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SCHOOL OF ELECTRICAL AND ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION ENGINEERING

UNIT – I – Instrumentation in Industries – SIC1404

I. Overview Description of Industrial Processess

Description of process in Paper Industries Description of process in petrochemical industries: Description of process in iron and steel and mining industries - Description of process in pharmaceutical and nuclear industries

1.1 Description of process in Paper Industries

This section gives an evolutionary introduction about the paper – Papyrus. Written records have been an important part of communication since the beginning of civilization. Our ancestor had tried many things like cloth, wood, leaves, bark, ceramics etc for maintaining the write-ups. For maintaining history people drawn the records on walls, tablets etc which they feels difficult to let somebody make out of it after years. About 5000 years ago, the Egyptians used strips of Papyrus plant found near Nile River to create smooth sheets for writing by macerating the plant into pulp, drying and pressing it whereas Greeks and Romans used waxed tablets. The word '**paper**' is derived from the Greek term called '**papyrus**' which was used by Egyptians.

Tsai Lun, a Chinese, is credited to have invented paper in 105 AD which made it one of the four greatest inventions of the Chinese. He mixed water with pour out of Mulberry or bamboo tree and squeezed them to make a paste and further to obtain sheets of paper. Thus, he improved the technique of making paper and used materials like bark, hemp, rags etc. which were lightweight and easy to make. The **best known paper** was the one that, the **Chinese used for painting and calligraphy** called the **Xuan Paper**. Chinese made few other improvements to techniques of paper making like use of starch and yellow die.

In 6th century AD, paper making began in **Korea** as well. A Korean monk introduced paper making to **Japan** in 610 AD. Paper making got introduced in **the west** in the 8th century and the first paper mill was built in Europe in 1009. The **invention of the printing press** in 1448 by a German called Johannes Gutenberg, led to rapid increase in demand of paper with the advent of books and newspapers. It was in the 19th century though, that paper production became industrialized.

The **paper** available to us **nowadays** is a commodity made of **amalgamated fibers made up of cellulose** held together by hydrogen bonding. Usually the fibers are natural but synthetic fibers are often added to give it desirable physical properties. The common sources of natural fibers are wood pulp from trees, vegetable fibers like cotton, rice, hemp etc. and those of synthetic fibers are polypropylene and polyethylene. Paper has been put to **various applications** like educational, cultural, storage etc. since its invention and is now available in a range of grades. Even though paper can be made from cloth, grass etc., largely paper is made by using natural resources i.e. trees. Paper has **evolved** over the years and is not limited to be used for writing. In fact paperboard, one of the paper products is used to shift more than 90%

manufactured good. It is now one of the essential material in a lot of processes; handling delicate items like bulbs or glasses, storing food products, juices, storing goods etc.

Paper touches nearly every aspect of our lives and life without paper is unimaginable.

1.1.1Traditional Raw Materials

Probably half of the fiber used for paper today comes from wood that has been purposely harvested. The remaining material comes from sawmills, recycled newspaper, some vegetable matters and recycled cloth. Coniferous trees, such as spruce and fir, used to be preferred for papermaking because the cellulose fibers in the pulp of these species are longer, therefore making for stronger paper. These trees are called “softwood” by the paper industry. Deciduous trees (leafy trees such as poplar and elm) are called “hardwood”. Because of increasing demand for paper and improvements in pulp processing technology, almost any species of tree can now be harvested for paper.

Some plants other than trees are suitable for paper making. In areas without significant forests, bamboo has been used for paper pulp, as has straw and sugarcane. Flax, Hemp and jute fibers are commonly used for textiles and rope making, but they can also be used for paper. Some high-grade cigarette paper is made from flax. Cotton and Linen rags are used in fine-grade papers such as letterhead and resume papers and for bank notes and security certificates. The rags are usually cuttings and waste from textile and garment mills.

The rags must be cut and cleaned, boiled and beaten before they can be used by the paper mill. Other materials used in paper manufacture include bleaches and dyes, fillers such as chalk, clay or titanium oxide and sizing such as rosin, gum and starch.

1.1.2 Basic Process Of Paper Making

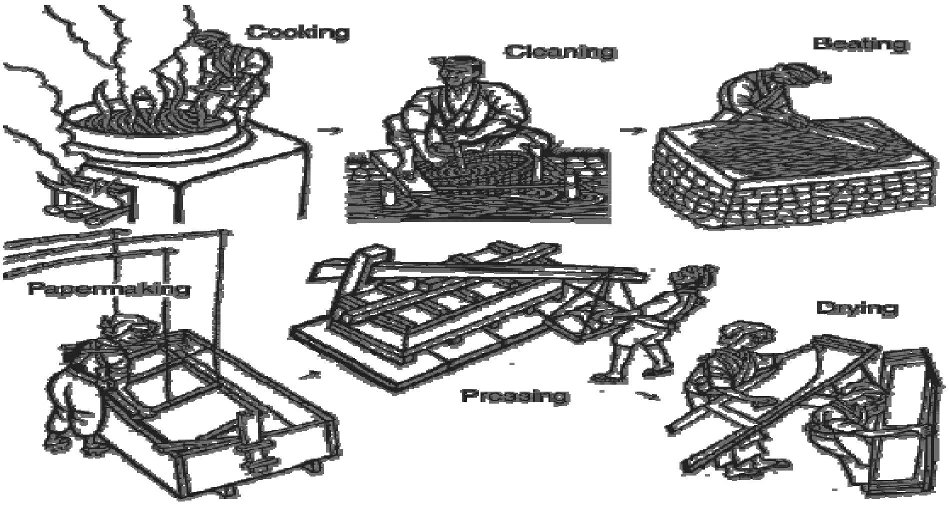

Figure 1.1: Basic process of paper making

The definition of Paper is that of producing a sheet of relative homogenous thickness and surface smoothness from a suspension of fibers in water, by draining, pressing and drying.Archeological inventions depicting that Africans had used 200 – 500 years before Chinese and the Rennet of paper is available at Technical Museum in Munich. The Process for making paper has in its fundamentals had not yet changed, although technological advancements of the highest degree in terms of mechanization and automization have been achieved in the last 150 years. Essentially, Paper is manufactured using the following main operations.

Paper production is basically a two-step process in which a fibrous raw material is first converted into pulp, and then the pulp is converted into paper.

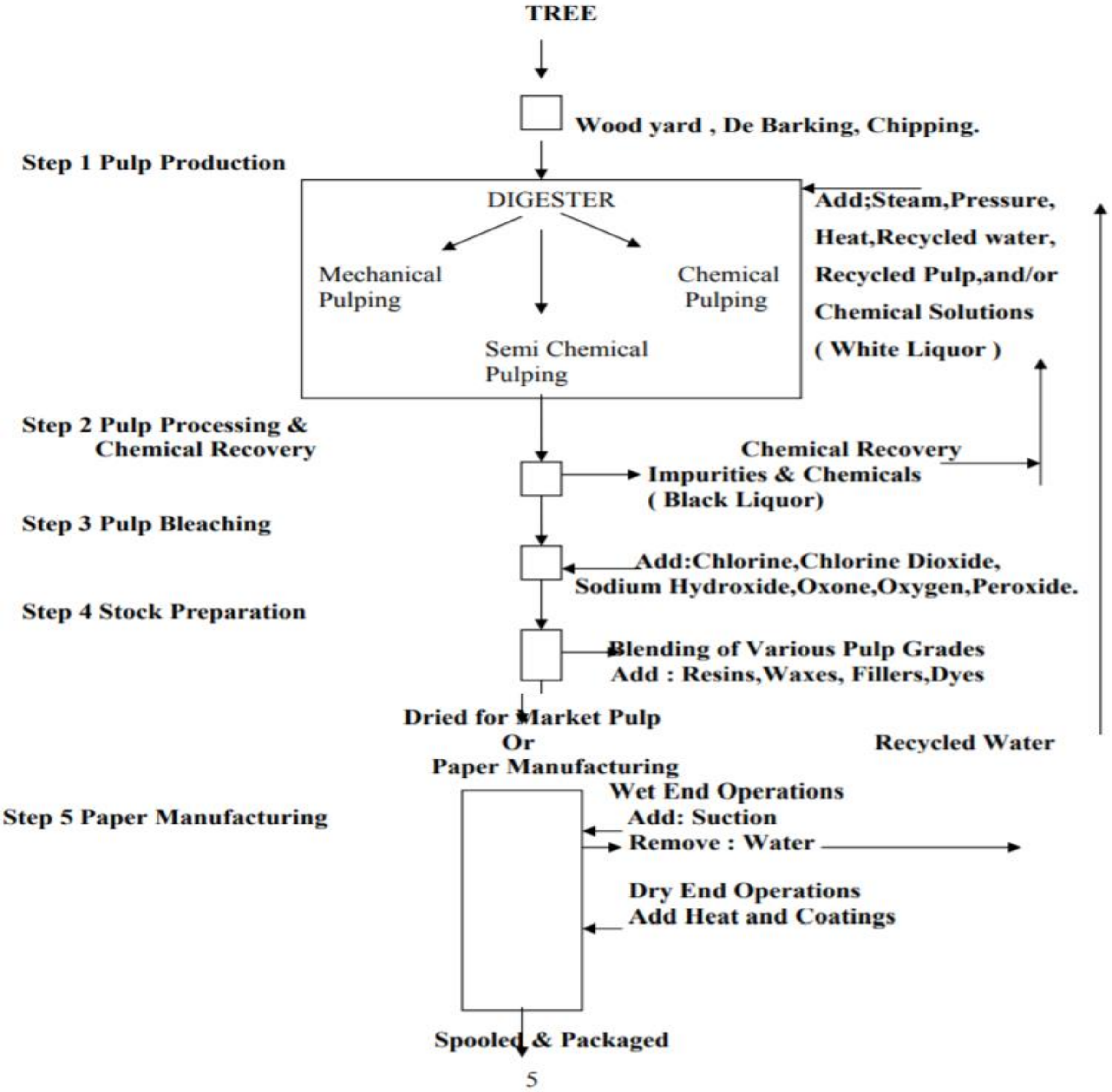

Figure 1.2: flowchart for paper making

1.1.3 Pulp Production

Pulp is a dry fibrous material prepared by chemically or mechanically separating fibres from wood, fiber crops or waste papers. There are several different methods of pulp production to make different strengths and grades of paper.

- **Mechanical Pulping**

Mechanical pulping utilizes steam, pressure, and high temperatures instead of chemicals to tear the fibers. The fiber quality is greatly reduced because mechanical pulping creates short, weak fibers that still contain the lignin that bonds the fibers together. The presence of the lignin limits the amount that the pulp may be bleached because the lignin binds with the bleaching chemicals. Newspaper and paperboards are typical products of the mechanical pulping process. Mechanical pulping requires materials such as 300 series stainless steel to prevent corrosion. Manufactured grindstones with embedded silicon carbide or aluminium oxide can be used to grind small wood logs called "bolts" to make stone ground wood pulp (SGW). If the wood is steamed prior to grinding it is known as pressure ground wood pulp (PGW). Most modern mills use chips rather than logs and ridged metal discs called refiner plates instead of grindstones. If the chips are just ground up with the plates, the pulp is called refiner mechanical pulp (RMP) and if the chips are steamed while being refined the pulp is called thermo mechanical pulp (TMP). Steam treatment significantly reduces the total energy needed to make the pulp and decreases the damage (cutting) to fibers. Mechanical pulps are used for products that require less strength, such as newsprint and paper boards.

- **Semi-Chemical Pulping**

Semi-chemical pulping techniques use weak chemical solutions composed of sodium sulfite (Na2SO3) and sodium carbonate (Na2CO3) to help digest the lignin in the pulp. In addition to the chemical solutions, mechanical refining is used to separate the fibers.

- **Chemical Pulping**

Chemical pulping uses various chemicals to produce long, strong, and stable fibers and to remove the lignin that bonds the fibers together. The chemicals used will vary depending on the type of chemical pulping used. In the United States, there are two main types of chemical pulping performed: Kraft (sulphate) pulping and sulfite pulping. The corrosion rate in these processes can be significant depending on the amount and kind of chemicals and the type of materials used.

Kraft pulping

- Kraft pulping is an alkaline process wherein lignin is removed by the action of sodium hydroxide and sodium sulfide. The pulping digester operates at about 175 °C for 2–5 hours. The presence of sodium sulfide makes bleaching of pulp easier and the paper produced has better strength.

Sulfite pulping

- Sulfite pulping is an acidic process that produces lower yields than the kraft process, and the fibers are also weaker. Its advantage is that a greater percentage of lignin is removed, making the resulting fibers more suitable for high-quality paper .The wood is treated with magnesium bisulfite and excess sulfur dioxide for 6–12 hours at about 175 °C.

1.1.4 Pulp Processing and Chemical Recovery

To further remove impurities and recycle the cooking liquor, also known at this stage as black liquor, the pulp is processed through a series of washes. The removal of the black liquor takes place in washers and is necessary to reduce the chemical costs of the liquor, generate energy from pulp residue burned in the recovery boiler, and prevent the cooking liquor from binding to the bleach chemicals. In addition, by recycling the cooking liquor back into the pulping process, environmental issues and costs are negated since there are no chemicals that must be discharged from the system.

1.1.5 Chemical Recovery Process:

The liquor passes through evaporators, recovery boilers, and causticizers to eventually produce white liquor. The first step of chemical recovery is the evaporation process, which increases the concentration of solids from approximately 15 percent to more than 60 percent. The concentrated slurry contains approximately 50 percent organic solids and 6 percent total sulfur in the form of sodium sulfate (Na_2SO_4) and sodium thiosulfate ($Na_2S_2O_3$) and is placed into a recovery boiler. The organic solids are burned for energy while the inorganic process chemicals, also know as smelt, flow through the floor of the recovery boiler to be recausticized.

