975 estimates) are thought to represent the global proved gas

reserves, while 1358 billion boe are thought to be the global undiscovered resources. The discovery and development of the anticipated undiscovered resources in North America and Western Europe will have a significant impact on a variety of factors. Nearly all of the NG now produced in the globe is delivered by pipeline. Liquefied natural gas is transported by tankers as an alternative to gas pipes (LNG). Since the 1960s, the technology has been commercially accessible, although the prices are still expensive. In order to transport the gas in specially engineered chilled tanks and re-gasify it at the receiving terminals, the gas must first be liquefied by cooling to  $-161^{\circ}\text{C}$ . Only roughly two thirds of the initial supply of gas is supplied to the user since around 25% of the energy is wasted during LNG processing and shipping. The high capital costs associated with an LNG processing and transportation infrastructure will impede the pace of expansion of LNG trading internationally. NG offers a handy and clean fuel as well as a crucial chemical feedstock.

## Coal

In China, coal has been utilized as a fuel for many centuries. Greek settlers in Europe became aware of coal and gave it the name "anthrax," from whence the word "anthracite" is derived. Its usage was very restricted up until the English firewood shortage in the 16th century, which encouraged Darby to explore the use of coke for reducing iron ore. The change in the nature of markets accounts for the fluctuating rates of coal output. The demand for coal surged immediately as railroad construction got underway, and it was also possible to transport it for considerably less money. The quick market expansion for oil and subsequently NG disrupted the coal sector in the USA. Formation. Although it also includes hydrogen, oxygen, variable minor quantities of nitrogen, sulfur, and other components, the major component of coal is carbon. It was created by the decay of plants that had formerly grown in swamps or huge river deltas that were periodically subsiding. Bacterial activity initially converted the decayed plant and tree debris into peat, which was eventually covered by sedimentary layers. The layers of peat were later deeply buried by the movement of the earth's crust, and under the influence of heat and biochemical reactions, they were converted into different types of coal or lignite. During this coalification process, the carbon content rose as oxygen and hydrogen were released from the earth's interior. Methane ( $\text{CH}_4$ ) was created and either emitted into the atmosphere or moved until it was caught in a geological trap, forming a natural gas reservoir enclosed by an impermeable layer like to those found in petroleum reservoirs. Properties. Carbon concentration determines how coals are rated. The lowest rank coals, which are made up of lignite and brown coal, were created under moderate heat and pressure conditions. Sub-bituminous and bituminous coals were created at greater temperatures and pressures, and the highest rank coals, known as anthracites, were created at very high pressures. The anthracites have a carbon content of over 92%, 2-3% hydrogen, oxygen, volatiles, and impurities. Bituminous coal has a carbon content of 70–80% and includes roughly 5% hydrogen. Brown coal and lignite at its lowest grades may contain less than 50% carbon. Although there is significant overlap across classes, the ranking by carbon concentration roughly corresponds to a ranking by heat content. The coking characteristics for mechanical strength, ash content, and volatile matter content are further categories of relevance. Due to its presence in combustion products as oxides of sulfur ( $\text{SO}_2$ ), which damage the environment, sulfur is a significant contaminant. Mining. The majority of hard coal (bituminous and anthracite) is obtained through deep mining, but thanks to modern technology, open-cast methods are being used more frequently. These methods make use of large excavators that can move hundreds of tonnes per hour, and the mines can go down several hundred feet. Surface mining is less expensive than deep mining, and it may grow quickly. Deep mining needs at least two shafts and is anticipated to take ten years to implement. The ventilation provided by the mining shafts is essential for removing coal-related methane, lowering temperature, and reducing humidity.

## Reserves and Resources

All coal that might one day become economically viable is included in geological resources. All coal that is now known to be economically and technically recoverable is included in reserves. These projections were made in 1978, thus they are out of date. The estimated global coal resource totals are (in billion tonnes): Brown coal: 2399 and Hard coal: 7725. The reserves are 493 and 144, respectively. More than any other fossil fuel, coal is the most abundant fuel in the world. The USSR (45%), US (24%), China (13%) and Australia (6%), however, account for about 90% of the world's coal reserves. About 60% of the coal produced is produced by the US, USSR, and China, with the remaining 25% being produced by Poland, Germany, the UK, Australia, South Africa, and India. The majority of the coal produced today is still used in the nations where it is mined. Only 10% of commerce is done globally. Coal is mostly utilized for the production of power.

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## CHAPTER 6

### AERONAUTIC ENERGY

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The energy produced when an atomic nucleus, like uranium, undergoes fission after absorbing a neutron to create a compound nucleus is the basis for the creation of nuclear power. This compound nucleus is unstable and may split into two or three smaller atomic nuclei, releasing a significant amount of energy and multiple neutrons at once. If enough of these other nuclei are uranium nuclei, which may happen if these neutrons are absorbed by them as well, a chain reaction may occur. A nuclear reactor's functioning is based on chain reactions. One uranium atom's fission produces 200 MeV ( $= 3.2 \times 10^{-11}$  J), but one carbon atom's oxidation only produces 4 eV. Only 0.7% of the lighter isotope  $^{235}\text{U}$ , which makes up 99.3% of natural uranium, provides the majority of the fission energy in nuclear reactors. Any nuclear reactor's design goal is to maintain a chain reaction in which precisely one neutron (on average) finally results in another fission. Generation of nuclear energy. In order to benefit from the increase in fission cross section for low energy neutrons, it is necessary to make arrangements for the neutrons to be slowed down by a moderator (a light material like water, heavy water, helium gas, beryllium, or carbon, mixed, typically in homogeneously, with the fuel). It is feasible to develop reactors based on the fission brought on by rapid (high energy) neutrons if the ratio is high. In contrast to fast reactors, which are built to employ fission brought on by rapid neutrons, thermal reactors use slow neutrons. It is feasible to enrich uranium, which is to improve the fissile  $^{235}\text{U}$  in some percentage of the accessible natural uranium at the cost of the remaining, in order to lower the size and extend the possibilities for the choice of materials for a reactor. The simpler it is to sustain the chain reaction, the higher the enrichment, therefore the reactor's capacity may be decreased and a moderator with a lower moderating ratio can be utilized. Uranium that is 0.7% to around 3% enriched is used in light water reactors. The creation of fissile isotopes in a thermal reactor is less than the fissile component of uranium  $^{235}\text{U}$  in the fuel is burned off. The number of neutrons produced per fission in a fast reactor, using high-energy neutrons, is higher than in a thermal reactor, and some  $^{238}\text{U}$  fission also takes place. As a result, there are more spare neutrons obtainable for absorption by the common uranium isotope  $^{238}\text{U}$ , leading to a higher rate of fissile decay products. It is possible to design the conversion gain such that it produces more fissile material than it consumes. Fast breeder reactors are the name given to this kind of reactor.  $^{235}\text{U}$  is used as a fuel in almost all operational nuclear reactors. Resources. To supply the present demand, around 150 tonnes of natural uranium must be produced each year. 219 1000 tonnes of resources are known. There might be 2177000 tonnes more resources accessible. Future requirements are anticipated to be handled by FBR, hence there may not be a significant rise in demand.

#### **LPG (Liquefied Petroleum Gas) (Liquefied Petroleum Gas)**

In many houses, LPG is the fuel of choice. Where does this come from? As you well know, fractional distillation is a process used to create petroleum gas from petroleum. It will liquefy if this gas is put under a lot of pressure. This substance is LPG (Liquefied Petroleum Gas). This is supplied after being poured into sturdy cylinders. Butane is the major ingredient in this. There are also trace amounts of propane and ethane. Accident through LPG. The gases in LPG have no smell. What happens if there is a leak? Even if it occupies the whole space, we won't



know. What will happen if an electric switch is turned on or a matchstick is struck in such case? There will be a large explosion or fire. Due to its distinctive fragrance, another gas called ethyl merchantman is added to LPG in order to identify leaks. When the gas cylinder is opened, this smell may sometimes be detected. Never attempt to light a match or use an electrical device if this fragrance is detected. Open all of the doors and windows and look inside the cylinder for any leaks. It is preferable to keep the cylinder's valve closed while it is not in use.

### **Alcohol**

For experiments, spirit lamps are utilized in schools. Alcohol is the spirit used in spirit lamps. A nice fuel, this. Burning it produces far less atmospheric pollution. In certain nations, gasoline and alcohol are combined to be used as vehicle fuel.

### **Gasohol**

Automobiles in Brazil and Zimbabwe are fueled with a blend of gasoline and alcohol. Gasohol is this fuel. 'Gasol' is short for gasoline, while 'Hol' is for booze.

**High Power** The only unconventional energy source that has been extensively used by humans is water. The technology is well-developed and straightforward. The industrial infrastructure for the construction of water turbines, valves, gates, generators and related electrical equipment are well developed in many nations. It might be a micro, mini, small, or large power plant, depending on capacity. It is referred to as a low head because of the head (50 m). It might be base load or peak load depending on the kind of load. It might be of the traditional, pumped storage, or tidal variety depending on the hydraulic properties. Depending on how it was built, it might be a run-of-river, valley dam, diversion canal, or high head diversion facility.

### **Energy Overlapped**

Both conventional and unconventional resources can be used to make energy, but traditional resources are running out. These are fossil fuels: coal, natural gas, and oil. Millions of years were required to accumulate these resources. Solar energy, wind energy, water energy, and biomass are examples of non-conventional resources. Fossil fuels account for over 80% of the energy generated worldwide. But in France, the French Atomic Energy Commission built nuclear reactors that can provide 70% of the nation's energy needs. 47 Global oil consumption increased from 436 million tonnes in 1960 to 2189 million tonnes in 1970 and to 3200 million tonnes in 1999, according to UN estimates. For natural gas, the comparable numbers are 187, 1022, and 2301; for coal, they are 1043, 1635, and 2146. The demand will keep increasing. China has the greatest per capita energy usage among the emerging nations. India has a lower per capita consumption rate than China. It should be noted that consumption figures only reflect the energy used for business purposes and do not account for the non-commercial energy consumed in developing nations by the underprivileged who harvest wood for free. The greatest non-conventional resource is hydropower. Both industrialized and developing nations have hydropower projects operational; prominent examples of the latter include China, India, and Brazil. Only 15% of the hydropower capacity in the developing world is now being used, despite its enormous potential. Additionally, wind power has a lot of promise. Since ancient times, people have used sails and windmills. It is a resource with rapid growth. Ten megawatts of wind energy were produced globally in the 1980s. It reached 14,000 megawatts in the year 2000. According to Green Piece International, wind power might provide 10% of the world's energy by 2020 if the current trend holds. Solar energy is used by photovoltaic cells. According to the photovoltaic news, the global photovoltaic output increased from 0.1 megawatt to 200 megawatts in 1999. Many different varieties of farmed or wild plants make up the biomass resources. In Africa and Asia, wood is the main resource and the main source of fuel for the

population. The destruction of forests is a result of overuse of wood. Our nation's primary energy sources include coal, oil, gas, and water. Coal (56%) and petroleum (32%) make up the majority of the many energy sources used in the commercial energy sector. Other sources include nuclear, natural gas, and water. In addition to using commercial energy, a lot of traditional energy sources including fuel wood, agricultural waste, and animal waste are also employed. From 130.7 MTOE (million tonnes of oil equivalent) in 1991–1992, to 176.08 MTOE in 1997–1998 commercial energy consumption has increased. The associated structural shift in economic development, an increase in population, and fast urbanization are the key causes of this increase. The industrial sector consumes the majority of the commercial energy generated in the nation—about 50%—followed by the transportation sector. Fertilizer, aluminum, textiles, cement, iron and steel, pulp and paper, and chloro-alkali are some of the most energy-intensive sectors, accounting for about 80% of all industrial energy use. Nearly 50% of all petroleum products are used by the transportation sector, mostly in the form of high-speed diesel and gasoline. The amount of commercial energy used by the agricultural sector has increased significantly as a result of increased automation and modernisation of its operations. From just 3.9% in 1950–51 to around 32.5% in 1996–97, the agriculture sector's percentage of total electrical energy use has expanded. The amount of natural fuel (mainly wood) used for energy in the household sector is relatively high. 30% of urban families and 78% of rural households respectively rely on firewood. However, the proportion of conventional fuels in the country's energy mix is decreasing as more effective commercial fuels take their place. A household's yearly use of electricity increased from 7 kWh to 53 kWh between 1970–1971 and 1994–1995; that of kerosene increased from 6.6 kg to 9.9 kg; and that of cooking gas increased from 0.33 kg to 3.8 kg. However, there is a noticeable difference in the amount of energy and fuel used in rural and urban regions.

### **Demand for energy**

With the current energy crisis, humanity is on the edge of yet another disaster. Owing to the depletion of resources and energy, environmental issues are becoming more severe due to increasing industrialization and inappropriate consumption practices. The unsustainable use of renewable resources and the production of harmful compounds are posing threats to the environment, human health, and biodiversity. In each industrial process, energy is a key input. In addition to the extensive variety of services needed in the residential and industrial sectors, energy is a vital input in industries like commerce, transport, and telecommunications, among others. Utilizing energy is not a goal unto itself. Energy has two functions. It is a contribution to the economy's productive sectors, which include industry, agriculture, and the transportation system's auxiliary infrastructure. It is also a consumer good since residential energy consumption directly affects people's quality of life. India's per capita consumption is 25 percent lower than that of the United States and one-quarter of the global average. Crop residue accounts for 30% of the nation's overall energy use, with modern fuels progressively replacing traditional fuels like animal dung and fuel wood. Large investments are required to fulfill the demand for energy for various consumer sectors, and the development of energy sources is very capital intensive. If gasoline rose in price above food, it would be quite comical. The energy crisis was also thrown into closer light by the Gulf War and the Iran-Iraq War. The economic principle of finite resources and insatiable desires does not apply to the need for energy. The rate of energy resource extraction has been increasing over time, which has led to a progressive depletion of the limited supplies. The crucial relationship between energy and the economy has made it clear how susceptible different countries are to the erratic energy market. Energy is now a crucial consideration for determining a product's price at the micro and macro levels, as well as the inflation and debt load. Cost of energy is a major component in economic activity, on par with other production inputs like capital, land, and labor. Energy

conservation measures, which basically involve consuming less energy for the same amount of activity, are necessary in an energy shortage scenario. The need for energy is growing, but at the same time, energy supplies are getting more expensive and limited. Technocrats and decision-makers in the industry have been forced to develop new energy-saving measures as a result of this steadily widening gap. They have also been forced to take a systematic approach to the current trend in energy consumption through energy auditing and the use of cutting-edge techniques and methods to reduce energy waste. Energy conservation is seen as a fast and affordable solution to the issue of power shortages as well as a strategy to protect the nation's limited energy resources. Energy saving solutions are affordable, need for only modest financial outlays, and have quick payback and gestation times. According to research by the Energy Management Centre in New Delhi, the industrial sector has a 25% potential for energy saving. Different basic energies, processing, useable energies, and related plants and processes are all covered by energy technology. Exploration, transportation, conversion, and usage are all included. Energy technology is concerned with the "demand" for different secondary energy sources (usable energy) as well as the "supply" strategies. Energy-technology encompasses a variety of aspects that influence "demand" and "supply." The main component of domestic demand, industrial growth, and economic growth is energy. Additionally, it is necessary for maintaining industrial expansion. The need for energy has increased steadily along with industrialization and urbanization. The demand for it has increased dramatically during the last several decades. Energy is now needed for a very wide range of uses. The key ones are given below. To operate the turbine in power plants. The alternator is then rotated to produce energy using the rotation of the turbine. In the transportation industry, to power vehicles such as cars, trains, ships, submarines, helicopters, and airplanes. To power rockets, tanks, weaponry, etc. in military lists. In industrial sectors, such as those that produce cement, plastics, chemicals, fertilizers, steel, aluminum, and other metals, as well as those that refine oil, among others. For home use, such as in washing machines, refrigerators, air conditioners, fans, lights, and music systems.

### **Power Management**

The long-term policies, short- and mid-term plans, economic planning, and social and environmental elements of different energy pathways are all included in the energy strategies. These are examined from the viewpoints of the globe, region, country, states, sub-regions, different economic sectors, communities, and people. Power industry has been given great priority in the country's development plans because of its significance to the overall growth of the nation. About 29% of investments made under the sixth plan are in the energy industry alone. The entire investment in the energy industry will make up around 40% of the projected investments when transportation investments for coal and oil as well as other infrastructures are included. The fact alone is sufficient to demonstrate the significance of the power sector for the development of the nation. The amount spent on electricity during the sixth plan era has climbed to Rs. 15750 crores from only Rs. 149 crores under the First Plan. Between 1951 and 1978, the installed generating capacity increased ten-fold, from 2300 MW to 25900 MW. Of this, 12,000 MW came from hydropower, 14,000 MW from thermal power, and less than 1,000 MW from nuclear power. At the end of March 1978, there were 127 power plants with capacity of 20 MW or more, of which 65 were hydroelectric, 60 were thermal, and 2 were nuclear. From 1950–1951 to 1978–1979, power production increased by 103754 million kWh, or about 15 times, or 7514 million kWh. The number of people who used electricity in total increased from 15 lakhs in 1950 to 2641 lakhs in 1978–1979. Electricity use per person increased from 18 kWh in 1950–51 to 121 kWh in 1978–79. This industry is unable to fulfill demand despite these steps. Power shortages are becoming a common occurrence throughout the nation. The actual availability in 1978–1979 was just 97588 million kWh, which was less than the predicted need

of 108656 million kWh, representing a shortfall of around 11070 million kWh or 10.2°C. The country's need for electricity is rising quickly as a result of a large-scale industrialization program and growing agricultural activities. Power consumption would be between 125 and 150 million kW by the end of the century if the current trend holds. By the year 2000, to fulfill the predicted needs, a total generating capacity of 175 to 200 million kW would be necessary, taking into account the sufficient reserve margins needed for periodic maintenance. This would result in an 8–10 times increase in current capacity.

To accomplish the necessary expansion, the nation's hydro, thermal, and nuclear resources must be properly developed. Only 16% of the overall hydel-potential (41,000 MW) has been exploited, therefore there is still room to expand this form of energy in the future. The northern area has the most hydel potential. Even if all of the hydel potential is realized, the rising demand cannot be satisfied. As a result, thermal potentials must be added to hydel potentials. Although India only has around 176 tonnes of coal per person, compared to nations like China with 1170 tonnes, the United States with 13500 tonnes, and the former Soviet Union with 22000 tonnes, India is undoubtedly underdeveloped in terms of coal reserves. The country's coal supply is likewise unequally distributed, with 60% of it located primarily in Bihar and Bengal. It is also impossible to rely only on the growth of thermal power, since this necessitates the creation of transportation infrastructure. Future nuclear fuel consumption for electricity generation must also be taken into account, especially in areas with limited hydel potential and inaccessible coal deposits. Future planning for power development should focus on maximizing the use of existing resources to reach a power mix of hydro, thermal, and nuclear. The establishment of central sector super-thermal power plants around the nation is a further step to be made in the power development business.

The Farakka, Ramagundam, Korba, and Singrauli super-thermal power plants have been providing electricity for the last 20 years. At the moment, all of them are providing deficit states with electricity through the national grid. Even 20 MW hydro potentials have not been exploited in our nation, despite the fact that it would seem beneficial to construct even 20 kW units. The stress on already-existing plants has been significantly lessened by the development of minor hydro potentials, such as those in China. The growth of biogas may reduce the pressure on household users' access to oil, which would otherwise be used to generate electricity. Energy plantations are another solution to the nation's frightening current electricity crisis. India gets a lot of solar radiation, and green plants use the process of photosynthesis to transform solar energy into food and fuel. Fast-growing tree species produce between 15 and 35 tonnes per hectare per year. The land, which is not currently utilized for either farming or forestry, may be used for energy plantations in areas with an average annual rainfall of 80 to 100 cm. Planned production forestry presents an exceptional potential with the state of forest technology today. After 20 years, the forest area can provide enough energy if it is raised from the current 22 to 30% (an increase of 30 million hectares of land). Although the government does not take this stage of energy generation seriously, it seems like a good idea. According to current Government planning, the issue of growing power consumption will only be resolved by suitable blended development of hydro, thermal, and nuclear for at least another ten years. The severity of the electricity issue may be somewhat mitigated through power conservation. The highest thermal power plant efficiency is 35%. It is barely 25% in India. Even after accounting for line loss and auxiliary use, the efficiency is still only around 16%. By performing routine maintenance and supplying high-quality fuel, the issue may be partially resolved. The kWh produced per kW installed ratio is another way to measure the efficiency of a power plant's operation. Maximum annual kWh per kW is 8760. The use rate in India is just 45%, as seen by the average number of barely 4000. The requirement for additional power

producing capacity will be decreased if this use is raised. Increased load factors may lower the power industry's capacity.

### **A Variety of Energy Sources**

There are primarily two categories of energy sources.

1. Traditional Energy Sources (Non-Renewable Sources of Energy)
2. Non-Traditional Energy Sources (Renewable Sources of Energy).

These supplies are limited and eventually run out. These sources cannot be refilled after they have been consumed. Coal, wood, oil, lignite, natural gas, fossil fuels, nuclear fuels, etc. are a few examples. Examples include fossil fuels; nuclear power; hydropower; and have you not witnessed cars being filled with fuel? What kind of fuels are used by automobiles? What kind of energy sources are they? Do they deviate from the norm? A priceless source of energy, fossil fuel is created when plants and animals that have been buried deep in the earth's crust for millions of years undergo chemical transformations without oxygen. This process results in the formation of fossil fuels including coal, petroleum, and natural gas. These energy sources are traditional ones. Energy sources including petroleum, natural gas, coal, and nuclear power are a few examples. Radiant power about 70% of India's electricity is produced by thermal means. Coal, furnace oil, and natural gas are the primary fuels used to generate thermal energy. Energy may be produced via the steam cycle, ranking cycle, or sterling cycle. Now, commercial-scale thermal power plants are using clean coal technology (with 10% ash content). Thermal Power National Corporation (NTPC) it was established in November 1975 as a public sector enterprise with the primary goals of organizing, developing, and planning integrated thermal power development. NTPC projects have an installed capacity of 16000 MW.

These resources are endless and are continually created by nature. Examples include wood, solar energy, biomass, geothermal energy, wind, tidal energy, nuclear fusion, gobar gas, and so on. The following are some examples: (i) solar energy; (ii) wind energy; (iii) geothermal energy; (iv) ocean energy such as tidal and wave energy; and (v) biomass energy such as gobar gas. It is obvious that all fossil fuel-based energy sources have their supply limits and will eventually run out. Therefore, the only choice for long-term energy supply is non-conventional energy sources. For the foreseeable future of hundreds of thousands of years, these resources remain inexhaustible. Non-conventional sources of energy are those that are evergreen, continually provide energy, and do not exhaust with usage. As an example, consider energy from sun, bio, wind, geothermal, wave, tidal, and OTEC sources.

### **(Renewable) Energy Resources**

The development of renewable energy is progressing in India. It has become a practical means of achieving the objective of sustainable development. However, the Indian initiative for renewable energy needs greater momentum right now. India now boasts the biggest program in the world for the deployment of renewable energy systems and goods, and the country's adoption of diverse renewable energy technologies has been aided by a number of legislative changes and financial incentives. In light of the risks to the environment presented by the over use of conventional fossil fuels, power production from non-conventional renewable sources has gained relevance. Renewable energy technology have made it possible to augment traditional power production rather than completely replace it. At the moment, the installed generating capacity of renewables is over 3500 MW, or about 3.5 percent of the overall installed generating capacity of 1 lakh MW from all sources. A total of 1617 MW of this comes



from wind energy alone, while 450 MW comes from biomass energy and 1438 MW from minor hydroelectric plants. During the Tenth Five Year Plan (2002-07) era, an additional 4000 MW of electricity from renewable sources is to be added, mostly via wind, biomass, small hydros, waste energy, and solar energy systems. India has also set a target to increase the proportion of renewable energy sources in power production to 10% of new capacity expansion, or 10,000 MW, by 2012. The world's biggest decentralized solar energy program, second-largest biogas and improved stove programs, and fifth-largest wind energy program are all now being implemented in India. The development of a sizable manufacturing base in a number of renewable energy technologies has put India in a position to not only export innovations but also to provide technical assistance to other nations.

### **Atmospheric Emissions from Power Stations Control**

Combustion emissions from fossil fuel power generating facilities may include contaminants in the gas phase as well as suspended solid or liquid particles. Environmental laws and regulations set limits on how much gas, solid, or liquid pollution is allowed to be released into the atmosphere. This chapter provides an overview of combustion gas emission monitoring and reduction methods. Chapter 26 discusses various facility design concerns as well as regulatory programs and related requirements relating to air and water emissions. By switching to, blending with, or cofiring with fuels that have less sulfur and ash, as well as by utilizing alternative fuels with lower pollutant contents, potential air pollutant combustion gas emissions may be decreased before combustion. Furthermore, cleaning coal by beneficiation may lower the amount of contaminants in the fuel. Additionally, energy saving techniques and improved plant thermal efficiency help minimize pollution. The methods used to regulate combustion gas emissions that are discussed in this chapter are presently in use and are found within or after the combustor. The management of liquid and solid waste, as well as emissions related to the processing of coal and limestone, are discussed in Chapters 5 and 16, respectively. The remainder of the combustor pollutants are recovered, treated, and disposed of as explained in Chapter 16, Liquids and Solids Waste Treatment. Some combustor pollutants are converted to harmless gases, some are recovered or converted to useful byproducts, and some are recovered or converted to useful byproducts. So that regulatory requirements are reliably met at the lowest possible cost, the atmospheric emissions control design, including balance-of-plant implications, should be included into the design of the power plant. In designing new or modified current plants, designers should also take into account any future emission restrictions or regulatory programs. Laws and regulations governing atmospheric emissions are continually changing to control additional contaminants or bring present controlled emissions under control. For instance, the US Department of Energy (DOE) recently received proposals for an integrated demonstration power plant that would use technologies to meet future hazardous pollutant limits, reduce NO<sub>x</sub> and SO<sub>2</sub> emissions to 0.06 lb/MBtu, reduce particulate emissions to 0.003 lb/MBtu, and increase overall thermal efficiency. The emission restrictions for this program are about ten times stricter than the current emission restrictions. The different control technology sections of the Clean Air Act and its accompanying modifications will help to support the trend in the United States of regulating additional pollutants and lowering emission levels as technology advances. A new emissions control design would ideally comply with (or be compatible with retrofit additions that will comply with) laws in effect at the time of the plant's construction.

### **Control of portions**

The majority of fossil fuels produce residual particles after burning, with the exception of natural gas and liquified petroleum gas. Ash and carbon that hasn't been burnt are the main components of a panic attack. Silica, alumina, and other noncombustible chemicals make up



the ash. Ash content varies greatly, perhaps surpassing 50% by weight. These particles exit the boiler as fly, bottom, or economizer ash. The boiler's bottom ash collects there and is routinely removed. The ash from the economizer typically contains bigger particles, separates from the flue gas, and falls into hoppers for disposal. Fly ash, which exits the boiler entrained in the flue gas, is rather little. For a range of boiler types, the following table gives typical ash distributions: Type of boiler shredded coal Thor's Cyclone fluidized bed that is rotating (%) bottom ash 10-30 60-80 50-80 5-90 (%) fly ash 70-90 20-40 15-50 10-95 Ash from an economizer (%) 0-10 0-5 0-10 0-5 The size of the fuel particles, boiler temperatures, ash fusion and deformation temperatures, ash particle sizes, densities, and morphologies, as well as boiler flue gas velocity locations, all influence how the ash splits. The biggest particles are produced by stoker-fired equipment. Smaller, spherical particles are produced by pulverized coal (PC)-fueled boilers that are corner- and wall-fired. Similar to ash from PC boilers, cyclone-fired unit particles are usually spherical and smaller. Fluidized bed units generate a large variety of asymmetrical, non-spherical, and more crystal-like-shaped particles. 418 Power Plant Atmospheric Emissions Control 419 (Stultz and Kitto 1992). The choice and design of a suitable particulate removal control system depends heavily on the boiler type, fuel properties, the resulting fly ash mineral analysis, particle loading, and particle sizes. The most popular options are cloth filters and electrostatic precipitators. The choice that is ultimately made is often determined by economics, compatibility with the design fuel, operating circumstances, legal requirements, and other pollution control technologies that are necessary for the unit. Either option generally offers guaranteed outlet emissions of particles in the 0.01 to 0.015 lb/MBtu range. MEASUREMENT TECHNIQUES FOR PARTICULATES In accordance with 40 CFR 60, Appendix A, Methods 5 and 17, the US EPA offers reference test procedures that are sufficient for calculating emission rates as low as 0.001 grains per dry standard cubic foot (gr/dscf). If the test equipment user utilizes the equipment appropriately and for an adequate period of sample time, these test procedures are accurate to extremely low levels. However, sustaining steady-state conditions is also more challenging with longer testing (needed by extremely low emission limits). In order to provide reliable and consistent results, test techniques to establish extremely low emission rates should be carefully developed and implemented.

### **Electrostatic Precipitators Electrostatic precipitators (ESP)**

It is operating across the whole spectrum of utility power plant applications and is sized for the efficiency necessary to comply with current particle emission restrictions. ESPs are the most often used utility particulate reduction device as a result. To activate the discharge electrodes and create a high-voltage direct current (dc) electrical field between the discharge electrodes and grounded collection plates, ESPs employ transformer-rectifiers (T-Rs). When a particle enters an electrical field, it picks up a negative charge and moves toward grounded collection plates. This migration, which occurs in a turbulent flow regime with the particle entrained inside the turbulent gas patterns, may be described in engineering terms as an experimentally established effective migration velocity. Therefore, the charged particles are really captured when the particulate matter is brought near enough to the collecting surfaces due to the interaction of electrical attraction and gas flow patterns. On the collecting plates, a layer of gathered particles develops and is regularly shifted by mechanically rapping the plates. The ash handling system removes the accumulated particles from the hoppers underneath the precipitator. Additionally, some particulate is reentrained and is either ejected from the precipitator or collected in later electrical fields. The needed particle removal efficiency, the anticipated electrical resistance of the fly ash to be collected, and the anticipated electrical properties of the energization system all contribute to the physical size of an ESP. The ESP's

capacity to gather particulates is affected by a number of factors. The most crucial topics are covered in the sections that follow.

### Particular Collection Region.

The specific collecting area is a common unit of measurement for ESP size. Units for a precipitator's specific collection area (SCA) are square feet per 1,000 actual cubic feet per minute (acfm) of flue gas flow. The Deutsch-Anderson equation, which relates the collection efficiency ( $E$ ) to the unit gas flow rate, the particulate's effective migration velocity (see preceding section), and the collecting surface area, may be used to determine the SCA for the needed performance.

$$1 - E = e^{-\frac{wA}{V}}$$

or

$$A = \left[ \ln \left( \frac{1}{1 - E} \right) \right] \frac{V}{w}$$

where

$$E = \text{ESP removal efficiency, \%}$$

$$= 100 \left( \frac{\text{Inlet dust loading} - \text{Outlet dust loading}}{\text{Inlet dust loading}} \right),$$

$w$  = effective migration velocity, ft/min (m/s);

$A$  = collection surface area, ft<sup>2</sup> (m<sup>2</sup>), and

$V$  = gas flow, ft<sup>3</sup>/min (m<sup>3</sup>/s).

The empirical aspect of ESP design is clear given the need for an effective migration velocity to employ this scaling calculation. Suppliers are more precisely able to forecast the necessary effective migration velocity for a new application the more application experience and performance testing they do for a specific ESP design. Suppliers of ESPs scale ESPs in accordance with their test results for their unique designs and to satisfy the required specifications. Without a wealth of application-specific data, providing useful migration velocities is all but impossible. Sizing an ESP is still, in general, more of an art than a science. In order to compare the SCA across designs, adjustments must be made for any different collecting plate spacing (typically ranging from 9 in. to 16 in. for coal-fueled ash applications). For instance, the collection plate distance between two ESPs with the same treatment duration or volume may change. The SCA comparisons must be placed on an equal basis in order to represent this size equivalence. Despite the fact that it isn't truly an industry-wide standard, this base is often compared to a similar SCA with a 12 in. plate spacing. To achieve this, divide by the referred gas passage width, which will serve as the equivalent basis, and multiply the estimated collecting plate area by the actual gas passage width. Calculate the equivalent SCA using this computed equivalent area. 420 Electrical Engineering Higher voltage (bigger TRs)

are needed to achieve a same particulate removal performance with greater plate spacing and smaller plate surface per unit volume. However, since current flows and related spark rates are lower, the total power consumption and efficiency of the ESP may increase. The collecting plate spacings utilized by ESPs installed in the 1970s and 1980s were 9 or 12 inches. The gas route width between collecting plates is determined by this distance. The horizontal middle of this area is where the vertical discharge electrodes are positioned. With ESPs, performance might be equivalent with collecting plates separated by 14, 15, 16, 18, or 21 inches. Wider plate spacing and caution are required while adjusting other ESP settings in order to prevent "space charge" issues in the intake fields caused by significant dust loading.

**14.2.1.2 Duration of care.** The flue gas' exposure to the electric and collecting fields of the ESP is referred to as the treatment period. Treatment times for high efficiency ESPs are generally in the range of 7 and 20 seconds. High-sulfur fuels with higher permitted emissions have shorter durations. Low-sulfur fuels with low sodium oxide fly ash concentrations or lower permitted emissions call for longer durations. Flue Gas Velocity

**14.2.1.3 The design and size of the ESP depend on how quickly the flue gas passes through it.** Smaller ESP cross-sectional area inlets are produced by higher design velocities, however this may lead to an undersized ESP with large ash reentrainment losses and short treatment times. With coal fuel fly ash, a design gas velocity of around 4 ft/s is the most practicable. On oil-fueled boilers, ESPs typically move at 3 to 4 feet per second. A greater velocity may be suitable in certain circumstances, but generally, higher velocities cause worry about reentrainment of the collected ash. For ash with a high potential for reentrainment, such as particulate with a high carbon content, lower velocities are advised. However, it's also important to take into account the consequences of too low a velocity, which would occur during low boiler load operation. If the ESP's velocity is too low, the flue gas may meander and perhaps get ionized, which would impair performance and cause spark over.