- The combustion is carried out such that sodium sulfate is reduced to sodium sulfide by the organic carbon in the mixture:

$$Na_2SO_4 + 2\ C \rightarrow Na_2S + 2\ CO_2$$

- This reaction is similar to Thermo chemical Sulfate Reduction (TSR) in geochemistry.
- The molten salts ("smelt") from the recovery boiler are dissolved in a process water known as "weak wash".
- The resulting solution of sodium carbonate and sodium sulfide is known as "green liquor".
- This liquid is mixed with calcium oxide, which becomes calcium hydroxide in solution, to regenerate the white liquor used in the pulping process through an equilibrium reaction

$$Na_2S + Na_2CO_3 + Ca(OH)_2 \longleftrightarrow Na_2S + 2\ NaOH + CaCO_3$$

Calcium Carbonate precipitates from the white liquor and is recovered and heated in a lime kiln where it is converted to calcium oxide (lime).

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$$CaCO_3 \rightarrow CaO + CO_2$$

- Calcium oxide (lime) is reacted with water to regenerate the calcium hydroxide used in Reaction 2:

$$CaO + H_2O \rightarrow Ca\ (OH)\ _2.$$

- The combination of reactions 1 through 4 form a closed cycle with respect to sodium, sulfur and calcium and is the main concept of the so-called recausticizing process where sodium carbonate is reacted to regenerate sodium hydroxide.
- The recovery boiler also generates high pressure steam which is fed to turbogenerators, reducing the steam pressure for the mill use and generating electricity.
- A modern kraft pulp mill is more than self-sufficient in its electrical generation and normally will provide a net flow of energy to the local electrical grid.
- Additionally, bark and wood residues are often burned in a separate power boiler to generate steam.
- Recausticizing is the process used to transform the inorganic smelt recovered from the recovery boiler into white liquor so that the chemicals may be recycled.
- The recycled inorganic chemicals are discharged as molten smelt from the recovery boiler and then dissolved using water to form green liquor. Any unwanted substances are precipitated out.
- Lime is then added to the clarified green liquor to produce sodium hydroxide (NaOH) from the remaining sodium carbonate (Na_2CO_3). The resulting solution (white liquor)

contains sodium hydroxide, sodium sulfide (Na_2S), and a solid phase of calcium carbonate (lime mud).

- Before the white liquor is recycled back to the digester, the white liquor is clarified further to remove the lime mud.

1.1.6 Pulp Bleaching

Pulp bleaching is performed on the pulp in order to increase its brightness. Bleaching is an extremely corrosive process that is executed under acidic conditions with strong oxidants such as chlorine, chlorine dioxide, sodium hydroxide and hydrogen peroxide. The bleaching process is normally having three to five stages in which the pH of the pulp is alternated between acid and alkaline conditions. During the acid cycle, chemical reactions between the bleach and the lignin bonds turn the pulp lighter in color. During the alkaline cycle, the reaction products from the acid stage are removed.To produce white paper, the pulp is bleached. The chemicals used to bleach pulp must be environment friendly.Bleaching with chlorine produces dioxins and other undesirable products. So, nowadays pulp is bleached with hydrogen peroxide, ozone, chlorine dioxide, oxygen etc.

1.1.7 Stock Preparation

After bleaching, the pulp is processed into (liquid) stock that can be transferred to a paper mill. This processing is performed to get the required paper product and quality specified. It can include blending various pulps together, beating and refining, dispersion in water, and the addition of any wet additives such as resins, waxes, fillers, or dyes for coloring. Many pulp mills have a paper mill adjacent to them; therefore, transferring the products is not costly. The pulp mills, which produce market pulp, dry the pulp and transfer it by truck, train, or ship. The equipment used to store and transport the pulp can undergo crevice corrosion and pitting; therefore, they are usually completely or at least partially clad with Type 304L stainless steel.

1.1.8 Paper Manufacturing

The creation of the paper is performed through wet-end and dry-end operations. Using a paper production machine, the processed pulp is converted into a paper product. Paper machine used to transform processed pulp into paper product. At the beginning of this stage, the water content of the paper is greater than 99 percent. The most common machine utilized is the Fourdrinier paper machine.

1.1.8.1Wet-End Operations

In the wet-end operation, the slurry of pulp is deposited onto a continuously, moving belt that suctions the water from the slurry using gravity, vacuum chambers, and vacuum rolls. The continuous sheet then moves though additional rollers that compress the fibers and remove the residual water.

1.1.8.2 Dry-End Operations

Following the pressing of the wet-end operations, the continuous sheet is compressed by steam-heated rollers to allow the fibers to begin bonding together. Coatings are then applied to add to the surface appearance before the sheet is spooled for storage.

1.1.9 Converting

Calandering is a smoothening process, by which the paper is passed between rolls of alternating material: steel and pressed paper at high pressure. High gloss coated papers are calandered to render them suitable for artistic printing jobs. After leaving the actual paper manufacturing (production) department, the paper reels are cut to sheets, if so ordered, or they are packed directly in a reel packaging machine. In the sheeter, up to 6 reels can be cut simultaneously. Modern sheeters run at quite high speeds and cut at very high precision (size +/-0,2mm). After sheeting, the pallets of paper are normally wrapped with shrinkfoil, which ensures that the paper retains its original moisture. Once the paper is made, a great deal of it is converted into a product. Converters specialize in transforming reels and sheets of paper and board into a vast array of finished products for distribution such as boxes, cartons and stationery. Converters sell their products to the public or to other manufacturers. Not all paper and board is processed by converters. Some papermakers do their own converting, for example, the manufacturers of soft tissues market their own products and sell directly to the public. The printing industry converts large quantities of paper and board, much of which reaches the customer as newspapers, magazines or books.