### **Ratio of aspects.**

Installing an ESP with a larger aspect ratio is another strategy for overcoming reentrainment issues. The ratio of the treatment length (effective ESP length excluding walkways) to the collecting plate height is known as the aspect ratio. The particles collected at the top of the input collecting plates may enter the hoppers before leaving the ESP thanks to higher aspect ratios. Aspect ratios for several of the current ESPs range from 0.8 to 1.2. These small aspect ratios can be suitable for situations where reentrainment issues are not anticipated or where regulatory requirements are not stringent. However, aspect ratios between 1.2 and 2.0 are often required to comply with modern particulate emission standards.

### **Distribution of Gas.**

For the best particle removal, there must be minimum gas bypass or "sneak age" around the discharge electrodes or collecting plates and consistent gas velocity across the whole precipitator treatment volume. The particle removal will decrease and entrainment losses would rise in high velocity zones if the flue gas distribution is uneven. As a result, collection efficiency will decline generally. The minimum allowable gas flow distribution inside an ESP was defined by standards and test procedures created by the International Conference of Clean Air Companies (ICAC, previously IGCI). The IGCI Publication EP-7 describes these standards. It could be reasonable to demand that the flue gas display a velocity variation of 15% in addition to achieving IGCI EP-7 criteria. To find and create flow correction devices that will allow for satisfying these criteria, physical scale models in conjunction with gas flow measurement investigations are required. Additionally crucial are the proper manufacturing and placement of these devices inside the ESP. When high efficiency are required, these conditions must be met.

### **Control of the electrostatic precipitator.**

The ESP control system's goal is to establish and maintain an electrical field in order to facilitate the proper collection of fly ash. Minimizing power consumption while maintaining performance is another control goal. T-Rs, current-limiting reactors, and a supervisory control system all work together to achieve this. Depending on plate spacing and particular electrical resistivity, the T-Rs increase the voltage from 480 V to between 25 and 125 kV and convert alternating current (ac) to direct current (dc). In comparison to an ESP with narrow plate spacing, an ESP with wide plate spacing requires T-Rs with greater voltage ratings and larger current capabilities. The effective voltage and current are maximized using the ESP control mechanism. Electrical arcs or sparks consume the input power and potentially harm the internals of the ESP. When an arc or spark is detected, the control system cuts power to the afflicted electrical bus segment. Thus, the power input is controlled by the "weak link." A single discharge electrode would be present in the "ideal" bus segment. The number of electrically independent bus sections is often capped at 1 per 25,000 ft<sup>2</sup> of collecting area since doing otherwise would be prohibitively expensive. Despite the fact that additional bus sections increase removal efficiency, many ESPs are able to fulfill emission regulations with fewer and bigger bus sections. Cost growth is the trade-off. Analog controllers restrict power input when they detect sparks or arcs. Modern digital computerized control systems respond considerably more quickly. Instead of waiting for a spark to happen, they respond when they see a change in the shape or slope of the power input curve. They provide the operator control over the power down voltage, power down time, power up ramp rate, and power up duration. They also enable the ESP to run at the greatest feasible voltage and current with automated phase back if the spark rate is exceeded and interrupt/pedestal/ramp or phase back if an arc forms, resulting in the most effective particle removal. With a computer control system, discharge opacity may also serve as an input power limiting parameter. By altering the apparent current limitations of the regulated T-Rs, an opacity control Power Plant Atmospheric Emissions Control 421 system may reduce the amount of energy used. Power is dialed back when the opacity falls below the preset threshold to save energy. The input power is instead permitted to seek up to the level established by the spark or arc characteristics when the opacity rises above a certain point. A portion of the ac half-cycles are cut off during intermittent energization, which makes advantage of the huge capacitor behavior of the ESP. Because the ac power to the T—Rs is cut off for brief, programmable intervals measured in fractions of a second, the input power to the ESP is decreased. Because the ESP voltage is maintained and the particle charging rate is not severely reduced, the ESP works as a huge capacitor during these brief times, maintaining the removal efficiency.

### **Rapping Devices.**

Electrodes for collecting and discharging retain particles on their surface. If this substance becomes too thick, collection reduces and the electrical properties deteriorate (spark or arc over, back-corona, or reduction in corona generation). For the ESP to operate properly, periodic knocking cleans the collecting and discharge electrodes. Rapping involves applying brief, strong intermittent energy inputs to clusters of these electrodes using vibrators, revolving hammers, or falling weights. Large sheets of fly ash fall from the collecting electrodes into the hoppers as a consequence of the shear and acceleration forces. Fly ash is unduly reentrained into the gas stream if the acceleration forces perpendicular to the plate surfaces are too great. The top, bottom, or side (edge) of the collecting plates and discharge electrodes receive the rapping energy. The three areas are all prosperous. The capacity to modify the rapping frequency, sequence, intensity, or combinations of these factors online in response to changes in the load or the fly ash characteristics may enhance total collection or electrical efficiency.

This skill helps to increase operating or fuel flexibility. However, a lot of ESPs with fixed internal online rapping intensity or sequence designs work well. By improving the plate and discharge electrode cleaning to match the pace at which particulate is accumulating in any particular mechanical segment, advances in rapper control technology may boost ESP efficiency. By thoroughly measuring the ESP operational parameters, the rapper control system adjusts the rapper sequence, frequency, and intensity to the user's preferences.

### **Resistivity.**

The level of resistance indicates how quickly ash or other particulates pick up an electric charge. The typical range of resistivity values is between  $1 \times 10^8$  and  $1 \times 10^{14}$  ohm-cm. As a result of its difficulty accepting a charge, high-resistivity particle is challenging to remove. In contrast, the collected particles may quickly lose their charge and get reentrained with extremely low resistivity particulate. Particles with a higher resistance need a bigger ESP than those with a lower resistivity. For high resistivity, the effective migration velocity,  $w$ , is smaller.  $5 \times 10^9$  to  $5 \times 10^{10}$  ohm-cm is the best resistivity range for electrostatic precipitation. Operating resistance changes with temperature, ash chemical composition, flue gas moisture and  $\text{SO}_3$  concentration, and ash content. The operational resistivity is most significantly influenced by the  $\text{SO}_3$  concentration. The sulfur concentration of the coal, the rate of  $\text{SO}_2$  oxidation to  $\text{SO}_3$ , and the operating temperature of the ESP all influence how much  $\text{SO}_3$  condenses on the fly ash. Precipitation is controlled by the particulate's surface  $\text{SO}_3$  resistivity for fuels with medium and high sulfur content. Precipitation is regulated for low-sulfur fuels by the volume resistivity, which is established by the chemical makeup of fly ash. The major influence on these is sodium oxide concentrations exceeding 0.5 weight percent. Fly ash's resistivity has a bell-shaped distribution, reaching its peak at a temperature of roughly  $300^\circ \text{F}$ . In either case, the resistance decreases with temperature. Low sulfur fuels create particulate that is challenging to precipitate at the standard  $300^\circ \text{F}$  air heater output temperature since they can only form trace levels of  $\text{SO}_3$ . Ash that is readily precipitated is produced by high-sulfur coals with correspondingly high  $\text{SO}_3$  production. Low-volume resistivities are advantageous for designing an ESP to function on the hot side of the air heater at temperatures between  $700$  and  $750^\circ \text{F}$ . Volumetric gas flow rates are much greater at hot-side temperatures, but low-sulfur coals' dramatically lower resistivities more than make up for this drawback. Precipitators were bought in the 1970s and installed on the air heater's hot side. However, for the majority of these installations, the charge-carrying sodium ions seem to have traveled to the exterior of the ash layer and were removed during rapping because to the high temperature and severe electric field. High particle emissions were produced as a consequence of the highly resistant, tenacious ash coating that was left on the plates. Many of these machines were changed to cold-side operation as a result of this issue and other maintenance-related issues; hot side precipitators are often not sold nowadays.

### **Design Features of ESP**

Specific key component design features are available from ESP providers. Discharge and collection electrodes, gas flow distribution tools, casing and structural support, high voltage dc distribution, insulators, electrodes for the electrical power supply, rapper cleaning systems, and controls are a few of them. To enable thermal expansion, the ESP internal components are top-supported. The discharge electrode and support design essentially define the primary design categories. Early ESP discharging electrodes consisted of lines up to 30 feet long with alignment weights attached to the bottom end and hung from horizontal frames at the top. The 1970s saw the construction of these early US ESP versions, which came to be known as the "American" or "weighted wire" variety. Due to electrical erosion or stress, the wires gradually showed signs of break age. A bus section may be grounded by a single damaged wire, which



will severely degrade performance and eventually the dependability of the precipitator. By employing relatively short (15 ft or less) discharge electrode strips (or wires) placed inside vertically oriented structural support frames, 422 Power Plant Engineering was able to solve the wire breakage issue in Europe. These patterns were known as "rigid frame" or "European" kinds and were referred to as "pipe frame," "bed spring," or "mast" types. This design is characteristic of the Babcock & Wilcox/Rothemule rigid frame precipitator. The rigid discharge electrode design was motivated by the superior dependability of the "rigid frame" with no noticeable wire breaking over the less expensive "weighted wire." In the "American" design, stiff discharge electrodes took the role of "weighted wires." For corona generation, these are pipes or other thin structural components having tips, scallops, or other sharp edges. As a result of this design, precipitators may be made higher and less expensively, with collecting plate heights and 50-foot-long discharge electrodes. The classic example of the modern American type design is the Enelco precipitator with Rigitrode discharge electrodes.

### **ESP Size Variation for Various Coals**

The many potential fuels have an impact on the ESP design parameters for boilers. The significant variation in ESP size, performance, and price illustrates how sensitive ESPs are to the characteristics of the coal burnt. The design fuels, needed outlet emissions, and ESP performance factors are taken into account for calculating the necessary SCA or treatment volume (time). Some coals have ash characteristics that make collection in an ESP very challenging, if not impossible. Electrical insulators silica (SiO<sub>2</sub>) and alumina (Al<sub>2</sub>O<sub>3</sub>) are difficult to precipitate due to the high ash resistivity since they do not readily acquire an electric charge. Because certain coals, like Australian coals, have significant silica and alumina concentration in their ash, a very large ESP is necessary to capture fly ash effectively.

### **Fly Ash Treatment.**

The effective migration velocity and, thus, the size and price of the ESP are influenced by the ash's operational resistivity. The effective ash resistivity is changed by fly ash conditioning devices, which also make the ash simpler to collect. To increase the cohesion or resistivity of the fly ash, they apply a variety of conditioning chemicals. By condensing the additive on the ash particle, the majority of conditioning methods lower the surface resistivity. Even if the flue gas is above the water dewpoint temperature, increased moisture levels in the gas reduce ash resistance. The resistivity may get so low if temperatures drop below the 30° F threshold for water saturation, which might lead to greater emissions from particle re-entrainment. SO<sub>3</sub> is the most often used conditioning agent.

The most typical method for producing gaseous SO<sub>3</sub> in bigger facilities is to burn sulfur to produce SO<sub>2</sub>, which is then catalytically oxidized to produce SO<sub>3</sub>. The insertion of tiny quantities of SO<sub>3</sub> into the flue gas before of the ESP commonly reduces the surface resistivity of low-sulfur coal fly ash at or below the acid dew point temperatures. This permits a new plant to have a smaller ESP. It enables an existing plant to burn coal with a greater intake ash content or lower sulfur content than that for which the ESP was initially built, or to minimize emissions. The emission levels of SO<sub>3</sub> are not considerably impacted since almost all of the SO<sub>3</sub> condenses on the particulate matter and is later collected in the precipitator. When the ESP is banged, very minute particles may not be caught or might be re-entrained. The particles often aggregate and accumulate after being exposed to ammonia injection. Additionally, ammonia improves ash particle adhesion to lessen reentrainment. The lower resistance caused by the injection of SO<sub>3</sub> and the improved particle assembly and cohesiveness caused by the addition of ammonia (NH<sub>3</sub>) both benefit dual-conditioned units. A gas cooling system might make an ESP 20% to 30% smaller.



### Precipitators of Wet Electrostatics.

The possibility for reentrainment is all but removed with the usage of wet ESPs. This is due to the fact that to eliminate accumulated particulate, the plates and discharge electrodes are washed with water rather than rapped. In order to wash the whole surface without impairing the ESP performance, many wet ESPs employ vertical flow via cylindrical, hexagonal, or rectangular collecting "tubes" surrounding each discharge electrode. In order to prevent solid formation, preserve electrical clearances, and maintain collection properties, the collecting and discharging electrodes must be uniformly wetted. In order to prevent water evaporation, the flue gas is moistened before entering the wet ESP. The water cleaning systems commonly combine intermittent or continuous upflow and downflow spray nozzles with overflow irrigation. A few horizontal flow plate wet ESPs are also already in use commercially. After a wet scrubber, a wet ESP may be utilized as a polishing device for particulate-control and as a mist-eliminator. The wet ESP may also remove these substances since many gaseous emissions condense and create a fine liquid mist at or above the water saturation temperature. For controlling fine particulate (PM10 and PM25) emissions, the wet ESP is also highly effective. The particulate slurry that results from wet ESPs and the following dewatering needed for suspended particles disposal are two issues. Before liquid is released from the plant, soluble components may also need to be removed from the water.

Textile filters Flue gas is passed through media filters like fabric filters or bag houses to eliminate particulate. Fabric filters were the most practical and cost-effective option for many new utility boilers in the United States during the last ten years because of reduced particulate emission limitations and the choice of low-sulfur fuels. The design and performance outcomes of fabric filters are influenced by factors such as media flue gas velocity (air-to-cloth [A/C] ratio), fabric and dust layer pressure drop, media life and cleanability, media, flue gas, and dust cake characteristics, and cleaning system type. The pore structure of certain membrane-type textiles or ceramics is noticeably finer than that of traditional woven or felted materials. These media may provide reduced emissions and pressure differentials and essentially replace the particle cake's filtering abilities. Ceramics or bags made of membrane fabric might cost much more than regular textiles. The media flue gas velocity (A/C ratio) is the rate at which the flue gas passes through the media used for collection. By dividing the volumetric flow of the actual flue gas by the filter area, the crucial A/C ratio is calculated. The capital cost lowers as the filtering area becomes smaller. As the A/C ratio rises, the flue gas pressure will undoubtedly reduce over the media and cause the cake to rise. Additionally, there is more potential for increased emissions and media failure with a higher A/C ratio. The right balance of capital and operational expenses, as well as emissions, depend on the A/C ratio. Typically, cloth filter material is stitched into cylindrical tubes known as bags. These filter bags might number in the hundreds for each fabric filter. A typical filter unit has compartments that allow for online maintenance or bag change. The maximum economic compartment size, total gas volume rate, A/C ratio, plus cleaning system design all influence the number of compartments. Additional compartments for offline cleaning or maintenance raise the price but decrease dependability. At least one hopper is included in each compartment for short-term storage of the gathered fly ash. The A/C ratio is referred to as "gross" in 424 Power Plant Engineering because all compartments are online. The "net" A/C ratio is the A/C ratio after taking one compartment out of service for maintenance or cleaning. The A/C ratio rises once again and is referred to as a "net-net" state if two compartments, one for each of maintenance and cleaning, are taken offline. The composition, length, and cross-section of fabric bags vary (diameter or shape). Cleaning technique, emissions restrictions, flue gas and ash characteristics, intended bag life, capital cost, A/C ratio, and pressure differential all affect bag selection characteristics. Fabric bags commonly survive more than 5 years and are normally guaranteed for 3 years. A high flue

gas pressure differential indication, a timer, or both may start the media cleaning process. Cleaning reduces the pressure difference, which rises progressively as the dust layer thickens. The accumulated cake serves as the main filtering medium in conventional nonmembrane bags, resulting in clean bags having greater emissions. The cleaning frequency normally rises as particle burden grows. It is necessary to strike a compromise between emissions, low operating costs (coming from routine cleaning with small pressure differentials), and extending bag life. In addition to operating temperature, pressure, flue gas composition, and particle qualities, filter bag life is influenced by media characteristics, cleaning frequency, and force, as well as operating temperature and pressure.

### **Types of fabric filters.**

The ways in which they are cleaned are used to classify fabric filters. Applications for reverse gas (also known as reverse air) or pulse jet cleaning are often used in utility coal-fired boilers. With a few exceptions, most American power plants first employed reverse gas cleaning. United States utilities typically chose pulse jet fabric filters during the last ten years for financial and site layout considerations as pulse jet experience, bag life, bag lengths, and compartment sizes grew. The majority of pulse jet cleaning has been employed by utilities as they have embraced fabric filtering globally. Successful utility pulse-jet installations in Australia and South Africa have expedited the trend.

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## CHAPTER 7

### GAS FABRIC FILTERS

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#### Gas Fabric Filters In Back.

The flue gas enters the reverse gas fabric filter (RGFF) horizontally towards the top of the hoppers and slightly below the tube sheet floor of the compartment (a horizontal plate with rows of vertical thimbles to which the bags are attached). Through the thimbles and into the bottom of the bags, the flue gas travels. The particle deposits on the interior of the bag form when the particulate-laden flue gas rises and passes through it (Fig. 14-3). The RGFF bags normally have a diameter of 8 or 12 in. and lengths of up to 24 or 35 ft., respectively. In the net-net situation, the filtering cloth velocity is approximately 2.3 acfm/ft<sup>2</sup> of cloth area. The RGFF bags are typically composed of woven fiberglass that has been treated to prevent abrasion and provide the glass fibers chemical resistance to the flue gas acids. Through poppet valves, the cleaned flue gas leaves the compartments and travels to the exit duct manifold and ID fans. During the cleaning cycle, reverse gas blowers and ducts recycle some of the clean flue gas from the entrance manifold back through the compartment in Figure 7.1. The fabric bends as a result of the momentary change in flue gas direction, loosening the filter cake, and gently blowing the dust cake off the filter medium. The hopper then receives this dust cake for removal. Reverse gas leaves the cleaning chamber and enters the filthy gas input manifold. To prevent the reverse gas from collapsing this same bag and trapping the particles, anti-collapse rings are sewed into the bag. Snap rings are used to join the bags' bottoms to the thimbles. They hang from the top of the compartment housing by a tensioning mechanism. Cleaning is always done when the compartment is unplugged. Typically, a reverse gas cleaning system is only big enough to clean one compartment at once. The bags must be properly tensioned to improve the cleaning process. Springs or eccentric weights are used to do this. Too much bag tension reduces the life and cleanliness of the bag. When cleaning, too little tension allows for folding, which reduces life and cleaning effectiveness.

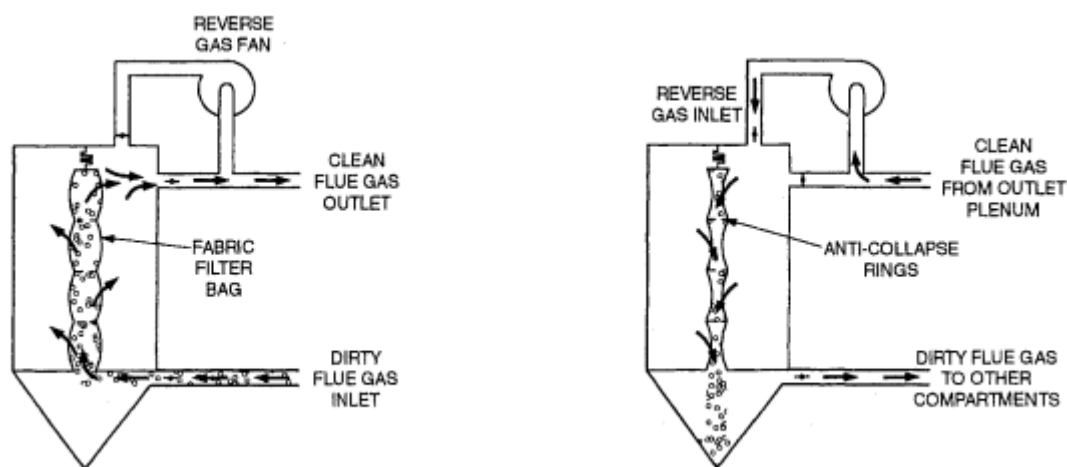


Figure 7.1: Illustrates the Gas Fabric Filters.

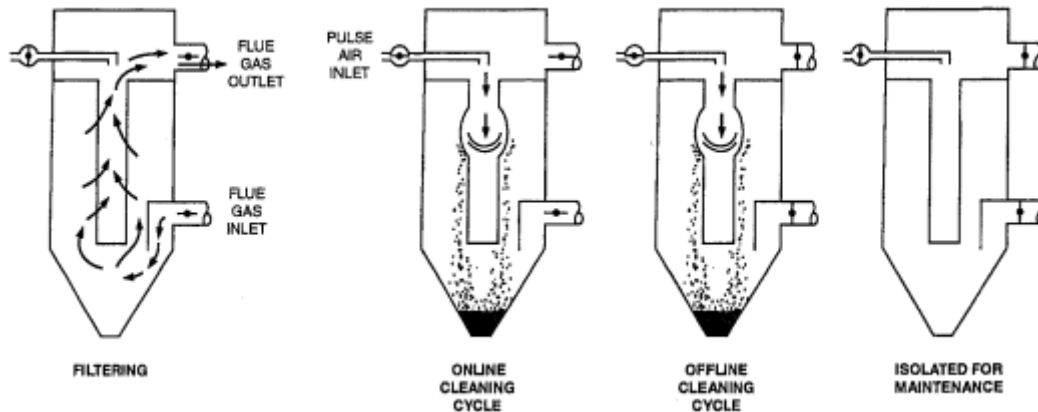
The total gas flow required to clean the remaining compartments increases when fabric cleaning is started. The extra flow is brought on by the clean flue gas that is cycled during cleaning. The usual clean flue gas flow rate is 1.5 to 2 acfm/ft<sup>2</sup> of the cleaned cloth surface area. This comparatively low cloth velocity is used by RGFFs to gently clean the bags. Because the whole dust layer shouldn't be removed from the media surface using RGFFs, gentle cleaning is crucial. The emissions may actually rise if the bags are overcleaned as a result of particle migration through the cloth. A rise in the pressure difference as a result of tiny particles being entrenched in the cloth is another impact of overcleaning. It's known as "bag blinding." In addition, residual oil from oil burning, sticky particulate from operations below the dew point, and deliquescence and particle stickiness brought on by excessive calcium chloride levels may all contribute to bag blindness. Sonic horn aided cleaning may be implemented if reverse gas cleaning is insufficient. When a high-pressure difference occurs across the bags as a result of "bag blindness" or an exceptionally thick or poor permeability dust coating, sonic horns may be helpful. A large amount of dust coating might put stress on the fabric and tensioning mechanism. The bag material vibrates at the horn's sound frequency, releasing more dust cake.

### **Pulse jet filters made of fabric (PJFF)**

Typically, flue gas enters the PJFF compartment hopper and moves from the bag's outside to its inside, depositing particles on the exterior in Figure 7.2. The interior of the bag has a metal cage inserted to keep it from collapsing. The output plenum is reached by the flue gas ascending through the bag's core. At the top of the compartment is where the PJFF's horizontal tube sheet is positioned (as compared to the bottom of the compartment for the RGFF). The tube sheet suspends the bags and cages. Cleaning is accomplished by sending a downward air pulse into the bags top. The length of the bag ripples as a result of this pulse. The dust cake is released from the bag surface by this ripple, and it then falls into the hopper. The compartment may be cleaned either online or offline. Care must be made in the input plenum design since the compartment may be cleaned online. The flue gas goes upward to the bags if it is introduced via the hopper. The particle that was just released from the bag surface may be reentrapped by upward flow. With correct bag spacing and, in certain systems, by entering the flue gas at the compartment sidewalls, by utilizing particle impingement baffles, upward velocity between the bags, also known as "can velocity," is reduced. Within the compartment, the PJFF cleans the bags in rows that are often staggered and sequential. If online cleaning is employed, the next rows of bags may catch some of the dust cake from of the row of bags being cleaned. Online cleaning is used on many big PJFF devices effectively despite this apparent drawback. Because of the difference in filter material, the PJFF bags' relatively high cleaning pressures provide an adequate life. PJFF bags are often composed of felted textiles, which can be cleaned more thoroughly since they don't depend as much on the dust cake's capacity to filter. The PJFF can run at a cloth velocity in the net condition of around 4 acfm/ft<sup>2</sup> of cloth area, which is almost double that of the RGFF, in large part because of the felted material. Due to variations in cleaning pressures and volumes, the PJFF cleaning technique is further divided into three groups.

- Low-pressure/high-volume (LP/HV) <15 psig
- Intermediate-pressure/intermediate-volume (IP/IV) 15 to 40 psig
- High-pressure/low-volume (HP/LV) > 40 psig

According to the current thinking, the cleaning energies of low- and intermediate-pressure pulses travel down the bag more efficiently than do the energies of high-pressure pulses. Therefore, compared to low- or intermediate-pressure cleaning methods, high-pressure systems often have shorter bags. Currently in use are low- and intermediate-pressure types with bags that are 7 and 8 m long as opposed to the normal maximum high-pressure length that is 5 m. As findings from fabric filter installations using high-pressure pulsing as well as 7 m lengths become available, this bag length and cleaning distinction will be examined more closely.



**Figure 7.2: Illustrates the procedure of filtering of fabric.**

The top door and the walk-in plenum are the two different kinds of PJFF outlet plenum designs. One tiny door, usually 2 feet by 4 feet, is included in each compartment of the walk-in plenum and is utilized to access the tube sheet top surface where the bags are hanging. The cages and sacks may be taken out since this walk-in plenum is tall enough. The length of the cage determines the plenum height. Long sacks were followed by two- and three-part interlocking cages. To reduce the needed plenum height and price, these cages are built in short pieces.

The output plenum height is low in the top-door or roof top hatch configuration. Lifting a cover that normally covers the top of the whole compartment is required to get access to the bags. The bags may then be examined or changed once this cover has been laid aside. The technology of the outlet plenum must be carefully chosen. Everyone has benefits and drawbacks. The top-door design's wide doors need greater seal maintenance and leakage. The walk-in plenum design facilitates bag inspection. However, the top-door technology improves the working conditions while the bags are being changed. The majority of manufacturers claim that the price of both outlet plenum types is same.

### **An evaluation of PJFF and RGFF**

A PJFF is smaller than an RGFF due to a greater AC ratio, online cleaning design, and no interior pathways. Even though the RGFF may be taller owing to longer bags, the PJFF footprint may often be up to 50% less than the RGFF footprint. The PJFF's capital expense may be less than 80% of the RGFF's capital expense. In comparison, the RGFF's bag expenses are much less than the PJFF's. Woven fiberglass is less expensive than felted materials, and support cages are also needed for the PJFF bags. The design, operating, and excursion temperatures for the RGFF woven fiberglass bags are greater than those for the felted materials commonly utilized with PJFFs. (Bag materials may physically break down at operation temperatures that are too high.) Operating bag lifetimes for RGFF are assured to be longer than those for PJFF.



### Comparison of ESPs and fabric filters.

The advantage for fabric filters (FFs) over electrostatic precipitators (ESPs) in terms of emissions is mostly due to the FFs' constant emissions regardless of the fuel ash characteristics or intake particulate load. The performance of an ESP is greatly influenced by fuel changes, which also cause variations in the ash load and resistivity at the intake. Emission spikes may happen with the ESPs when the boiler blows soot or while the ESP is banging. Rarely do these actions have an impact on fabric filter emissions. With fabric filters, there may be infrequent emission spikes brought either by overcleaning or the installation of new bags. Higher incoming particle loads because fabric filters to lose pressure, however this may be offset by cleaning them more often. ESPs have a pressure difference from flange to flange that is generally less than 2 in. wg as opposed to a cloth filter, which has a pressure differential of around 6 in. wg. The dust cake and cleaning frequency have a major role in the change of the fabric filter pressure difference. The ID fan uses more energy than the ESP due to the larger fabric filter pressure difference. The ESP's T-Rs power needs sometimes outweigh the operating cost reductions that arise from its lower ID fan energy level. Due to the need of bag replacement, fabric filters often have greater maintenance expenses than ESPs. Because modern ESP designs often function for many years without substantial maintenance, they usually need little upkeep. Control of Atmospheric Emissions from Power Plants 427 14.2.4 Alternative Technologies for Particulate Control

#### Cyclone Collectors (14.2.4.1).

In order to separate the fly ash from the flue gas, centrifugal collectors called cyclones depend on the particle density and velocity. The particulate-filled flue gas enters the cyclone from the top or the side, as shown in Fig. 14-6. The flue gas is given a rotating velocity by vanes, which pushes the fly ash to the cylinder's edge. The fly ash subsequently falls out the bottom of the cyclone while the flue gas leaves the middle out the top. This method can efficiently remove particles >20 microns in size at pressures around one atmosphere and 2 to 5 in. wg pressure differential.

#### Wet Venturi Scrubber

Fly ash is collected using liquids in wet venturi scrubbers. In the venturi throat, flue gas is accelerated to 12,000–18,000 fpm. Typically, liquid is only delivered upstream or in the throat. Water is sheared into droplets when high-velocity flue gas crosses the flow of liquid. The pressure drop affects droplet size. The size of the fly ash and droplet particles and their initial differential velocities determine the impact between the two. Cyclonic action, impingement trays, or interception with liquid sprays, mist eliminators, or all, are used to remove the liquid droplets containing the fly ash. This method is uneconomic for new electrical power plants because to the flue gas pressure drop necessary to comply with the regulations for particle emissions and the resulting higher ID fan auxiliary power expenses. Wet venturi scrubbers are still in use in certain older installations. Venturi scrubbers are efficient at removing particles of all sizes, but they need a 30 to 40 in. wg difference to operate at the present removal efficiency for fly ash size particles in modern plants. The resulting fly ash slurry increases operational costs, challenges with SO<sub>2</sub> scrubbers, and water treatment requirements.

#### Control of Nitrogen Oxide Emissions

A common criterion for both new and existing power plants is the reduction of nitrogen oxide (NO<sub>x</sub>) emissions. The relationship between NO<sub>x</sub> Emission and ambient ozone concentrations is the main reason for this. Therefore, the 1990 CAAA Title I, Title IV, and BACT for new units will gradually mandate lower NO<sub>x</sub> emissions from power plants in the United States. In

Europe and Japan, strict NO<sub>x</sub> emission limits are the norm. Nitric oxide (NO) accounts for 90% to 95% of NO<sub>x</sub> in flue gas, with nitrogen dioxide making up the remainder (NO<sub>2</sub>). Despite being by far the least prevalent element, the industry standard for expressing emissions is based on the molecular weight of NO<sub>2</sub>. NO<sub>x</sub> is a byproduct of the oxidation of either the nitrogen in the fuel (fuel NO) or the nitrogen in the combustion air (thermal NO). Less than 25% of the NO<sub>x</sub> generated while burning coal is typically thermal NO<sub>x</sub>, with the remainder being fuel NO<sub>x</sub> (Stultz and Kitto 1992). However, firing procedures that restrict fuel NO<sub>x</sub> generation are more effective in reducing total NO<sub>x</sub>, than lowering combustion zone temperatures in reducing boiler thermal NO<sub>x</sub> emissions. Reactions leading to fuel NO<sub>x</sub> production are poorly understood. The primary chemical step seems to be the devolatilization of fuel intermediate molecules that produce nitrogen, such as NO, NO<sub>2</sub>, NH<sub>3</sub>, and HCN (Blair and Wendt 1981). The fuel/air ratio has a significant impact on subsequent N<sub>2</sub> or NO production. Because of this, the majority of low NO<sub>x</sub> burner designs deliberately lower oxygen levels for fuel combustion. The volatile reactants that the fuels create seem to be necessary for the fuel NO<sub>x</sub> conversion processes. Bench scale combustion experiments, for instance, show that there is no association between the nitrogen bound to the fuel and the NO<sub>x</sub> produced by the fuel (Singer 1981). Generally speaking, a gasoline with less nitrogen than one with more nitrogen generates less total NO<sub>x</sub>. However, studies have shown that the conversion of fuel-bound nitrogen to NO is largely unaffected by ordinary flame temperatures (Singer 1981). 428 Electrical Engineering

The combustion NO<sub>x</sub> emission reduction techniques may reduce the NO<sub>x</sub> emissions from a boiler burning coal, oil, or gas to around 0.3, 0.2, and 0.1 lb/MBtu, respectively. This decrease may be achieved in two ways: combustion control and postcombustion control. Low-NO burners, air staging, fuel staging, operational adjustments, and combustion turbine NO<sub>x</sub> controls are some of the main options for reducing NO<sub>x</sub>. Selective catalytic reduction (SCR) and selective noncatalytic reduction are examples of postcombustion controls (SNCR).

### Control of Combustion

In contrast to postcombustion processes, which lower the concentration of these pollutants in the flue gas, combustion control methods are used to reduce the amount of NO<sub>x</sub>, carbon monoxide, and unburned hydrocarbons (generally regulated as nonmethane hydrocarbons or volatile organic compounds emissions). Unburned carbon is an issue for plant efficiency and the economy and, at certain levels, impacts the marketability of fly ash and the effectiveness of an electrostatic precipitator. Unburned combustibles in the ash have not been a regulatory concern. Decreased oxygen concentration, reduced combustion temperature, and reduced reaction time in oxygen-rich, high-temperature circumstances are the combustion control procedures that lessen the formation of NO<sub>x</sub>. But generally speaking, these circumstances will lead to an increase in the creation of CO and VOC in the flue gas as well as unburned carbon in the ash. Therefore, maintaining acceptable low levels of CO, VOC, and unburned carbon while minimizing NO<sub>x</sub> emissions is a fundamental design requirement for combustion control of NO<sub>x</sub>. Low-NO burners, air staging, fuel staging, operational changes, and design alterations are the main NO<sub>x</sub> reduction combustion control strategies for new equipment and retrofit applications. Later, a detailed discussion of these primary control approaches will take place.