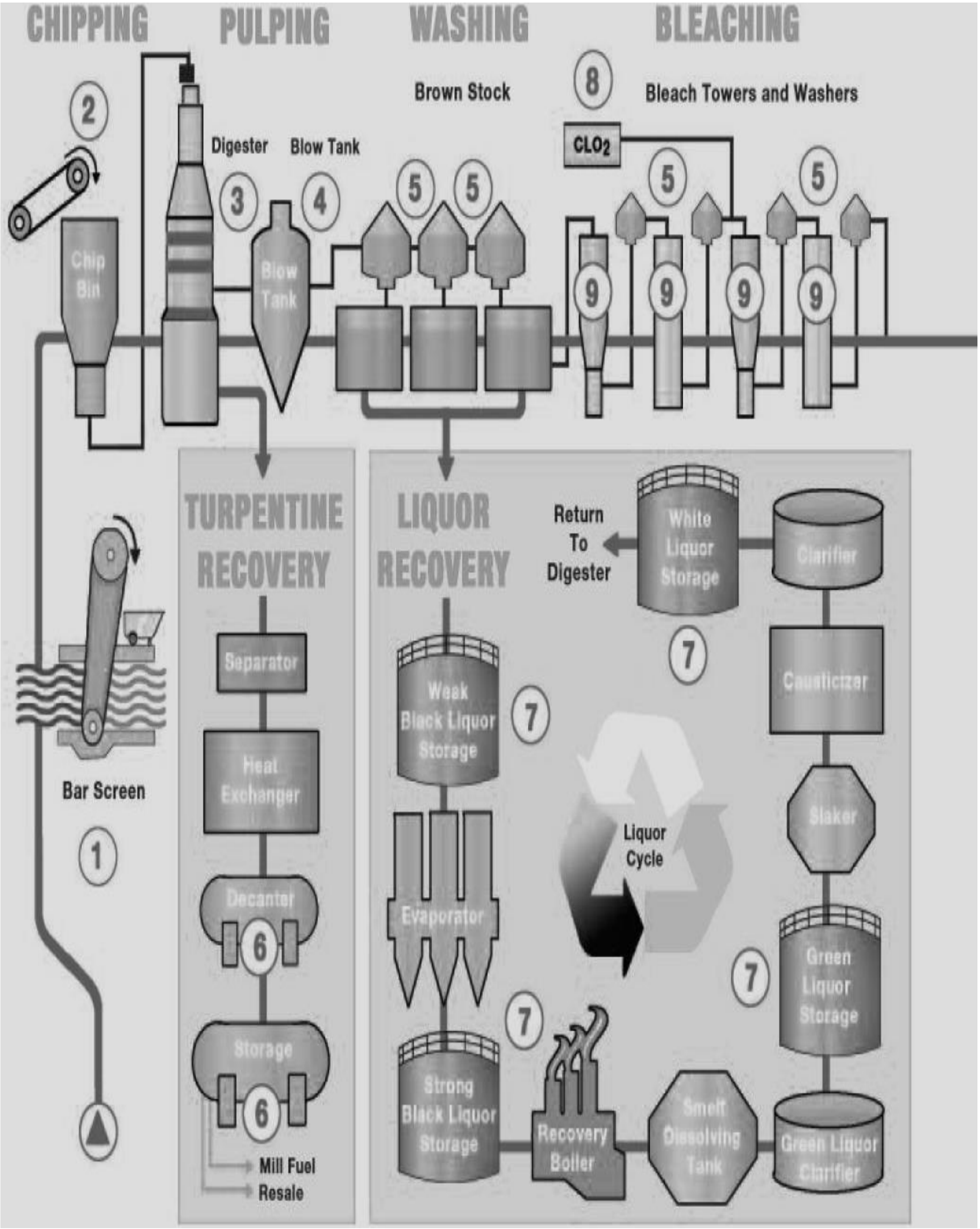


Figure 1.3: Process diagram for paper making

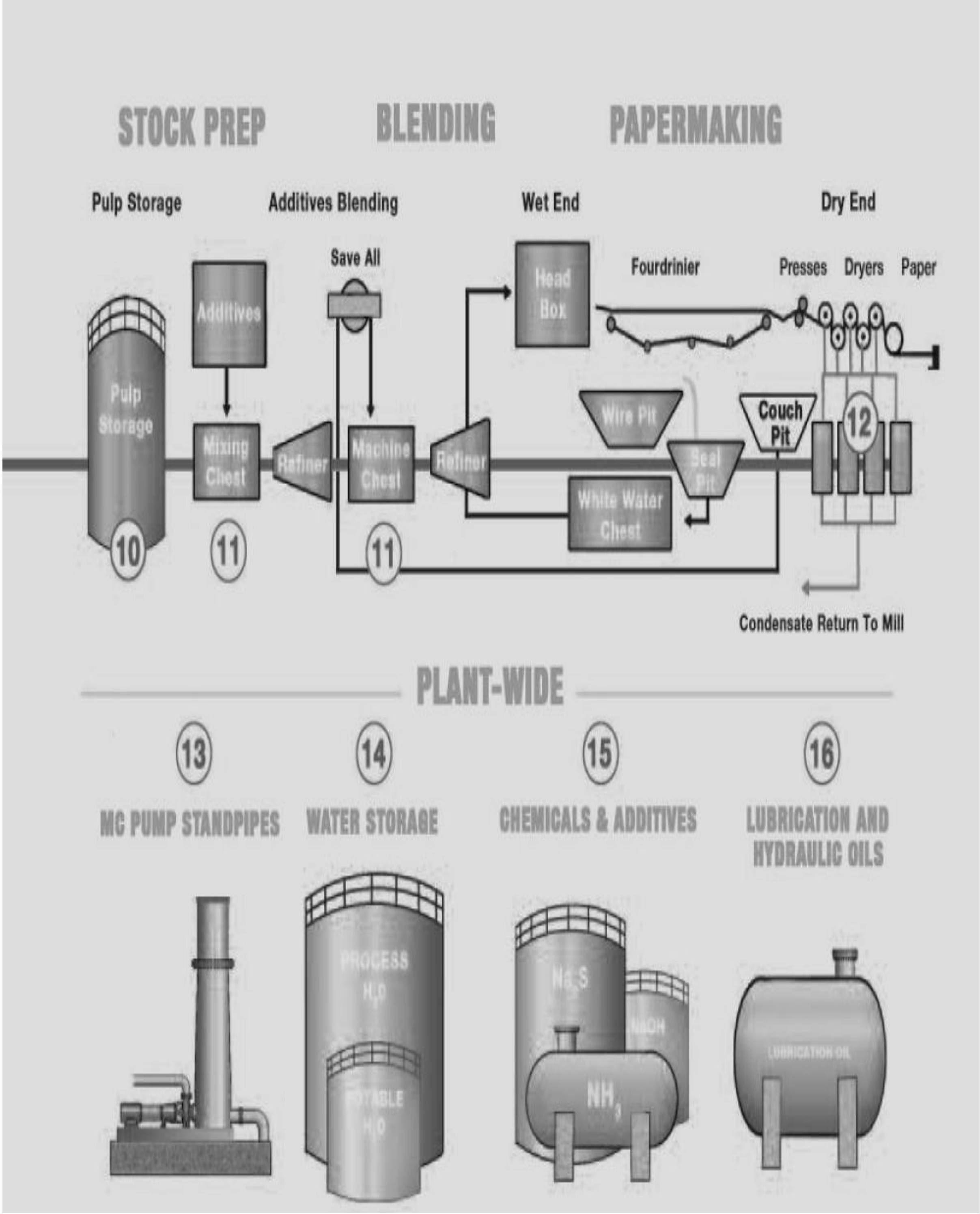


Figure 1.4: Process diagram for paper making

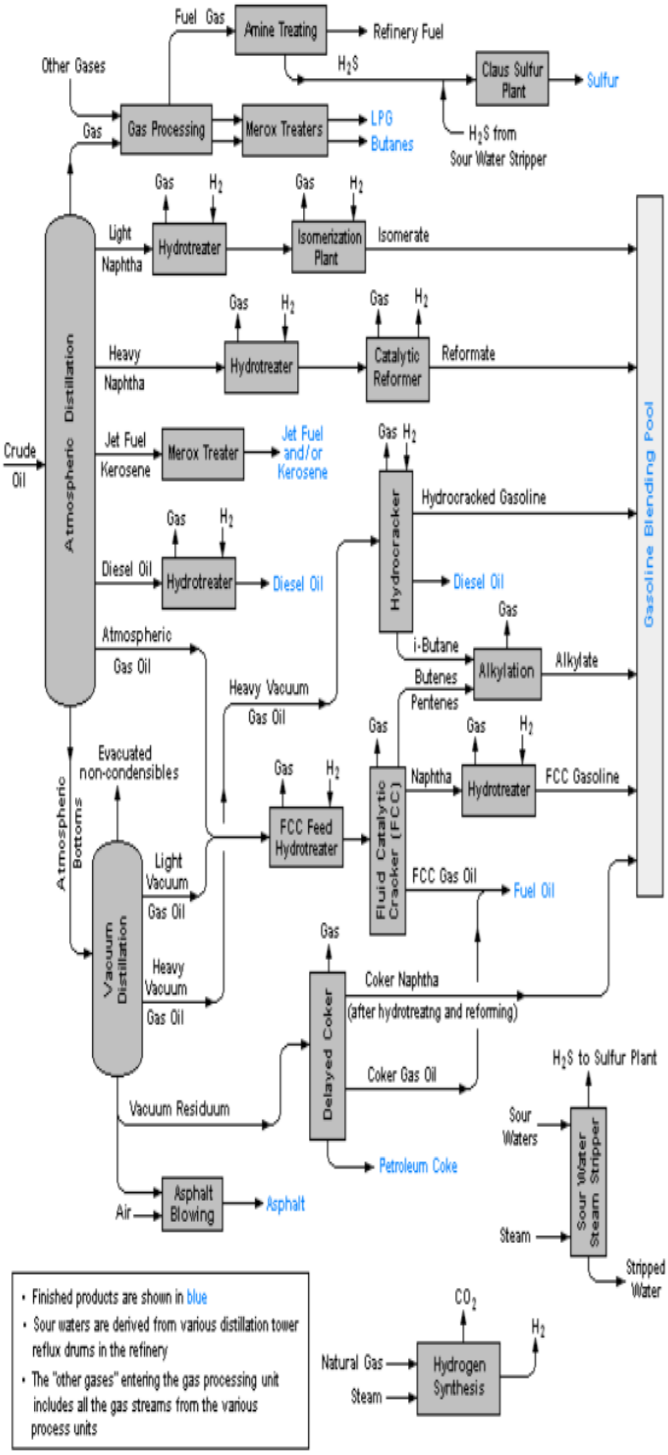
1.2 Description of process in petrochemical industries

- Petroleum refining processes are the chemical engineering processes and other facilities used in petroleum refineries (also referred to as oil refineries) to transform crude oil into useful products such as liquefied petroleum gas (LPG), gasoline or petrol, kerosene, jet fuel, diesel oil and fuel oils etc.
- Crude petroleum is made up of thousands of different chemical substances including gases, liquids& solids ranging from methane to asphalt. Major constituents are hydrocarbons. But there are significant amount of compounds containing Nitrogen (0-0.5%), Sulfur (0-6%) & Oxygen (0-3.5%) **.**
- Petroleum products are usually grouped into three categories: light distillates (LPG, gasoline, naphtha), middle distillates (kerosene, diesel), heavy distillates and residuum (heavy fuel oil, lubricating oils, wax, asphalt). This classification is based on the way crude oil is distilled and separated into fractions (called distillates and residuum).
- Liquified petroleum gas (LPG)
- Gasoline (also known as petrol)
- Naphtha
- Kerosene and related jet aircraft fuels
- Diesel fuel
- Fuel oils
- Lubricating oils
- Paraffin wax
- Asphalt and tar
- Petroleum coke
- The heaviest fractions, including the gas oils and residual oils, are lower in value than some of the lighter fractions, so refiners go through a process called “cracking” to break apart the molecules in these fractions.
- This process can produce some higher-value products from heavier fractions.
- Cracking is most often utilized to produce gasoline and jet fuel from heavy gas oils.
- Reforming is typically utilized on lower-value light fractions, again to produce more gasoline.
- The reforming process involves inducing chemical reactions under pressure to change the composition of the hydrocarbon chain.
- For crude oil to be used effectively by modern industry, it has to be separated into its component parts and have impurities like sulfur removed.
- The most common method of refining crude is the process of fractional distillation.

- Actual refinery operations are very complicated, but the basic functions of the refinery can be broken down into three categories of chemical processes:
- Distillation involves the separation of materials based on differences in their volatility. This is the first and most basic step in the refining process, and is the precursor to cracking and reforming.
- Cracking involves breaking up heavy molecules into lighter (and more valuable) hydrocarbons.
- Reforming involves changing the chemical nature of hydrocarbons to achieve desired physical properties (and also to increase the market value of those chemicals)
- The quantities of the fractions initially produced in an oil refinery don't match up with what is needed by consumers.
- There is not much demand for the longer chain, high molecular weight hydrocarbons, but a large demand for those of lower molecular weight-- for example, petrol.
- A process called cracking is used to produce more of the lower molecular weight hydrocarbons.
- This process breaks up the longer chains into smaller ones. There are many different industrial versions of cracking, but all rely on heating. When heated, the particles move much more quickly, and their rapid movement causes carbon-carbon bonds to break.
- The most effective process in creating lighter alkanes is called catalytic cracking.
- The long carbon bonds are broken by being heated to around 500 degrees Celsius in an oxygen-free environment,.
- A catalyst is a substance that speeds up a reaction or allows it to proceed at a lower temperature than would normally be required.
- During the process, the catalyst, usually in the form of a powder, is treated and reused over and over again.
- Catalytic cracking is the major source of hydrocarbons, with 5 to 10 carbon atoms in the chain.
- The molecules most formed are the smaller alkanes used in petrol, such as propane, butane, pentane, hexane, heptane, and octane, the components of liquid petroleum gas.
- In hydrocracking, crude oil is heated at very high pressure, usually around 5,000 kiloPascals, in the presence of hydrogen, with a metallic catalyst such as platinum, nickel, or palladium.

- This process tends to produce saturated hydrocarbons, such as shorter carbon chain alkanes, because it adds a hydrogen atom to alkanes and aromatic hydrocarbons.
- It is a major source of kerosene jet fuel, gasoline components, and LPG.
- In the coking unit, bitumen is heated and broken down into petrol alkanes and diesel fuel, leaving behind coke, a fused combination of carbon and ash. Coke can be used as a smokeless fuel.
- Reforming involves the breaking of straight chain alkanes into branched alkanes. The branched chain alkanes in the 6 to 10 carbon atom range are preferred as car fuel.
- Smaller hydrocarbons can also be treated to form longer carbon chain molecules in the refinery.
- This is done through the process of catalytic reforming,
- When heat is applied in the presence of a platinum catalyst, short carbon chain hydrocarbons can bind to form aromatics, used in making chemicals.
- A byproduct of the reaction is hydrogen gas, which can be used for hydrocracking.
- Hydrocarbons have an important function in modern society, as fuel, as solvents, and as the building blocks of plastics.
- Crude oil is distilled into its basic components.
- The longer carbon chain hydrocarbons may be cracked to become more valuable, shorter chain hydrocarbons, and short chain molecules can bind to form useful longer chain molecules.
- **Crude Oil Distillation unit**: Distills the incoming crude oil into various fractions for further processing in other units.
- **Vacuum distillation unit**: Further distills the residue oil from the bottom of the crude oil distillation unit. The vacuum distillation is performed at a pressure well below atmospheric pressure.
- **Desalter unit** washes out salt from the crude oil before it enters the atmospheric distillation unit.
- **Atmospheric distillation unit** distills crude oil into fractions.
- **Vacuum distillation unit** further distills residual bottoms after atmospheric distillation.
- **Naphtha hydrotreater unit** uses hydrogen to desulfurize the naphtha fraction from the crude oil distillation or other units within the refinery..Must hydrotreat the naphtha before sending to a Catalytic Reformer unit.
- **Catalytic reformer unit** is used to convert the desulfurized naphtha molecules into higher-octane molecules to produce reformate, which is a component of the end-product gasoline or petrol. An important byproduct of a reformer is hydrogen released

during the catalyst reaction. The hydrogen is used either in the hydrotreaters or the hydrocracker.



A schematic flow diagram of a typical petroleum refinery.

Figure 1.5: Schematic flow diagram of petroleum refinery

- **Distillate hydrotreater unit** desulfurizes distillates (such as diesel) after atmospheric distillation.
- **Fluid catalytic cracker (FCC) unit** upgrades heavier fractions into lighter, more valuable products.
- **Hydrotreater unit** uses hydrogen to upgrade heavier fractions into lighter, more valuable products. This removes sulphur by reacting with hydrogen in a reactor at relatively high temperatures and at moderate pressures.
- **Merox unit** treats LPG, kerosene or jet fuel by oxidizing mercaptans to organic disulfides.
- **Coking units** (delayed coking, fluid coker, and flexicoker) process very heavy residual oils into gasoline and diesel fuel, leaving petroleum coke as a residual product.
- **Alkylation unit** produces high-octane component for gasoline blending.
- **Isomerization unit** converts linear molecules to higher-octane branched molecules for blending into gasoline or feed to alkylation units. Also used to convert linear normal butane into isobutane for use in the alkylation unit.
- **amine gas treater, Claus unit, and tail gas treatment** convert hydrogen sulfide from hydrodesulfurization into elemental sulfur.

Petroleum refineries change crude oil into petroleum products for use as fuels for transportation, heating, paving roads, and generating electricity and as feedstocks for making chemicals.

Refining breaks crude oil down into its various components, which are then selectively reconfigured into new products. Petroleum refineries are complex and expensive industrial facilities. All refineries have three basic steps:

- Separation
- Conversion
- Treatment

1.2.1Separation

Modern separation involves piping crude oil through hot furnaces. The resulting liquids and vapors are discharged into distillation units. All refineries have atmospheric distillation units, while more complex refineries may have vacuum distillation units.

1.2.1.2 Distillation Unit

- A crude oil refinery is a group of industrial facilities that turns crude oil and other inputs into finished petroleum products. A refinery's capacity refers to the maximum amount of crude oil designed to flow into the distillation unit of a refinery, also known as the crude unit.

- Crude oil is made up of a mixture of hydrocarbons, and the distillation process aims to separate this crude oil into broad categories of its component hydrocarbons, or "fractions." Crude oil is first heated and then put into a distillation column, also known as a still, where different products boil off and are recovered at different temperatures.
- Lighter products, such as butane and other liquid petroleum gases (LPG), gasoline blending components, and naphtha, are recovered at the lowest temperatures. Mid-range products include jet fuel, kerosene, and distillates (such as home heating oil and diesel fuel). The heaviest products such as residual fuel oil are recovered at temperatures sometimes over 1,000 degrees Fahrenheit.

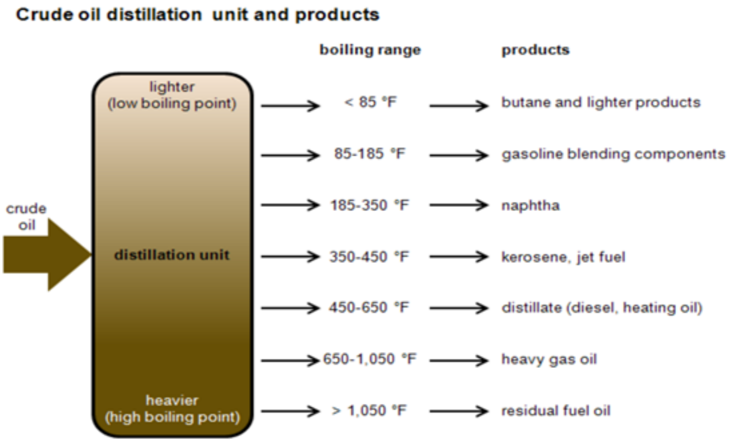


Figure 1.6: Distillation unit of petroleum refinery

- Inside the distillation units, the liquids and vapors separate into petroleum components called fractions according to their boiling points. Heavy fractions are on the bottom and light fractions are on the top.
- The lightest fractions, including gasoline and liquefied refinery gases, vaporize and rise to the top of the distillation tower, where they condense back to liquids.
- Medium weight liquids, including kerosene and distillates, stay in the middle of the distillation tower.
- Heavier liquids, called gas oils, separate lower down in the distillation tower, while the heaviest fractions with the highest boiling points settle at the bottom of the tower.

1.2.1.2Vacuum Distillation Unit

- About 80% of the refineries operating have a vacuum distillation unit (VDU), a secondary processing unit consisting of vacuum distillation columns.

- Vacuum distillation is a part of the refining process that helps to produce petroleum products out of the heavier oils left over from atmospheric distillation.
- As the name vacuum distillation implies, the distillation column is under a vacuum, or significantly less than atmospheric pressure of 760 millimeters of mercury (mmHg).
- At low pressures, the boiling point of the ADU bottoms is low enough that lighter products can vaporize without cracking, or degrading, the oil.
- Vacuum distillation produces several types of gas oil.
- These are slightly heavier than middle distillates such as jet fuel, kerosene, and diesel.
- In the next stage of refining, these gas oils are further refined to make products such as light-cycle oil (a type of distillate), gasoline, and naphtha.

Figure 1.7: Distillation unit

1.2.2 Conversion

- After distillation, heavy, lower-value distillation fractions can be processed further into lighter, higher-value products such as gasoline.
- This is where fractions from the distillation units are transformed into streams (intermediate components) that eventually become finished products.
- The most widely used conversion method is called cracking because it uses heat, pressure, catalysts, and sometimes hydrogen to crack heavy hydrocarbon molecules into lighter ones.