### Low-NO<sub>x</sub> Burners

For new and retrofit applications on boilers and combustion turbines using almost any fuel, low-NO burners are readily available. The following explanation focuses on low-NO burners placed on pulverized coal (PC) boilers, despite the fact that their operating principles are essentially the same. Low-NO burners are not used for NO<sub>x</sub> control in circulating fluidized bed (CFB) boilers. NO emissions from CFB boilers may be as low as 0.2 lb/MBtu by maintaining low combustion temperature and close mixing inside the combustion chamber. See

more information on CFB boilers. Wall-fired and corner-fired low-NO burner systems for PC boilers are easily distinguished from one another. There are normally two distinct secondary air flow channels that pass via wall-mounted burners and into the furnace. These burners are often of the multiple-register (damper) kind. Common characteristics include separate specialized dampers or vanes to regulate the flow and spin of the different secondary air flows through the burner as well as dedicated overall secondary air flow control dampers. Typically, at first starting, the vanes that govern spin or flame form are set and then locked in place. A fundamental need for all manufacturers is the control and balancing of the secondary air, primary air, and coal distribution among the burners. Individual burner air and coal flow variations from the mean are typically 10%. Due to this need, individual burner level turn down at part load operating methods may need to modify. To maintain the capacity to function with imbalanced firing at part load, on the other hand, extra control measures and flow monitoring capabilities may be needed. Manufacturers normally recommend coal fineness of 65% to 70% through 200-mesh (0.074 mm) and 98% to 99% through 50-mesh in retrofit circumstances (0.297 mm). Although manufacturers concur that the fineness of the coal grind has little to no impact on NO<sub>x</sub> emission, the burners perform better with a finer coal grind. If coal fineness deteriorates, the amount of unburned carbon in the ash will rise.

### **Air staging**

OFA ports make up the air staging outside the burner. Depending on the fuel and the required NO<sub>v</sub> emission, OFA may or may not be utilized in combination with low-NO<sub>x</sub> burners. A new or retrofit low-NO<sub>x</sub> burner system's usual result of adding OFA is an additional 10% to 20% decrease in NO<sub>x</sub> emissions. However, the inclusion of OFA may result in an increase in unburned carbon and flammable materials. By generating a combustion zone that is fuel-rich, OFA systems lower NO production. In order to complete fuel burnout at a lower temperature and with less volatile combustion products that include nitrogen, the OFA is injected above the primary combustion zone. The simplest OFA system consists of ducts attached to the top of the windbox and equipped with flow control dampers. On a front wall fired unit, however, side wall and rear wall OFA ports that are positioned above the top burner elevation have been proposed. A separate secondary air to OFA duct connection upstream of the windbox intake may improve balancing and management of both the windbox and the OFA system in retrofit circumstances with imbalanced windbox flow.

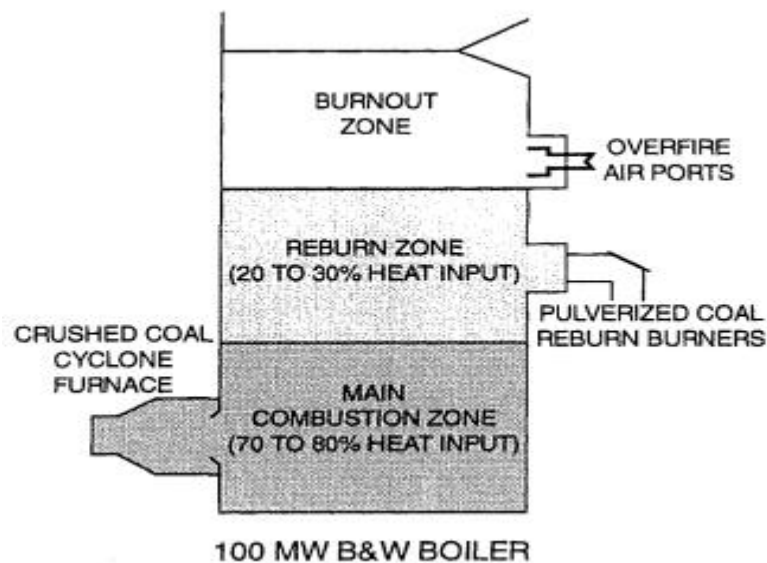
### **Energy Staging**

One way to manage the generation of NO<sub>v</sub> is by staging the entry of fuel into the furnace. The most popular method of fuel staging is reburning technology. As shown in Fig. 14-11, the reburn method uses three distinct combustion zones to lower NO<sub>x</sub> emissions. The first zone is the lower furnace's regular combustion zone, which, depending on the kind of furnace, is created by cyclone burners or pulverized coal burners. 70% to 80% of the total fuel heat input is introduced in this zone. About 10% more air is used to run the first zone burners (a 1.10 stoichiometric ratio). By running a row of typical pulverized coal or traditional natural gas burners at a stoichiometric ratio significantly less than 1.0, a second combustion zone (the reburn zone) is generated above the bottom furnace. The mixture of reburn fuel and lower furnace combustion products, or the stoichiometric ratio for the reburn zone, ranges between 0.80 and 0.95. Because the oxygen taken from the NO<sub>x</sub> molecules is coupled with more active carbon monoxide molecules to generate carbon dioxide, the substoichiometric reburn zone allows NO produced in the lower furnace units to be converted to molecular nitrogen and oxygen. The inclusion of OFA completes fuel burnout in the burnout zone. With a 15% to 20% total extra air for the boiler, enough OFA is provided to fully burn the unburned materials in the top furnace. Reburn technology has shown removal efficiencies of NO<sub>x</sub> ranging from 40%

to 65%. Reburning provides a way to restore load to boilers that have lost efficiency due to restrictions on fuel processing or firing capacity. Reburn zone burners are added, increasing heat input while significantly lowering NO<sub>x</sub> emissions. However, for this technological upgrade to be effective, the boiler must have enough room to provide for enough respite time for both the increased burning zone and the corresponding OFA burnout zone. Reburning can be efficient when this space is available, but a short residence duration can hinder system performance.

### Modifications to operations.

On existing boilers, operational modifications have been made to reduce NO<sub>x</sub> by 5% to 15%. Operational changes have often been made when marginal NO<sub>x</sub> reductions are all that are needed in. Figure 7.3 Operational changes are appealing since there is little to no need for capital expenditure, even if operating expenses can go up. Flue gas recirculation, decreased air preheat, water injection, reduced surplus air, biased firing, burners out of service, and fuel switching or dual fuel firing are a few examples of operational adjustments. One of the easiest operational changes for NO<sub>x</sub> reduction is to reduce the flow rate of surplus air, especially if the baseline excess air comprises a significant margin beyond the level needed for full combustion. Eliminating extra air also lowers stack loss and increases boiler efficiency. Normally, NO<sub>x</sub> decrease with less surplus air is 10%.



**Figure 7.3: Illustrates the modification operation of nitrogen oxide.**

Biased firing is another pretty easy operational change. Biased firing achieves restricted fuel staging through the furnace by running lower burner levels fuel rich and higher burner levels air rich. Biased firing often only reduces NO<sub>x</sub> by 8% to 10%. The amount of fuel biasing that may be achieved may be limited by coal mill capacity restrictions, and existing units' control system constraints may make consistent biased firing challenging (Miller 1985). A lower furnace with localized decreasing atmosphere conditions due to excessive biasing may see an increase throughout unburned combustible and waterwall corrosion.

#### 14.3.1.5 NO<sub>x</sub> controls for combustion turbines.

One way to reduce NO<sub>x</sub> production in a combustion turbine unit is to inject water or steam into the combustion zones. Because of the lower combustion temperatures brought on by the injection of water or steam, thermal NO<sub>x</sub> production is prevented. The quantity of water or

steam pumped into the turbine has a slightly inverse relationship with the degree of reduction in NO<sub>v</sub> generation. The ability of combustion turbine units to withstand the water or steam required to reduce NO<sub>t</sub> emissions has increased recently. There is, however, a limit to how much water or steam the turbine can handle before its dependability and lifespan are significantly compromised.

Without using water or steam injection, modern combustion turbine designs may achieve minimal uncontrolled NO<sub>j</sub> emissions. With the use of these dry low-temperature burners, NO<sub>A</sub> emissions from combustion turbines may be reduced from 42 to 9 ppmvd.

The technology is not an add-on, but rather an integral element of the combustor architecture. The system's advantages include a demonstrated capacity to reduce NO<sub>r</sub> and a general hardware resemblance to that seen in standard gas turbine combustor designs. Increased carbon monoxide and unburned carbon emissions are disadvantages. Lean premixed combustion is the foundation of this combustion system.

By preventing high, almost stoichiometric flame temperatures from developing inside the main combustion zone, lean-premixed combustion lowers the conversion of atmospheric nitrogen to NO<sub>A</sub>. Considering that NO<sub>A</sub> generation rates are exponentially correlated with temperature, decreasing the temperature has a significant impact on NO<sub>A</sub> emissions. Any area with high temperatures has the potential to significantly increase total NO<sub>y</sub> emissions.

If the flame zone has a high fuel/air ratio, extreme temperatures may be experienced locally. When fuel is pumped into the main zone of a traditional combustion device, the processes of fuel/air mixing and combustion take place concurrently. The mixing and combustion stages are separated in lean pre mixed combustion.

Upstream of the combustion zone, the fuel and primary combustion air are combined. Premixing avoids high NO<sub>v</sub> generation zones within the combustor and results in a more uniform flame temperature. Additionally, NO<sub>v</sub> control for combustion turbines is covered.

**Systems for Selective Catalytic Reduction after Combustion** A postcombustion NO<sub>v</sub> emission reduction system is selective catalytic reduction (SCR). With the help of a catalyst and vaporized ammonia fed into the flue gas stream, SCR systems may reduce NO<sub>x</sub> emissions by up to 95%. Nitrogen and water are produced via the reaction between NO<sub>A</sub> and ammonia (NH<sub>3</sub>).

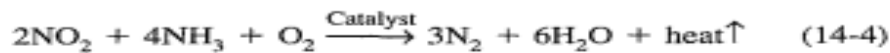
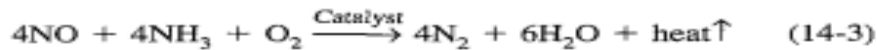
With a reagent stoichiometry of around 1.0 (moles of NH<sub>3</sub> per mole of NO<sub>0</sub> reduced) and very minimal ammonia slip, the reaction mechanisms are quite effective (unreacted ammonia emissions). The range of design ammonia slip values is 2 to 10 ppm. SCR systems may be retrofitted into PC, CFB, or combustion turbine units that are powered by coal, oil, or natural gas without significantly affecting the balance of the plant's machinery or the availability of the unit if they are designed properly.

The following outlines the fundamental process reactions, other SCR system options, system setup, considerations for the catalyst, and the state of SCR system development.

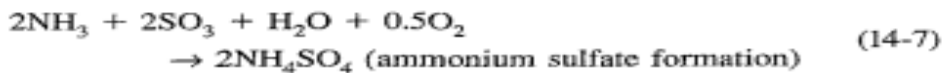
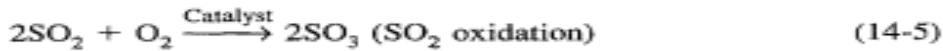
### **Process Reactions**

As ammonia and NO<sub>x</sub> pass over the catalyst, an exothermic reaction occurs, generating nitrogen and water vapor. The most common process reactions are listed below.

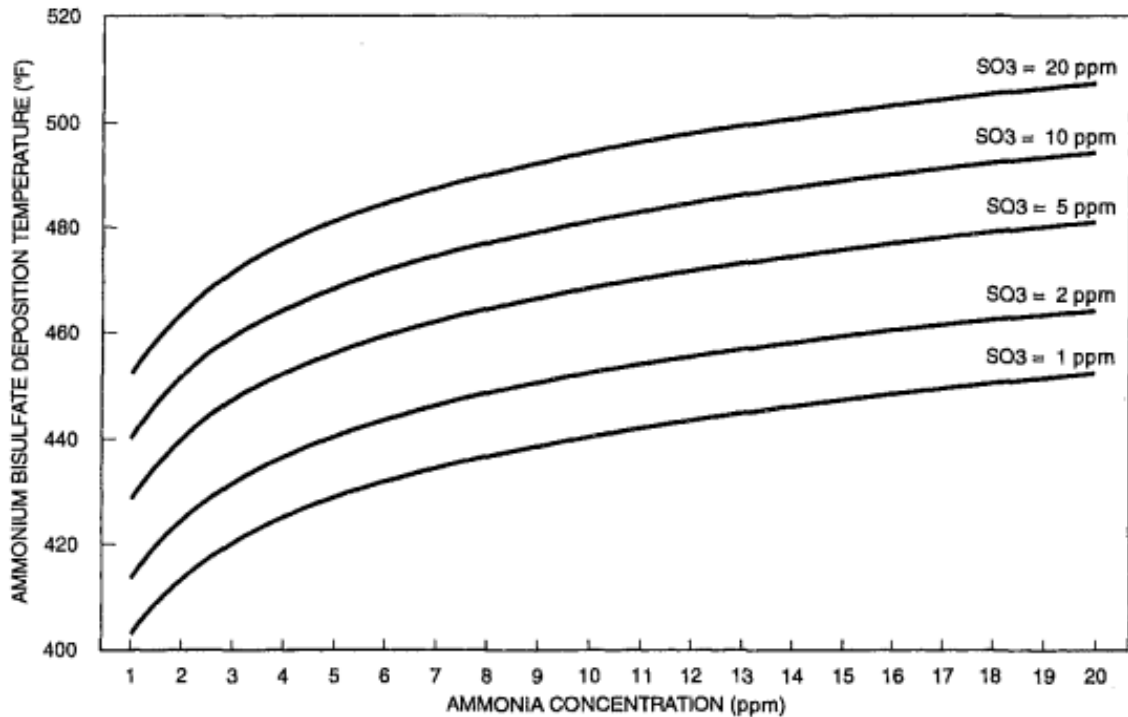




Unfortunately, the following undesirable reactions can also take place:



The oxidation of SO<sub>2</sub> to SO<sub>3</sub> (Interaction 14-5) and the subsequent reaction of SO<sub>3</sub> with unreacted ammonia to produce ammonium bisulfate are the two reactions on the list that might be the most problematic (Reaction 14-6). Temperatures over around 700° F significantly enhance the conversion of SO<sub>2</sub> to SO<sub>3</sub>. Therefore, ammonia injection (SCR operation) should be restricted to temperatures between 660 and 700 °F for applications employing sulfur-containing fuels. Operation within this temperature range should keep the oxidation of SO<sub>2</sub> to SO<sub>3</sub> to 1% or less with the proper catalyst composition. For optimal ammonia reactivity and to aid in preventing the production of ammonium salts, ammonia reagent for SCR systems should be administered at temperatures above roughly 570° F. In the presence of ammonia, sulfur trioxide (SO<sub>3</sub>) transforms into the 432 Power Plant Engineering salts of ammonium sulfate and ammonium bisulfate. According to Figure 7.4, the relative concentrations of ammonia and SO<sub>3</sub> in the flue gas determines the precipitation temperature of these salts from the flue gas. On catalysts, air heater baskets, steam heat recovery generators, and other downstream equipment, ammonium bisulfate may deposit as a sticky material. Because the resulting ammonium bisulfate and sulfate salt particles have a diameter of 1 to 3 microns, they may contribute to PM<sub>10</sub> (paniculate matter) at 570 degrees Fahrenheit. These ammonium salts may accumulate on the surfaces of air heaters in boiler units, requiring more regular soot removal and offline cleaning. To reduce the risk of air heater fouling, it may be essential to keep ammonia slip below 5 ppm, depending on the sulfur content of the design fuel. Due to the fact that the acid dew point temperature of the flue gas is closely proportional to SO<sub>3</sub> content, the oxidation of SO<sub>2</sub> to SO<sub>3</sub> may also need a modification in the minimum air heater output temperature. The acid dew point of the flue gas rises as the SO<sub>3</sub> content climbs, potentially causing corrosion throughout downstream equipment. Installing enameled baskets that are resistant to corrosion is an option to adjusting the air heater outlet temperature. For coal-fueled boilers, up to 80% of the ammonia slip that leaves the SCR system condenses on the fly ash gathered in the particle removal apparatus (electrostatic precipitator or fabric filter). The disposal of trash or the possibility of waste product sales may be impacted by the ammonia level of the fly ash. Ammonia in the fly ash is produced at an increased pH, which might result in odorous emissions. Additionally, fly ash used as an additive in cement production or other pozzolonic purposes, or for fixing FGD reaction products, may cause spontaneous ammonia emissions. This might, in rare circumstances, constitute a safety issue. According to German experience, fly ash ammonia concentrations of >80 to 100 ppm (mass basis) might cause issues with reuse or disposal. Current SCR systems employ anhydrous ammonia, and ammonia slip emissions may need to be restricted to 95% of alkaline ashes. Because the majority of these facilities are in densely populated regions, safety is a top priority.



**Figure 7.4:** Illustrates the relative concentrations of ammonia and SO<sub>3</sub> in the flue gas determines the precipitation temperature of the salts from the flue gas.

Because it is less costly than aqueous ammonia and a more concentrated chemical with less storage requirements, anhydrous ammonia is the chosen reagent. Additionally, compared to the energy and equipment needed to evaporate aqueous ammonia, anhydrous ammonia requires substantially less of both. However, the usage of aqueous ammonia is being encouraged in several parts of the United States.

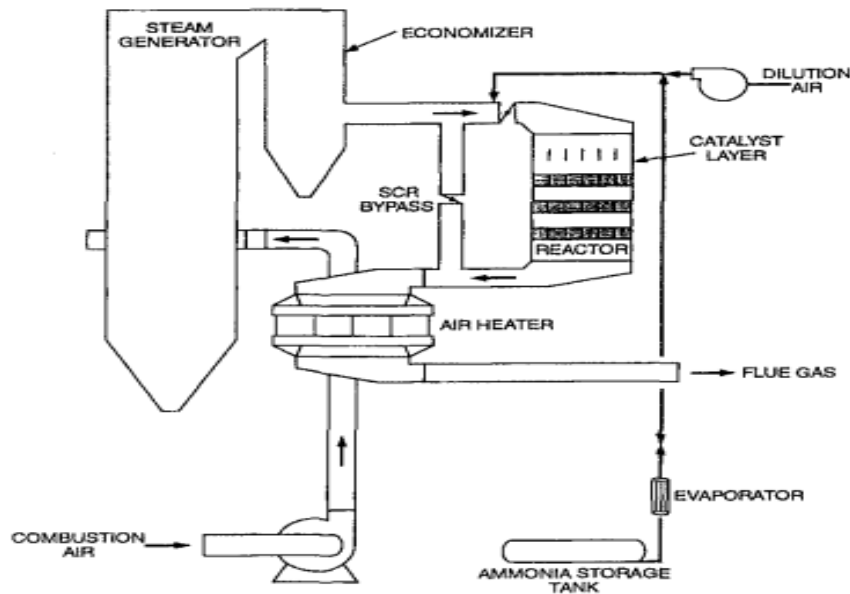
### SCR System Configurations

Three possible system configurations should be taken into consideration for installation on a PC boiler based on the previously specified temperature constraints for SCR system use: High dust Catalyst is upstream of the air heater and at the economizer's output. Low dust Catalyst is upstream of the air heater and at the hot-side ESP's outflow in Figure 7.5. Tail end the catalyst is situated upstream of the stack and at the FGD and particle removal systems' outlets. In Japan and Europe, applications using coal have been effectively implemented using all three configurations.

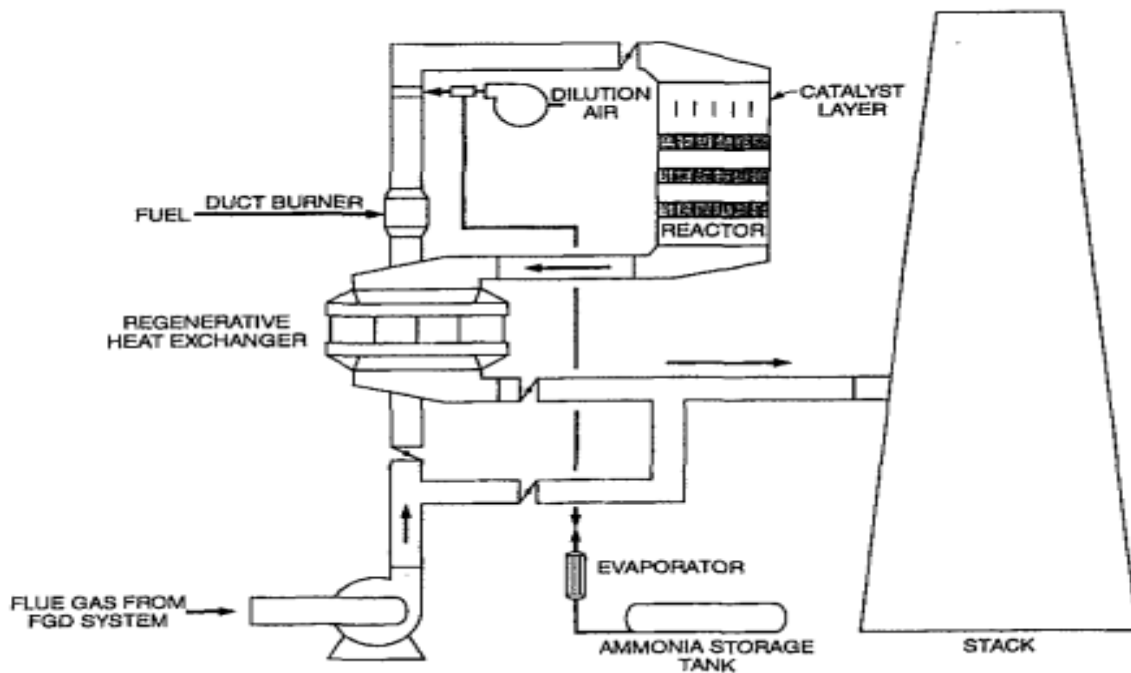
Due to the removal of the main catalyst degradants and poisons (particulate, sulfur compounds, and trace elements) from the gas stream, more reactive catalyst formulations are used in tail-end applications to optimize catalytic life and reduce catalyst cost. However, it is rather costly to reheat the flue gas since it needs a gas-gas heat exchanger and an additional heat source, either natural gas or steam from the boiler.

Catalyst lifetimes for low- and high-dust SCR configurations are comparable, but the low-dust catalyst may have a smaller catalyst pitch (the size of the catalyst open regions), which may result in a more economical catalyst installation.

To retrofit either a low- or high-dust SCR system, there has to be enough room close to the boiler area.



**Figure 7.5:** Illustrates the schematic diagram of specified temperature constraints.



**Figure 7.6:** Illustrates the boiler economizer outflow for systems powered by oil and gas.

SCR catalyst is often installed at the high-dust position near the boiler economizer outflow for systems powered by oil and gas in Figure 7.6. However, given how relatively clean the flue gas is, a more reactive catalyst with a narrower pitch is acceptable. The orientation of catalyst beds might be either vertical or horizontal. For high-dust systems, vertical flow is favored because it enables efficient online sootblowing to prevent clogging the catalyst bed. Vertical or horizontal flow arrangements may be used for low-dust and tail end setups. SCR systems on combustion turbines (CT) may be installed either within the HRSG (horizontal flow) or at the CT output. The conventional vanadium/titanium catalyst has a maximum working temperature

of 780° F. This kind of catalyst must be put within the HRSG unit since the temperature of the flue gas leaving the CT is almost never lower than 900° F. Alternatively, as zeolyte can function at temperatures beyond 1,150° F, using it as a catalyst enables SCR installation at the CT exhaust.

### **Storage and vaporization of ammonia.**

Anhydrous ammonia is kept in a pressure tank with a 250–300 psig rating. Typically, aqueous ammonia is kept in a tank with a 25–30 psig rating. For spills from the storage tanks to be contained, the storage area has to have a diked foundation with the proper drainage. Pressure release valves, liquid level sensors, and high and low temperature and pressure alarms should all be installed in the storage vessel. Trucks, trains, and barges may all transport ammonia to the storage facility in any form. Ammonia cannot transition from a liquid to a gas without first being vaporized. A control valve regulates the flow of ammonia vapor. Air is used to dilute the gaseous ammonia to a mixture that ranges from 2% to 5%. The dispersion of ammonia in the flue gas is made more effective by the air's relatively constant flow rate.

### **Control and injection of ammonia.**

Based on unit load or gas flow, intake NO<sub>x</sub> concentrations, and the desired output NO<sub>x</sub> concentration, SCR ammonia flow rates are regulated. For practically perfect SCR system stoichiometries, high reaction efficiencies and minimal ammonia slip requirements are necessary. The ammonia flow control valve is controlled by feedforward using the intake total NO<sub>x</sub> concentration and flue gas flow indicator. The reagent feed control valve receives a signal from the output total NO<sub>x</sub> concentration feedback to adjust the ammonia injection rate. Ammonia slip emissions are reduced by this very fine control concept. For the uniform injection of vaporized, diluted ammonia in the flue gas stream, there are two basic options: an ammonia injection grid (AIG) made of manually operated throttling valves on the injection lines, or a more straightforward matrix of injection headers that relies on a flow mixing device (static mixer) to distribute reagent. To maintain "cause and effect" tuning capabilities and to minimize overall system pressure decreases, usage of AIGs is often used. Experience has shown that AIG adjustments are often uncommon (once per year or less).

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## CHAPTER 8

### DESIGN AND DEACTIVATION OF THE CATALYST

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20% to 30% of the overall capital cost of an SCR system is generally spent on a catalyst. As a result, the choice of catalyst materials and catalytic design are very important. Flue gas temperature, inlet NO<sub>x</sub> concentrations, NO<sub>x</sub> emission limits, allowed ammonia slip, required catalyst life, oxygen content of flue gas, permitted SO<sub>2</sub> to SO<sub>3</sub> conversion rate, inlet dust loading, distribution of flue gas and NO, concentrations of flue gas catalyst poison, and permitted pressure drop across the catalyst are all factors that must be taken into account. Typically, vanadia-titania mixtures are the main component of catalysts utilized in utility service. However, a variety of active metals and support materials may make up the final catalyst composition. Vanadium pentoxide (V<sub>2</sub>O<sub>5</sub>), the active catalyst component, is often supported and dispersed by titanium dioxide (TiO<sub>2</sub>). The SCR industry makes extensive use of vanadium pentoxide because of the substance's resistance to sulfur poisoning. Unfortunately, the amount of vanadium in the catalyst regulates its reactivity and catalyzes the conversion of SO<sub>2</sub> into SO<sub>3</sub>. Vanadium content must be kept to a minimum in fuel applications using fuels with moderate to high sulfur concentration in order to decrease SO<sub>2</sub> conversion. The oxidation of SO<sub>2</sub> to SO<sub>3</sub> is prevented by the addition of tungsten oxide (W<sub>2</sub>O<sub>3</sub>), which is employed in a variety of catalyst compositions to decrease excess surface oxygen. The catalyst benefits from the mechanical and thermal stability that tungsten oxide offers. To fulfill the unique needs of each SCR installation, the amounts of vanadium pentoxide, titanium dioxide, and tungsten oxide may be changed. The NO reduction rate is directly influenced by parameters for gas hourly space velocity, catalyst pitch, area velocity, and flue gas temperature in addition to the ammonia injection rate and catalyst composition. The volumetric flow rate of the flue gas (ft<sup>3</sup>/h) divided by the catalyst volume results in the gas hourly space velocity, which is the reciprocal of residence time (1/h) (ft<sup>3</sup>). Thus, when the gas hourly space velocity rises, the gas's duration in contact with the catalyst shortens, reducing the possibility for NO<sub>x</sub> reduction overall (due to rising NO emissions, possible ammonia slip, or both). The cell wall thickness plus the flow channel width is known as the catalyst pitch. The catalyst pitch is closely correlated with the pressure decrease through the catalyst. The system pressure drop rises as the catalyst pitch falls. The catalyst pitch is often determined by the fuel's characteristics and the application type (high-dust, low-dust, or tail-end). The biggest pitch is needed for coal-burning plants with high-dust applications to handle the significant volume of fly ash in the flue gas. Catalyst pitches for high-dust SCR catalysts used in coal-fueled facilities typically range from 6 to 7.5 mm. Catalyst pitches for low-dust or tail-end catalysts installed in coal-fueled reactors typically range from 3.3 to 5 mm. The catalyst pitch might be as low as 2 to 3 mm in applications with extremely low particulate (fuel oil or natural gas). Regarding optimizing catalyst pitch for low-pressure drop based on increasing the frontal area rather than reducing the catalyst bed depth, site-specific concerns must be taken into account.

Area velocity (ft/h) is a more accurate indicator of catalyst design since it takes the pitch into account and is calculated by dividing the volumetric flow of the flue gas (ft<sup>3</sup>/h) by the surface area of the catalyst (ft<sup>2</sup>). By dividing the space velocity by the effective surface area of the Power Plant Atmospheric Emissions Control 435 catalyst, the area velocity may be converted to the space velocity. The specific surface area is calculated by dividing the catalyst's surface



area by its entire volume (ft<sup>2</sup>/ft<sup>3</sup>). It should be noted that the surface area refers to the geometric value and not the surface area of the microporous structures on the catalyst's surface. A temperature that is ideal for NO. Vanadium-titanium catalyst emission reduction typically occurs between 600 and 700° F, although it may also occur between 550 and 780° F. Each kind of catalyst has an optimal temperature range that is particular to the flue gas composition. When temperatures fall below the ideal temperature range, NO, Efficiency of reduction quickly declines. SO<sub>2</sub> to SO<sub>x</sub> conversion rates rapidly rise when temperatures rise over the ideal temperature range. As a consequence, factors associated to effective SCR operation may have an impact on the design and operation of the economizer. A catalyst loses some of its initial activity over time. In the end, this deterioration necessitates the addition of new catalyst to the reactor vessel or its replacement.

In SCR systems, the first catalyst charge is normally covered by a 2- to 4-year manufacturer warranty. The catalyst is poisoned by certain alkali metals and trace elements, which has a negative impact on life and reactivity. The following is a list of known poisons: Arsenic Cadmium Beryllium Calcium Chromium Copper, Lead, Manganese, Mercury, Nickel, Thorium, and Uranium are just a few of the elements that make up the periodic table. When present as gaseous arsenic oxide, the primary toxin, arsenic, may deposit on catalyst surfaces and block the catalyst's tiny pores. This restricts the flow of the ammonia–NO. Combination to the catalyst sites that are active. By making the catalyst's pores bigger to lessen the amount of blockage of active sites, this impact may be partly mitigated. However, over time, the active sites on the catalyst surface may be chemically attacked (neutralized) by arsenic and the other poisons mentioned, decreasing the catalyst's efficiency. When a catalyst is exposed to flue gas, the consequences of poisoning develop gradually over time. More ammonia must be introduced to maintain NO, emission limitations when the catalyst deactivates. As a consequence, more ammonia slips out for a given degree of performance.

### **Management by catalyst.**

As previously mentioned, the catalyst accounts for around 20% to 30% of the cost of an SCR system. Therefore, the relative economics of the SCR are significantly impacted by catalyst life and the corresponding addition or replacement schedules. The catalyst's initial charge may achieve the performance goals based on the design. Whenever catalyst activity has dropped to the point that outlet NO<sub>x</sub> emission requirements cannot be met while staying within ammonia slip limitations, augmentation or replacement of the original catalyst charge is required. This initial catalyst charge deactivates at a reasonably uniform pace. It is preferable to add catalyst rather than entirely replace it in order to more effectively use the remaining catalyst activity since the activity levels in the first catalyst charge are still quite high (between 50% and 75%). Therefore, it is advised to provide the reactor shell some flexibility so that more catalyst layers may be added in the future. This adaptability significantly reduces an SCR system's life cycle expenses.

The life cycle cost of the SCR system may be significantly impacted by a catalyst management plan (CMP). For instance, if a CMP is not utilized, a unit with an SCR system that needs 1,000 ft<sup>3</sup> of catalyst (with a guaranteed life of 3 years) and a design trees and plants of 20 years would need a total of 5,500 ft<sup>3</sup> of catalyst, and 3,000 ft<sup>3</sup> if room for a spare layer is provided in the design and a CMP is used. When the installation of a spare layer is permitted by the physical restrictions, including a CMP in the SCR design is cost-effective. The total pressure drop in the SCR system is increased with the addition of a future catalyst layer. As a result, there is a trade-off between the price of a new catalyst and the rise in total power consumption that comes with an increase in pressure drop. This tradeoff often strongly favors a CMP.

### Recycling or Disposal of Catalyst.

Although certain regions may designate new, fresh catalyst as dangerous due to the high vanadium content, it is typically not thought of as a hazardous substance. The catalyst may, however, absorb or gather enough of the trace pollutants in the flue gas over the course of years of operation on a coal- or oil-fueled boiler in the presence of the gas to be regarded as harmful. Most of the substances formerly designated as poisons are among the potential dangerous compounds. Spended catalyst typically does not fit the criteria of a hazardous waste, according to preliminary testing.

Catalyst recycling is the preferred procedure for the final removal of used catalyst, according to major providers in both Germany and the United States. It is typical for the user and the catalyst provider to come to an agreement outlining the terms and conditions under which the catalyst supplier will accept the used catalyst for ultimate disposal when fresh catalyst is bought.

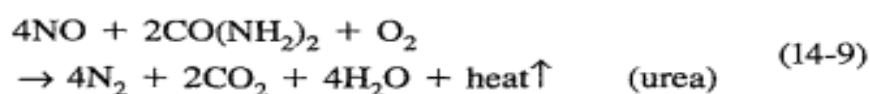
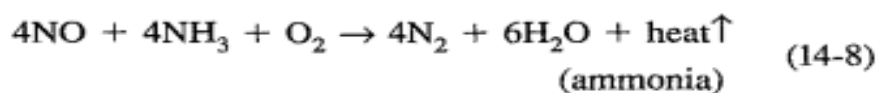
Systems for selective noncatalytic reduction in post-combustion control. Another economically viable approach to reduce NO<sub>x</sub> emissions from fossil fuel powered boilers is selective noncatalytic reduction. Instead of using a catalyst, SNCR systems accomplish NO<sub>x</sub> reductions by using an acceptable reagent injection temperature, excellent reagent-gas mixing, and an optimum reaction duration. Ammonia or urea may be used in SNCR systems as reagents (marketed as Thermal DeNO<sub>x</sub> or NO<sub>x</sub>OUT® systems, respectively). In sections of the steam generator in which the flue gas temperature is between 1,500 and 2,200° F, ammonia or urea is injected. In ideal conditions (sufficient reaction time, temperature, and reagent-flue gas mixing), SNCR systems may reduce NO<sub>x</sub> by as much as 70% to 80% with ammunition drops of 10 to 50 ppm.

However, potential performance depends greatly on the site and is different depending on the fuel type, steam generator size, and steam generator heat transfer characteristics. For coal-fueled steam generators bigger than 100 to 150 megawatts, these characteristics may restrict potential SNCR efficacy to as low as 20% to 30% NO reduction (MW).

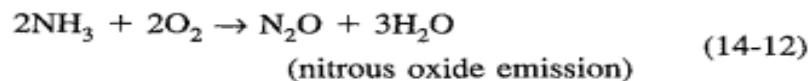
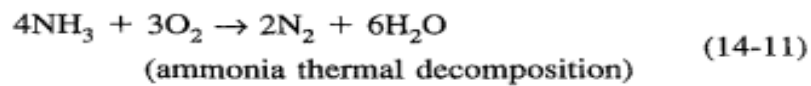
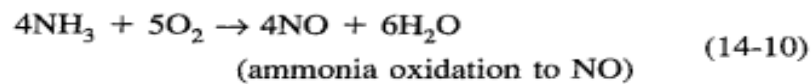
The presence of the hot cyclone allows appropriate retention time at temperatures that are almost optimal for NO<sub>x</sub> reduction in circulating fluidized bed (CFB) applications where SNCR systems have shown excellent performance (50% to 70% NO<sub>x</sub> reduction). The following details the fundamental system capabilities, process interactions, and current state of SNCR system development.

### Reactions in the process

Based on a thermally based exothermic reaction between reagent and NO, SNCR systems lower NO<sub>x</sub> emissions. The most common reactions in ammonia and urea-based systems are as follows:



With the exception of the oxidation of  $\text{SO}_2$  to  $\text{SO}_3$  (Reaction 14-5), all of the undesirable reactions that can occur for SCR systems occur for SNCR systems (Reactions 14-6 and 14-7). In addition, the following reactions can significantly affect the performance of SNCR.



It is estimated that the majority of boiler applications' NO<sub>x</sub> emissions will generally be composed of 95% NO and 5% NO<sub>2</sub>. Only NO is removed from the flue gas by SNCR systems (Reactions 14-8 and 14-9), and NO<sub>2</sub> emissions are not taken out of the flue gas stream. Due to the greater NO emission reductions need to make up for the absence of NO<sub>2</sub> reduction, this restricts the total NO reduction potential of SNCR systems. The ammonia slip from SNCR does not rely on time. Once initial operation starts, there is an imminent risk that ammonia will leak from SNCR systems. SNCR ammonia slip is quite varied (10 to 50 ppm). Higher ammonia slip emissions in applications using sulfur-bearing fuel increase the risk of ammonium bisulfate and sulfate fouling (Reactions 14-6 and 14-7) in the air heater. As a consequence, more frequent offline cleaning of the air heater and online soot blowing may be necessary, which might increase the frequency of forced outages for the whole unit. NO<sub>x</sub> emissions are increased when urea or ammonia, an SNCR reagent, is injected at temperatures over around 2,200° F. (Reaction 14-10). When SNCR reagent is injected at temperatures over 1,700° F, the reagent decomposes without correspondingly reducing NO emissions (Reaction 14-11). In light of this, NO<sub>x</sub> reductions and overall reaction stoichiometry are very sensitive to the flue gas temperature at the time of reagent input. One of the byproducts of SNCR operation is nitrous oxide (N<sub>2</sub>O). Ammonia's oxidation to N<sub>2</sub>O (Reaction 14-12) wastes reagent and emits a sizable amount of a gas with a strong greenhouse impact (N<sub>2</sub>O). Additionally, a series of intermediary processes may convert NO to N<sub>2</sub>O and account for 10% to 15% of total SNCR apparent NO reductions (Muzio et al. 1991). N<sub>2</sub>O emissions are not currently mandated to be monitored or reported.

#### 14.3.3.2 System capabilities and configuration.

The SNCR systems' ability to reduce NO<sub>x</sub> is limited by two factors: (1) boiler geometry and temperature profile, which vary depending on load and effect reagent and flue gas mixing; and (2) ammonia slip. Depending on the kind of reagent and NO inflow concentration, the optimal SNCR temperature window spans from 1,500 to 2,200° F. Increased NO<sub>x</sub> emissions occur when the injection temperature is over the upper limit of the temperature range. The SNCR method may be made to operate down to 1,300° F by adding hydrogen to ammonia (or other additions with the urea reagent). Boilers generally run between 2,500 and 3,000 °F in temperature. Therefore, in a boiler without significant boiler changes, the ideal SNCR temperature window often occurs either around the top of the furnace or in the boiler's tubed backpass. The design difficulty for bigger boilers is to achieve suitable dwell periods in the preferred temperature range. Due to the lengthy injection distance necessary to cover the relatively wide cross-section of a boiler bigger than 100 to 200 MW, reagent distribution might be challenging. In the past, wall injectors have often been used to inject reagent into the SNCR

system. For wide boiler expanses, these wall injectors are ineffective, necessitating the use of steam-cooled injection lances to cover a greater surface. Even under less-than-ideal mixing circumstances, residence periods longer than 1 second at optimal temperatures would result in significant NO reduction levels. To guarantee the SNCR performs at least as well as it should, a residence time of at least 0.3 seconds is necessary. To determine the best ammonia injection sites and flow patterns, computer-based flow/temperature modeling is often used. To make it easier to position the injection lances in the ideal temperature range, new boilers may include facilities for an SNCR system with more room between the pendent superheat portions. To install SNCR injector lances in an existing boiler, water wall and steam pipe changes would likely be required. Three to four tiers of injection sites are normally required to satisfy the SNCR reaction temperature and boiler Power Plant Atmospheric Emissions Control 437 turndown criteria. However, after the first SNCR system operation, it could be essential to modify the injectors or install more injectors. SNCR system vendors have the ability to predict boiler temperature profiles to enable the selection of injector sites. The main issue with using SNCR on steam generators bigger than 100 to 200 MW is reagent usage. To achieve NO<sub>x</sub> reductions of 30% to 50%, stoichiometries (moles of NH<sub>3</sub> per mole of NO eliminated) may vary from 3.0 to 4.0. Due to reagent thermal breakdown, fluctuating temperatures, and a lack of a real steady-state regulated environment, the reagent consumption has risen, which tends to increase ammonia slip emissions. From the standpoint of process chemistry, nitrogen is the common reactive agent component that affects NO<sub>x</sub> reduction for either ammonia or urea. Dollars per ton of nitrogen is a precise measurement of relative reagent cost as a result. Aqueous ammonia and urea nitrogen cost around two and three times as much as anhydrous ammonia, respectively. These comparisons are based on historical data and affected by local demand and variables like freight distance.

### **Storage and Vaporization of Reagents**

The same safety measures, holding containers, and vaporizers that are mentioned for SCR installations must be used when using ammonia.

As a nonhazardous substance, urea has no particular storage or use restrictions. A pumping skid is used in urea reagent-based processes in place of a vaporizer or blower. A liquid form of urea is pumped and injected. Before being injected into the flue gas stream, one system provider catalytically transforms the urea-based solution to ammonia. 14.3.3.4 Injection and control of reagents to reduce reagent use and ammonia slip, reagent injection management should ideally be exact. For the SNCR NO reduction to work properly, precise reagent injection is essential. When burning fuels containing sulfur, it's crucial to keep ammonia leaks to a minimum in order to prevent harmful side effects. Unfortunately, there are presently no devices that can precisely measure ammonia slip emissions at levels as low as the necessary 2 to 10 ppm. As a result, NO<sub>x</sub> emission feedback must form the basis for SNCR reagent control. Since low total ammonia slip limitations must be dependably satisfied, SNCR NO<sub>x</sub> reduction capabilities may be severely constrained. Additionally, precise tuning of reagent injection is impossible without reliable ammonia slip input. Postcombustion Effects on the Plant's Balance. In the sections below, we'll go through potential design and operational effects of installing post-combustion NO reduction technologies.

### **Impacts of a steam generator.**

Gas temperature and response time concerns have a direct impact on SNCR's performance. For optimal SNCR system performance, the majority of an existing boiler convection pass is fairly crowded. If left unaltered, this can result in insufficient NO reduction abilities or excessive ammonia leak. Therefore, effective boiler changes with related balance-of-plant effects may

be necessary for retrofit SNCR utilization. By using open space in locations that correspond to the proper temperatures, the design of a new boiler may accommodate the installation of SNCR.

### **Impacts of air heaters.**

Ammonia and sulfur trioxide ( $\text{SO}_3$ ) combine to generate ammonium sulfate and ammonium bisulfate compounds. Ammonium bisulfate deposits may contaminate the surfaces of air heaters, causing pressure decreases, and perhaps necessitating recurring offline cleanings. According to past experience, deposits in the baskets often tend to sweep out of the air heater without any trouble. However, persistent deposits have a tendency to accumulate if the condensation temperature occurs between layers. In general, cold end soot blowers are ineffective in locating and eliminating these deposits online. Offline water cleansing can be required to get rid of any potential deposits. Ammonium bisulfate may clog the air heater while both the SCR and SNCR are operating. This scenario is not time-dependent with SNCR systems, however. The whole spectrum of ammonia slip is possible with SNCR at any moment the system is in operation. Ammonia slip with SCR catalyst is very low while the catalyst is new and gradually rises when the catalyst is deactivated. An SNCR system is considerably more likely to have air heater fouling and more forced outages if ammonia slip emissions are not well controlled. The fact that  $\text{SO}_3$  emissions stay the same is one benefit of SNCR. However, 1% to 3% of the  $\text{SO}_2$  will be converted to  $\text{SO}_3$  in the combustor if a fuel containing sulfur is combusted. Therefore, there is still a great deal of worry given the greater availability of ammonia slip from SNCR.

### **System Impacts in Draft.**

The boiler system may experience a pressure decrease of 3 to 5 in. wg if an SCR system is placed in an area with a lot of dust. The SNCR system shouldn't make the pressure decrease during normal operation more than 1 in. wg. The risk of depositing ammonium bisulfate in the air heater is raised with SNCR, however. Worst-case SNCR circumstances would be reasonably covered by a draft design margin of 3 to 6 in. wg.

### **Impacts of the precipitator.**

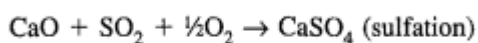
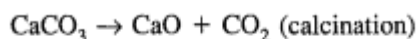
The precipitator shouldn't suffer any harm from correctly working SCR or SNCR systems. The ammonia slip that does not react with  $\text{SO}_3$  improves the collectability of fly ash in the precipitator in boilers with low  $\text{SO}_3$  concentrations. Impacts of waste solids handling and disposal. Ammonia slip from an SCR or SNCR system condenses onto fly ash gathered in an electrostatic precipitator, is absorbed in a FGD system, or leaves the system via the stack. The fly ash's ammonia level may have an effect on how garbage is disposed of or reused. Ammonia in the fly ash is produced at an increased pH, which might result in odorous emissions. Experience has shown that ammonia ( $\text{NH}_3$ ) concentrations  $>100$  ppm (mass) in fly ash cause a stench to be perceptible and may lead to the ash being rejected for use in the cement industry. According to testing, ammonia slip must be kept below 2 ppm for coal with 7% ash in order to prevent any possible issues with fly ash sales. Ammonia-contaminated alkaline fly ash may cause disposal issues. Visible Plume, 143.4.6 Ammonium chloride condensation when the flue gas cools has the potential to create a separate plume. Although a threshold concentration has not been set, if both ammonia and chlorides are over 15 ppm, it should be taken into consideration. The postcombustion NO system is the source of ammonia, while the FGD system or the fuel might be the source of chlorides. It has not been shown that ammonia slip analyzers are accurate enough. As a result, these analyzers are not often used. If ammonia quantities in the fly ash are regularly checked, an ammonia slip monitor may not be necessary. Ash sampling could be a suitable stand-in for measurement. 14.4 CONTROL OF SULFUR



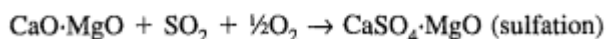
**DIOXIDE EMISSIONS** The dry and wet techniques for removing sulfur dioxide (SO<sub>2</sub>) from combustion and postcombustion that are now commercially accessible are covered in this section. SO<sub>2</sub> is an acid gas created when sulfur in the fuel is burned with oxygen. In most cases, removing this acid gas necessitates a reaction with an alkali substance. There are novel methods for catalytically converting SO<sub>2</sub> to SO<sub>3</sub> and condensing the resulting H<sub>2</sub>O+SO<sub>3</sub>H<sub>2</sub>SO<sub>4</sub> sulfuric acid. Flue gas desulfurization (FGD) procedures are differentiated by the kind of alkali, preparation, adding techniques, and interactions with SO<sub>2</sub>.

**SO<sub>2</sub> Emission Control Trends** There are many current trends in SO<sub>2</sub> emission reduction. Retrofit scrubbers bought to comply with United States CAAA Title IV Phase I compliance were solely wet designs. Significant usage of low sulfur fuel switching to accomplish the United States CAAA Title IV Phase I and Phase compliance. Scrubber SO<sub>2</sub> elimination levels are typically 95% or higher at the time of purchase. Without spare modules, the assured scrubber availability ranges from 96% to 98%. The most common designs for calcium reagents are less expensive; many of these methods also produce gypsum as a byproduct. Semidry scrubbers may remove SO<sub>2</sub> from fuels with low or high sulfur levels by 95% or more. For wet scrubbers, single module size ranges are 600 to 1,000 MW and for semi-dry scrubbers, 200 to 250 MW. Quick lime produced in the boiler is used in the downstream semi-dry scrubbers of some of the most recent contract awards. Fluid bed boilers employ inexpensive limestone beds for SO<sub>2</sub> removal. There are other processes that combine SO<sub>2</sub> removal alongside NO<sub>x</sub> reduction or particle removal. **Combustion Processes** Furnace Sorbent Injection, or 14.4.2.1 when used in conjunction with low-NO<sub>x</sub> burners, dry furnace sorbent injection (FSI) is also known as limestone injection multistage burners (LIMB). It entails injecting a calcium-based reagent into the furnace, such as limestone powder. Calcium oxide (CaO), which is created when limestone calcines, combines with oxygen and sulfur dioxide to create calcium sulfate (CaSO<sub>4</sub>). The reagent is pneumatically pumped either via the installed ports in the furnace, such as the burners, overfire air ports, or even other ports, or through wall jets or lances that pierce the furnace. Amounts between 1% and 5% of the total combustion air are needed for transport air. Possible reagents include limestone, dolomite, limestone, and hydrated lime. In the oxidizing atmosphere of the furnace, lime (CaO), commonly known as quick lime, interacts with sulfur dioxide (SO<sub>2</sub>) at a temperature of around 1,600 to 2,200° F to produce calcium sulfate (CaSO<sub>4</sub>). The standard responses are:

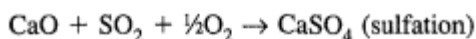
#### Limestone



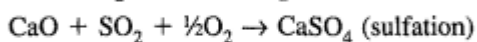
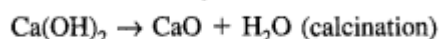
#### Dolomitic limestone



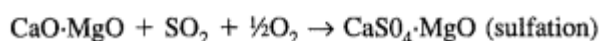
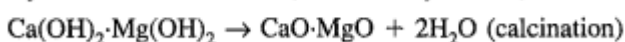
#### Quick lime



#### Hydrated lime (calcium hydroxide)



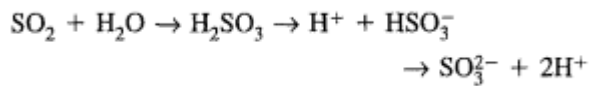
#### Hydrated dolomitic lime (dolomitic hydroxide)



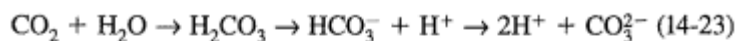
For a given calcium/sulfur (Ca/S) ratio, more material is needed when using dolomitic limestone or lime since the magnesium oxide component does not react with  $\text{SO}_2$  there at temperatures and pressures in the furnace. Temperature, residence period, reagent dispersion within the furnace, Ca/S ratio, reagent surface area, and reagent type all have a significant impact on FSI  $\text{SO}_2$  capture. It's crucial to have the flue gas and the reagents mixed well. When injecting reagent above the burners in the larger furnaces, good mixing is difficult to obtain. The Power Plant Atmospheric Emissions Control 439 is used most effectively at reagent surface regions with the highest concentrations.  $\text{SO}_2$  collection rose when sorbent particle size was decreased to 2 microns, but further reduction was ineffective. Utilization may rise, but energy expenditures to generate smaller particles may be countered. Limestone and more costly hydrated lime seem to remove  $\text{SO}_2$  from furnaces more efficiently. This is most likely due to the higher specific surface areas that arise from heating hydrated lime. On boilers ranging in power from 15 MW to 700 MW, FSI has been commercially proven. The bulk of this expertise involves injecting chemicals far from the burners in the top part of the furnace. 1990 saw the start of two FSI experiments in the United States: the 105-MW Edgewater Station wall-fired Unit 4 of Ohio Edison and the 60-MW White Water Valley tangentially fired Unit 2 of Richmond Power & Light. With a calcium-to-sulfur ratio of 2.0, preliminary data show  $\text{SO}_2$  reductions of 40% at Whitewater and 50% at Edgewater. The limestone injection furnace activation of calcium (LIFAC) process developed by Tampella Power Corporation went into service at Whitewater Valley Unit 2 in 1990 and at Saskatchewan Power Corporation's 300-MW Shand Station in October 1992. In the Shand furnace, LIFAC achieved 10% to 15%  $\text{SO}_2$  removal at full load and up to 25% at lesser loads; 25% was anticipated. On half of the exit gas flow, an additional 85%  $\text{SO}_2$  removal was accomplished in a downstream humidification activation reactor (Ball and Ewald 1993). The particulate loading to the convection section is greatly increased by FSI. More frequent soot blowing is necessary due to the higher solids deposition, and more soot blowers may need to be installed. Ash resistivity will rise along with increased particle collector intake loadings. For medium- and high-sulfur coals, Babcock & Wilcox's combined limestone injection - 5 and dry scrubbing process enables significant  $\text{SO}_2$  removal at a reasonable cost. Fluid Bed Combustion Scrubbing. Fluid bed compressors, especially the circulating fluid bed kind, are a cost-effective option for  $\text{SO}_2$  removal. The discussion of limestone reagent sizes, feeding systems, bed composition, flow diagrams, chemical reaction equations, and module sizes is covered in Chapter 21 on Fluidized Bed Combustion.  $\text{SO}_2$  removal parameters are summarised in Tables 21-2 and 21-3 of Chapter 21. Supplemental postcombustion semidry scrubbing may lower combustion fluid bed Ca/S ratios for higher sulfur fuels with low  $\text{SO}_2$  emissions. Comparing this range to the higher ratios. Quick lime is produced by calcining inexpensive limestone ( $\text{CaCO}_3$ ) reagent in a fluid bed combustor ( $\text{CaO}$ ). In the combustion chamber, some of the  $\text{CaO}$  interacts with  $\text{SO}_2$  to produce calcium sulfate ( $\text{CaSO}_4$ ).

The most popular FGD technique in use today is wet scrubbing. When using high- to low-sulfur fuels in boiler applications, several procedures are employed. Wet scrubbers continue to be competitive despite the development of semidry scrubber procedures, especially for bigger units using medium-to-high sulfur fuel. The operational availability and design dependability of wet scrubbers have improved with better understanding and management of the process chemistry. These advancements, which began in the early 1990s, resulted in significant cost savings, including the use of single-absorber modules without spares for extremely large units. The FGD Chemistry and Analytical Methods Handbook of the Electric Power Research Institute is a significant resource for wet scrubbing process chemistry and analytical methods. An alkaline solution or slurry is in contact with the flue gas during the wet scrubbing FGD process within the absorber. The absorber releases a cleansed, moisture-saturated exit flue gas together with a liquid or slurry that contains the sulfur dioxide that was taken out of the gas.

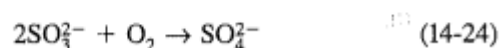
Sulfuric acid,  $\text{H}_2\text{SO}_3$ , is formed when the gaseous  $\text{SO}_2$  was absorbed by the liquid.  $\text{H}_2\text{SO}_3$  then dissociates into hydrogen ( $\text{H}^+$ ) and bisulfate ( $\text{HSO}_3^-$ ) ions. In accordance with the following equilibrium process, the latter likewise dissociate into sulfite ( $\text{SO}_3^{2-}$ ) and another hydrogen ( $\text{H}^+$ ) ion.



More  $\text{SO}_2$  is absorbed in liquid phase processes that remove or couple up with  $\text{H}^+$ ,  $\text{HSO}_3^-$ , or  $\text{SO}_3^{2-}$  ions. The partial pressure of  $\text{SO}_2$  in the gas phase must be higher than the vapor pressure of  $\text{SO}_2$  in the liquid for  $\text{SO}_2$  absorption to take place. When a result, absorption reduces as gas phase  $\text{SO}_2$  concentration and partial pressure drop as the gas approaches the gas exit. As the quantities of  $\text{H}^+$  and  $\text{HSO}_3^-$  ions rise, so does the absorption of  $\text{SO}_2$ . (This would occur if the elimination of or teaming up with  $\text{H}^+$ ,  $\text{HSO}_3^-$ , or  $\text{SO}_3^{2-}$  ions were prevented by a paucity of reagents.) Due to the equation's reactions moving more often to the left as a result, the liquid's  $\text{SO}_2$  concentration and vapor pressure would rise. Hydroxide ( $\text{OH}^-$ ), sulfite ( $\text{SO}_3^{2-}$ ), carbonate ( $\text{CO}_3^{2-}$ ), and bicarbonate ( $\text{HCO}_3^-$ ) are the main alkaline scrubber ions that are more reactive than the alkaline  $\text{HSO}_3^-$  ion so this remove or couple up with Power Plant Atmospheric Emissions Control 441  $\text{H}^+$  ions. Therefore, effective  $\text{SO}_2$  removal reagents include lime or limestone (calcium) slurries that may dissolve to offer a supply of these alkaline ions as well as highly soluble sodium, ammonia, or magnesium solutions that include these alkaline ions. Additionally, positive ions including sodium ( $\text{Na}^+$ ), potassium ( $\text{K}^+$ ), ammonium ( $\text{NH}_4^+$ ), calcium ( $\text{Ca}^{2+}$ ), magnesium ( $\text{Mg}^{2+}$ ), and sodium ( $\text{Na}^+$ ) couple up or react with  $\text{HSO}_3^-$  or  $\text{SO}_3^{2-}$  ions to decrease the amount of their free ions in solution, which, as mentioned above, improves  $\text{SO}_2$  absorption. Since they remove carbonate ( $\text{CO}_3^{2-}$ ) ions from solution, chloride ( $\text{Cl}^-$ ) ions have a detrimental effect on  $\text{SO}_2$  absorption. The liquid phase of the FGD scrubber is a non-ideal concentrated solution that includes water, all soluble ions from the makeup water, reagent, but also flue gas sources, as well as reaction products from the FGD. Temperature, pressure, ionic concentrations, activity coefficients, solubility coefficients as well as relative saturation of solid compounds that might also dissolve into or precipitate from the liquid, and partial or vapor pressure of gases that may absorb into or desorb from the liquid are all factors that affect the reactions that occur between water and all of the ions. Scrubber features, such as  $\text{SO}_2$  absorption capacity, may be predicted using computerized species distribution modeling. When the exact absorber design has indeed been calibrated using real field operating test results, these models perform at their peak. Buffering reactions as a function of pH ( $\text{H}^+$  ion concentration) are provided by the preceding  $\text{SO}_2$  absorption and liquid phase dissociation equilibrium reaction (14-22) and the subsequent  $\text{CO}_2$  equivalent reaction.



These equilibrium reactions plus the following key oxidation equilibrium reaction of sulfite to sulfate:



Scrubber absorption, sulfur byproduct production, and recovery are all influenced greatly by pH and elemental oxygen concentration. Limestone, lime, magnesium oxide, soda ash, fly ash, ammonia, and sea water are some of the current utility commercial wet scrubber  $\text{SO}_2$  removal agents. Table 14-1 compares the features of the four utilities economic wet scrubber methods

now in use. This section goes through these four procedures. Numerous variables that impact the cost of the whole system must be taken into account when choosing a FGD procedure or reagent for a particular location.

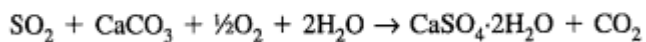
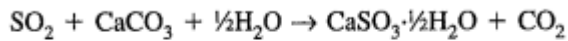
14.4.3.1 Wet limestone forced oxidation FGD. The most used wet process nowadays is forced oxidation wet limestone FGD because to the high SO<sub>2</sub> removal, high unit availability, and limestone's usage and cheap cost. Additionally, reactive limestones are often accessible everywhere. Due to these reasons, this section will concentrate on the forced oxidation wet limestone FGD system. Fig. 14-19 depicts a typical limestone system with exit flue gas reheat. The kind and final design of auxiliary equipment needed depend on the reagent being used, although other chemicals also need comparable subsystems for reagent preparation, absorption, dewatering, and flue gas handling. For a variety of coals, forced oxidation wet limestone FGD methods can reliably remove 95% to 98% SO<sub>2</sub>.

### **Prepare the Reagent**

The equipment required to unload, store, transport, and prepare the reagent for use in the system makes up the reagent preparation system. The need for an on-site reagent storage and processing facility is determined by the frequency of deliveries, the possibility of supply interruption, the amount of site area available, the climate, the need for storage, and the cost. Limestone should be crushed to a size where 90% to 95% of the material will pass through a 325-mesh screen in order to achieve the surface area and reactivity needed to fulfill average reaction design rates. Although using bigger grind materials may reduce grinding costs, these savings are compensated by higher reaction tank capacity requirements, reduced reactivity, and lower limestone use. Some vendors' processes can even call for a lower particle size. The limestone is ground to the desired size in ball mills. The limestone is crushed in the ball mill system, combined with water to create a fine slurry, and then hydroclones are used to determine the required particle size. A few scrubber vendors add calcium to limestone via dry grinding and air classification the ball mill provider often offers a whole grinding and sizing system. The size of the ball mill system is determined by the work index, or hardness, of the limestone, the grind size, the necessary limestone flow rate, and the desired running time. Because the limestone work index, which may range from 2 to 13, is related to the amount of energy required to operate the ball mill system, careful consideration of prospective limestone sources is required.

### **Absorber.**

The cleaning liquid in the absorber comes in touch with the flue gas. An open spray tower absorber with countercurrent flue gas flow is often used in forced oxidation wet FGD processes. Pumps continually recycle reaction products and fresh limestone from an inbuilt reaction tank through the absorber and into the flue gas. Pipe headers carry this slurry to nozzles, which spray the liquid into the absorber at an angle. The nozzles divide the slurry into droplets between 200 and 2,000 microns in size in order to provide the necessary liquid surface area. Both pigtail-style nozzles and tangential sprays are effective. In order to allow for any liquid phase reactions, the reaction tank must have enough retention time to capture the falling recycling slurry. The Power Plant Atmospheric Emissions Control 443 serves as a feed point for the recycling pumps and prevents the buildup of gypsum particles. In order to maintain the pH, water level, and slurry solids content and to obtain the best reaction rates and byproduct gypsum properties, limestone slurry, oxidation air, and makeup water are introduced to the reaction tank. The following general processes take place when sulfur dioxide is absorbed from of the flue gas into the slurry liquid in the absorber:



Although there are some intermediate processes, sulfur dioxide from the flue gas is typically absorbed into the slurry liquid. Then, gypsum is created as a result of liquid phase chemical reactions involving the reagent's dissolved alkalinity, oxidizing air, and the absorbed acidic SO<sub>2</sub> component (CaSO<sub>4</sub>·2H<sub>2</sub>O). The equilibrium between these processes and the pace at which they occur are both influenced by several variables. These variables include pH, temperature, the quantity of oxygen present in the air, and the chemical species present in the liquid, such as sodium, magnesium, calcium, potassium, carbonates, sulfates, chlorides, and fluorides. In order to optimize the chemistry of the whole process and convert the majority of the calcium sulfite (CaSO<sub>3</sub>) to gypsum, modern forced oxidation wet limestone designs immediately inject air into the reaction tank (CaSO<sub>4</sub>·2H<sub>2</sub>O). This transformation into gypsum has various uses. It reduces the amount of hard calcium sulfate scaling that forms on the inside surfaces of the absorber when oxidation (the conversion of sulfite to sulfate) is between 15% and 85%. (By managing the oxidation conversion below or above these thresholds, the scaling of the absorber may be reduced.) Scaling on the absorber surfaces is decreased in completely oxidized systems because the dissolved CaSO<sub>4</sub> precipitates mostly onto the suspended CaSO<sub>4</sub> crystals, which have a relatively high relative surface area. The form and size of the leftover gypsum crystals make dewatering them simpler. Lower moisture and solid content as a consequence facilitate landfill disposal or sales to the wallboard and cement sectors. Alternatives include the use of oxidation inhibitors like thiosulfate or liquid sulfur. By limiting oxidation to 15%, scaling is also reduced. CaSO<sub>3</sub> is produced as flat platelet crystals that develop into rosettes and hold onto water. They lack the physical qualities that make them suitable for landfilling since they are thixotropic. For the mixture to have qualities that are appropriate for landfill disposal, fly ash, lime, or both must be added. Mist eliminators located close to the absorber output remove slurry droplets entrained in the flue gas. Before the mist eliminators, a vertical disengagement zone is often provided to enable big slurry droplets to fall back into the absorber. The mist eliminators reduce the residual entrained slurry to as little as 0.0001 gpm/ft<sup>2</sup> of eliminator area, and are often of chevron pattern. The flue gas velocity of a mist eliminator is around 15 ft/s; however, modern designs enable speeds of up to 20 ft/s with the same effectiveness. Chevron's METAdek mist-eliminator. To avoid solid scale formation, wash systems with a nozzle array are placed between the phases of the mist eliminator. Sections have been created inside the washing systems. Typically, the pieces are cleaned intermittently and individually. The degree of clogging may be significantly impacted by the wash water's quality. To minimize the formation of particulates, modern designs utilize clean cosmetic wash water with little alkaline species. The quantity of reactant needed depends on the particular FGD design, incoming SO<sub>2</sub> flow rate, and necessary SO<sub>2</sub> removal efficiency. For wet limestone scrubbers, the stoichiometric ratio (the quantity of reagent input needed per quantity of SO<sub>2</sub> removed) falls between 1.02 and 1.06. The cross-sectional area or diameter of the absorber is determined by the needed SO<sub>2</sub> mass transfer volume (including L/G ratio), the volumetric flow rate of water-saturated flue gas, and the maximum flue gas velocity. The arrangement of the flue gas intake and exit ducts, the design of the mist eliminators and wash system, the height of the reaction tank, and any internal reheaters, if any, all contribute to the determination of absorber height. The size and layout of the reaction tank are determined by the liquid reaction time (usually 3 to 10 minutes) and the suction requirements of the recycling pumps. The range of particle sizes in the gypsum byproduct is determined by the reaction tank geometry, agitator and oxidation air designs, limestone input, intake SO<sub>2</sub>, liquid recycling rate, and absorber blowdown rate. The liquid to gas ratio (L/G), which is represented in gallons per thousand cubic feet (gal/1,000 ft<sup>3</sup>)



or liters per cubic meter (L/m<sup>3</sup>), is the volumetric flow of recycled slurry divided by the volumetric flow of saturated flue gas. The amount of SO<sub>2</sub> mass transfer units necessary to achieve a certain removal efficiency is reflected in the L/G ratio, flue gas velocity, and gas treatment time. For a limestone system, typical L/G ratios vary from 80 to 120. For high incoming sulfur dioxide concentrations and removal efficiency, the L/G ratio is higher. The main source of power consumption for wet FGD systems is the size of the huge pumps needed to recycle the slurry within the absorber. The L/G ratio gives a clear idea of how different the auxiliary power requirements are for various wet processes. As was mentioned before, the concentration of particular chemical species may affect how the absorber's overall processes play out. With chlorides, this is particularly accurate. As the chloride content rises, the forced oxidation system's efficacy in removing SO<sub>2</sub> reduces precipitously. Increasing the salt content of the fuel or water supply might prohibit the FGD from operating at its intended efficiency. Both the process design and the choice of materials must take other dissolved solids, such as fluorides or carbonates, into account. When assessing the fuels or water supply at the plant, it's crucial to take the scrubber water chemistry into account.