- A cracking unit consists of one or more tall, thick-walled, rocket-shaped reactors and a network of furnaces, heat exchangers, and other vessels.
- Complex refineries may have one or more types of crackers, including fluid catalytic cracking units and hydrocracking/hydrocracker units.

1.3 Description of process in iron and steel industries

- Iron is most widely found in the crust of the earth, in the form of various minerals (oxides, hydrated ores, carbonates, sulphides, silicates and so on).
- Since prehistoric times, humans have learned to prepare and process these minerals by various washing, crushing and screening operations, by separating the gangue, calcining, sintering and pelletizing, in order to render the ores smeltable and to obtain iron and steel.
- In historic times, a prosperous iron industry developed in many countries, based on local supplies of ore and the proximity of forests to supply the charcoal for fuel**.**

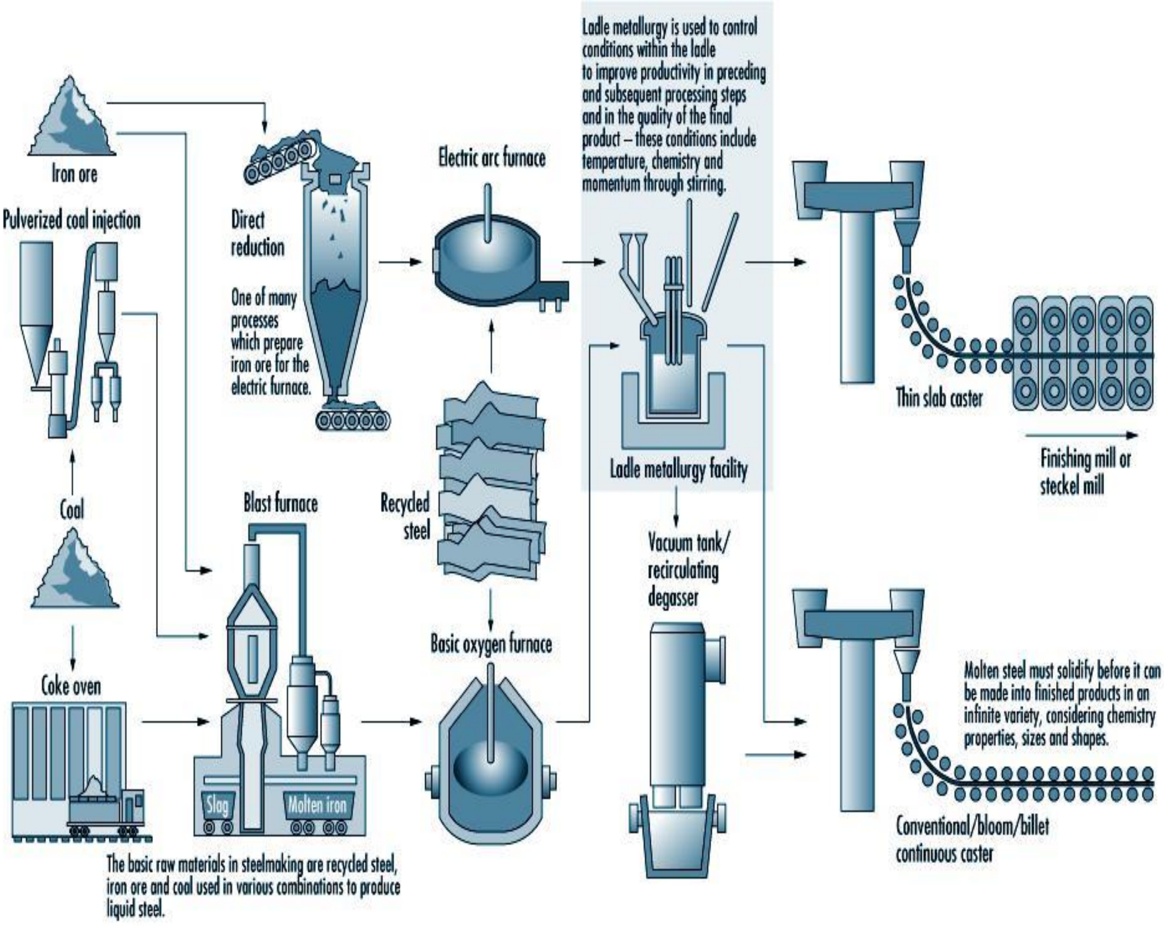
1.3.1 Raw materials for iron & steel making

- Iron ore, coal and fluxes(limestone,dolomite)
- Heating coal to high temperatures in the absence of air; the organic molecules decompose to form gases and organic compunds of a lower molecular weight, leaving a residue of coke which generally has a carbon content of more than 90%.
- The ores used in making iron and steel are iron oxides, which are compounds of iron and oxygen.
- The major iron oxide ores are hematite, which is the most plentiful, limonite, also called brown ore, taconite, and magnetite, a black ore.
- Magnetite is named for its magnetic property and has the highest iron content.
- Taconite, named for the Taconic Mountains in the northeastern United States, is a low-grade, but important ore, which contains both magnetite and hematite.
- The three raw materials used in making pig iron (which is the raw material needed to make steel) are the processed iron ore, coke (residue left after heating coal in the absence of air, generally containing up to 90% carbon) and limestone (CaCO3) or burnt lime (CaO), which are added to the blast furnace at intervals, making the process continuous.
- The limestone or burnt lime is used as a fluxing material that forms a slag on top of the liquid metal.
- This has an oxidizing effect on the liquid metal underneath which helps to remove impurities.

- Approximately two tons of ore, one ton of coke, and a half ton of limestone are required to produce one ton of iron.

There are essentially 3 steps to steelmaking-

- Ironmaking Process
- Steelmaking Process
- Continuous Casting Process



Ladle metallurgy is used to control conditions within the ladle to improve productivity in preceding and subsequent processing steps and in the quality of the final product – these conditions include temperature, chemistry and momentum through stirring.

The basic raw materials in steelmaking are recycled steel, iron ore and coal used in various combinations to produce liquid steel.

Molten steel must solidify before it can be made into finished products in an infinite variety, considering chemistry properties, sizes and shapes.

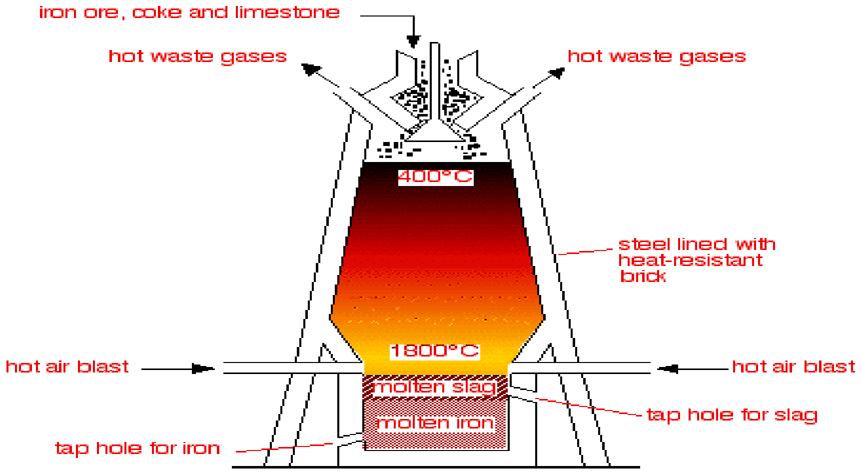
Source: American Iron and Steel Institute.

Figure :1.8 Flow diagram of process of iron & steel industry

1.3.2 Ironmaking Process

- For iron making, the essential feature is the blast furnace, where iron ore is melted (reduced) to produce pig iron.

- The furnace is charged from the top with iron ore, coke and limestone; hot air, frequently enriched with oxygen, is blown in from the bottom through the pipes called as tuyeres;
- The Coke burns to increase the temperature in the Furnace
- the carbon monoxide produced from the coke transforms the iron ore into pig iron containing carbon.
- The limestone acts as a flux.
- The Limestone attracts the impurities in the Iron Ore and forms Slag. This Slag is lighter than the molten Iron and so floats on top of it.
- At a temperature of 1,600°C the pig iron melts and collects at the bottom of the furnace, and the limestone combines with the earth to form slag.
- The furnace is tapped (i.e., the pig iron is removed) periodically, and the pig iron may then be poured into pigs for later use (e.g., in foundries), or into ladles where it is transferred, still molten, to the steel-making plant.
- Some large plants have coke ovens on the same site.
- The iron ores are generally subjected to special preparatory processes before being charged into the blast furnace (washing, reduction to ideal lump size by crushing and screening, separation of fine ore for sintering and pelletizing, mechanized sorting to separate the gangue, calcining, sintering and pelletizing).
- The slag that is removed from the furnace may be converted on the premises for other uses, in particular for making cement.
- Slag is the less dense material and it floats on the surface of the iron.



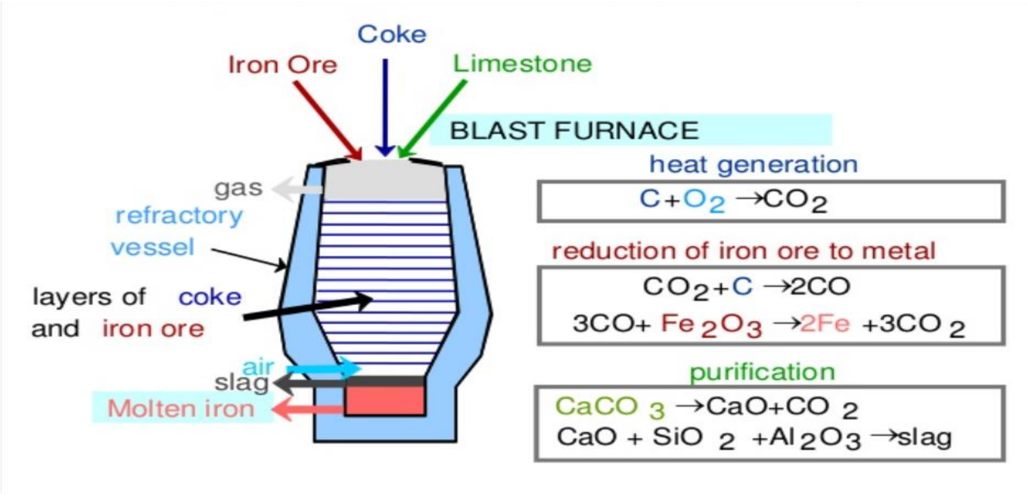


Figure 1.9 Blast furnace

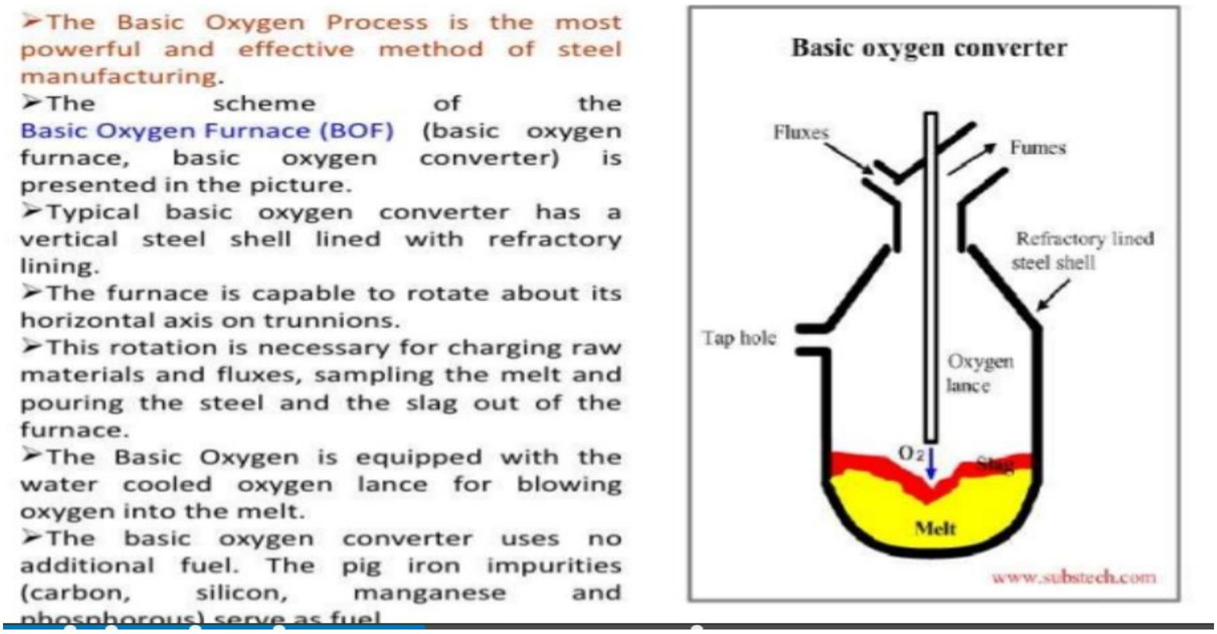
1.3.3 Stoves

- The hot blast air is produced by passing cold blast air through preheated chambers or ‘stoves’, and heating the air to above 1000°C.
- The stove is first heated up by burning gas and combustion air within the chamber and allowing the heat to be absorbed into the brickwork, or ‘chequerwork’.
- This mode is calledon-gas.
- When sufficient heat has been absorbed, the stove is put on-blast.
- In this mode, no combustion takes place, but cold blast air is forced through the stove and absorbs the heat to become hot blast.
- This is then mixed with cold blast to bring it to the right temperature, and is then forced into the blast furnace via the tuyeres near its base
- It is quite common to have three or four stoves, so that at any time one stove is on-blast while the others are on-gas or boxed. A boxed stove has been heated up to temperature and sealed, so that it is ready to go on-blast. If one stove is down for repair, it is possible to run on just two stoves.