### **Dewatering.**

The blowdown slurry stream from the absorber discharges the FGD byproducts created during the forced oxidization of wet limestone. The majority of the solid components in the blowdown stream are gypsum byproducts, with small amounts of calcium sulfite, unreacted calcium carbonate, and limestone inerts, as well as significant amounts of dissolved solids in the liquid phase. Due to the dissolved alkalinity and water recovery, recycling the liquid enables reduced limestone and water composition rates. Typically, two dewatering stages are used. Hydroclones concentrate the bigger gypsum particles in the underflow and recycle the smaller unreacted limestone solids with the main liquid overflow. The ultimate liquid separation and recycling occurs at a vacuum filter or centrifuge using this underflow. This two-step method decreases the total size and expense of the dewatering process. Gypsum solids from the oxidized systems are bigger and simpler to settle, making hydroclones the first step possible. To fulfill standards and further minimize the moisture, the second phase uses belt filters and centrifuges to wash the chlorides from the byproduct gypsum. Low moisture levels and chloride concentrations in FLUE GAS HANDLING. The flue gas handling system is made simpler by using big, single absorbers without spares or flue gas bypass. To distribute and regulate the flue gas, multiple absorber systems need input and outlet ducts as well as dampers for each absorber module per unit. A single module does not need dampers or several flues. To achieve equal gas distribution, fluid modeling of the ductwork and absorber is often performed. Inefficient gas transport between or within absorbers might lower performance.

### **Design considerations for wet scrubbing.**

The design and operation of the power plant are significantly impacted by wet FGD scrubbing in various ways. Wet flue gas discharge or reheat, electricity use, water balance, and waste disposal are some of these effects. The majority of wet processes have similar design and installation challenges, with the exception of byproduct control, hence these topics are covered jointly in this section.

### **Saturated flue gas management**

In wet scrubbing systems, the flue gas handling design from of the absorber's departure to the stack discharge is a crucial factor. At the adiabatic saturation temperature, flue gas with some entrained liquid or slurry exits the absorber. An extremely corrosive low pH environment is created by the dissolved chlorides, SO<sub>2</sub>, and SO<sub>3</sub> in the entrained liquid. Since the flue gas is already saturated, cooling leads to more condensation on the equipment downstream. A facility

may either reheat the flue gas to partially evaporate the entrained liquid and reduce downstream condensation or utilize suitable corrosion-resistant materials downstream of the absorber to avoid corrosion. Flue gas reheating alternatives include combining treated flue gas with hot bypassed flue gas, tubular (steam) type repeaters, and regenerative type heat exchangers between the scrubber's intake and exit flue gas ducting. Each of them has benefits and drawbacks that must be weighed for each project. In the US, it has become popular to operate the duct and stack in a wet mode, which involves entrained slurry and condensation in the liquid phase without any flue gas reheat. The benefits include cheaper operating costs, minimal performance deterioration of the facility, and lower capital expenses. These systems could have operational issues such as acid droplet fallout from stack exit gas or more corrosive conditions than expected when the corrosion-resistant material or liners were chosen.

### **Consumption of Power**

Without taking into account flue gas reheat, the power consumption of a wet FGD may vary from 1% to 2% of the whole plant's electric Power Plant Atmospheric Emissions Control 445 output. The main power consumers are the recycling pumps.

### **Waste Water/Water Use**

Being both a water consumption point and a source of waste water, a FGD system has the potential to affect the plant's water balance. Other plant water outflows, such as cooling water blowdown, are utilized as the FGD makeup water to reduce the amount of FGD water required. As was already said, the performance of a FGD may be impacted by the quality of the water utilized in it; as a result, the influence of other accessible water sources must be considered. Because of the reduced moisture, there is a chance that net wastewater FGD production may occur. To fulfill byproduct criteria or to cut down on disposal quantities and expenses, FGD release solids. The concentration of dissolved solids (such chlorides) in the system rises if adequate water is not entrained within the solid byproduct. High concentrations of dissolvable solids may increase SO<sub>2</sub> emissions or contribute to material deterioration. A purge blowdown stream might be economically beneficial. The plant's waste water treatment design has to take into account the amount and quality of the liquid blowdown.

### **Material Choice**

Wet flue gas desulfurization systems may employ a wide range of materials, and the choice of material is dependent on a variety of variables, such as operating circumstances, corrosion and erosion potential, temperature, starting cost, and maintenance philosophy. Metal, organic, and inorganic materials may all be categorized as being utilized in FGD services. A broad variety of materials are classified as metals, including titanium, duplex steels, carbon steel, stainless steels (316 series, 317 series, etc.), nickel-based alloys (625, C-276, C-22, etc.), and other corrosion-resistant alloys. Closed loop systems have led to rising chloride levels as the requirement for minimum water output has increased, which presents significant corrosion concerns for many metals and necessitates the use of more unusual alloys. Many alloys are used as a 3/16 in. cladding or "wallpaper" over a carbon steel basis due to their high cost. Epoxy, vinyl ester, polyester, and rubber are examples of organic lining materials that may be used over a basis of carbon steel. These linings are used to prevent corrosion. Construction of tanks and vessels using fiberglass-reinforced plastic in the field has lately become competitive. These materials often have modest initial capital costs but typically need more frequent maintenance. These organic materials must be protected against excessive temperatures brought on by malfunctioning air heaters and the loss of absorber recycling pumps when they are in the flue gas stream. Therefore, it is recommended to add an emergency quench system upstream of the absorber gas intake module. Prefired bricks, ceramic tiles, hydraulically or chemically bonded

concretes, and mortars are examples of inorganic materials. These materials are often used as linings for tanks, stacks, silos, and sumps. Given that these are the most frequent failure mechanisms, the mortar selection and adhesion techniques utilized to connect these materials are crucial. With regard to all of these materials, installation quality is crucial, particularly when it comes to substrate preparation and lining application. Even the greatest materials have failed as a consequence of subpar installations and quality assurance/control. Mist eliminators may be made of a variety of materials, although fiberglass-reinforced plastic (FRP) is the most typical. Other options include stainless steel, high nickel metals, and fiberglass polypropylene. Because of the high chloride content, stainless steel mist eliminators are not recommended for many FGD systems. When high-pressure water washing or mechanical cleaning is necessary to remove solids clogging or scaling, maintenance interruptions are the major reason for mist eliminator damage. Systems for wet lime FGD. Slaked lime is used as the scrubbing agent in a spray tower scrubber in the wet lime FGD that is offered by several FGD vendors. The most often used lime procedure in the United States is thiosorbic (magnesium enhanced). As a result, the process is discussed in the paragraphs that follow because it competes more fiercely with the forced oxidation wet lime stone method and has superior performance and lower prices than those for wet lime alone. Black & Veatch received helpful information on the magnesium enhanced wet lime process.

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## CHAPTER 9

### PREPARATION OF QUICK LIME

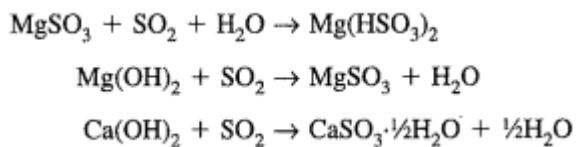
Archana S, Assistant Professor

Department of Chemistry, Faculty of Engineering and Technology, JAIN (Deemed-to-be University), Karnataka  
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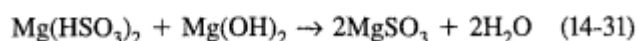
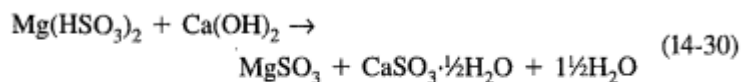
Email Id- s.archana@jainuniversity.ac.in

#### Transaction Description

Quick lime (CaO), which contains 4 to 7 weight percent magnesium oxide (MgO), is slaked in the magnesium-enhanced wet lime process to create a slurry of calcium hydroxide (Ca[OH]<sub>2</sub>) and magnesium hydroxide (Mg[OH]<sub>2</sub>). Sulfate ions (SO) are produced when SO<sub>2</sub> was absorbed, similar to the equilibrium processes. Magnesium sulfite is extremely soluble when the alkalinity (pH) levels are high. According to the following fundamental processes, the magnesium-enhanced lime scrubbing reagent combines with SO<sub>2</sub> to produce magnesium bisulfite (Mg[HSO<sub>3</sub>]<sub>2</sub>), magnesium sulfite (MgSO<sub>3</sub>), and calcium sulfite hemihydrate (CaSO<sub>3</sub>·½H<sub>2</sub>O):



The SO<sub>2</sub> gas combines with the dissolved magnesium ions to create soluble molecules after being absorbed into the liquid. Additionally, several precipitation and solids dissolution processes exist. In comparison to a calcium carbonate slurry, the slurry of calcium hydroxide and soluble magnesium compounds is substantially more reactive and soluble. The pH of the fresh magnesium enhanced lime slurry varies from 10.0 to 12.0, which is much higher than the pH of a limestone slurry. SO<sub>2</sub> removal efficiency between 98% and 99% are therefore feasible. In comparison to limestone scrubbers, the higher SO<sub>2</sub> reactivity greatly reduces the necessary liquid to gas (L/G) ratio for the same FGD demand. The magnesium-enhanced lime slurry may be made in a ball mill, paste, or detention 446 Power Plant Engineering slaker. Prepared slurry is kept in a slurry feed tank and is ready to be automatically injected into the reaction tank of the scrubber module as needed to keep the tank's target pH between 6.0 and 7.0. When combined with a boiler load signal, the pH in this pH range, which is sensitive to the relative amounts of HSO and SO ions, tells you when you need to add additional fresh lime. The reagent regeneration reactions in the reaction tanks are:



The reaction tank's liquid residence duration is generally 2 minutes. Magnesium sulfate (MgSO<sub>4</sub>), which would precipitate and lead to scale formations, would not be employed or desired if oxidation occurred in the reaction tank. Spray towers for wet lime processes with magnesium enhancement resemble those used in wet lime stone FGD processes architecturally. Due to the slurry's greater reactivity, there are three clear benefits: Three factors are decreased: (1) the height of the absorber tank; (2) the height of the pumping heads; and (3) the necessary

L/G. Due to the smaller number of spray levels (lower L/G), the lime spray tower may be 10 to 30 feet shorter than the limestone scrubbers with the same SO<sub>2</sub> removal effectiveness. Depending on the application, the L/G ratio might range from 20 to 70 gallons per 1,000 acfm of flue gas. Typically, the stoichiometric ratio is between 1.01 and 1.05. The slurry's higher pH causes amounts of naturally occurring sulfites to sulfates oxidation to be lower than those attained during a wet limestone process. As a result, hard gypsum scale is less likely to develop in wet lime FGD processes that have been augmented with magnesium. However, it is probable that soft sulfur scale will emerge. Sulfate scale is easier to remove off the mist eliminators and other surfaces in the magnesium-enhanced wet lime spray tower because it does not solidify. Usually, the sulfurate scale does not pose a major threat. The synthesis of gypsum as a marketable byproduct by forced oxidation of magnesium-enhanced lime systems is still being studied. Slurry blowdown from the reaction tank may either be vacuum-filtered and thickened before being piped to a pond for settling. Recovered water is put back into use during the FGD process. The thickener under flow normally contains 15 or less particles by weight. For these byproducts, the maximum solids concentration at vacuum filter discharge is between 50% and 65%. As a result, the particles ejected include more liquid blowdown than wet limestone gypsum solids.

**Considerations for Design.** The management of saturated gas, water usage/waste water, and material selection design issues for a magnesium-enhanced lime system are quite similar to those mentioned for a wet limestone system. Below is a description of the variations in various design factors. A magnesium-enhanced lime system uses 1% or less of the electrical production from the whole plant, which is much less than the 1% to 2% used by a wet limestone system.

**DISPOSAL BYPRODUCT.**

A magnesium-enhanced lime system produces solid waste that is more difficult to handle. First, since the solid result has a greater moisture content and is thixotropic, it is often more challenging to handle. The thixotropic character and greater moisture content are caused by the flat platelet CaSO<sub>3</sub> crystals.

These little crystals develop into rosettes and store water in the spaces in between the platelets. The water that is retained when the delicate rosettes break during handling serves as a lubricant for the individual platelets, causing the thixotrop behavior. These FGD byproducts should be combined with fly ash and lime in order to acquire the appropriate physical properties for landfilling. The development of process adjustments resulting from research into the enhancement of the magnesium-enhanced lime system, such as the oxidation of the CaSO<sub>3</sub> to CaSO<sub>4</sub>, would enable the formation of easier-to-handle solids with the potential to provide a salable solid byproduct.

14.4.3.4 Emerging Technologies for Wet Scrubbing. The utility FGD experience of wet forced oxidation limestone, wet magnesium-enhanced lime, and semidry lime systems is substantial. Emerging SO<sub>2</sub> removal technologies are still being developed. Seawater and ammonia scrubbing are two new wet FGD scrubbing methods that are available.

### **Cleaning with Seawater**

Due to its high natural alkalinity, seawater may efficiently reduce SO<sub>2</sub> emissions without the need of additional chemicals. For fifteen years, this method has eliminated SO<sub>2</sub> from industrial uses. The first utility saltwater scrubber was put into operation in 1988 at a 500 MW power plant application not far from Bombay, India. 25% of the flue gas is controlled by it, with another 25% set to go into operation in late 1994. Beginning in 1995, two further Spanish power facilities that each generate 160 MW of electricity will use saltwater scrubbers to reduce their sulfur dioxide emissions description of the process A seawater FGD procedure. A once-through seawater spray tower is used in this procedure. Significant amounts of alkaline ions,



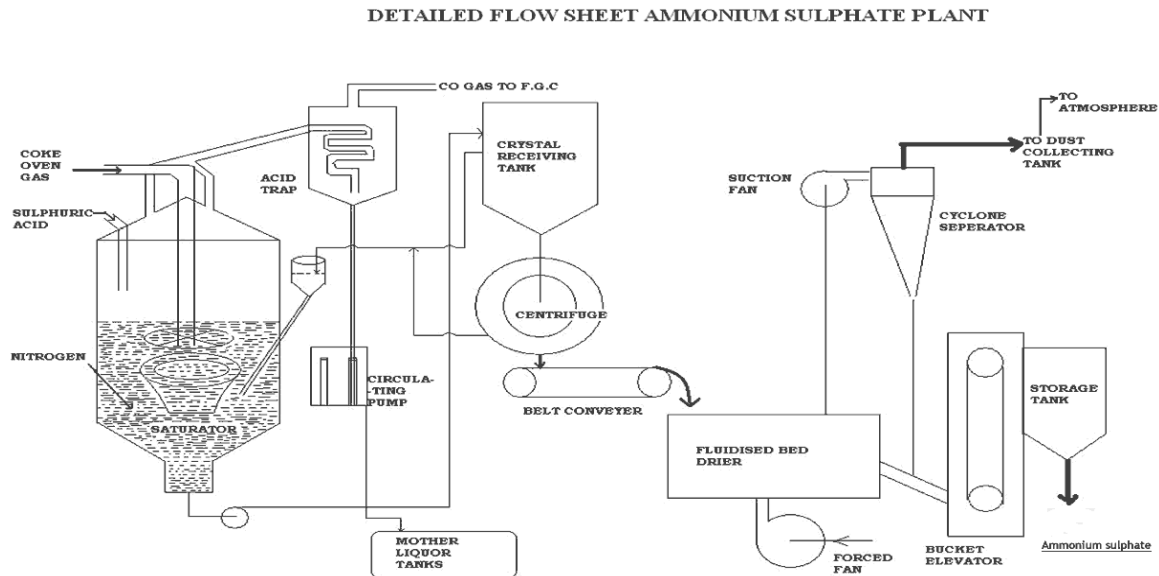
such as sodium, magnesium, potassium, calcium, carbonates, and bicarbonates, are present in seawater. Significant amounts of chloride and sulfur ions are also present. Before hitting the seawater absorber's bottom, flue gas flows via induced draft fans, fabric filters, and electrostatic precipitators. Through overflow nozzles, seawater is poured into the absorber's top where it passes through wet saddle-type packing and travels in the opposite direction of the flue gas. Before being released into the environment via the chimney, the cleansed gas is passed through a mist eliminator to get rid of entrained liquid. Only a portion of the condenser cooling water is normally used for the procedure, which employs seawater. It is once-through piped to the scrubber from the cooling water system at the condenser's outlet. The condenser's discharge temperature, the amount of oxygen in the flue gas, and the necessary SO<sub>2</sub> removal efficiency all affect the L/G ratio. There is a 30 to 130 gpm/1,000 acfm L/G ratio range. The absorber receives no recycling. The liquid effluent from the absorber is piped to the aeration pond. The liquid effluent from the absorber is diluted by adding the leftover condenser seawater straight to the aeration pond. A fan is used to aerate the diluted effluent of the absorber in order to remove the CO<sub>2</sub>. Before rerouting the stream to the sea, this lowers the acidic content and raises the pH to between 6 and 7 to oxidize the HSO<sub>3</sub> and SO<sub>3</sub> to HSO<sub>4</sub> and SO<sub>4</sub>. As the ocean mixing zone's pH rises to around 8, this conversion to SO<sub>4</sub> continues.

Efficiency of the upstream particulate collection, the presence or absence of volatile air toxics in the flue gas, and an appropriate ocean mixing zone are a few parameters that affect whether the procedure is appropriate for a certain application. The impact of this system's effluent on the maritime environment is a common worry.

The ocean receives the sulfur that has been removed from the flue gas. Per tonne of natural saltwater, there are around 1 kilogram of sulfates. Sulfate content in the output from the aeration pond is around 3% higher than in saltwater. The introduction of the acidic liquid effluent, which has a pH of 6 to 7, into the main body of alkaline saltwater, which has a pH of around 8, is another issue. The alkalinity of the seawater, however, soon elevates the liquid scrubber effluent pH to that of natural sea water when combined and transforms the majority of the residual HSO<sub>3</sub> to SO<sub>4</sub>. Another significant worry is the possibility of heavy metal and air hazardous emissions into the ocean. As certain air toxics from the flue gas may be eliminated by the saltwater, those removed would end up in the effluent liquid that is discharged to the ocean. In order to reduce particulate concentration and remove air toxics and heavy metals from the FGD system, high-efficiency particulate removal is necessary upstream of the seawater scrubber. Mercury and other air toxics that are present as vapor or gas might be an issue. At the temperatures encountered in the particulate control mechanism, elemental mercury is a vapor, therefore very little collection is accomplished. As a result, mercury may be absorbed when some of it does condense at the lower temperatures present in the scrubber. The usefulness of injecting activated carbon at a common air heater exit temperature of 300° F has not been proven, although it is one option to the particulate removal equipment. There may be a need for further liquid effluent treatment.

### **Ammonia Scrubbing**

A novel ammonia wet scrubber process creates a marketable byproduct of ammonium sulfate fertilizer and has very high SO<sub>2</sub> removal efficiency. A 3-MW pilot plant that ran in North Dakota from September 1992 to January 1993 is considered field experience in. Figure 9.1 The Dakota Gasification Company granted General Electric Environmental Systems a commercial ammonia scrubber contract for a 300 MW facility, with commercial operation scheduled for March 1997.



**Figure 9.1: Illustrates the schematic diagram of ammonium Sulphates plant.**

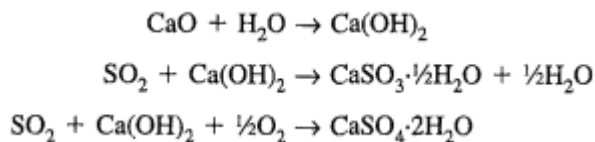
The process flow diagram for this. Hot flue gas is sprayed with saturated ammonium sulfate liquid as it enters the chamber. Prescrubber crystallizes ammonium sulfate by evaporating water from the saturated ammonium sulfate solution and cooling the flue gas to the temperature of adiabatic saturation. After passing through a bulk entrainment separator and the SO<sub>2</sub> absorber, the flue gas exiting the pre-scrubber. Flue gas moves in the opposite direction of the cleaning liquid, which is blasted via nozzles after being pumped from the reaction tank. Ammonia is added to the reaction tank after being diluted in air to create ammonium compounds. Ammonium sulfate is created when the absorbed SO<sub>2</sub> is oxidized by the ammonia and diluting air ( $[\text{NH}_4]_2\text{SO}_4$ ). The absorber receives makeup water to keep the scrubbing fluid diluted. To eliminate any droplets, the flue gas is next sent via a mist eliminator. The prescrubber receives the blowdown from the absorber liquor, where ammonium sulfate crystallizes and water is evaporated. The liquid blowdown from the pre-scrubber tank, which contains ammonium sulfate crystals, is sent to the main dewatering hydroclones. In a centrifuge, secondary dewatering takes place. This device produces ammonium sulfate cakes with a moisture content of 2%.

The system's principal advantage is the marketable byproduct. Price per ton for ammonium sulfate varies between \$75 and \$130 based on transportation expenses and demand. Therefore, before choosing this procedure, a market analysis must be done. Considering the high expense of the ammonia reagent, this assessment is particularly crucial. Due to the price of the equipment required to dry, compress, and granulate the product as well as the prescrubber/crystallizer, an ammonia scrubber has greater capital expenses than a wet limestone system. One major drawback is that since anhydrous ammonia is a toxic substance, it must be handled and stored on-site with considerable caution. For the workers at the project site, a ruptured storage tank or an ammonia leak from the transport pipe might be hazardous to their health and safety.

#### **After combustion: scrubbing with sulfur**

In these procedures, slurry or dry solid  $\text{Ca}(\text{OH})_2$  comes into touch with the gas. Before the solids leave the scrubber vessel, the water that was supplied is dried. Processes for semi-dry

cleaning work above the flue gas water saturation temperature. The SO<sub>2</sub> absorber does not have any liquid levels or discharge streams. In the form of free-flowing solids, the fly ash and SO<sub>2</sub> reaction products are discharged from the particle collector. There is no need for dewatering. The current commercially available reagents are quick lime (CaO) and hydrated lime (Ca(OH)<sub>2</sub>). CaO is hydrated to Ca(OH)<sub>2</sub> either within the absorber or before to addition. For the removal of byproduct particulates, this SO<sub>2</sub> removal process occurs either upstream of an ESP or FF. Particulate collection may take place both upstream and downstream of the operation if the cost of fly ash is considerable. Circulating dry scrubbers (CDSs) and spray dryers are two examples of semidry cleaning techniques. A significant technological advancement is made by the addition of reagent that is independent of the humidification water. Lime is often administered as a dry hydrated solid in the CDS. Upstream of a spray dryer vessel and lime slurry atomizing equipment in the spray dryer, more dry hydrated lime may be added. With these adjustments, it will be possible to handle high intake SO<sub>2</sub> concentrations and obtain high SO<sub>2</sub> reductions by adding the necessary reagent. The only factors preventing wet scrubbing from becoming competitive are financial ones. The process's overall responses are:



Fly ash and much more calcium sulfite than calcium sulfate may be found in FGD byproducts from a semidry lime absorber operation. The procedure demands that all liquid entrapped in the flue gas evaporate before it leaves the absorber modules. The SO<sub>2</sub> must, however, interact with the reagent before evaporation is complete since the procedure depends on chemical reactions that take place in the liquid phase. The quantity of liquid present and the pace of drying affect reaction speeds. The following benefits of semidry scrubbing over wet FGD processes: Reduced slurry pumping requirements, dry FGD byproduct collection, flue gas discharge temperatures above saturation, less complicated and more affordable equipment, no exotic metals or coating materials needed for the scrubber or ductwork, and fewer operator and maintenance hours are just a few of the benefits. The drawbacks include the requirement for more reagent and the production of more solids compared to standard wet calcium reagent spray tower procedures. The semidry scrubber byproducts' unreacted lime and fly ash might promote fixation processes that would raise the disposal byproduct's unconfined compressive strength and reduce permeability. These characteristics could facilitate landfill disposal or improve byproduct utilization.

### **Dry Scrubber That Rotates (CDS)**

In this part, the circulating dry scrubber method developed by Enelco and Lurgi is explained. Similar methods are being developed by Graf-EPE GmbH (Graf et al. 1993) and AirPolTnc, a Division of FLS Miljo, in addition to the commercially available technique owned by Enelco/Lurgi. FF PROCESS OR CDS/ESP. SO<sub>2</sub> removal may be more than 98% using the circulating dry scrubber, electrostatic precipitator, or fabric filter technique. The utilization and cost are practically the primary constraints on the lime addition, which is independent of the flue gas's ability to evaporate. Even on high sulfur coal-fueled combustors, there does not seem to be any obvious restriction on the CDS's practical SO<sub>2</sub> removal other than the expense of the reagents. Flue gas is sent to the CDS for acid gas scrubbing before being cleansed of particulates by an ESP or fabric filter (FF). The procedure is dry and often results in a dry, freely flowing waste product. The first form of hydrated lime is a dry, free-flowing powder. By cooling the flue gas via evaporation (low-quality water may be utilized) and recirculating the

calcium throughout the process, lime usage is enhanced. As the CDS is run closer to the adiabatic saturation temperature, this usage increases. In order to facilitate material handling, reduce cold spots and corrosion, and enable affordable carbon steel construction, the outlet approach temperature is often kept at least 30° F above adiabatic saturation. Over 90% of the solids, including unreacted lime, that are released from the ESP or FF are gravity-fed back to the CDS via air slides, which necessitates a greater height for the ESP or FF. A rotating feeder feeds fresh hydrated lime into the air slides. The air slides are very capable and cost-effective to operate and maintain. A minimal plan area is needed for the CDS/ESP or FF, which is suitable for both retrofit projects and new installations with severe space limitations. Figure 14-25 depicts the Neil Simpson Unit 2 turbine-generator, boiler, and CDS-ESP configuration's relative sizes for the Black Hills Power and Light Company. Equipment including lime hydration, boiler water purification systems, air compressors, and pumps were all enclosed in the area underneath the ESP. The streamlined CDS absorber with the feed points for hydrated lime, recycled dust, and cooling water is shown in Figure 14-26. For the purpose of absorbing gaseous pollutants, such as air toxics, the absorber functions as both an evaporator and a chemical reactor. By increasing the slip velocity (differential velocity) between the solid particles and the flue gas, heat and mass transmission are increased. The following traits are typical: The hydrated lime particle structure and the very tiny average particle diameter of 5 to 10  $\mu\text{m}$  result in high mass transfer rates inside the lime particles. Extremely long solids retention period, which enhances lime use and enables significant absorption of gaseous contaminants. The  $\text{CaSO}_3$  and  $\text{CaSO}_4$  surface that covers the active lime particle cores is removed by continuous abrasion at the lime surface. It is possible to operate at temperatures that are very near to the adiabatic saturation temperature, which results in a greater reagent consumption but may necessitate the use of alloy materials. The turndown is between 100% and 30% of the boiler load; Wastewater may be utilized as the flue gas cooling water injection. By using a booster fan to recycle some of the exit gas, lower turndowns are made practical.

### **Process management.**

Three main independent control loops make up the process control, which allows for completely autonomous operation. In theory, this procedure is quite straightforward and dependable. For various semidry scrubber processes, the process  $\text{SO}_2$  and temperature control ideas are comparable.  $\text{SO}_2$  control: The quantity of  $\text{SO}_2$  in the entrance flue gas and an exit flue gas  $\text{SO}_2$  signal govern the rate at which hydrated lime is fed. Temperature control—through high-pressure single fluid flow nozzles, the temperature of the gas exiting the absorber directly regulates the rate at which cooling water is injected. Solids discharge the amount of solids loaded into the absorber, as determined by the differential pressure over the absorber height, controls the amount of solids released from the system. Fly ash, hydrated lime, and  $\text{SO}_2$  enter the system at the same rate as solids are discharged from it. This keeps the mass of solids in the system constant, except from startup and shutdown.

### **Lime Spray Dryer/Absorber**

Lime slurry is used in the spray dryer/absorber  $\text{SO}_2$  removal operations to remove  $\text{SO}_2$  from the flue gas and provide a dry byproduct. The gas absorption component of this process was included by Joy/Niro, ABB Environmental Systems, Environmental Elements Corp., General Electric Environmental Systems, and Babcock & Wilcox for use in utility FGD applications. Today, flue gas from more than 17,000 MW of coal-fueled boilers is treated using spray dryer/absorbers. Fig. 14-28 shows a schematic representation of a lime spray dryer/absorber process. As flue gas passes through the absorber module, lime slurry is fed into the stream and atomized into tiny droplets. A high-speed rotary atomizer or spray nozzles may atomize a substance. Rotary atomizers are often employed in utility applications because they offer

superior abrasion resistance, are less likely to clog, and utilize a lower pressure slurry feed system. Rotating at 12,000 to 17,000 revolutions per minute, rotary atomizers atomize lime slurry using a precisely balanced wheel with interchangeable ceramic inserts. The rotating atomizer in an operational module may be quickly removed and replaced using a spare atomizer. Because to wear, ceramic nozzle maintenance is often needed every 2,000 to 4,000 hours of operation. Flue gas enters the absorber module and comes into contact with the atomized slurry.  $\text{SO}_2$  from the flue gas is taken up by the atomized slurry droplets and interacts with the calcium there. When used properly, the byproduct is dry and freely flowing. The module's walls seldom accumulate much in the way of byproducts. Slurry feed rate, gas and slurry distribution, slurry droplet size, exit gas temperature, droplet/particle residence time (5 to 12 seconds), and lime concentration in the slurry feed are among the parameters that need to be controlled. The temperature of the flue gas drops to 20 to 40° F (11 to 22° C) above the saturation temperature of the gas as a result of water evaporation from the slurry. Greater approach temperatures need higher calcium-to-sulfur ratios because the presence of liquid moisture, which is being evaporated, limits the reaction rate. To avoid moisture condensation in the spray dryer module, the majority of manufacturers advise a minimum approach temperature of 18 to 20° F. However, many systems run at temperatures that are 30 to 40 degrees above the gas saturation temperature in order to minimize reheat and to avoid condensation in downstream particulate removal equipment. If hygroscopic calcium chloride (from hydrogen chloride removal) is present, even higher approach temperatures are necessary to prevent corrosion and clogging. Typically, fly ash and the FGD byproducts are gathered in a cloth filter. This material, which includes unreacted lime, is sometimes recycled to increase reagent efficiency. The remaining material, which usually has a moisture content of 1% to 3%, is used for storage and disposal. The flue gas travels through a dust coating of unreacted lime and reaction byproducts in a cloth filter. Up to 20% more  $\text{SO}_2$  elimination might arise from this extra interaction. In an electrostatic precipitator, less  $\text{SO}_2$  is removed. However, compared to a fabric filter's propensity for bag binding, an electrostatic precipitator is less prone to solids pluggage from condensation and solids agglomeration. Fig. 14-28 depicts a typical utility-sized spray dryer with a quick lime storage chamber and a slaked lime feed system to the spray dryer atomizers. On coals containing up to 3.0% sulfur, current generation lime spray dryer/absorber FGD processes can remove 95% of the  $\text{SO}_2$ . An activated carbon injection system may be added to the spray dryer/absorber system to further limit vapor phase emissions like mercury and dioxins. For injecting additives, particularly upstream of the spray dryer/absorber, this comprises of a dry additive system.

### **Reduction Of Combination No./ $\text{SO}_2$ Removal**

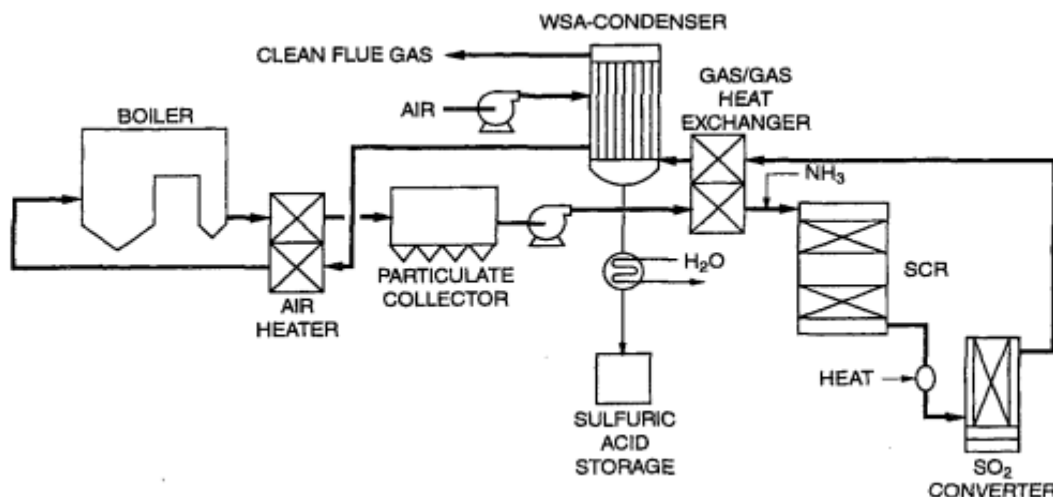
Processes that remove both  $\text{SO}_2$  and NOx have recently been included to air quality control systems by way of the flue gas. There aren't many commercial installations of these systems at the moment. Commercial utility installations exist for both the Mitsui-BF Activated Coke System and the Haldor Topsoe/ABB SNOX® technology. Both of them result in the production of sulfuric acid or elemental sulfur. There must be a long-term market for these byproducts.