1.3.4 Steel making

- Pig iron contains large amounts of carbon as well as other impurities (mainly sulphur and phosphorus).
- It must, therefore, be refined.
- The carbon content must be reduced, the impurities oxidized and removed, and the iron converted into a highly elastic metal which can be forged and fabricated.

- This is the purpose of the steel-making operations. There are three types of steel-making furnaces: the open-hearth furnace, the basic-oxygen process converter and the electric arc furnace.



➢The Basic Oxygen Process is the most powerful and effective method of steel manufacturing.

➢The scheme of the Basic Oxygen Furnace (BOF) (basic oxygen furnace, basic oxygen converter) is presented in the picture.

➢Typical basic oxygen converter has a vertical steel shell lined with refractory lining.

➢The furnace is capable to rotate about its horizontal axis on trunnions.

➢This rotation is necessary for charging raw materials and fluxes, sampling the melt and pouring the steel and the slag out of the furnace.

➢The Basic Oxygen is equipped with the water cooled oxygen lance for blowing oxygen into the melt.

➢The basic oxygen converter uses no additional fuel. The pig iron impurities (carbon, silicon, manganese and phosphorous) serve as fuel

Basic oxygen converter

- The oxygen steelmaking process converts the molten iron from the blast furnace - with up to 30% steel scrap - into refined steel. High purity oxygen is blown through the molten bath to lower carbon, silicon, manganese, and phosphorous content of the iron, while various fluxes are used to reduce the sulfur and phosphorous levels.

- The impurities and a small amount of oxidized iron are carried off in the molten slag that floats on the surface of the hot metal.

Scrap Charging

- The first step for making a heat of steel in a BOF is to tilt the furnace and charge it with scrap. The furnaces are mounted on trunnions and can be rotated through a full circle.

Molten Iron Charging

- Hot metal from the blast furnace accounts for up to 80% of the metallic charge and is poured from a ladle into the top of the tilted furnace.

Furnace Operation

- The charged furnace is returned to an upright position and a water cooled oxygen lance is lowered from the top; oxygen is blown into the bath at supersonic speeds causing rapid mixing and heat from the oxidation of iron and impurities. Fluxes (burnt lime, burnt dolomite, and fluorspar) are added to help carry off the impurities in the floating slag layer. This step requires only about 15 minutes of an overall 45 minute tap to tap cycle time.

Tapping

- After the steel has been refined, the furnace is tilted (opposite to the charging side) and molten steel is poured out into a preheated ladle. Alloys are added to the ladle during the pour to give the steel the precise composition desired. In some steelmaking applications, further refining is conducted in the ladle to remove oxygen and sulfur from the molten steel.

❖ **Operation over-view of Basic Oxygen Process:**

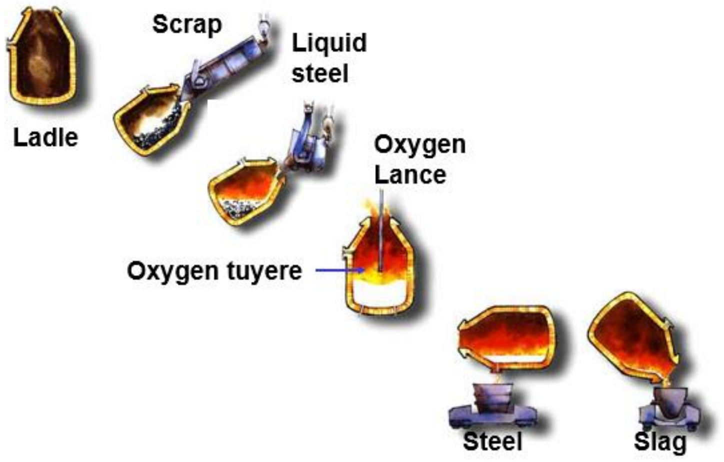


Figure 1.10 Overview of basic oxygen process

1.3.5 Electric arc furnaces

- An electric arc furnace (EAF) is a furnace that heats charged material by means of an electric arc.
- The charged material is directly exposed to an electric arc and the current in the furnace terminals passes through the charged material.
- Electric arc furnaces (EAF) are used to produce carbon and alloy steels. The input material to an EAF is typically 100 percent scrap.
- Cylindrical, refractory lined EAFs are equipped with carbon electrodes to be raised or lowered through the furnace roof.
- With electrodes retracted, the furnace roof can be rotated aside to permit the charge of scrap steel by overhead crane.
- Alloying agents and fluxing materials usually are added through the doors on the side of the furnace.
- Electric current of the opposite polarity electrodes generates heat between the electrodes and through the scrap.

- After melting and refining periods, the slag and steel are poured from the furnace by tilting.
- The production of steel in an EAF is a batch process.
- Cycles, or "heats", range from about 1-1/2 to 5 hours to produce carbon steel and from 5 to 10 hours or more to produce alloy steel.
- Scrap steel is charged to begin a cycle, and alloying agents and slag materials are added for refining.
- Stages of each cycle normally are charging and melting operations, refining (which usually includes oxygen blowing), and tapping.

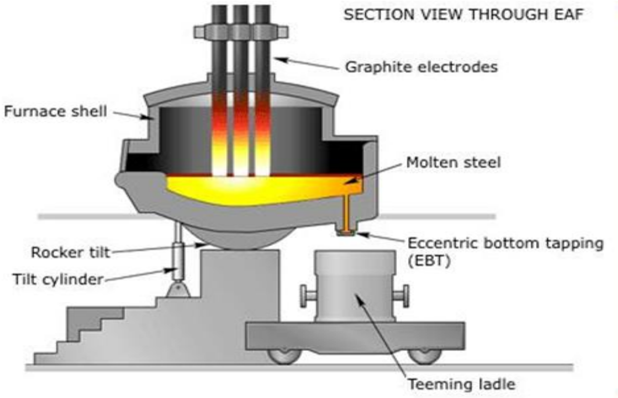


Figure 1.11 Blast furnace

1.3.6 Open Hearth Furnaces

- The open hearth furnace (OHF) is a shallow, refractory-lined basin in which scrap and molten iron are melted and refined into steel.
- Scrap is charged to the furnace through doors in the furnace front.
- Hot metal from the blast furnace is added by pouring from a ladle through a trough positioned in the door.
- The mixture of scrap and hot metal can vary from all scrap to all hot metal, but a half and-half mixture is most common.
- Melting heat is provided by gas burners above and at the side of the furnace.
- Refining is accomplished by the oxidation of carbon in the metal and the formation of a limestone slag to remove impurities.
- Most furnaces are equipped with oxygen lances to speed up melting and refining.

- The steel product is tapped by opening a hole in the base of the furnace with an explosive charge.
- The open hearth steelmaking process with oxygen lancing normally requires from 4 to 10 hours for each heat.

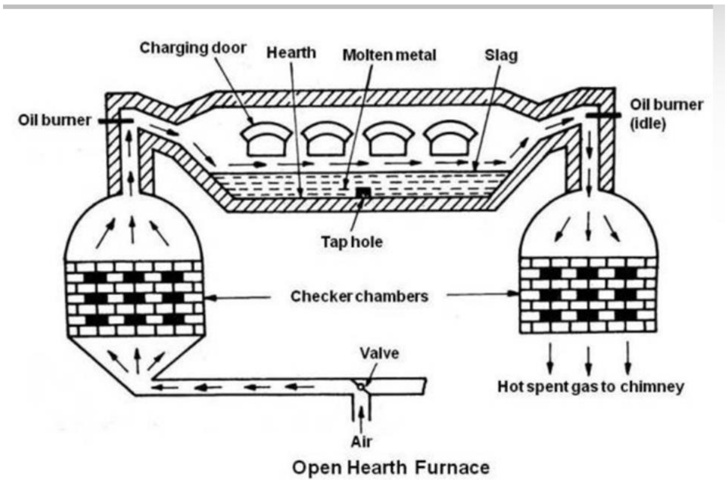


Figure 1.12 Open Hearth furnace

1.3.7 Ladle metallurgy

- To adjust the final chemical composition and temperature of the steel after tapping.
- Apart from primary steelmaking process, there is secondary steelmaking process commonly performed in ladles.
- This is this method is often called as ladle (metallurgy). There are a few operations conducted in ladles include de-oxidation (or “killing”).
- There are alloy addition, inclusion chemistry modification, inclusion removal, homogenisation, vacuum degassing, and de-sulphurisation.
- Exposing steel to vacuum conditions has a profound effect on all metallurgical reactions involving gases. First, it lowers the level of gases dissolved in liquid steel.

1.3.8 Continuous casting

- Continuous casting, also called strand casting, is the process whereby molten metal is solidified into a "semifinished" billet, bloom, or slab for subsequent rolling in the finishing mills.
- The molten metal is then allowed to solidify until it becomes a semi-finished slab that is later rolled in the finishing mill.
- The basic principle of the continuous casting process is that the steel is shaped while it is still largely liquid, with only the exterior solidified. When it is in this form, a steel shell filled with molten steel, it is referred to as a strand

- It is used to cast metals of uninterrupted lengths.
- In this process, the molten metal is continuously supplied to the mold.
- The mold has an indeterminate length.
- When the molten metal is cast through a mold, it keeps travelling downward increasing in its length as the time passes by.
- The molten metal is continuously passed through the mold, at the same rate to match the solidifying casting.
- This results in casting of long strands of metal.
- The solidification rate of the molten metal is also ten times faster than the solidification of the metal in ingot casting method.
- The metal is first liquefied and poured into a tundish, which is a container that leads to the mold that will cast the steel.
- The tundish is placed about 80-90 feet above the ground level and the whole process of casting sues gravity to operate.
- The tundish is constantly supplied with molten steel to keep the process going.
- The whole process is controlled to ensure there is smooth flow of molten steel through tundish.
- Further, the impurities and slag are filtered in tundish before they move into the mold
- The entrance of the mold is filled with inert gases to prevent reaction of molten steel with the gases in the environment like oxygen.
- The molten metal moves swiftly through the mold and it does not completely solidify in it.
- The entire mold is cooled with water that flows along the outer surface.
- Typically, steel casting solidifies along the walls of the casting and then gradually moves to the interior of the steel casting.
- The metal casting moves outside the mold with the help of different sets of rollers.
- While one set of rollers bend the metal cast, another set will straighten it.
- This helps to change the direction of flow of the steel slab from vertical to horizontal.

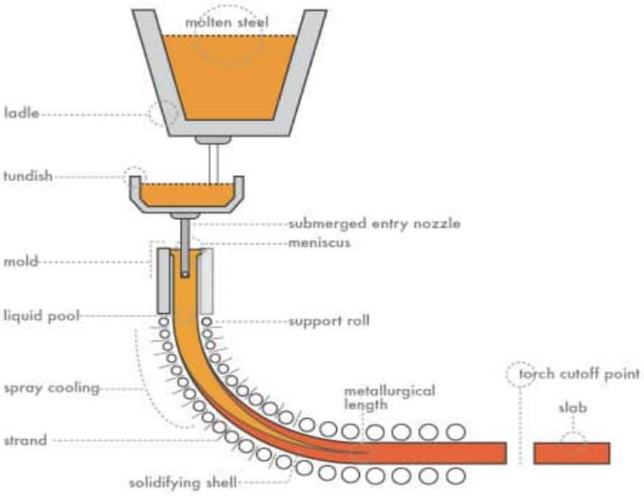


Figure 1.13 Continuous casting process

- Once the strand of steel exits the bottom of the mold, it can be easily bent by more rollers to flow horizontally, which is where cutting and working of the steel occurs.
- Once it flows horizontally, the interior is cooled to solidification. Finally, the solid strand of steel is periodically cut into lengths, forming pieces of steel that are either ready to sell (in the case of structural shapes) or are ready to roll into more complicated shapes (in the case of blooms, billets, and slabs).

1.4 Description of process in mining industry

- The objective of mining is to extract from the ground a marketable raw material for industry.
- Mining is the extraction of valuable minerals or other geological materials from the Earth.
- minerals in rocks cannot be used.
- Many processes are used to make minerals available for our use.
- Rocks with large concentrations of minerals, are called ores.
- Mining depends on finding good quality ore, preferably within a small area.
- The minerals are need to be located.
- The next step is to get the rocks which contain the mineral out of the ground.
- Once the ore is on the surface, the process of getting the mineral is startded.
- Once the mineral is separated from the rest of the rock, the mineral needs to be cleaned so that it can be used.