### **Process of Haldor-Topsoe/ABB SNOX**

Haldor-Topsoe A/S and its associate Snamprogetti developed the SNOX® Process in Europe as a fully catalytic method for reducing sulfur and nitrogen oxides from gaseous streams. ABB Environmental Systems offers the procedure in North America under license in Figure 9.2. Nitrogen oxides are broken down in this process into elemental nitrogen, water vapor, and ammonia. Catalytic conversion of sulfur dioxide ( $\text{SO}_2$ ) to sulfur trioxide occurs ( $\text{SO}_3$ ). In a falling film condenser, the  $\text{SO}_3$  and water from the flue gas are subsequently condensed into sulfuric acid. Particulate collection, NO reduction,  $\text{SO}_2$  oxidation, sulfuric acid ( $\text{H}_2\text{SO}_4$ )



condensation, and acid conditioning are the five main process regions that make up the SNOX technology. The SNOX® technology incorporates heat addition, heat transmission, and heat recovery in considerable amounts. The flue gas from the boiler air preheater is handled in a particulate control device and flows through the main side of a gas/gas heat exchanger (GGH), raising the gas temperature to over 700° F (370° C). A process flow diagram combining these separate phases is illustrated in Fig. 14-29. The gas is then mixed with ammonia and air before going through the selective catalytic reactor (SCR), which converts nitrogen oxides into free nitrogen and water. As the flue gas exits the SCR, its temperature is slightly changed before it reaches the SO<sub>2</sub> converter, where SO<sub>2</sub> is converted to sulfur trioxide (SO<sub>3</sub>). As the entering flue gas is heated, the SO<sub>2</sub> laden gas is cooled as it travels through the secondary side of the GHH. The flue gas is cooled before passing through a falling film condenser (the wet-gas sulfuric acid condenser, or WSA-Condenser), where it is further cooled by outside air to below the sulfuric acid dewpoint. On the inside of borosilicate glass tubes, acid condenses from the gas phase and is then collected, cooled, diluted, and stored. A small portion of the cooling air that exits the WSA-Condenser at a temperature of around 400 degrees Fahrenheit (200 degrees Celsius) is utilized for process support; the rest is transferred to the boiler's air preheater and used for combustion air.

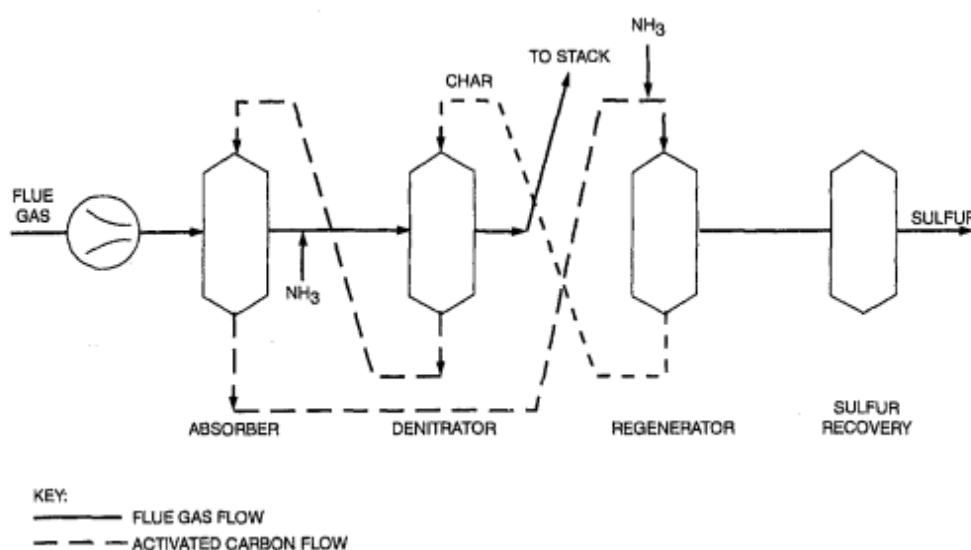


**Figure 9.2:** Illustrates the schematic diagram of Haldor-Topsoe procedure.

### Mitsui-BF System 14.5.2 (Activated Coke Process)

The Mitsui-BF DeSC/DeNC system uses a dry technique to remove SO<sub>2</sub> and NO<sub>x</sub> together. The licensee for the United States is General Electric Environmental Systems, Inc. (GEESI). The system's necessary equipment is shown in Figure 9.3. The air heaters are situated upstream of all processing equipment. Before the flue gas reaches the activated coke reactor, the fly ash is cleaned from the gas through a cloth filter or ESP. The NO<sub>x</sub> is converted to nitrogen and water by the catalytic action of the activated coke bed, which also absorbs SO<sub>2</sub>. It is possible to produce a stream of sulfur or sulfuric acid byproducts. A two-stage, activated coke adsorber is used to remove the SO<sub>x</sub> and NO<sub>x</sub> in two consecutive process phases. In contrast to many other methods, the SO and NO removal stages may be found in the lower temperature region (212 to 392) after the air heater. Before the NO is converted, the SO must be absorbed from the exhaust gas. The bottom portion of an activated coke bed that is travelling downward in the adsorber receives the flue gas first and is passed through in a crossflow fashion. In this step of the process, sulfur dioxide and a tiny quantity of extra fly ash are removed. The flue gas is injected with ammonia as it exits the first stage carbon bed adsorber and then runs crossflow into the

second activated coke bed, which acts as a catalyst for the  $\text{NO}$ . Water and nitrogen are produced during the ammonia-based decomposition process. The coke gets saturated with  $\text{SO}$  as it passes between the two sections of the activated coke bed, decreasing its capacity for adsorption. The  $\text{SOV}$  and other impurities are removed from the coke by heating it to a temperature between 570 and 932 degrees Fahrenheit. An induced draft blower removes the coke's emitted stream of  $\text{SO}_2$ -rich gas from the regeneration/desorption module. This  $\text{SO}_2$  stream may be processed to create sulfur in a Claus unit or high-quality sulfuric acid in a scrubbing system. Degraded coke fines, which may be utilized as boiler fuel, are removed from the regenerated coke using screening. Coke that has been properly rejuvenated and additional fresh coke are added back to the moving bed (Figure 9.3).



**Figure 9.3: Illustrates the filtering of Activated Coke Process.**

### Hazardous Emissions Control

The Hazardous Air Pollutants (HAPs) requirements of Title III of the CAAA as enacted by the United States are covered in Chapter 26. The list of 189 substances (pollutants) at the center of Title III poses potential risks to both human health and the environment when released. The US EPA is not presently obligated to promulgate regulations for HAPs released by steam generators used by electric utilities. However, the EPA is mandated to conduct a study of the risks to the public's health that may be foreseen as a consequence of emissions from steam generating units used by electric utilities. The EPA has said that the study would not be released until November 1995 in order to incorporate the emissions data that the EPRI and the US Department of Energy are now generating at different locations (DOE). If the EPA determines that HAP emissions rules for electric utility steam producing units are reasonable and required after taking the study's findings into account, then these units will be regulated. The CAAA also mandated that the EPA research mercury emissions, particularly those from steam-generating units used by electric utilities, and deliver a report to Congress by November 1994. In November 1995, a revision of this study that specifically addresses utility emissions is expected to be submitted to Congress. Mercury emissions from these sources would also be controlled if the EPA determined that it was necessary and acceptable. MACT and Emission Standards the EPA will create emission limits for new and existing sources that call for the greatest possible reduction in HAP emissions while taking into account the cost of doing so, any potential effects on air quality, and energy needs. Greatest attainable control technology refers to emission regulations related with the needed maximum degree of reduction (MACT).

The MACT standard will not be less strict for new sources in a category than the emission control now achieved in practice by the best regulated comparable source. The MACT requirement must be at least as strict as the average emission limitation attained by the top 12% of current sources in a category, however it may be less strict.

### **Potential Control Technologies 14.6.2**

Due to a lack of precise testing data and operational experience with fossil fuel-fired utility steam generators, the removal efficiencies of various control systems in regulating HAPs, including mercury, are presently not well characterized. Trace metal concentrations in fuels may vary significantly depending on the location where the fuel was produced, and even within a single mine for coal. Depending on the element and furnace operating conditions, the partition of trace metals between bottom ash and fly ash as a consequence of coal combustion might differ. As a result, it is anticipated that HAP control devices will need to achieve strict outlet emission limitations over a variety of input HAP concentrations. When evaluating prospective control strategies, two crucial aspects of HAPs released by power plants must be taken into account.

The first is that the HAPs, which include most other heavy metals as well as vanadium, nickel, cadmium, and lead, are concentrated in the particulate fraction with size less than 10 microns (PM<sub>10</sub>). Control of those particulate emissions will have an impact on the HAPs that have been identified as present in the fine particle fraction (PM<sub>10</sub>). The second is that HAPs that are volatile, such as selenium and elemental mercury, may result in emissions in the gas phase. Therefore, traditional particle control systems would have little effect on these gaseous pollutants. Controlling HAPs that are present as gases usually entails cooling, sublimation, condensation, and removal as particles, or absorption, adsorption, and removal using the recovery liquid or solid.

Wet scrubbers and semidry spray absorbers made of water are examples of possible control measures. Both require lowering the flue gas temperature. Despite the fact that both are often used on coal-fueled steam generators to cut SO<sub>2</sub> emissions, little testing and data reporting have shown how well these devices really function in reducing HAPs. For the control and removal of fine particulate matter linked to certain characteristic HAPs, notably trace metals, semidry absorber scrubbers may be useful.

The dry spray absorber's cooling feature creates conditions that are believed to be helpful in managing a number of HAPs. The chemical makeup of the mercury and the total amount of carbon in the flue gas are two important variables influencing the removal of mercury from the flue gas. As particles, mercury salts may be eliminated. Another efficient way to increase the removal of volatile elemental mercury by adsorption is to introduce carbon into a dry spray absorber. In the event that future air toxic regulations call for it, one new, 80-MW power plant in the United States has been designed with the capacity to add carbon injection to the fluidized bed lime scrubber by 454 Power Plant Engineering.

In terms of reducing HAPs and mercury emissions, wet scrubber control systems that are utilized as quenchers and particulate control devices may be pretty effective. Wet scrubber control systems are widely recognized for their effectiveness in removing SO<sub>2</sub> and particulates, and the related reduction in flue gas temperatures may be particularly effective in reducing condensible HAPs like mercury (Wet scrubber additive injection systems that solubilize mercury with substances like sodium hypochlorite may significantly increase removal efficiency).

Removal efficiency of more than 95% are reportedly attainable, according to reports from both pilot plant and full-scale incinerator installations (Neme 1991). The removal and management of tiny particulate linked to certain characteristic HAPs, particularly trace metals, is best handled using fabric filters. It is anticipated that pulse jet or reverse air fabric filters will be more effective than 98% in reducing particulate HAPs (Laudall et al.). It is not anticipated that fabric filters will be very effective in reducing mercury. However, when used in combination with upstream additives like sodium sulfate or activated carbon, fabric filters may be quite effective at controlling mercury.

If properly constructed, high-efficiency ESPs may provide control efficiencies of more than 98% for the majority of particular HAPs (Tumati and Devito). To ascertain its impact on HAP management, flue gas conditioning with dual injection of sulfur trioxide/ammonia upstream of the ESP is being examined. However, the available information and experience are scarce. Applications downstream of wet scrubbers or other procedures where the flue gas has been quenched with moisture to create the saturated conditions are where wet ESPs are especially well suited. Mercury and other gas phase toxics may condense and be collected as particulates or absorbed into the water stream under the perfect circumstances offered by a wet ESP. Other benefits of a wet ESP include lower size due to the wet gas's smaller gas volume, less reentrainment, and the avoidance of ash resistivity issues.

To help with the management of fine particle emissions, one American utility built a retrofit wet ESP downstream of the mist eliminators within an 80-MW capacity wet scrubber at the beginning of 1995. Due to the fact that the wet ESP is situated within the area that was once utilized for SO<sub>2</sub> absorption, this EPRI-sponsored demonstration project is noteworthy. Wet ESP technology has to properly solve design concerns related to wet ESP flushing water, corrosion, and wastewater treatment before being widely used in combination with utility scrubber applications. A novel utility application called condensing heat exchangers is being researched as a way to reduce HAPs and improve plant efficiency. The condensing heat exchangers are positioned near the conclusion of the procedure where they condense water, acid, and other volatile substances while removing heat from the flue gas. Additionally, submicron-scale condensation takes place, which improves the removal of tiny particulate debris. Process water or intake combustion air are also possible choices for the cooling medium. Effects of Potential HAP Controls 14.6.3 the environmental, operational, and financial effects on the sources must be taken into account throughout the design and installation of air quality control systems to reduce the emissions of HAPs, including mercury, from utility combustion sources. For installations that are retrofits, this is particularly true. Numerous plant adjustments, including those to ducting, fans, water treatment systems, and solids stabilization systems, may be necessary to implement potential control methods. In conclusion, the power generating sector has to develop solutions for addressing dangerous air pollution. Assessment of prospective control systems that would be necessary as MACT for combustion sources should be one of these tactics.

### **Gaseous Emissions Monitoring**

This section summarizes the continuous emissions monitoring (CEM) technologies, analytical methodologies, and CEM system types used for continuous emissions monitoring. These monitors are needed by United States rules for all new units and many existing units.

### **Analytical Techniques**

CEM employs several analytical approaches. These techniques include absorption and luminescence spectroscopy, and electroanalytical procedures. Absorption or scattering of incoming light by solids or gases is the foundation for studies employing absorption

spectroscopy. The basic concept is stated by the Beer-Lambert law, which says that the transmittance of light is equal to the ratio of the intensity of the light leaving this same gas stream to the intensity of the light entering the gas stream. An exponential connection exists between transmittance as well as the attenuation coefficient of a pollutant, the concentration of a pollutant, as well as the distance the light travels through the gas. This connection applies to both light absorption and light dispersion. The approach is sensitive to focus and route length. This approach is utilized for measuring opacity and for different gases as mentioned in the following paragraphs.

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## CHAPTER 10

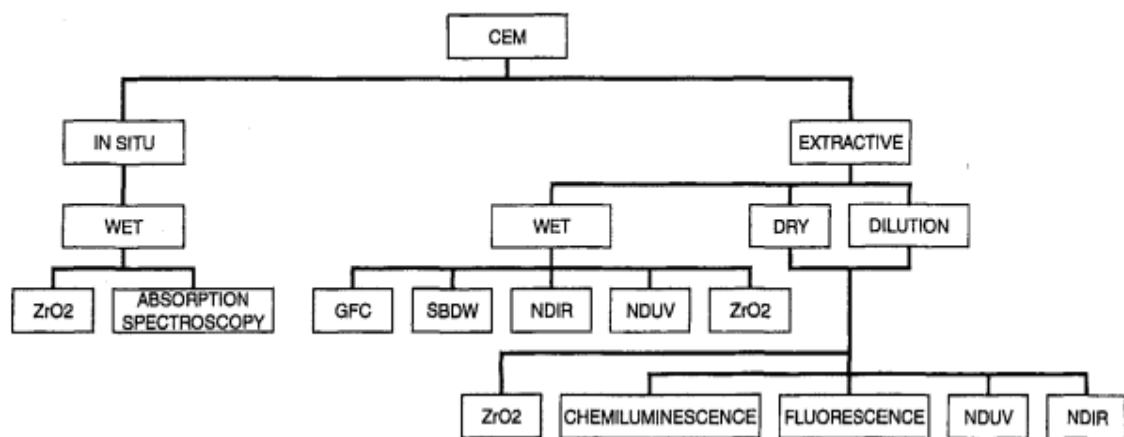
### OPACITY MONITORING

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Opacity monitors employ light in just the visible spectrum since opacity must correspond to measurements done with the human eye. The light attenuation coefficient is based on particle size distribution and the reflectance of the particulate. The link of these characteristics to the measurement of particle mass emissions is quite complicated and site dependent. Therefore, opacity monitors are not capable of precise mass emission measurements in Figure 10.1.



**Figure 10.1:** Illustrates the classification of precise mass emission measurements.

#### Gas Monitoring

Nondispersive infrared analysis is a technique that uses band pass filters or diffraction gratings to select the appropriate wavelengths from an infrared source. Nondispersive means that the infrared light is not separated into its component wavelengths and only part of the infrared spectrum is used for analysis. The wavelengths sensitive (light is absorbed) to the gases of interest with the fewest interferences are selected. Nondispersive infrared analysis is sensitive to  $\text{SO}_2$ ,  $\text{NO}$ ,  $\text{NO}_2$ ,  $\text{CO}$ ,  $\text{CO}_2$ , and  $\text{H}_2\text{O}$ , although the technique is not equally sensitive to all of these gases. Nondispersive ultraviolet analysis is another absorption spectroscopy technique used for gas analysis. Band-pass filters or diffraction gratings are used to select particular wavelengths in the ultraviolet part of the spectrum. This technique is sensitive to  $\text{NO}$  and  $\text{SO}_2$ . To determine the total  $\text{NO}_x$ , an  $\text{NO}_2$  monitor would also be required. However, since  $\text{NO}_2$  is generally  $<5\%$  of the total  $\text{NO}_x$  from pulverized coal boilers, the  $\text{NO}_2$  fraction is sometimes ignored in determining the approximate  $\text{NO}_x$  concentration. The differential absorption analysis technique compares an absorbed wavelength of light to a nonabsorbed wavelength of light to determine gas concentrations. These measurements can be made only over limited path lengths, and therefore these analyzers are single-pass type or limited path length type. Differential absorption is used for  $\text{NO}$  and  $\text{SO}_2$  measurements using nondispersive ultraviolet light and for  $\text{CO}_2$  and  $\text{H}_2\text{O}$  measurements using nondispersive infrared light. The gas filter correlation analysis technique compares a split beam of light in the analyzer. After passing through the measurement cell, the light beam is split. One beam passes through a gas filter

correlation cell containing a high concentration of the subject pollutant. After passing through the gas filter correlation cell, nearly all the light in the wavelengths of interest will be absorbed. The difference in energy levels between these beams in the wavelengths of interest is related to the pollutant concentration. This technique is limited to analyzers measuring  $\text{SO}_2$ ,  $\text{NO}$ , and  $\text{CO}_2$  concentrations. The single-beam dual-wavelength analysis technique uses narrow-band optical filters to select infrared wavelengths. One wavelength is selected so that it is absorbed by the gas to be measured, and the other wavelength is not absorbed by the gas. The ratio between the two energy levels is proportional to the concentration of gas. Second-derivative spectroscopy uses ultraviolet light to measure  $\text{SO}_2$  and  $\text{NO}$  concentrations ( $\text{NO}^x$  is determined from the  $\text{NO}$  concentrations), and is based on the varying spectral absorption of gas molecules. A diffraction grating is used to select a range of wavelengths, centered about a wavelength that is absorbed most readily by the subject pollutant. As the range of wavelengths selected by the diffraction grating change, the absorption measured by the detector varies. The absorption is greatest at the wavelengths closest to the central wavelength and as the band selected moves away from the central wavelength, and a sinusoidal signal is generated. The amplitude of this signal is proportional to the concentration of the gas. This amplitude is determined by the second derivative (slope) of the sinusoidal curve.

### **Luminescence Spectroscopy**

Gas monitoring techniques using luminescence spectroscopy are based on specific gas molecules giving off light when excited. Three types of luminescence spectroscopy techniques are fluorescence, chemiluminescence, and flame photometry. Fluorescence techniques use light to excite the gas molecules so that the difference in the wavelength of the exciting light and the emitted light can be determined. Fluorescence is often used to determine  $\text{SO}_2$  concentration. However, this technique has interference from  $\text{H}_2\text{O}$ ,  $\text{CO}_2$ , and  $\text{O}_2$ , which quenches the emitted light. These interferences can be calibrated out with some sacrifice in accuracy. This technique requires a clean, particulate free, and essentially moisture free gas stream for analysis and is limited to the extractive systems. Chemiluminescence uses a chemical reaction to stimulate molecules to give off light.  $\text{NO}^x$  analyzers apply this technique using the chemical reaction between  $\text{NO}$  and ozone. For determination of total  $\text{NO}_x$ ,  $\text{NO}_2$  must first be reduced to  $\text{NO}$  catalytically.  $\text{O}_2$ ,  $\text{N}_2$ , and  $\text{CO}_2$  quench the reaction but can be compensated for by excess dilution with ozone. Because the technique requires a clean, dry sample and the reduction of  $\text{NO}_2$  to  $\text{NO}$ , this technique is limited to extractive systems. Flame photometry is a technique that excites the gas sample to luminescence by introduction into a hydrogen flame. The spectra given off by the hot gases are analyzed in the ranges of interest. This technique is sensitive to all forms of sulfur and thereby yields total sulfur data unless sample conditioning is used to absorb sulfur species that are not of interest. This technique requires a clean, dry sample and is limited to extractive systems. Flame photometry has been most widely used for ambient level monitoring.

### **Electro Analytical Techniques**

The previously described methods of analysis rely on spectroscopic or electrooptical techniques for measuring particulate or gas concentrations. Electroanalytical instruments measure electrical impulses from various chemical reactions. This technique is most often used to determine  $\text{O}_2$  concentrations using zirconium oxide and paramagnetic cells. The zirconium oxide cell uses a reference solution of air with 21%  $\text{O}_2$  which is fed to one side of the zirconium oxide cell, while the other side of the zirconium oxide is exposed to flue gas. The current flow through the zirconium oxide as a result of the  $\text{O}_2$  difference from one side to the other is measured. Zirconium oxide analyzers are relatively insensitive to vibrations in the measurement area and as such are frequently used for in situ monitoring, especially for excess

air monitoring in boiler control systems. Paramagnetic analyzers are also capable of accurately measuring oxygen concentrations. A magnetic field in the measurement chamber is changed by the presence of oxygen which is bipolar, and concentrations can be determined by the displacement of a platinum ribbon in a permanent magnetic field. This technique requires a sample stream that is clean and free of water droplets. Paramagnetic analyzers are highly susceptible to vibration and are limited to extractive type systems.

### **Monitoring Alternatives.**

Two primary kinds of CEM systems (classified by sampling system type) are available: In situ systems—Measure the flue gas there at conditions present in the stack at the monitoring station. Extractive systems Draw a gas sample from the stack but rather duct to a distant site for sample conditioning and analysis. This category comprises wet extractive, dry extractive, and dilution extractive systems.

### **In Situ CEM Systems**

In situ systems monitor gas concentrations directly in the stack or duct without collecting samples for external analysis and may conduct real-time gas measurements. In situ analyzers generally accessible today for gas concentration measurements employ two separate techniques of gas analysis: differential absorption as well as second derivative spectroscopy. The differential absorption type is an across-flue system that examines the gas that travels via a certain "line of sight" of the monitor, often ranging from a few feet to the complete distance across the inner diameter of the flue. The second kind of in situ system is a point measuring equipment that examines the gas at one particular place or along a short route (a few inches) in the flue or duct in a hollow, shielded by a ceramic filter. Particulate stuff cannot flow through the filter. NO<sub>x</sub> and SO<sub>2</sub> readings normally are conducted utilizing an ultraviolet light source and second-derivative spectroscopy. CO<sub>2</sub> and H<sub>2</sub>O normally are measured using infrared radiation in a different device using the same approach. O<sub>2</sub> may be detected in situ using a zirconium oxide probe. Calibration is achieved by flooding the measuring cavity with the appropriate calibration gas at a little higher pressure than the measurement site such that no flue gas remains or may seep into the cavity. After calibration, the flue gas returns to the cavity whenever the calibration gas flow is switched off. One form of across-flue in situ analyzers employs a Xenon bulb light and, when connected with a spectrum analyzer, is sensitive to SO<sub>2</sub>, NO<sub>x</sub>, CO<sub>2</sub>, and H<sub>2</sub>O. This sensitivity may be increased to accommodate more gases (up to 30) with minimal modifications. The transmitter flashes a light through the stack or duct to the receiver which transfers this light to the analyzer unit where the concentrations are calculated by examining the spectrum of the light from the receiver. This example route is a simplified installation inside a power plant application. Similar systems employing various light sources are available. Calibration of a cross-flue analyzer is achieved by flooding part of a second, sealed tube (which also crosses the flue) with calibration gas. The light source is also directed via this calibration gas cell to the detector. The same light source is employed and mirrors perform the path splitting. Since the tube or a cell inside the tube may be filled with new calibration gas each time calibration occurs, this technique fulfills EPA criteria for instrument calibration.

### **Extractive CEM Systems**

There are three kinds of extractive CEM systems. One kind measures pollutants on a dry basis, another measures contaminants on a wet basis, and the third dilutes this same sample prior to analysis. Dry extractive CEM systems. Dry extractive CEM systems utilize analytical methods or analyzers that need a particulate-free, moisture-free, low-temperature sample stream. Therefore, the sample must be evacuated from the flue and conditioned before reaching the

analyzers. As such, dry extractive CEM systems include of sample extraction, Transport, conditioning, and analysis subsystems. Particulate is eliminated via filtering at the probe tip. Dust free sample gas is conveyed via heat traced lines to a remotely positioned analysis container. Moisture is removed by refrigeration condensation and by permeation tube dryers that pass the sample through membranes that do not allow water to pass. This sample extraction/conditioning is the crucial component of dry extractive gas analysis. Poorly constructed sample conditioning systems need extensive maintenance, inhibit correct measurement by the analyzers, and contribute to poor monitor and system dependability. The analytical methodologies utilized in dry extractive CEM systems differ from one system provider to another. Typically, these methods employ spectrum absorption (nondispersive infrared, nondispersive ultraviolet, and gas filter correlation) or luminescence spectroscopy (fluorescent techniques for  $\text{SO}_2$  and chemiluminescence for  $\text{NO}^x$ ). Material selection for probable corrosion occurrences is crucial in this subsystem.

### **Wet Extractive CEM Systems**

Wet extractive CEM systems eliminate the particle at the probe then keep the sample in a heated state. The moisture is preserved through the gas concentration measurements. Accordingly, this technique demands that the gas sample be kept above the acid dew point temperatures (280 to 320° F) throughout the whole CEM system, including the analyzer. Infrared analyzers usually used with this approach determine NOA. utilizing absorption spectroscopy techniques in a wavelength region that includes interference from moisture. In reality, infrared energy absorption by water vapor is a wide band (many wavelength) phenomena. As a consequence, such infrared analyzers also monitor water vapor concentration and adjust the  $\text{NO}_x$  concentration data for water vapor. In particular instances with high moisture content in the flue gas, this has produced accuracy difficulties with  $\text{NO}_x$  readings. The important component of a wet extractive CEM system is the heat tracing employed throughout the system. Manufacturers of this technique maintain sample temperatures between 360 and 480° F. A temperature of 360° F would be above most acid dew point temperatures observed in fossil-fueled applications.

### **Dilution Extractive CEM Systems**

Dilution extractive CEM systems avoid the requirement for heat tracing and conditioning of extracted samples by accurately diluting the sample stream with extremely dry (with a moisture dew point as low as 100°F), clean, instrument air. Measurement of pollutant concentrations is conducted using analyzers intended for ambient level pollutant measurements (at or below 1 part per million [ppm] precisely) (at or below 1 part per million [ppm] accurately). Particulate is filtered out before to dilution. Precise dilution of the sample gas stream is performed utilizing critical orifice Venturis to determine both sample and dilution air flow volumes. Based on the undiluted concentration of the subject pollutant in the flue gas stream, a critical orifice may be determined such that the diluted sample fits within the sampling limits of the ambient concentration sensors. Standard critical orifice diameters are available that may dilute flue gas any place from 12 to 1 to upwards of 700 to 1. Dilution extraction systems need the use of dilution air that is free from  $\text{SO}_2$ ,  $\text{NO}_x$ ,  $\text{CO}_2$ ,  $\text{CO}$ , or moisture to prevent errors. An air cleaning system is equipped with filters and catalytic converters that remove these interferents from the dilution air. Dilution extractive sample conditioning is based on choked flow (constant mass flow) flue gas sampling with a sonic (critical) aperture and precision dilution by an air-driven aspirator. The aspirator provides a high vacuum that assures constricted flow through the aperture. Maintaining sonic velocity through critical orifices is dependent on operating at an absolute pressure downstream of the critical orifice that is 0.53 may undermine the accuracy of a dilution extraction system. An adjustment must be applied to the

dilution ratio if the gauge pressure at the orifice entrance is negative (with respect to atmosphere) (with respect to atmosphere)

### Technical Comparison

The following discussion highlights benefits and downsides of the previously stated CEM technologies. Table 14-2 highlights the benefits and the downsides of the different CEM technologies. The fundamental benefit of in situ analysis is that the gas sample that is tested is basically unaltered from the bulk of the gas stream, and the integrity of the sample is extremely high. Some in situ analyzers are built with relatively small route lengths across which gas concentration measurements are taken. This restricted route length may lead to lower accuracy and sensitivity capabilities at low concentrations, and lack of representativeness if stratification of gases is present. Diminished precision capabilities are particularly of concern considering 40 CFR 75 criteria. Since the gas is evaluated at the sample point, electronic signals from the monitors are transferred to the remote data recorder. No walk-in analyser enclosure is required. However, monitor maintenance might be challenging since convenient and quick access to the monitor position (usually on the stack) is necessary, but not always accessible. In addition, some end-users are cautious to place sensitive electronic measuring instruments atop stacks that may be hit by lightning. Weather factors, ambient temperature variations, and vibration at the monitoring site may all effect monitor accuracy, repeatability, and maintenance needs.

**Extractive CEM Systems.** Since adoption of early EPA CEM system quality assurance criteria (40 CFR 60 Appendix F), extractive CEM systems have been utilized at a considerable number of facilities. However, these systems are relatively sophisticated and are often more costly than in situ monitoring. This disadvantage is largely mitigated by the precision of extractive system measurements. However, these systems face the same stratification of gas limitation that point or short route in situ systems do; they are of uncertain accuracy if gas stratification is present in the stack or flue. Because of the relatively high sample volumes for wet extractive and dry extractive systems (about 300 ft<sup>3</sup> / day), filter pluggage is a possible concern. However, back purging the filter routinely decreases filter pluggage difficulties.

### Dry Extractive CEM Systems.

Dry extraction systems have been implemented on various coal-fueled boilers. The accuracy of these devices is great since the moisture and particles have been eliminated from the sample. A drawback of dry extractive methods for estimating pollutant mass flow (lb/h) is that sample conditioning systems remove the moisture in the flue gas prior to sample analysis. This does not influence the computation of lb/MBtu emissions using EPA Method 19. However, it introduces a potential source of error into the computation since the gas moisture content must be employed to convert the dry basis concentration measurement to wet basis. Wet Extractive CEM Systems. The benefits of wet extractive CEM systems include good sample integrity, as only particulate is removed before analysis, and that sample analysis is done on a wet basis, enabling uncorrected conversion to mass flow (lb/h). The primary drawbacks of wet extraction systems are the necessity for heat tracing throughout the system and potential moisture interference for NO<sup>x</sup> readings. The heat tracing must be capable of maintaining a sample temperature that is above the acid dew point temperature of the gas sample. Moisture interference for NO<sup>x</sup> measurements restricts the use of this method when a significant moisture content is present in the gas stream or where extremely precise NO<sup>x</sup> readings are needed.

### Dilution Extractive CEM Systems.

Potential benefits for dilute extraction CEM systems are the relative simplicity of operation and inexpensive cost. Accordingly, these technologies have been deployed at a considerable



number of recent installations. There may be an accuracy difficulty due of sample dilution, especially at low pollutant concentrations for as at the exit of a SO<sub>2</sub> scrubber or on combustion turbine applications. However, this approach is extensively used, certifiable, accurate, and acceptable to the EPA. Another benefit of the dilution extraction technique is that the sample conditioning does not remove the water prior to analysis. As indicated previously, analysis of a wet basis sample permits direct connection of the reported pollutant concentration to the wet basis mass flow without the mistake inherent in assuming or measuring a moisture content for correction.

### 14.7.2 Gas Flow Monitoring

The 1990 CAAA mandates monitoring and recording SO<sub>2</sub> concentration (in ppm) and flue gas volumetric flow as standard cubic feet per hour (scfh) to compute SO<sub>2</sub> mass emissions in pounds per hour (lb/h). If the CEM system monitors the CO<sub>2</sub> content in the flue gas, the volumetric gas flow monitor may also be utilized to report CO<sub>2</sub> emissions (in lb/day). 14.7.2.1 Measurement Techniques. Three kinds of flue gas flow rate measuring methods may be used: differential temperature using heated temperature sensors, differential pressure employing annubar or pitot tube type probes, and differential frequency/transit time utilizing ultrasonic sound (Doppler principle) (Doppler principle). Essentially, these flow measurement systems indirectly assess the flue gas velocity (ft/min), then compute the flow rate (ft<sup>3</sup>/min) based on the specified geometry (cross-sectional flow area, ft<sup>2</sup>) of the measuring point. Some of the monitors presently available employ more than one approach.

#### Differential Temperature

This approach detects a temperature difference between heated and the unheated RTDs positioned in the gas flow at numerous places. This temperature disparity reduces when the heated RTD is cooled by increased flue gas flow. Direct variations in flow may progressively impact the amount to which heat is lost from the sensor probe. Consequently, the size of the temperature difference between the matched RTDs may be calibrated to flue gas flow rate.

#### Differential Pressure

Differential pressure measurement monitoring gas flow is based on the pressure differential between the upstream (total pressure) and the downstream (nearly static pressure) sides of the probe which is associated to flow. Differential pressure measurements may be conducted using either an annubar or pitot type probe. Annubar probes commonly span the cross-section of a flue, yielding an average reading from many positions along the probe. Pitot probes offer point measurements of the velocity inside the flue and are often clustered to offset the effects of stratified flow. For any measurement configuration, back purge devices are necessary to regularly remove blockages from the pressure detecting orifices.

#### Transit Time.

The transit time approach (also known to as ultrasonic flow monitoring) is based on measuring the transit time through the flue from the source to the detector (the transducers) for acoustic pressure, which changes with the relative velocity of the gas stream. Ideally, the transducers should be positioned at a 45-degree angle across the flue. Each transducer functions alternatively as a receiver or a transmitter of ultrasonic sound.

When a tone burst is delivered through the gas stream from one transducer to the other, the movement from across gas stream modifies the time necessary for the tone to cover the distance across the flue. If the tone burst is going with the gas stream, the time is shortened. If the tone burst is going against the gas stream, the time is now increased. The flow velocity is directly

proportional to the difference in the time needed for the tone bursts to cross the stack in both directions. As demonstrated in Fig. 14-36, Differential Frequency Typical Installation, ultrasonic monitors are not immediately situated in the flue gas flow stream. Like opacity monitors, they are positioned on each side of the flue gas flow stream. Nevertheless, purge airflow and careful selection of the materials of build structure are still essential. This sort of flow rate monitor needs the two transducers to be positioned at an angle of roughly 45 degrees (upstream/downstream) towards the direction of flow. Therefore, one of the transducers must be situated on a separate platform.

### **Technical Comparison.**

A measurement difficulty gives rise for all the flow rate monitors because, in addition to gas flow, other considerations such as the gas density (affected by temperature and pressure), orientation of the flow vector (affected by cyclonic flow), and flue gas molecular structure also affect the measured parameters. However, only the flue gas temperature and pressure which impact gas density, may be monitored constantly to adjust flow rates. The flow vector angle but also flue gas molecular weight can indeed be determined constantly. Flow meters often work in a corrosive and erosive environment. If the stack is moist (after a wet scrubber), the low temperature facilitates the condensation of acidic mist onto the probe. Also, any particulate carryover from the scrubber is likely to attach to the probe, possibly clogging the sample ports. In dry stack applications, particulate might gather on the probe as a consequence of electrostatic forces. Because of the possible harshness of the operational environment, high-nickel alloys are generally utilized as the materials of construction again for probe for both wet and dry installations.

### **Differential Temperature**

Thermal flow monitors are not suggested for wet stack applications due to impingement of water droplets. These droplets generate significant increases in heat transmission from the heated RTD. This leads to erroneous measurements of the temperature difference between the two RTDs.

### **Differential Pressure**

Differential pressure measurement is an established technique that has been extensively utilized in measurement of flue gas flow rates on a variety of power plants and is the EPA reference method measuring gas flow measurement. A back purge mechanism is necessary for differential pressure flow meters to avoid probe pluggage. Differential pressure point readings are pneumatically averaged by manifolding all total pressure lines together and all static pressure connections together to minimize a possible inaccuracy produced by electronic averaging of the recorded data.

### **Transit Time**

Ultrasonic systems typically are more expensive than differential temperature or differential pressure systems, however may be less vulnerable to mistakes owing to gas flow circumstances or features. A differential frequency system frequently needs the building of a new platform, and sensitive electrical components would be installed in stack or duct-mounted enclosures. Also, a differential frequency system allows line averaging in just one direction. If the flue gas supply is stratified along another axis inside the flue, a single set of monitors may not be able to account for the stratification. In these instances, another set of transceivers is necessary to construct a cross-beam system for precise measurement across both axes (many directions) of stratification.

## Water Treatment

Water is a vital necessity for steam-generating power plants, and its availability and quality were essential considerations in placing significant steam-generating facilities. Water is utilized for a myriad of functions in power plant operations, including equipment cooling, maintenance cleaning, air pollution control (scrubbing), solids transporting, and as the working fluid for the steam cycle. Proper treatment and conditioning of water to minimize scaling and corrosion in modern, efficient high-pressure power cycles is vital to avoid economic losses resulting by lower output capability and higher operating expenses. In a broad sense water treatment would be any physical or chemical technique that enhances the usefulness of the water treated. Management of plant water consumption to fulfill ever higher quality criteria as well as more rigorous environmental limitations creates complicated problems for both the construction and operation of power plants

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## Chapter 11

### WATER SOURCES

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Water resources normally are separated into two primary categories: surface water and ground water. Surface water is available from rivers, lakes and other impoundments, as well as the sea. Ground water is present below the earth's surface, restricted inside layers in aquifers, and extracted by springs or wells. Only around 3% of the earth's water is considered fresh, and 75% of this is trapped as ice in glaciers and polar ice caps. Of the remaining 25%, more than 24% is groundwater, with ground and atmospheric water making up the remaining 1% (Moffat). All water supplies are the product of precipitation from the atmosphere, which is part of the continual evaporation and polymerization reaction termed the hydrologic cycle. A simplified schematic of the hydrologic cycle is provided. Rainfall or snow, on reaching the ground surface, either evaporates, penetrates, runs off, or infiltrates the soil. Depending on atmospheric conditions and geography, approximately 25% of precipitation flows off to surface waters, less than 10% infiltrates, and the remaining returns to the atmosphere through evapotranspiration. Only a minor fraction of the entering fluids reaches the ground water aquifers. Most of this ultimately emerges at the surface and contribute to streamflow. Aquifers close to the surface (surficial aquifers) capture practically all of the infiltrating water. Water contained in deep aquifers, isolated from the surficial aquifers by bed rock, frequently originates in regions other than the site of the aquifer. Some extremely deep aquifers contain water that gathered in a faraway site and in a prior geologic epoch. Naturally occurring waters offer a broad variety of properties. If water was free from dissolved and suspended particles, treatment would be quite straightforward. Water has been nicknamed the "universal solvent" simply because it is capable of dissolving, in whole or in parts, so many things. Thus, even when originally created by condensation, it will never be totally devoid of dissolved elements.

#### Water Quality

Precipitation, when it descends through the atmosphere, absorbs gases, chiefly oxygen and carbon dioxide, which contribute substantially to the dissolving power of water. As rain falls on the soil, flows over it, and soaks into the ground, the rainfall entrains and dissolves a range of compounds from the various faces it encounters. The type of these compounds and the quantity dissolved are factors of the features of the terrain on which the rain falls and of the subsurface formations into which the rainfall penetrates. Surface runoff brings different quantities of silt, sand, leaves, dead plants and organic detritus, and dissolved mineral components from rock formations that it meets. Surface waters from rivers, lakes, and impoundments, so far, virtually generally include turbidity, suspended matter and color, in various levels as well as modest amounts of dissolved solids. Surface waters progressively rise in solids content as a consequence of concentration generated by evaporation. High dissolved solids concentrations are noticeable in the seas because of the huge surface areas accessible for evaporation. Impounded surface waters such as ponds and lakes usually have less debris in suspension owing to natural settling of the suspended elements. Dissolved sediments, gases, and organic materials may remain in impounded waters. Organic growths such as algae also may be present. The fraction of rainwater that percolates into the soil and subsequently into subterranean formations, which is the source of supply of springs and wells, is "strained" or "filtered" in the process such that water from these sources is normally pure and colorless.

However, because of its longer and more intimate duration of contact with the geological formations through which it flows, water from wells and springs often contains moderate to considerable volumes of dissolved solids of various sorts. Inorganic Constituents The dissolved inorganic elements in water are listed in Table 15-1 (Davis and DeWiest 1966). (Davis and DeWiest 1966).

The concentrations of the major, secondary, minor, and trace inorganic constituents in water are controlled by the availability of the elements present in the soil and rock through which the water has passed, by physico-chemical constraints such as solubility and absorption, either by rates (kinetics) of geochemical processes, and by the sequence through which the water has come into contact with the various minerals in the geological materials along the flow paths. Water is a great solvent for many ionic substances.

The ionic compounds that are dissolved in natural waterways normally constitute substantial contributors to the pollutants present in the water. Typically, these pollutants are predominantly the cations (positively charged ions) of calcium ( $\text{Ca}^{2+}$ ), magnesium ( $\text{Mg}^{2+}$ ), and sodium ( $\text{Na}^+$ ), and the anions (negatively charged ions) of bicarbonate ( $\text{HCO}^-$ ), sulfate ( $\text{SO}_4^-$ ), and chloride ( $\text{Cl}^-$ ). The cumulative concentrations of these six key elements generally make up more than 90% of the total dissolved solids in natural water, irrespective of whether the water is dilute or has salinity higher than saltwater.

Human activity changes the concentrations of the dissolved inorganic components. Contributions from artificial sources may boost some of the minor or trace ingredients to concentration levels that are orders of magnitude over the usual values listed in Table 15-1. The word "hardness" has been attributed to the calcium and magnesium present in the water and is of importance in industrial purposes because of the potential of the calcium and magnesium compounds to form scale, particularly when the water is heated.

### Organic Constituents

Organic substances include carbon and generally hydrogen and oxygen as the principal elemental components in their structural framework. By necessity, carbon is the main element. However, the carbonate species—carbonic acid ( $\text{H}_2\text{CO}_3$ ), carbon dioxide ( $\text{CO}_2$ ), bicarbonate ( $\text{HCO}^-$ ), and carbonate ( $\text{CO}_3^{2-}$ ), which are key components in most natural waters—are not categorized as organic elements. Dissolved organic matter is common in natural water, but the concentrations are often modest compared to the inorganic elements. Investigations of soil-contacted water reveal that most dissolved organic molecules in subsurface flow systems are constituted of fulvic and humic acids. The molecular weights of organic compounds found in water may vary from a few thousand to several thousand grams per gram-mole. Carbon is generally roughly half of the formula weight. Analyses of a total organic carbon (TOC) content are becoming a standard feature of water investigations. Concentrations in the range of 0.1 to 10 mg/L are most typical, however in certain regions values are as high as several tens of milligrams per liter. The analysis for specific species is normally not indicated for most treatment applications, but may be essential to fulfill regulatory requirements, especially for potable water services or in circumstances where characterization of the organics is needed for wastewater disposal.

### Dissolved Gases

The most prevalent dissolved gases of water are nitrogen ( $\text{N}_2$ ), oxygen ( $\text{O}_2$ ), carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ), and hydrogen sulfide ( $\text{H}_2\text{S}$ ). The first three make up the earth's atmosphere, and thus, it is not unexpected that they appear in surface water. The gases  $\text{CH}_4$  and  $\text{H}_2\text{S}$  frequently exist in water in large quantities as a consequence of the product of



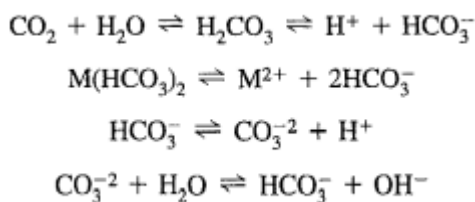
biogeochemical processes that occur in non-aerated surface zones. Dissolved gases may have a substantial impact on the usability of water and, in rare situations, can even cause major difficulties or risks. For example, because of its stench, H<sub>2</sub>S at quantities more than around 1 mg/L makes water unsafe for human consumption. The breakdown of CH<sub>4</sub> may result in buildup of this highly combustible gas in wells or structures and can generate explosion dangers. Gases flowing out of solution might generate bubbles in wells, screens, or pumps, lowering well productivity or efficiency. Radon-222, a common ingredient of water since it is a decay product of radioactive uranium and thorium, prevalent in rock or soil, may build to harmful proportions in unventilated places. Decay products of radon-222 may be dangerous to human health.

### Alkalinity

A fundamental grasp of alkalinity connections is important in the study of water chemistry. The alkalinity of liquid is the ability of the water to take protons. It is a measure of the ability of the water to neutralize acids. The alkalinity of natural waters is attributed mostly to the salts of weak acids. Alkalinity impacts hardness, related ion solubility, and pH. Although numerous bases may contribute towards the alkalinity of a water, in most natural waters the alkalinity is characterized by the following connection:

$$\text{Total alkalinity} = [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}] + [\text{OH}^-] - [\text{H}^+]$$

Bicarbonates (HCO<sub>3</sub><sup>-</sup>) constitute the predominant type of natural alkalinity, since they are generated in substantial proportions by the action of carbonic acid (carbon dioxide + water) against basic minerals in the soil. At low CO<sub>2</sub> content (higher pH), carbonate alkalinity may be found in natural waters. Hydroxide alkalinity is typically not found in natural waters that have not been treated or otherwise changed. Carbon dioxide as well as the three types of alkalinity are all part with one system that is currently in equilibrium, as can be demonstrated by the following equations. The sign  $\rightleftharpoons$  denotes a reversible response. M is a metallic ion.



A change in the concentration of any one component of the system creates a shift in the equilibrium, adjusts the concentration of the other ions, and changes the pH. Conversely, a change in pH alters the connections. The conventional assay for alkalinity is by two-step titration using sulfuric acid.

In the first stage, phenolphthalein indicator transforms the solution from pink to colorless at the end point. In the second phase, methyl orange indicator is added to the first-step liquid as well as the acid titration proceeds until a pink hue appears. At this stage, the pH is roughly 4.5 and all of the alkalinity has been neutralized.

The first end point is marked as the "P" alkalinity and the second end point as the "M" or total minerality. From these data, alkalinity correlations as illustrated in the following table are formed.

Titration Result	Hydroxide (OH <sup>-</sup> ) alk. as CaCO <sub>3</sub>	Carbonate (CO <sub>3</sub> <sup>-2</sup> ) alk. as CaCO <sub>3</sub>	Bicarbonate (HCO <sub>3</sub> <sup>-</sup> ) alk. as CaCO <sub>3</sub>
P = 0	0	0	M
P < ½M	0	2P	M - 2P
P = ½M	0	2P	0
P > ½M	2P - M	2(M - P)	0
P = M	M	0	0

**Water Analysis** Water treatment and water treating equipment deals with the removal or replacement of various suspended and dissolved substances to make the water acceptable for certain usage. Table 15-2 (Betz 1980) provides features and contaminants routinely evaluated in natural waters to estimate treatment needs for industrial usage of the waters. In addition to the therapy modalities listed in above table, more treatment technologies are always being explored. The types and quantities of different dissolved and suspended solids in a water sample are determined by standardized laboratory testing procedures such as those specified in Standard Methods for the Examination of Water and Wastewater. For each ingredient, the findings are presented in units (mg/L, ppm, or gr/gal) of that constituent indicated as ions such as Ca<sup>2+</sup>, Mg<sup>2+</sup>, SO<sub>4</sub><sup>2-</sup>, and Cl<sup>-</sup>, or alternatively stated as hypothetical chemical compounds such as Ca(HCO<sub>3</sub>)<sub>2</sub>, CaSO<sub>4</sub>, MgCl<sub>2</sub>, and NaCl. The ions, radicals, and combinations thereof most commonly involved in water and water treatment concerns, along with their chemical symbols. In many circumstances, water analyses are given in terms of CaCO<sub>3</sub> equivalents. One justification for selecting CaCO<sub>3</sub> as a standard is that it has a molecular weight of 100, simplifying the conversion mathematics. By using the conversion factors provided in Table 15-3, all constituents determined by analysis can easily be converted to CaCO<sub>3</sub> equivalents; for example, Ca concentration × 2.5 = Ca concentration expressed as CaCO<sub>3</sub> equivalents, and Mg concentration × 4.12 = Mg concentration demonstrated as CaCO<sub>3</sub> equivalents. Expression of the analysis in terms of CaCO<sub>3</sub> equivalents is a straightforward technique of validating the analysis for equivalents. In a fully right analysis, the total of the cations should be equal to the sum of the anions when both are written as CaCO<sub>3</sub> equivalents. The following example displays the conversion of a raw water analysis, initially reporting ions as such, to an analysis stated in CaCO<sub>3</sub> equivalents.

### Water Resources Data

Surprisingly, it is sometimes difficult to collect trustworthy water statistics for a specific location. The U.S. Corps of Engineers normally can offer complete flow data on all major and smaller rivers and streams, but quantity data on ground water and quality data for both surface and ground water are usually extremely restricted and sometimes erroneous. Among the sources of data that may have to be explored are the following: U.S. Corps of Engineers; United States Geological Survey; municipal and state geological, health, and water resources departments; Local public utility companies; Adjacent industries; State or local agricultural agencies; Local well drillers; and Environmental but instead pollution control organizations. If time and the scope of the project allow, sampling of surface water sources may be collected and evaluated, or, for potential ground water supplies, test wells sunk and ground water samples collected and analyzed. For surface water, particularly rivers or streams, repeated studies are necessary to identify seasonal and yearly variations. Ground water typically maintains a reasonably steady quality if the aquifer is not overpumped or replenished by a surface water source. When several quality data are provided, the analysis with the greatest total solids content is frequently selected for design. If a typical analysis is needed, it should be an actual analysis that is closest in composition to the average analysis of the supplied data. The use of an arithmetic average of the components for a design analysis should be avoided since it may

not offer the right connection of one element to another, which may negatively affect treatment design considerations.

### **Plant Water Requirements**

Water needs for a fossil-fueled plant cannot be estimated from the size of the plant alone. Water quality, plant location, fuel qualities, steam generator design pressure, and local regulatory requirements may all have a significant influence on the quantity needs. Although a typical power plant has a number of water uses, the principal uses may be grouped for convenience as cooling water, service water, and high-purity water. This section covers various applications and illustrates how to estimate the quantity of water necessary for each usage under varied circumstances.

### **Description of Usage**

Cooling water comprises the water used for condenser cooling in the turbine heat rejection system and for the cooling of auxiliary equipment. The condenser cooling system can be either a once-through system with the discharge returned towards the river or surface impoundment which is serving as the source, a forced circulation cooling system using a wet cooling tower, a closed system employing parched cooling, or a hybrid system using both wet and dry cooling for heat rejection. Once-through systems demand high flow rates but consume relatively modest amounts of cooling water, while cooling tower designs have considerable consumption rates as a consequence of the high evaporation rates but also blowdown requirements. However, once-through cooling from the river is carefully controlled and authorized only in rare circumstances. Dry cooling systems are highly costly and inefficient and are useful only when water is in extremely restricted supply. Consequently, recirculating cooling systems employing a wet cooling tower are most typically employed for main stream cycle heat rejection. A totally closed cooling water system is typically utilized for auxiliary equipment cooling. Service water is utilized for general plant services such as sanitary water, washdowns, ash transport, and flue gas desulfurization (FGD) system makeup, including pump seal water. However, many of these services may utilize recovered wastewater, depending on unique plant water and wastewater management design. A part of the service water is demineralized to provide a high-purity water to be used as cycle makeup, as chemical solution waters, as makeup to the closed auxiliary cooling system, and in the laboratory. System Requirements Proper plant operation reduces maintenance and preserves plant equipment, and necessitates that specific water quality requirements be set. Some of these are required, but most are adaptable. The following is a review of recommended guidelines and the relevance of each.

### **Main Steam Cycle Cooling Water**

For a once through cooling system, it may typically be considered that garbage racks and screens on the suction side of a circulating water pumps properly remove suspended materials from of the cooling water and that extra treatment for suspended solids removal is not necessary. With correct design considerations and materials choices, fluids with up to approximately 50,000 mg/L of total dissolved solids may be employed. Organic debris and microbes in the water provide the main challenge and biological growth is most usually managed by shock chlorination. Mechanical tube cleaning devices may be employed when marine vegetation tends to stick to the tube surface. Since suspended sand and grit may erode tubes, condenser tubes must be protected from erosion by suitable design of the intake structure, suitably low velocities, and selection of condenser tube materials to fit the operating requirements. The pH of once-through cooling water generally fluctuates between roughly 6 and 8.5; pH modification is seldom necessary. Treatment needed for cooling towers may be significantly more sophisticated. The evaporation of water as the cooling flow is recirculated

around the tower results in high concentrations of the dissolved species. As these materials begin to approach solubility limitations and the dissolved solids levels are raised, the potential for deposition, fouling, and corrosion of materials inside the cooling circuit is substantially enhanced. Chemicals are added for biological control and to ameliorate the impacts of the increased solids concentrations, and blowdown is applied to restrict the cooling water cycles of concentration to manage the dissolved solids within established control limits. Blowdown is also utilized to regulate the suspended particles in the circulating water and limit the accumulation of sediments in the cooling tower basin.

Typical control limits routinely applied for a recirculating cooling water system are described, Treatment Applications. The chemical composition of a cooling water is also essential from the aspect of tube material selection.

If the water is of brackish or saltwater quality, copper alloy tubes have historically been utilized; but, in recent years, alternative materials, including such ferritic stainless steels and titanium, have risen in favour. Copper alloy tubes are also satisfactory for use with freshwater, while stainless steel tubes are commonly employed as part of a copper-free condensate feedwater cycle.

### **Auxiliary Cooling Water**

A totally closed loop auxiliary cooling water system is typically recommended for oil coolers, air compressors, bearing water, etc. This facilitates the use of condensate grade water with corrosion inhibitors added for corrosion prevention, which results in extremely low corrosion rates in this system.

The heat in the closed cooling system is normally rejected to the condenser cooling water. If the condenser cooling water is of particularly high quality and low in suspended particles, it is occasionally utilized directly for cooling auxiliary equipment.

### **Service Water**

Service water is used for pump and instruments seal water, hose supply, fire water, demineralizer supply, sanitary water, or makeup to ash and flue gas cleaning systems. Service water should be substantially free of suspended particles, turbidity, and color. The pH will normally be between 6.0 and 8.5, and total dissolved solids ideally confined to fewer than 1,000 mg/L. If the service water is also used for potable water, it must be chlorinated and adhere to appropriate drinking water standards.

Residual chlorine must be limited or eliminated before the water is utilized for demineralizer supply to prevent deteriorating the demineralizer ion exchange resins. Unless a very small supply of potable grade water is required, it is often better to build the service water system to satisfy drinking water requirements.

This prevents duplicate plumbing systems and removes the requirement of marking valves and lines as usable or nonpotable. The water quality criteria for the potable water system are generally determined by regulatory standards. Federal, state, and municipal rules must be explored throughout the design process.

If the service water system provides supplying potable water, it must fulfill these criteria, as well as any more rigorous requirements specified by the end use. If a nonpotable service water system has been utilized, the service water quality standards of each of the end users must be evaluated.

## High-Purity Water

High-purity water is needed for makeup to the condensate-feedwater cycle, as solution water for condensate-feedwater chemicals, and also for different laboratory purposes. The quality of the water needed is governed by the quality necessary inside the condensate-feedwater system to avoid scaling and corrosion and also to prevent carryover of particles with the steam from the steam generator. These water quality requirements are based on the working pressure of the boiler, with a better grade water needed at higher pressures. A once-through cooling system is a basic heat exchanger, and the quantity of cooling water needed can be determined provided the amount of heat to be rejected, the condenser size, and the cooling water temperature are known. For a very rough approximation, a flow of 1,000 gpm (0.063 m<sup>3</sup>/s) per megawatt (MW) of plant electrical output may be utilized for a single-pressure condenser and 750 gpm (0.047 m<sup>3</sup>/s) per MW of plant electrical output for a dual-pressure condenser. With an all-wet, recirculating cooling system employing cooling towers, the water amount is dependent on the water quality and meteorological conditions. The quantity of makeup water is governed by a mass balance that may be stated as follows.

$$\text{Blowdown} = \frac{\text{Evaporation}}{\text{Cycles of concentration} - 1} - \text{Drift}$$

$$\text{Makeup} = \text{Blowdown} + \text{Evaporation} + \text{Drift}$$

Evaporation is the amount of water that enters the atmosphere as a consequence of vaporization produced by the heat. A heat and mass balance, such as that detailed in ASME Technical Paper 69-WA/PWR-3 (Leung and Moore, 1969), may be created for precise determination, but a "order of magnitude" Drift is the water lost when entrained water is transported out with the air. The drift carries the same dissolved solids content as the tower water. Modern cooling tower mist eliminator design decreases drift losses. The drift will typically be 0.005% or less of the circulating water flow. The cycles of concentration are defined as the numerous increases in concentration of dissolved solids inside the circulating water relative to the makeup water. For example, cycles of concentration of 4.0 imply that the dissolved ingredient concentrations in the circulating water are four times more than the concentrations in the makeup water.

In most situations, the limiting elements are calcium, alkalinity, and silica concentration of the circulating water. The total dissolved solids, chloride, and sulfate may also be limiting by presenting a corrosive state, however correct selection of construction components can frequently relieve this issue. Blow down is the water evacuated from the system to manage the concentration of a dissolved solids inside the circulating water. Chemical treatment of the makeup water may lower the calcium and alkalinity concentrations and, in certain situations, the silica. An economic review may be necessary to evaluate whether treatment is reasonable to lower circulation water blow down and makeup water needs. In certain circumstances, if treatment is necessary to remove suspended particulates or excessive iron concentration, calcium alkalinity reduction may be implemented at a very low extra cost. The previous explanation is for turbine condenser cooling exclusively, utilizing a 100% wet system. Usually the circulating water flow is raised by around 10% to accommodate cooling for auxiliary equipment.

In the absence of more specified plant design parameters, service water amounts may be estimated from the following:



General service	1% of maximum steam flow
Potable sanitary	50 gal (189 L) per day per person
Cycle makeup	1.5% of steam flow plus steam soot blowing requirements <sup>2</sup>
FGD system	
Lime	1 gal (3.785 L) per pound (0.45 kg) of lime <sup>3</sup>
Limestone	0.5 gal (1.89 L) per pound (0.45 kg) of limestone <sup>3</sup>
Makeup	Dependent on degree of flue gas saturation <sup>3</sup>
Fire protection	No regular usage

If the water will be chemically pretreated, roughly 5% to 10% should be added to the total for treatment losses, dependent on the kind of pretreatment utilized. The general service water use is mostly for plant wash down and various low-volume usages and is not directly connected to plant load. Potable water use might be based on the typical number of plant staff plus an allowance for visitors and special work teams. The cycle composition amount is based on boiler blow down and evaporative losses plus steam required for soot blowing and fuel oil atomization. Losses due to demineralizer regeneration must be accounted for in the demineralizer design and supply water needs. The cycle composition amount estimate supplied does not include the water needs for chemical cleaning. Flue gas desulfurization (FGD) system specifications should take into account the usage of reclaimed water for satisfying part of the makeup need. Additional service water may be necessary if wet sluicing is employed for bottom ash management. Ash transport system composition is based on recycling as much water as possible and is around 2% of the flow in a 20% by weight ash sluice system. Allowance must be made in water storage and pumping capabilities for fire water needs.

### High-Purity Water

In the context of this discussion, high-purity water is identical with cycle composition. The service water system provides for a quantity equivalent to 1.5% of the steam flow plus soot blowing needs. This is a maximum figure; the actual regular boiler composition in a well-maintained plant should be less than 0.5% plus soot blowing needs. A minor quantity of high-purity water is also needed for makeup towards the closed auxiliary cooling system and for usage in the laboratory; however, these requirements are minimal when evaluating total demand. During preoperational alkaline and acid cleaning of the preboiler and the boiler and in following periodic boiler acid cleanings, there is a short-term requirement for huge quantities of high purity water. This may equate to as much as 500,000 gal (1,890 m<sup>3</sup>) in 1 or 2 days. A considerable amount of such needs must be satisfied from storage or by outside acquisition.

**Water Usage Variations** Except for general service water and potable water, all plant water use should be more or less directly proportionate to unit load. But in real operation, some usages such as the following are not proportionate due of plant operating procedures: Circulating water pumps and ash sluice pumps are typically not throttled with load; flow fluctuations tend to be step changes when the number of pumps in operation are adjusted. Boiler blowdown may be at a constant rate. Circulating water evaporation rate displays substantial variance with climatic conditions. The quality of the raw water may greatly effect water use in the condenser cooling system. The degree of plant wastewater reuse may have a substantial influence on plant water needs. These variances must be addressed in the plant design for all of the factors and situations relevant to that particular design.

**Water Mass Balance** One of the early project design efforts should involve creation of the plant water mass balances. Water mass balances integrate both

water supply and wastewater re use and disposal factors. Water mass balances are generally constructed under varied variables such as operating loads and meteorology, and to suit both design and permitting demands. Plant water mass balances are particularly beneficial for the size of water supply and treatment facilities and are crucial to creating integrated plant municipal wastewater systems. These water mass balances may become complex with the addition of wastewater reuse, particularly for zero discharge design facilities. Development of water mass balances is studied further in Chapter 16, Liquid and Solid Waste Treatment.

### Treatment Processes

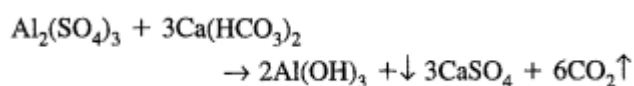
Water treatment procedures vary in complexity from basic sedimentation to multiple-bed ion exchange demineralization. This section outlines several treatment procedures, describes the fundamental chemical and physical reactions involved, and analyzes their relevance to power plants.

### Sedimentation and Clarification

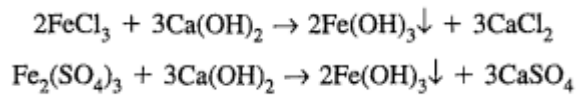
For many power plant purposes, it is essential liquid water be essentially free from suspended particles. This may be done by simple settling (sedimentation) in relatively huge bodies of water, such as lakes or reservoirs that enable extensive detention durations. Comparatively few water consumers, however, have the area necessary for successful settling by such techniques. Moreover, recurrent weather disruptions and organic growths such as algae typically demand supplemental supplies to provide pure water at all times. This has led to the development of equipment that clarifies the water more swiftly and with more certainty of the final result through chemical coagulation and the use of equipment to allow separation and removal of coagulated particles.

### Coagulation

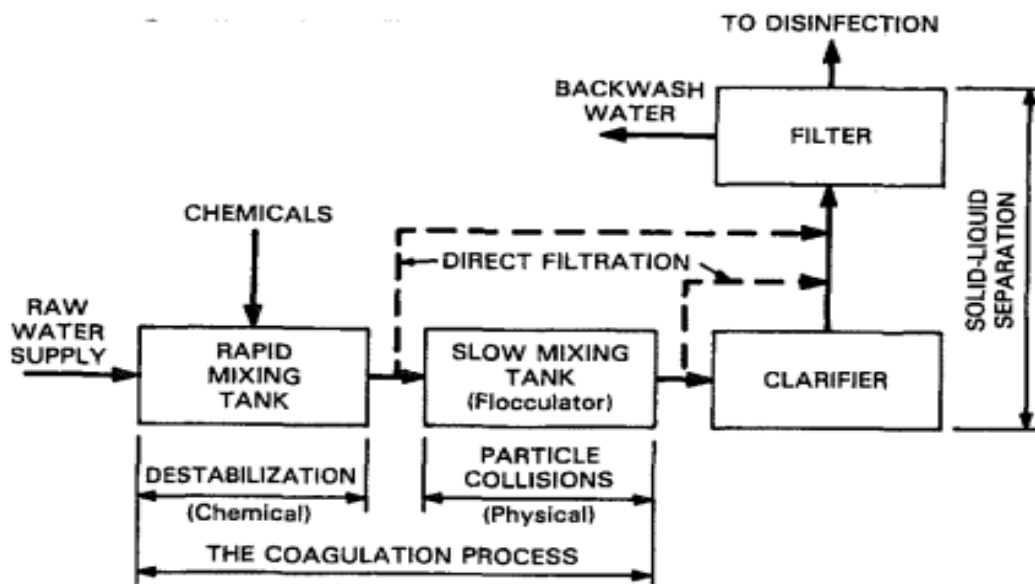
Chemical coagulation is the grouping of suspended materials existing in a finely split or colloidal condition into bigger and more quickly settling particles. To produce such chemical coagulation, different chemicals are utilized, the most frequent being aluminum sulfate,  $Al_2(SO_4)_3$ . Others include sodium aluminate,  $Na_2Al_2O_4$ ; ferrous sulfate,  $FeSO_4$ ; ferric sulfate,  $Fe_2(SO_4)_3$ ; and ferric chloride,  $FeCl_3$ . When ferrous sulfate is employed as a coagulant, oxygen or an oxygen molecule such as chlorine must be present to convert the ferrous salt towards the ferric form. These coagulants generate a jelly-like spongy mass of floe with vast surface area per unit of volume, which entraps and binds together the microscopic particles of silt, organic materials, and even microbes. The bigger precipitate so generated has several times the settling rate of the smaller particles it has ensnared, therefore increasing fine particle separation. In this technique, only suspended particles are impacted; hardness is not eliminated. Alum, as aluminum sulfate is often known, is most effective as a coagulant inside the pH range of 5.7 to 8.0. However, it is commonly utilized well in higher pH levels, particularly in combination with lime softening. Coagulation using alum, ferrous or ferric sulfates, and ferric chloride consumes alkalinity. The alkalinity necessary may be naturally present in the water either bicarbonates or carbonates. When alkalinity is not present in adequate quantity, alkaline substances such as lime  $[Ca(OH)_2]$ , soda ash  $[Na^2O]$ , or caustic soda  $[NaOH]$ , must be added. When sodium aluminate is employed, free carbon dioxide is decreased and alkalinity is enhanced. The breakdown of alum to create gelatinous aluminum hydroxide liberates sulfuric acid which combines with the alkalinity to form  $CaSO_4$ , the whole process being as follows:



The iron coagulants usually function best in the higher pH ranges, where hydroxide is present. Typical coagulation reactions for ferric chloride,  $\text{FeCl}_3$ , and ferric sulfate,  $\text{Fe}_2(\text{SO}_4)_3$ , in lime-treated water are the following:



Activated silica, bentonite clays, powdered activated carbon, and organic polymers (polyelectrolytes) are examples for additives used in the clarifying process to promote suspended solids removal. Clays and activated carbon are weighing agents used to assist the sedimentation process by creating heavier floc particles, therefore enhancing the settling properties of the floc. Coagulant aids, such as polyelectrolytes, are used to further agglomerate the coagulated particles to improve the size, the settling rate, and the stability of floc formed by aluminum or iron coagulants. Polyelectrolytes may be either manufactured or natural and are normally characterized by their charge as either anionic, cationic, or nonionic. To attain their full potential and to be successful, these coagulating agents and coagulant aids must be employed in appropriately built treatment equipment. The apparatus must offer quick and thorough mixing of coagulant and coagulant aid with the water, following gradual stirring to provide particle development, and a zone of quiescence to let coagulated solids to separate from either the water. These tasks may be done in separate phases by the employment of a flash mixing tank, a flocculation tank, and a clarifier unit as illustrated schematically in Figure 11.1; or they may be combined into a single unit, as in a solids contact unit. Figures 15-4 and 15-5 depict some of the numerous kinds of clarifying units often utilized. For most power plant applications, this slurry recirculation type of unit is recommended for the treatment versatility it affords, notably for softening applications.