1.4.1 Ores

- Ores -copper, lead, zinc,
- aluminium to the production of ferroalloys and speciality metals such as molybdenum, nickel,zirconium, rhenium,production of nonmetallic mnerals such as kaolin,phosphates and sulfur.
- Native Ores: Gold Au, Copper Cu, Platinum Pt
- Base Metal Ores: Bauxite (mostly Gibbsite $Al(OH)_3$), Hematite F
- e_2O_3, Magnetite Fe_3O_4
- Sulfide Ores: Silver as Argentite Ag_2S, Copper as Bornite Cu_5FeS_4, Chalcopyrite $CuFeS_2$, or Chalcocite Cu_2S, Mercury as Cinnabar HgS, Lead as Galena PbS, and Zinc as Sphalerite ZnS
- Oxide Ores: Uranium as Uraninite UO_2, Titanium as Ilmenite $FeTiO_3$,
- Deposit: Kimberlites for Diamond

Process flowchart diagram:

1.4.2Exploration

- Mining exploration is the term we use for finding out where the valuable minerals are.
- Today technology helps mining geologists and surveyors to find high quality ore without having to do any digging.
- When the geologists and surveyors are quite sure where the right minerals are, only then do they dig test shafts to confirm what their surveying techniques have suggested.
- Remote sensing is the term used to gain information from a distance. For example, by using radar, sonar and satellite images, we can obtain images of the Earth's surface. These images help us to locate possible mining sites, as well as study existing mining sites for possible expansion**.**

- Geophysical methods make use of geology and the physical properties of the minerals to detect them underground. For example, diamonds are formed deep in the Earth at very high temperatures.
- Geochemical methods combine the knowledge of the chemistry of the minerals with the geology of an area to help identify which compounds are present in the ore and how much of it is present. For example, when an ore body is identified, samples are taken to analyse the mineral content of the ore.
- Ore is either the surface or buried deep below it**.**

1.4.3 Mining: extract ore from ground

1.4.3.1Types of Mining:

- Surface Mining: Scoop ore off surface of earth.
- Surface mining, including strip mining, open-pit mining and mountaintop removal mining, is a broad category of mining in which soil and rock overlying the mineral deposit (the overburden) are removed.
- digging rocks out from the surface, forming a hole or open pit
- Open-pit mining, also known as opencast mining, is a surface mining technique that extracts minerals from an open pit in the ground. This surface mining technique is used when mineral or ore deposits are found relatively close to the surface of the earth.
- Open-pit mining, also known as open-cast or open cut mining, is a surface mining technique of extracting rock or minerals from the earth by their removal from an open-air pit, sometimes known as a borrow.
- funnel shaped hole in ground, with ramp spiraling down along sides, allows moderately deep ore to be reached.
- cheap.
- safe for miners.
- large environmental destruction.
- **Strip mining** is the practice of mining a seam of mineral, by first removing a long strip of overlying soil and rock (the overburden); this activity is also referred to as "overburden removal".
- It is most commonly used to mine coal and lignite (brown coal). Strip mining is only practical when the ore body to be excavated is relatively near the surface.
- Blast, scoop off rock overburden and then scoop out ore material.

1.4.3.2Mountain top removal mining:

- Mountaintop removal mining" (MTR) is a form of coal mining that mines coal seams beneath mountaintops by first removing the mountaintop overlying the coal seam. Explosives are used to break up the rock layers above the seam, which are then removed.

1.4.3.3Underground Mining:

- Use of adits and shafts to reach deeply buried ores.
- expensive.
- hazardous for miners and usually less environmental damage.

1.4.4 Crushing & milling

- The rocks from the mines are transported by conveyor belts to crushers. Jaw crushers and cone crushers break the huge rocks into smaller rocks.
- Crushing is the first step of mineral processing where the ore/rocks from the mine site is fed into the mechanical equipment in order to reduce the size of masses for subsequent usage by liberating the valuable mineral from the gangue.
- The smaller rocks are then moved to mills where large rod mills and ball mills grind them further into even smaller pieces until it is as fine as powder.
- Milling is required to separate pure ore minerals from useless "gangue" (pronounced "gang") minerals.
- Milling techniques:
- Grinding ore to fine powder.
- Separation using flotation techniques

1.4.5 Separation

- Iron is a metal with magnetic properties. Iron ore can be separated from waste rock by using magnetic separation techniques.
- Conveyor belts carry the ore past strong electromagnets which remove the magnetic pieces (containing the iron) from the non-magnetic waste.
- One of the first methods for mining gold was that of panning, a technique where ore is mixed with water and forms a suspension.
- When it is shaken, the dense particles of gold sink to the bottom and could be removed.
- Flotation makes use of density separation, but in a special way.
- Froth flotation is a process for selectively separating hydrophobic materials from hydrophilic.
- Chemicals are added to change the surface properties of the valuable minerals so that air bubbles can attach to them.
- The minerals are mixed with water to make a slurry, almost like a watery mud.
- Air bubbles are blown through the slurry and the minerals attach to the bubbles. The air bubbles are much less dense than the solution and rise to the top where the minerals can be scraped off easily.

- The final separation leaves a large quantity of tailings to be disposed off.
- Tailings are the waste materials left after the target mineral is extracted from ore.

1.4.6 Refining

- There are many different methods used to concentrate and refine minerals.
- The choice of methods depends on the composition of the ore.
- Most of the methods however, make use of chemistry to extract the metal from the compound or remove impurities from the final product.
- Refinement is the process that mined material undergoes so as to remove all undesirable minerals and separate the desired elements.
- The concentrate is recovered dried and smelted.
- Smelting is the process of removing the metal from the ore mineral by heating the ore with a flux, reducing the metal ion to its elemental form.
- In all the refining process attempts are made to eliminate the undesirable constituents in the ore.
- Leaching of ores followed by extraction of the metallic values from these solutions is called hydrometallurgy.
- Heap leaching is an industrial mining process used to extract precious metals, copper, uranium, and other compounds from ore using a series of chemical reactions that absorb specific minerals and re-separate them after their division from other earth materials.
- Removes metal from the ore by reaction with a solution, often using cyanide CN^- ion.
- Pyrometallurgy is carried out in furnaces to extract metals from their ore. Eg: roasting of sulfides and reduction of oxides to metal (with carbon)

1.4.7 Mining process

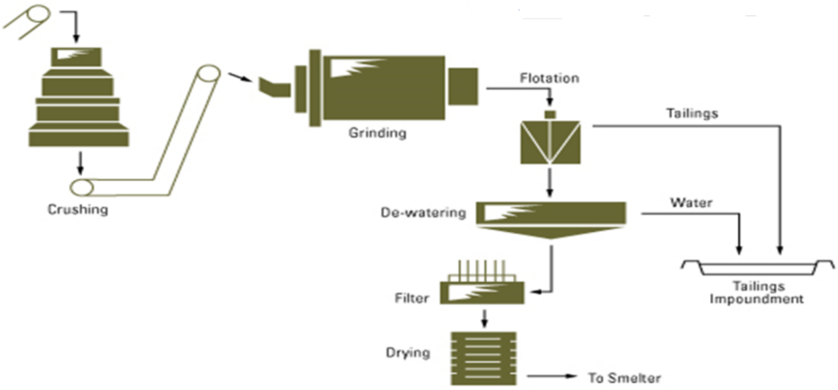


Figure 1.14 Mining process

1.4.8 Copper process

- Copper is found in natural ore deposits around the world.
- Copper minerals are found throughout the earth's crust.
- They occur in both sedimentary and igneous rocks.
- As well as the valuable copper there is much waste rock (called gangue) which has to be removed.
- Mining
- The ore is removed from the ground in either open pit or underground mines.
- Underground – sinking a vertical shaft into the earth to reach the copper ore and driving horizontal tunnels into the ore.
- Open-pit – 90% of ore is mined using the open pit method. Ores near the surface can be quarried after removal of the surface layers.
- An ore (copper pyrite)is a rock that contains enough metal to make it worthwhile extracting. In both mining techniques, the mined ore must be removed from the mine and transported to a plant for processing and refining. Trucks and trains are used for this purpose.

Grinding (or) comminution

- The ore is crushed, then ground into powder.

Concentrating

- The ore is enriched using a process called froth flotation. Unwanted material (called gangue) sinks to the bottom and is removed.
- The powdered ore is mixed with a special paraffin oil which makes the copper mineral particles water repellent. It is then fed into a bath of water containing a foaming agent which produces a kind of bubble bath.
- When jets of air are forced up through the bath, the water repellent copper mineral particles are picked up by the bubbles of foam. They float to the surface making a froth. The unwanted waste rock (gangue) falls to the bottom and is removed.
- The froth is skimmed off the surface and the enriched ore (mainly the copper mineral) is taken away for roasting. The mixture of water, foaming agent and paraffin is recycled.

Roasting

- This is where the chemical reactions start. The powdered, enriched ore is heated in air in reverberatory furnace between 500°C and 700°C to remove some sulphur and dry the ore, which is still a solid called calcine.

Smelting with fluxes

- A flux is a substance which is added to the ore to make it melt more easily.
- The solid calcine is heated to 1200°C and melts. (blast furnace)
- Some impurities are removed forming a matte (a mixture of liquid copper and iron sulphide).

Conversion of matte

- Air is blown into the liquid matte forming blister copper, so called because the gas bubbles trapped in the solid form blisters on the surface.

Anode casting

- The blister is cast into anodes for electrolysis.

Electrolytic refining

- The copper is purified to 99.99% by electrolysis.
- The anodes of 99% pure copper are sent to the electrolytic refinery for purification into very pure copper cathodes.
- They are immersed into a tank of electrolyte. The electrolyte is an aqueous solution of sulfuric acid and copper sulfate.
- The copper dissolves off the anode and is plated on the stainless steel, while all impurities remain in the electrolyte. After 7 - 14 days, the transfer to the cathode is complete and it is removed from the tank. The copper is stripped from the stainless steel sheet, washed and shipped to customers. It is now ready to be made into products we all recognize.
- Leaching
- Leaching offers an alternative to copper mining. First, the ore is treated with dilute sulphuric acid.
- This trickles slowly down through the ore, over a period of months, dissolving copper to form a weak solution of copper sulphate.
- The copper is then recovered by electrolysis. This process is known as SX-EW (solvent extraction/electrowinning).
- Advantages of these processes are:
- Much less energy is used than in traditional mining
- No waste gases are given off
- Low capital investment
- Ability to be operated economically on a small scale.

- It can be used on ore with as little as 0.1% copper – for this reason leaching extraction is growing in importance. It is estimated that SX-EW (virtually non-existent before 1960) will represent 21% of total copper refined production in 2019.

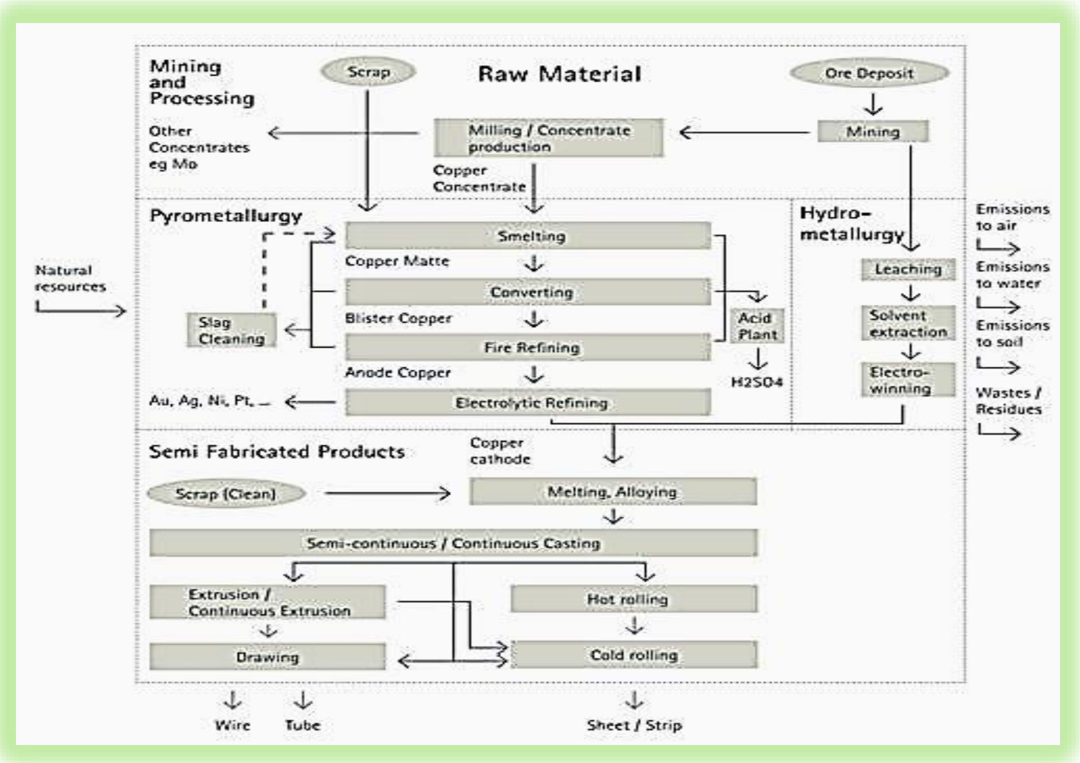


Figure 1.15: Mining process of copper

1.5 Description of process in pharmaceutical industries

Pharmaceutical processing is the process of drug manufacturing and can be broken down into a range of unit operations, such as blending, granulation, milling, coating, tablet pressing, filling and others.

Pharmaceutical Manufacturing Steps

- Powder feeding
- In continuous manufacturing, raw materials and energy feed into the system at a constant rate, and at the same time, a continual extraction of output products is achieved. The process performance is heavily dependent on the stability of the material flowrate.
- For powder-based continuous processes, it is essential to feed powders consistently and accurately into the successive processes in the line, as feeding is characteristically the first step in manufacturing.

- Feeders are designed to achieve performance reliability, feed rate accuracy, and minimal interruptions.
- **Blending**
- With pharmaceutical manufacturing, a wide range of non-active ingredients may be blended with the active pharmaceutical ingredient or ingredients to create the final blend used for the solid dosage form.
- The range of materials that may be blended (excipients, API), presents a number of variables which must be addressed to achieve target product quality attributes.
- These variables may include the particle size distribution (including aggregates or lumps of material), particle shape (spheres, rods, cubes, plates, and irregular), presence of moisture (or other volatile compounds), particle surface properties (roughness, cohesion), and powder flow properties.

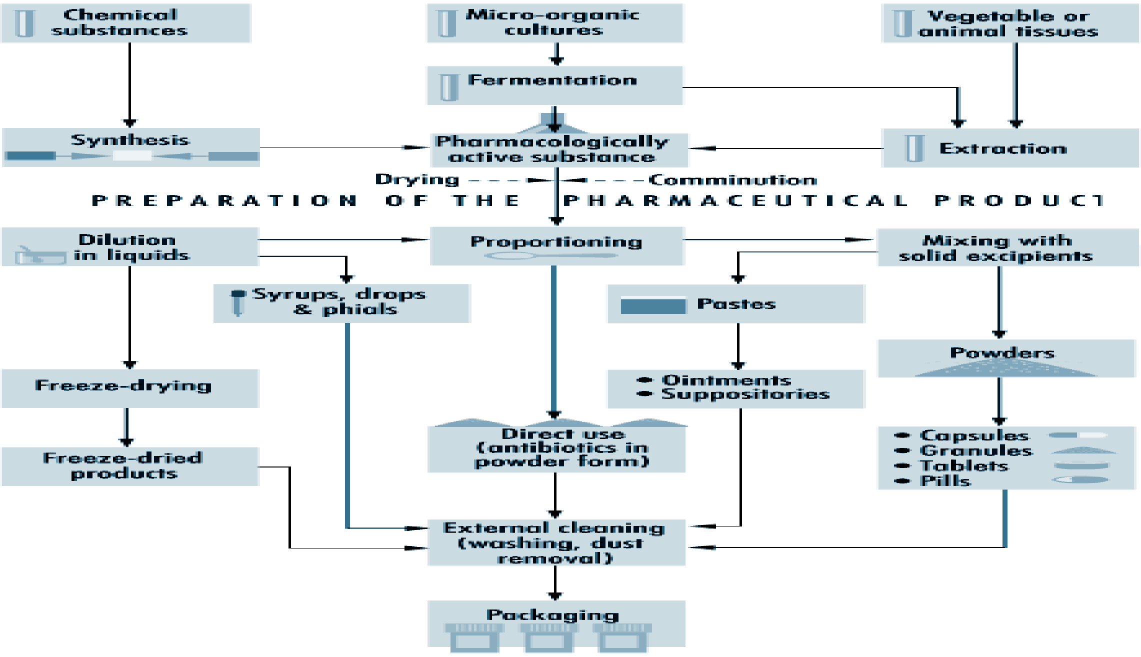


Figure 1.16: Preparation of the pharmaceutical product

- **Milling**
- During the drug manufacturing process, milling is often required in order to reduce the average particle size in a drug powder.
- There are a number of reasons for this, including increasing homogeneity and dosage uniformity, increasing bioavailability, and increasing the solubility of the drug compound.
- In some cases, repeated powder blending followed by milling is conducted to improve the manufacturability of the blends.

- **Granulation**
- In general, there are two types of granulation: wet granulation and dry granulation.
- Granulation can be thought of as the opposite of milling; it is the process by which small particles are bound together to form larger particles, called granules. Granulation is used for several reasons.
- Granulation prevents the "demixing" of components in the mixture, by creating a granule which contains all of the components in their required proportions, improves flow characteristics of powders (because small particles do not flow well), and improves compaction properties for tablet formation.
- **Hot melt extrusion**
- Hot melt extrusion is utilized in pharmaceutical solid oral dose processing to enable delivery of drugs with poor solubility and bioavailability. Hot melt extrusion has been shown to molecularly disperse poorly soluble drugs in a polymer carrier increasing dissolution rates and bioavailability. The process involves the application of heat, pressure and agitation to mix materials together and 'extrude' them through a die. Twin-screw high shear extruders blend materials and simultaneously break up particles. The resulting particles can be blended and compressed into tablets or filled into capsules. Basic production of bulk drug substances may employ three major types of processes: fermentation, organic chemical synthesis, and biological and natural extraction
- Fermentation is a biochemical process employing selected micro-organisms and microbiological technologies to produce a chemical product.
- Chemical synthesis processes use organic and inorganic chemicals in batch operations to produce drug substances with unique physical and pharmacological properties. Typically, a series of chemical reactions are performed in multi-purpose reactors and the products are isolated by extraction, crystallization and filtration. The finished products are usually dried, milled and blended.
- Drying-minimizes mod and bacterial growth.
- Sterilization- complete destruction or elimination of microbial life
- Compression- process of pressing material together to make it firmer and more solid, when applied to granulars results in the formulation of a compressed tablet.
- Tablet coating-sugarcoating,film coating etc.

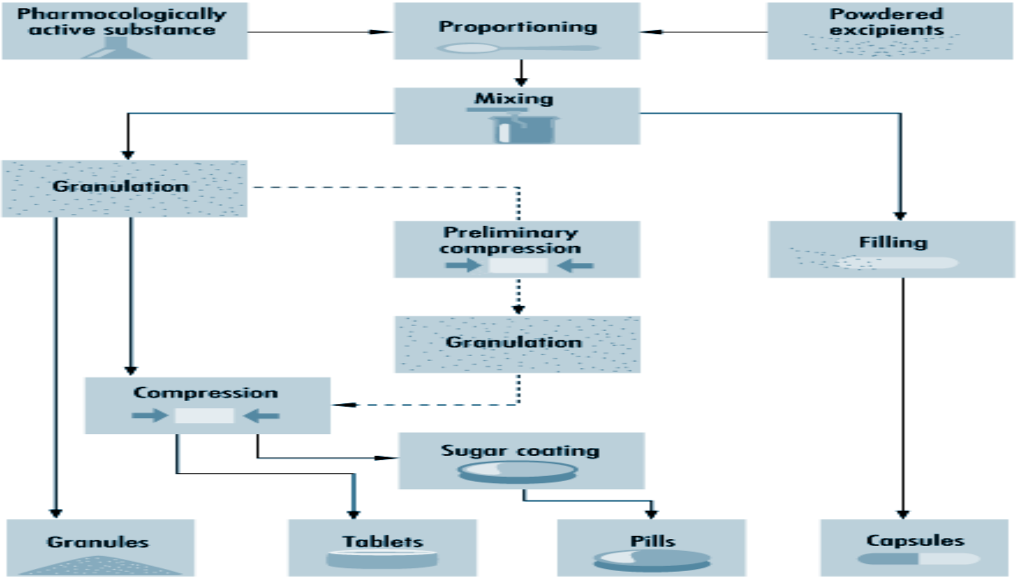


Figure 1.17: Description of process in pharmaceutical industry

TEXT / REFERENCE BOOKS

1. Considine D. M., “Process/Industrial Instruments and control Handbook”, McGraw Hill, 5th edition 1999.
2. Liptak B G, “Instrument Engineer’s Handbook, Vol. 2: Process Control and Optimization”, CRC Press, 2006.
3. BaskaraRao, “Petrochemicals”, Khanna Publishers, New Delhi, 1987.
4. Liptak B.G, “Process Measurement and Analysis”, Third Edition, Chilton Book Co., 2003
5. Considine D. M, “Hand Book of Applied Instrumentation”, Tata McGraw Hill, 1984

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DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION ENGINEERING

UNIT – II – Instrumentation in Industries – SIC1404

II. Instrumentation in Paper Industries

Measurement of Basic weight, thickness, density, Porosity, smoothness, softness, hardness and compressibility; selection of suitable measurement hardware for flow, pressure, level, temperature, density, solids, consistency - moisture analyzers oxidation - reduction potential and pH

2.1 Measurement of basis weight

The basis weight of a paper is the designated fixed weight of 500 sheets, measured in pounds, in that paper's basic sheet size. It is important to note that the "basic sheet size" is not the same for all types of paper. The weight of one ream of paper (500 sheets) when cut to the industry standard for that specific grade of paper.

The term “GSM” stands for “grams per square meter”.For this standard, the weight of various types of paper is measured from a sample sheet cut to one square meter in size. No matter the length or width the paper becomes, the weight measurement is always taken from the square meter sheet.

GSM Value is the unit to measure the weight of the paper. It stands for Grams per Square Meter. It is a very simple test to perform and tells a lot about the basic properties of Paper material which is very important to decide the quality. Other than Paper, It is also used for calculating the weight of , corrugated fibre board, includes a standardized Round Cutter and Digital Balance machine for Grammage measurement of Paper samples. With this advanced Grammage checking kit, it becomes very easy for the manufacturers to calculate GSM of Paper and ensure the best quality of final products.

Testing Procedure

- The kit comes with a standardised round cutter equipped with sharp blades.
- Place the Paper Specimen on the platform
- Remove any crease and cut a circular sample using the cutter.
- Now weigh the sample using the digital balance.
- Determine the Grammage of the Paper using the below mentioned formula GSM Formula: Grams per Square Meter = (Weight of Sample in Grams X 1000)/ Area of sample in cm^2

2.2 Measurement of thickness

- Contact type thickness gauge
- Non contact type thickness gauge

2.2.1Contact type thickness gauge

- The contact type devices are those which compare the thickness to a reference length for the measurement of thickness whereas noncontact device are those, which indicate the thickness, based on some physical relationship.

- Measurement is performed with a physical contact of the instrument and test piece.

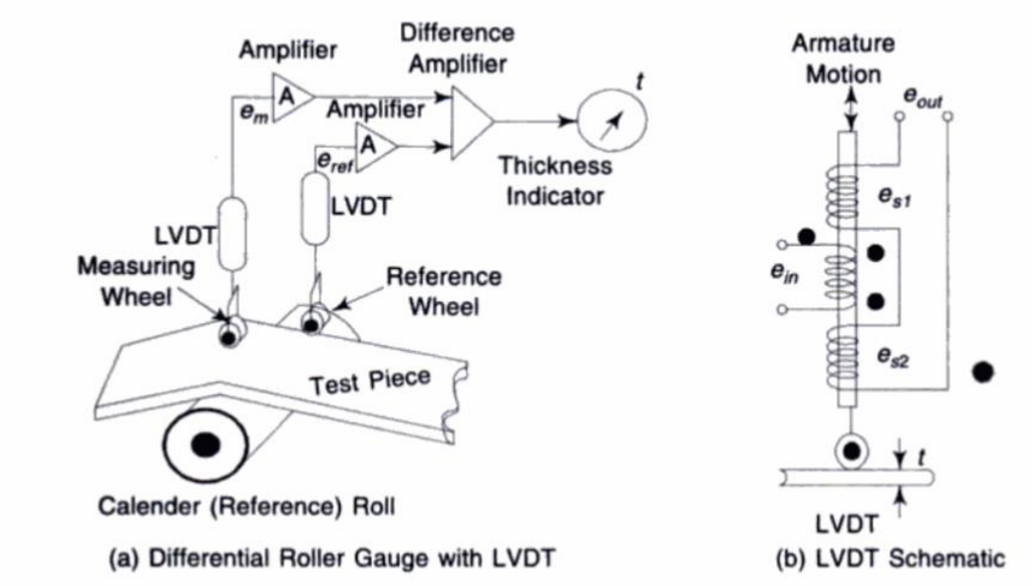
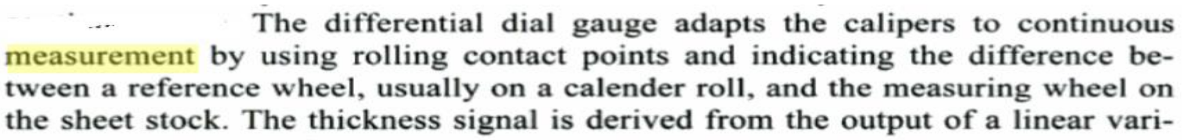
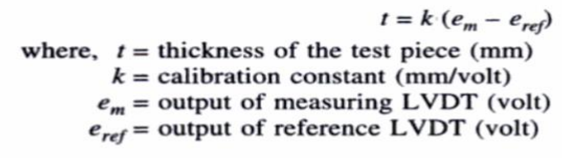
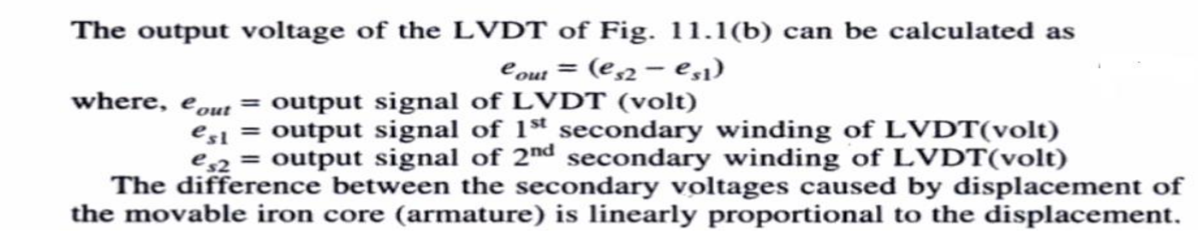


Figure:2.1 LVDT typeContact type thickness gauge


The differential dial gauge adapts the calipers to continuous measurement by using rolling contact points and indicating the difference between a reference wheel, usually on a calender roll, and the measuring wheel on the sheet stock. The thickness signal is derived from the output of a linear vari-


$$t = k\,(e_m - e_{ref})$$

where, t = thickness of the test piece (mm)
k = calibration constant (mm/volt)
e_m = output of measuring LVDT (volt)
e_{ref} = output of reference LVDT (volt)


The output voltage of the LVDT of Fig. 11.1(b) can be calculated as

$$e_{out} = (e_{s2} - e_{s1})$$

where, e_{out} = output signal of LVDT (volt)
e_{s1} = output signal of 1st secondary winding of LVDT(volt)
e_{s2} = output signal of 2nd secondary winding of LVDT(volt)

The difference between the secondary voltages caused by displacement of the movable iron core (armature) is linearly proportional to the displacement.

2.2.2 Radiation type non contact thickness gauge

This method uses either Alpha, beta, gamma or X-rays as radiation obtained from radioactive sources for thickness measurement. The radiation source is shielded all around except in the direction of the detector. A Radiation detector such as Geiger Muller tube ionization chamber or a scintillation counter is used for measuring the amount of radiation reaching the detector, used for hot or cold, stationary or moving parts of paper, over a wide range of thickness.