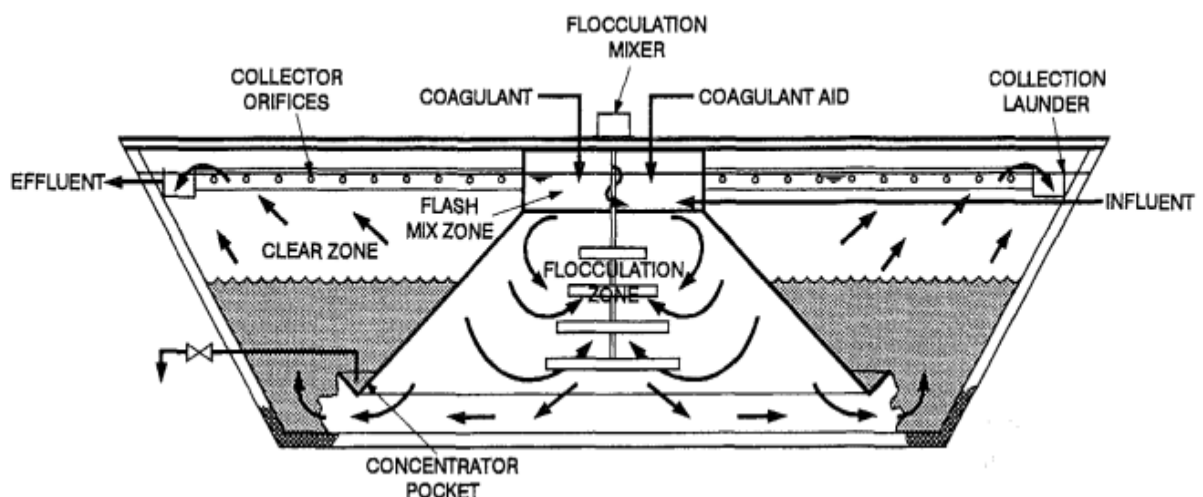
**Figure 11.1:** Illustrates the procedure of coagulation process.

Unlike other forms of chemical reactions in which chemical dosage requirements can be calculated with considerable accuracy, coagulant requirements could always be accurately predicted because of the many variables in water characteristics of that kind as kind and amount of suspended solids, color variations, and similar physical considerations. However, historical experience with comparable applications will typically suffice to establish fundamental design

principles and equipment sizing. Laboratory experiments ("jar tests") done on each water source under consideration are typically advantageous to identify the most efficient and cheap coagulant concentrations.

### Aeration

When used to water treatment, "aeration" is the mixing of air and water so gaseous substances are moved into or out of the water in Figure 11.2. For example, oxygen is introduced to water through aeration for oxidation of the iron, manganese, and to a lesser degree, organic materials in the water. Aeration of water hyper saturated with carbon dioxide, hydrogen sulfide, or other volatile compounds enables the concentration of these chemicals to be lowered to the equilibrium point. Aeration may be done via a number of means. The techniques most typically employed for treatment of fresh water are waterfall aeration and spray aeration. Waterfall aeration is commonly performed by sending water down flow countercurrent to air upflow. The effectiveness of waterfall aeration is enhanced by causing the water to be dispersed into thin sheets or films, increasing the contact duration and the area of water exposed per unit volume of air. Spray aeration consists of spraying water via nozzles to affect contact with the air. Nozzle design and spray pressure are critical elements to optimize the surface area of the water accessible for air interaction. Spray aeration is frequently used in combination with waterfall aeration. A version of the waterfall aerator utilizes a design that provides a jet action effect by discharging the raw water via several distribution orifices into such an aspirating chamber, resulting in an excess of air being sucked into in contact with the water. Another kind of aeration is the bubble or diffusion technique, which may be achieved by pushing air into the water via distribution devices such as perforated pipes or porous plates. This kind of aeration has the potential for great efficiency since bubbles of air rising through the water are repeatedly exposed to new liquid surfaces, maximizing water surface per unit of air. Mechanical aeration may also be employed. One technique includes motor-driven impellers that swirl the surface of the water being treated substantially increase the volume of water exposed to the atmosphere. Another type of mechanical aeration is the employment of a submerged mixer positioned immediately above an air diffuser, which is normally located at the bottom of an aeration tank. Mechanical aerators have perhaps greatest use in the treatment of wastewater. Aeration as a therapy procedure should be reviewed critically to see what can be done and at what expense. The economics of various treatment approaches to reach the same aim should be compared. In general, ground water sources are significantly more prone to be treated by aeration than surface water sources.



**Figure 11.2: Illustrates the water treatment by the aeration method.**

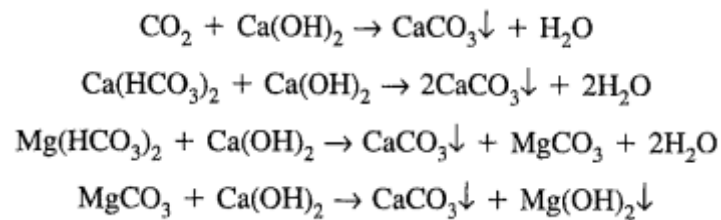
### Softening

Most Ca and Mg compounds create scale or sludge when water is heated or concentrated by evaporation. Because water is widely used as a heat exchange medium, the relevance of Ca and Mg removal for such water usage is clear. Softening of water is indeed the process of lowering or eliminating the Ca and Mg content. This is performed by two fundamental methods—chemical treatment and ion exchange. In chemical treatment softening, the chemicals most commonly employed are lime [in the forms of quicklime, CaO, or hydrated lime, Ca(OH)<sub>2</sub>], soda ash [Na<sub>2</sub>CO<sub>3</sub>], and to a lesser degree, sodium hydroxide [NaOH]. Ion exchange softening employs cation-type resin.

### Lime Softening.

The primary goal of lime softening is to lower the Ca and Mg hardness associated with carbonate and bicarbonate alkalinity. In addition, lime softening eliminates any carbon dioxide dissolved inside the raw water. These decreases may lessen the total dissolved solids as well as the alkalinity of the treated water. The chemical processes involved with lime softening are as follows

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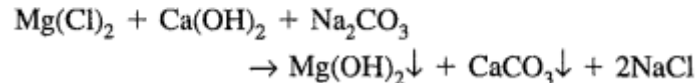
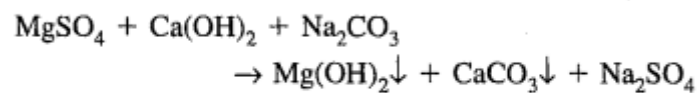
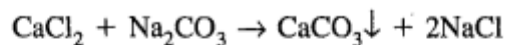
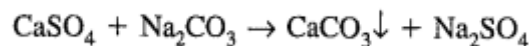
## CHAPTER 12

### SOFTENING OF LIME-SODA ASH

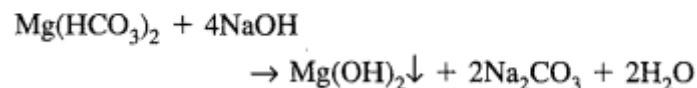
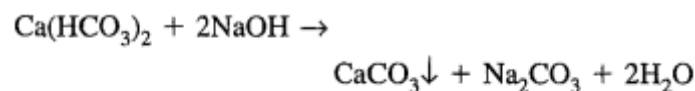
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#### Lime-Soda Ash Softening

When water has less M-alkalinity represented as  $\text{CaCO}_3$  than the total of calcium and magnesium stated as  $\text{CaCO}_3$ , the water includes noncarbonate hardness: calcium and/or magnesium ions even though associated with nonalkalinity anions including such chlorides, sulfates, or nitrates. Noncarbonate hardness is not lowered by lime softening; however, lime-soda ash softening decreases both carbonate and noncarbonate hardness. The following equations illustrate the reactions involved with noncarbonate hardness decrease. Carbonate hardness reduction formulae are as described in the previous section.



It is noted that while removal of noncarbonate hardness can lower calcium and magnesium levels, the impact on total dissolved solids will vary dependent on the original water composition since sodium is being supplied in a quantity corresponding to the noncarbonate hardness being removed. Caustic Soda (NaOH) Softening. Caustic soda is a frequent term for sodium hydroxide (NaOH). Caustic soda softening is a version of the combined lime-soda ash softening treatment procedure. The fundamental responses are as follows:

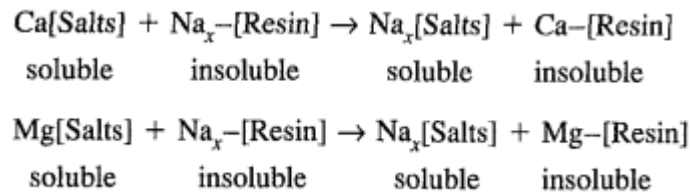


The sodium carbonate generated in the aforesaid reactions is available for additional reaction for noncarbonate hardness removal as described in Eqs. The decision between lime-soda ash softening vs caustic soda softening is mainly based on differential chemical costs against capital expenditures. The capital expenses of the chemical storage and feed equipment for lime-soda ash softening are normally greater. However, it is not unusual for the daily chemical costs of caustic soda softening to be between three and four times greater than the daily chemical

expenses of lime-soda ash softening. The lower the treatment flow rate, the smaller the chemical dose required, the more probable that caustic soda softening is cost efficient.

### Sodium Cycle Ion Exchange.

Sodium cycle ion exchange consists of sending raw water through a sodium ion exchange resin bed which has been replenished with sodium chloride (NaCl). Sodium ion exchange resins were insoluble granular solids that contain sodium radicals in their own morphology structure. These resins exchange sodium ions for something like the calcium and magnesium ions in the solution in contact with them without noticeable changes in their physical appearance and without degradation. The ion exchange softening processes are defined by the following:



### Filtration

Water filtration is the process of removing suspended and colloidal pollutants from the water by passing through a porous material. A bed of granular filter material or media is employed in most power plant operations. A variety of mechanisms are involved in the filtering process. Others of these processes are physical, while some are both chemical and physical. A filter may be described simply as a device consisting of the a tank, a method of maintaining a functioning filter bed inside the tank, sufficient filter medium, and associated piping, valving, and controls. Filters are meant for the following: Gravity flow, with natural head of water well above filter bed and low point of discharge at the filter bottom that provide the pressure differential needed to move the water through the filter bed. Pressure units, where it, as their name implies, are operated on line, under service tension, filtering the water as it flows through the tank on its manner to service or storage. Gravity units are the simplest in design of both the filters, with pressure filters being more advanced in engineering design and function. Filters are classed in a variety of different ways. A frequent categorization is by kind or form of filter medium to be applied, such as sand, anthracite coal, activated carbon, dual- or even multilayered media, diatomaceous earth, fabric, or porous membranes. Another difference is direction of flow—upflow or downflow. Also, they are sometimes described hydraulically as the "slow rate" or "fast rate" kind. Additional topics in this section include filtration categorised as granular media, activated carbon, cartridge, and ultrafiltration.

### Granular Media Filtration.

As the water to be treated is passed through a filter bed of granular media, the suspended particles are collected or held in the voids within the media. The retained suspended solids lower the void volume, which helps remove extra suspended solids but increases the pressure loss across the filter bed. The selection of a granular media filtering system is typically chosen by which filter type delivers the desired performance at the least expense. Table 15-7 includes most of the fundamental variants accessible. The quality of filter effluent water is a result of the filter media type, size, and depth. In general, the finer the filter medium size, the higher the water quality generated, but the head loss rises. The most often used granular filter media are silica sand and anthracite coal. Garnet sand is also utilized as a bottom layer in certain mixed media filter designs. When a single-filter media such as sand or coal is backwashed, the bedding becomes graded with the finest material on top and the coarser material just at bottom.

For a down flow filter, this forces the influent water to touch the finest grained material first. Upflow operation enables the influent water to encounter the coarsest grade material first, resulting in a more equal loading of the whole filter bed and longer service runs. To offer downflow filters a coarse-to-fine graded bed effect comparable to that from upflow filters, dual- or multimedia beds are deployed. Dual-media filters generally consist of silica sand and anthracite coal media. The coal is chosen such that the coarser coal stuff is even less dense than the silica sand. Therefore, following backwashing, the coarser coal medium stays on top of the sand medium. The inclusion of a layer of garnet sand, which is denser than silica sand, offers an even more defined coarse-to-fine flow pattern. The use of dual and triple-media filters often extends run lengths and generates higher quality water than single-medium filters. Filters may be built for either manual or automated operation. Automatic filters get their signal for backwash from controllers operated by pressure difference across the filter bed, by timers, or by turbidity breakthrough calculated by a turbid meter mounted in the filter effluent line.

### **Gravity Filters.**

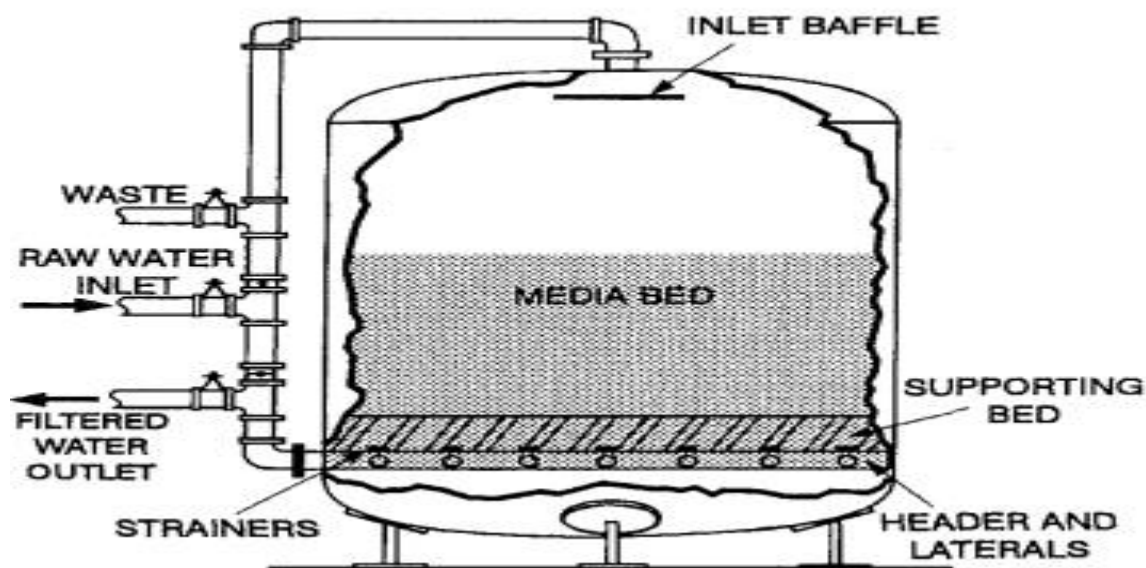
Gravity filters are generally utilised for municipal purposes and for certain industrial applications when significant amounts of filtered water are needed. Public health authorities tend to choose gravity equipment as gravity filters cannot be overloaded as readily as can pressure filters, and gravity filters are open at the top so the operator can watch the filter throughout operation, including backwash. Gravity filters generally utilize 8 to 12 ft (2.4 to 3.7 m) high tanks with obvious preference again for higher shell heights of 10 to 12 ft (3.1 to 3.7 m) to preclude operation of any section of the filter bed under negative head. Negative head operation may have the drawback of releasing dissolved air in the form of bubbles that may build in the filter bed and cause air binding. Gravity filter tanks are composed of steel or concrete. Concrete tanks are normally rectangular; steel tanks are circular or rectangular. Figure 15-6 illustrates a standard rectangular gravity filter. Conventional filter rates are normally 2 to 4 gpm/ft<sup>2</sup> of filter bed cross-sectional area (1.4 to 2.7 L/s per m<sup>2</sup>) with 3 gpm/ft<sup>2</sup> (2.0 L/s per m<sup>2</sup>) being a regularly chosen requirement for power plant service. For potable water delivery, regulatory regulations may define the filtration rate restrictions. The end of gravity filter runs is normally indicated by head loss or pressure loss produced throughout the filter bed, and backwashing is commenced on this basis. Water quality degradation (turbidity breakthrough) may also be employed. After pressure loss is the decisive factor, it is normally recommended that filters be backwashed when the pressure loss builds up to roughly 8 to 10 feet of water (24 to 30 kPa) over the initial pressure difference across the filter at the beginning of the run. Backwash should be enough in amount and duration to provide thorough bed cleaning.

### **Pressure Filters**

Three main kinds of pressure filters are vertical downflow, horizontal downflow, and vertical upflow. Each has its benefits and special strengths for general filtering needs. Vertical and horizontal downflow pressure filter units are the "work horses" of the filtration profession and normally give steady service. In a vertical downflow filter, unfiltered water enters the top of the filter tank and flows downhill into the bed of filter medium, whereupon the suspended matter is removed. The filtered water is collected at the bottom of the tank and given to service. A typical vertical downflow pressure filter is depicted in Fig. 15-7. As the name indicates, a horizontal downflow filter deploys the filter tank inside a horizontal position. Otherwise, the operation of the filter is similar to that of the vertical kind. By employing the filter tank in a horizontal orientation, a greater bed area is achieved, thereby improving the flow rate possible from a given tank size. The horizontal filters are generally 7 to 10 ft (2.1 to 3.1 m) in diameter and are 8 to 30 ft (2.4 to 9.1 m) long.

## Backwashing

Proper filter backwashing is likely the most critical aspect of the filter operating process, because excellent bed cleaning is necessary for consistently successful service cycles. Backwashing should increase the filter bed roughly 20% to 40% in Figure 12.1. The backwash flow rates utilized to produce this expansion vary with temperature; inside the winter when water is colder and more viscous, lower flow velocity elevate the filter beds more efficiently. Surface washers, either one of the rotating design or stationary kind, are utilized in many plants. The jets, pointed at high Fig. 15-7. Typical vertical down flow pressure filter. Velocity down onto to the surface of the filter media, break up hardened mats and assist prevent mud balls from forming up. Rotary washers, to also be appropriately used, need filter designs that minimize area not touched by the jets. With stationary washers, this design factor is of less consequence. Some manufacturers have adopted the use of a separate air distribution manifold in the bottom area of a filter tank to bubble air through a filter bed during in the backwash and bed cleaning process. The utilization of air with water is known as just an air-water system. Air-water systems have been effective for enhancing operations at several facilities. Air-water wash has been most efficiently employed when the amount of precipitate is substantial, and good agitation of the bed is required to remove coatings that have accumulated on the medium.



**Figure 12.1: Illustrates the Proper filter backwashing media bed.**

## Activated Carbon

The usage of activated carbon pressure filters is often indicated when adsorption is needed to remove pollutants such as chlorine, organics, hydrogen sulfide, or components creating tastes and smells. Typical uses for activated carbon filter media for a power plant include potable water polishing filtration to enhance taste and odor and polishing filtration in front of a cycle makeup treatment demineralization equipment to remove chlorine or organics. The relevance of lowering chlorine and organics in the demineralization system influent water is that both these contaminants damage resin performance, reducing ion exchange capacity. Some reverse osmosis membranes are also susceptible to chlorine. It is typically preferable to avoid its use of activated carbon medium for roughing filtering. As the activated carbon medium surface and interior pores are covered with suspended particles, the medium's adsorption capacity and, consequently, its ability to remove pollutants, is diminished dramatically. The activated carbon

medium removal efficiency should be monitored to notice any removal capacity reduction. As a general rule, the activated carbon medium should be changed every 12 to 24 months.

### **Cartridge Filtration**

Cartridge filtration generally employs filter components or cartridges installed in a pressure vessel. The filter cartridges are sheet or wrapped fiber material supported by screens or perforated plate made of stainless steel or plastic. Cartridge filters are mainly confined to polishing service because they clog fast in roughing service as well as the replacement cost is significant. A common use is the nearly full removal of suspended particles in cycle composition demineralizer influent water that has previously been filtered using granular media. Wound cotton or melted blown polypropylene fiber cartridges are suitable candidates for this function. Some of the newest cartridges are being developed with the fiber porosity rated much too tiny. This design delivers greater service life than single-size fiber cartridges.

### **Ultrafiltration.**

Ultrafiltration (UF) is a filtration method where the water being filtered is passed through a molecular sieve-type membrane. UF membranes are extremely comparable to reverse osmosis membranes. One noticeable difference is that reverse osmosis membranes reject the vast majority of dissolved solids. UF membranes reject colloid and high-molecular-weight dissolved organic solids such as humic and fulvic acids, viruses, and bacteria, but do not reject dissolved ionic elements such as calcium, magnesium, sulfate, and chloride. Reverse osmosis membrane components have been employed to make UF membranes. Other polymeric film-forming substances have also been employed. Membrane configurations are comparable as well. Spiral wound, tubular, and hollow fiber UF systems are provided. Pretreatment requirements to decrease suspended particles loading to UF membranes are comparable to those needed for the reverse osmosis membranes.

### **Iron/Manganese Removal**

Iron and manganese occur in nature in both the soluble ( $\text{Fe}^{2+}$  and  $\text{Mn}^{2+}$ ) and comparatively insoluble ( $\text{Fe}^{3+}$  and  $\text{Mn}^{4+}$ ) oxidation forms. The insoluble or precipitated iron and manganese are easily removed like other suspended particles by both clarifying and filtering. Iron and manganese in any oxidation state may get chelated with organic debris, which makes elimination more difficult. The fundamental treatment procedures utilized for iron and manganese removal are oxidation/filtration and chemical precipitation/ filtering, employing combinations of the treatment processes described before. The selection of the fundamental procedure and sequence is depending on the concentrations and characteristics of the iron and manganese pollutants. Ion exchange materials eliminate iron and manganese in the water being treated.

The procedure is confined to handling waters from which air has been removed so that oxidation does not occur. Some oxidized iron and manganese nearly inevitably precipitate, limiting the effectiveness of the ion exchange resin. Specially treated greensand zeolite resin with a manganese dioxide layer may be utilized to remove iron and manganese via oxidation. In this method, the raw water is passed through specific zeolites that are housed in a vessel and work as a filter. The zeolites are renewed using potassium permanganate, which may be given continually to the intake water to maintain the manganese-zeolite continuously regenerated. This technique is restricted by economics to applications where the water use is modest or if the iron and manganese levels are low but basically full removal is needed.

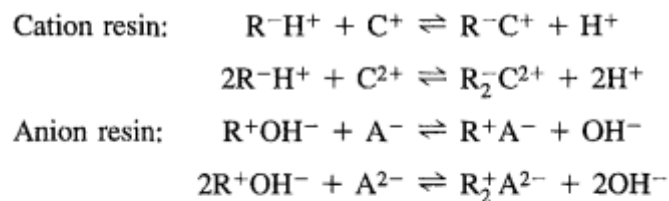


## Demineralization

Demineralization is the elimination of dissolved ionic impurities that are present in water. Demineralized water can commonly be generated by one or a mixture of the following processes: Ion exchange Membrane desalination Thermal desalination. The technique adopted to create demineralized water depends on the quality of the influent water, the desired quality of an effluent water, the availability of resources such as regenerant chemicals, as well as wastewater treatment and disposal needs. The economics of the procedures that generate acceptable effluent quality must be assessed to find the best cost-effective option for a certain application. Makeup water quality Guidelines produced by the Electric Power Research Institute (EPRI 1990) give guidance for evaluating the necessary quality of cycle makeup.

### Ion Exchange Process.

Ion exchange demineralization is one of the most essential and commonly employed procedures for the manufacture of high-purity water for power plant services, and it is performed utilizing resins that exchange one ion for another. Cation resins are solid spherical beads having permanent negatively charged sites but also exchangeable positively charged sites. Anion resins are solid spherical beads which feature permanent positively charged sites and interchangeable negatively charged sites. In its regenerated condition for demineralization application, cation resins are present in the hydrogen form while anion resins are present in the hydroxide form. The interactions of the resin beads with the dissolved contaminants in the water are depicted by the following:



where

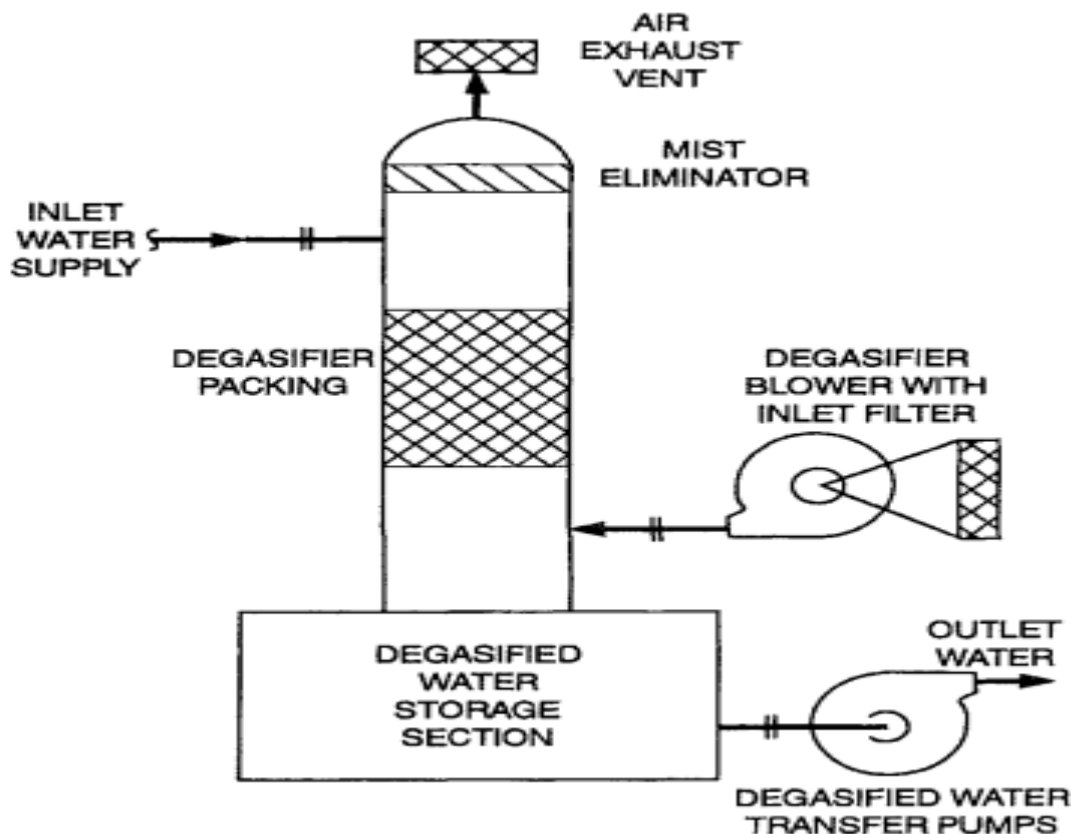
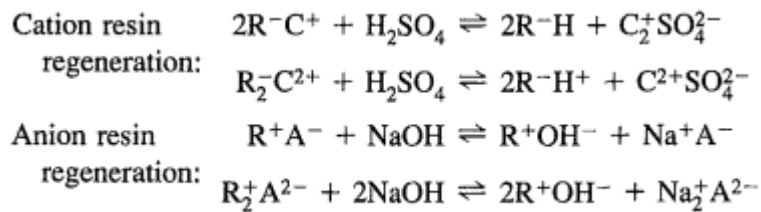
R = resin matrix and fixed charge site;

C = cations such as  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , and  $\text{Na}^+$ ; and

A = anions such as  $\text{HCO}_3^-$ ,  $\text{Cl}^-$ , and  $\text{SO}_4^{2-}$ .

The hydrogen ions ( $\text{H}^+$ ) displaced from the cation resin react with the hydroxide ions ( $\text{OH}^-$ ) displaced from the anion resin. The net effect is that dissolved ions are removed from the water and replaced by pure water ( $\text{H}_2\text{O}$ ). The ion exchange resins are contained in ion exchange pressure vessels. The ion exchange resin in the vessels is referred to as the resin bed. This process of exchanging dissolved impurities is cyclic. When a resin bed site is exchanged with a dissolved ion, the site becomes "exhausted" and cannot remove other impurities without releasing an impurity. Exhausted resins must be regenerated to return the resin beads to the original hydrogen form for cations and hydroxide form for anions before further ion exchange can take place. Cation resins are commonly regenerated with a strong acid solution of either sulfuric or hydrochloric acid. Sulfuric acid does not present the fuming problems associated with concentrated hydrochloric acid and is easier to handle (material Water Treatment 481 selection). Consequently, sulfuric acid is frequently the recommended re-generant for cation resins. Anion resins are commonly regenerated with a sodium hydroxide solution. As can be

seen from the regeneration reactions listed below, regeneration is the reverse reaction to the impurity exchange reactions.



**Figure 12.2:** Illustrates the schematic diagram of Ion Exchange Process.

Dissolved gases such as oxygen or free carbon dioxide are frequently removed via degasification. Oxygen is eliminated through vacuum degasification. Carbon dioxide may be eliminated by either vacuum degasification or forced airflow degasification. A vacuum degasifier is a packed tower in which the is sprayed with water and the gases are evacuated to a low level by main trained a vacuum in the tower. Figure 12.2 is a schematic illustration of a typical two-stage vacuum degasifier.

A forced draft degasifier is a packed towers in which the water is sprayed down the column and the carbon dioxide is extracted by air that is blasted up the column. A typical forced draft degasifier is depicted schematically in Figure 12.3.

Determination of whether a degasifier is to be employed and the kind of degasifier utilized relies on the quantity of CO<sub>2</sub> generated during cation exchange and the different wastewater quality (dissolved oxygen content) needed. For moderate to large amounts of carbon dioxide, it is cheaper to remove the CO<sub>2</sub> through degasification than it is by anion exchange.

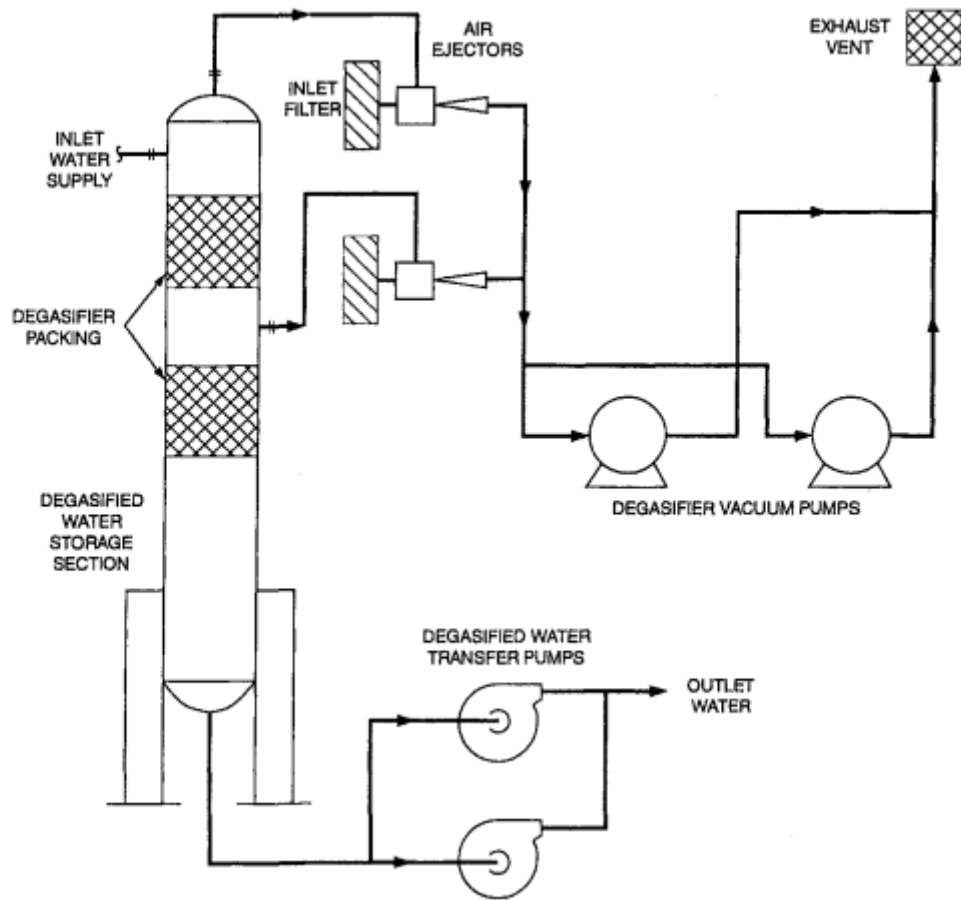


Figure 12.3: Illustrates A typical forced draft degasifier is depicted schematically.

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## Questions for Practice

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1. How to classify the power plant?
2. What are types of sources of energy?
3. What are properties of bio gas?
4. How to identify the economics of issue of wind power system?
5. How to calculate the efficiency of cells?
6. What are differences between the Thermionic Systems and Thennionic Emission?
7. How to differentiate between the ideal and actual efficiency?
8. What is the fly ash conditioning?
9. How to nitrogen oxides emissions control?
10. How to Catalyst Design and Deactivation?
11. What are procedure of Reagent Preparation?
12. How to accomplish Management of Saturated Flue Gas?

## References books for further reading

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1. Power Plant Engineering by Derbal L F and Boston P G
2. Power Plant Performance by Gill A B
3. "Power Plant Engineering by Nag
4. "Power Plant Instrumentation and Control Handbook" by Swapan Basu
5. Power Plant Engineering by Manoj Gupta
6. Power Plant Engineering by Dr S Ramachandran
7. Power Plant Instrumentation by Ponni Bala and krishnaswamy
8. Schaum's Outline of Electrical Power Systems by Syed Nasar
9. A Textbook of Power Plant Engineering by Rajput R K
10. Power Plant Engineering by D K Chavan and G K Pathak
- 11.