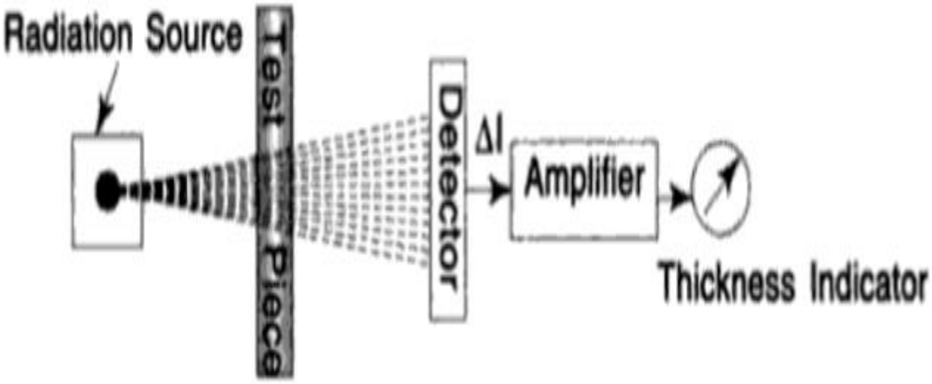


Figure:2.2 Radiation type non contact type thickness gauge

- Radiation source radiates to the detector through the sheet whose thickness is to be measured.
- Radiated rays received by the detector is dependent upon the thickness of the test piece.
- Radiated energy received at detector is amplified and calibrated to indicate thickness by the reading instrument.

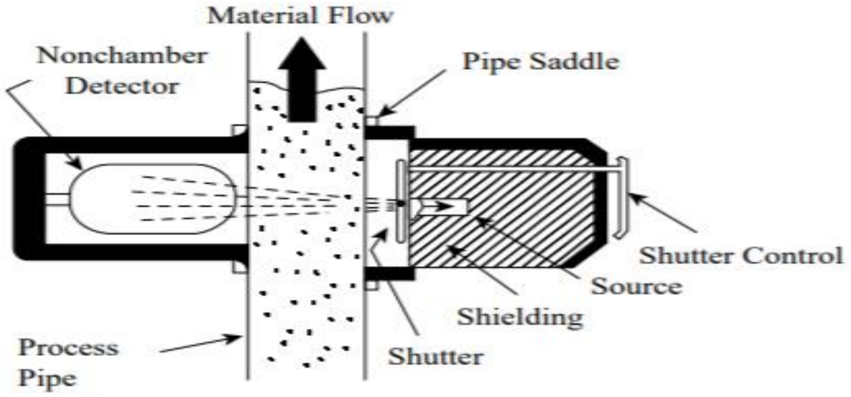
2.3Measurement of density

- the nature of the process fluid (slurry, viscous, or clean)
- the operating pressure and temperature conditions.
- cost of the instrument
- Accuracy
- Most density gauges are suitable only for use on process fluids that are clean and nonviscous. When that is the case, the densitometer is usually selected on the basis of the allowable error and economics. If the process fluid is viscous or of the slurry type, then the radiation, Coriolis, ultrasonic, vibrating, hydrostatic head, and U- or straight-tube type sensors can be considered. Of these types, the U- or straight-tube gauges are limited in their pressure and temperature ratings and can handle only moderately viscous or slurry-type streams.
- Density is defined as the quantity of matter per unit volume. The most common unit iskg/m3.
- Relative density, which in our everyday language is called specific gravity, is the ratio between the density of a process material to that of water or air at specified standard conditions.

2.3.1Radiation density sensors

- The basic components of the density gauge comprise a radioactive source beaming through a pipe and a detector system to measure the amount of transmitted radiation.

- When gamma rays pass through a process fluid, they are absorbed in proportion to the density of the process material .
- An increase in process density results in a reduced output current because a denser process fluid absorbs more of the gamma rays.



The gamma source is housed in a lead-shielded holder. When the shutter mechanism is opened, a collimated gamma beam passes through the pipe wall and the process material inside; its intensity at the detector is interpreted into process density.

- When the density inside large pipes (or containers) is measured, the radiation source and detector would be mounted as illustrated on figure.
- In a smaller diameter pipe (under 6 in., or 150 mm) the radiation path is not adequate to provide high accuracy and sensitivity. Therefore, the Z installation would be used. This method of mounting lengthens the radiation path and consequently increases accuracy.

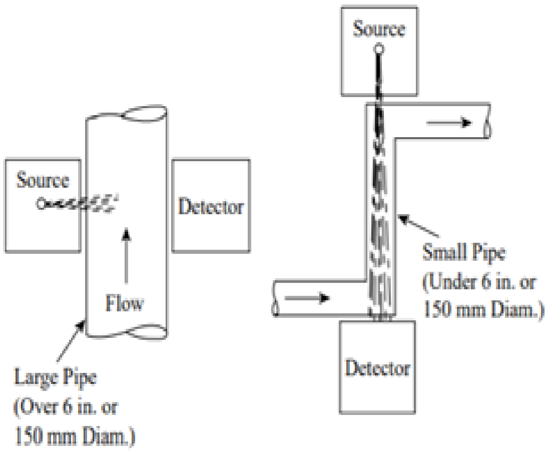


Figure:2.3 Radiation density sensors

2.4 Measurement of porosity

A measure of the void (empty) spaces within a material (such as paper). When fibres are bonded together to produce paper, they create tiny passages that may penetrate completely through the sheet or only extend part of the way down.Porosity can determine how much adhesive or ink will soak into a sheet of paper. A highly porous paper will have good adhesive or ink receptivity, resulting in a high quality adhesive bond or print respectively. Porous papers are ideal for high speed printing processes, as when printing newspapers, where the ink needs to be absorbed rapidly to reduce the risk of smudging. Low porosity papers can lead to print smudging, poor adhesion, and usually have greater problems with dimensional stability due to issues with moisture content. Porosity can be controlled to an extent by binding the fibres together more tightly during manufacturing. Porosity of paper is measured either by the time it takes for a particular quantity of air to pass through a sample (using a Gurley densometre) or how quickly air passes through a sample (using a Sheffield porosimetre). Densometers are the accepted standard for measuring the porosity of materials such as papers, wovens, plastics and membranes. All Densometers measure the time required for a given volume and of air (25cc to 400cc) to flow through a standard area of material being tested under light uniform pressure. The porosity is an indication of the openness of paper, as measured by resistance to the passage of air through the sheet. Two types of instruments are generally used to measure porosity - Gurley and Sheffield. The Gurley Instrument measures the seconds required for given volume of air to pasS through a single sheet of and is generally used for porous papers. A high reading indicates a less porous (or more dense) paper. Sheffield porosity measures the flow rate of air through a single sheet and is generally used for non-porous or dense sheet. A high Sheffield reading indicates a more open paper. A typical Gurley porosity test for 50 lb. smooth offset would be 10-20 seconds. Sheffield readings of 60 lb. coated paper would be 10-20 units of air flow.

2.5 Measurement of smoothness

The smoothness is a measure of paper surface irregularities. The property affects many end uses, particularly the appearance of printing. The test is conducted by clamping the paper against a flat surface and measuring rate of air flow passing between the two surfaces. The Sheffield Instrument is the most commonly used, a higher number indicating a rougher sheet. Some typical smoothness values are: 10-30 for very smooth coated paper; 100-150 for smooth offset and 200-250 for Vellum offset.A measure of paper smoothness is made using an air leak tester, which determines the time it takes for a volume of air to seep between a smooth glass plate and the paper sample. Smoothness can also be measured using a Bekk Smoothness Tester or a Gurley Smoothness Tester.More rapid measurements can be made with a Sheffield Smoothness Gauge or a Bendtsen Smoothness Tester. All these devices utilize rates of air flow over a paper surface as an indicator of smoothness.

2.5.1Sheffield Smoothness Gauge

A type of air leak tester, an instrument used to determine the smoothness of a paper surface, in which air at a specified pressure is pumped through a smooth glass column and seeps between a groove in the device's gauge head and the surface of the paper sample. An air-suspended metering float in the glass column moves up or down, the level of the float in the column indicating the rate of airflow and is thus a measure of the paper's smoothness.

2.5.2Gurley Smoothness Tester

A variety of air leak tester, an instrument used to determine the smoothness of a paper surface, in which air at a specified pressure is leaked between a smooth glass surface and a paper sample, and the time (in seconds) for a fixed volume of air to seep between these surfaces is the smoothness of the paper.

2.6 Measurement of roughness

A rougher surface causes higher airflow; Bendtsen roughness is achieved by clamping the test piece between a flat glass plate and a circular metal head and measuring the rate of airflow in ml/minute between the paper and head**.**

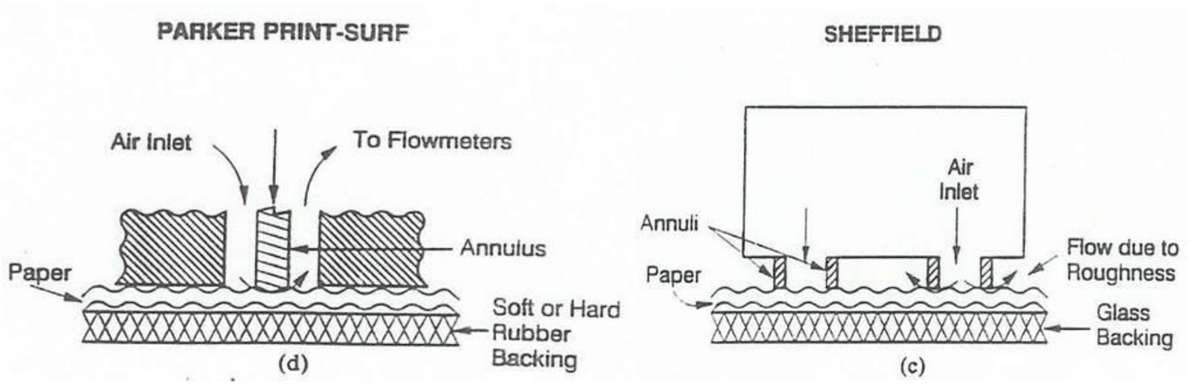


Figure:2.4Measurement of roughness

2.7 Measurement of hardness

The degree to which a paper will resist a reduction in thickness when exposed to a compressing force, as during printing, writing or typing. A low degree of hardness aids in producing a good printed image, as the squeezing down of surface contours enables the printing plate or blanket to contact the paper more completely. A hardness tester performs a measurement by determining the resistance of a material to penetration or to deformation at a given force. For testing paper rolls the measurement is generally a non-destructive deflection. Wireless is an advanced roll analyzer which can be used both paper and machine roll as well as plastic film roll or aluminium foil roll analysis. Measurement principle Hammer is moving up and down 30 times per second. The vertical position of the hammer is measured 100 000 times per second. Based on changes in the position as a function of time the velocity of the hammer can be calculated. When the hammer hits to the surface of the sample the movement stops. The harder the sample, the faster the hammer movement stops, and the higher the negative acceleration.

2.8 Measurement of compressibility

The degree to which a paper will reduce in thickness when exposed to a compressing force, as during printing. A high degree of compressibility aids in producing a good printed image, as the squeezing down of surface contours enables the printing plate or blanket to contact the paper more completely. Compressibility is a function of the paper's apparent density, the degree of refining the fibers have received during papermaking, and the degree of calendering and supercalendering.. A paper's compressibility is also increased by increased moisture content. Generally, easily-compressible paper is preferred for printing. A TMI Monitor/printing Surf System can be used to quantitatively measure the compressibility of a paper**.**

2.9 Selection of suitable measurement hardware for flow

There are many factors which are to be considered before drawing up specifications for a flow meter. They are:

1. Measurement requirements
2. External conditions of the flow pipe
3. Internal conditions of the flow pipe
4. Properties of the flowing fluid
5. Installation and accessories and
6. Cost consideration

1. Measurement requirements

- i) The measured variable like point velocity, average velocity or volume rate.
- (ii) The range of operation. For wide range of operation, electromagnetic, ultrasonic, turbine type etc. are suitable.
- (iii) Cost computation. If it is for costing purpose, the meter should have low and consistent uncertainty in measurement.
- (iv) Pressure head loss and maximum pressure of flowing fluid. For high pressure fluids the meter body and inner construction should be sturdy.
- (v) Accuracy, Precision and facilities available for maintenance.
- (vi) Speed of response. For fluctuating flow, response of the meter should be good with small time constants.
- (vii) Calibration facilities and Installation.

2. External conditions of the flow pipe

- Before selection of a flow meter, it is important to examine the environment and the place where the meter is going to get installed.
- The following points need to be considered
- Approachability. It is better to know that once the meter is installed whether it is accessible for removal, recalibration etc.
- It is important to note that the installation of the meter either in an air conditioned space or in a place which is vulnerable for wide temperature variation.

- Humidity condition, vibration, hostile environment and water facility are the important parameters to be considered.

3. Internal conditions of the flow pipe

- The conditions internal to the pipe affect the accuracy of measurement of flow meters.
- Some of the factors that affect the accuracy are protrusions, pipe bore, size, roundness, toughness, hydrodynamic noise pulsations etc.

4. Properties of the Fluid

- The properties of the fluid to be metered should be clearly understood by the person who is to select the meter.
- Many flow problems are due to the impurities present in the fluid, the effect of which cannot always be quantitatively established.

1. Viscosity of the flowing fluid is a critical factor. If the viscosity of the fluid changes, the Reynolds number changes, which in turn affect the calibration curve of the flow meter.
2. Fluid activity. The fluid to be metered may be radioactive or chemically reactive. Radioactivity presents special problems. For metering the velocity of fluids having high levels of radiation, flow meters offering long periods of reliable operation without maintenance are required. If the fluid is corrosive, then Electromagnetic flow meter or Vortex flow meter can be used.
3. Flammability. Fluids which are inflammable or react violently with other materials need flow meters like turbine and vortex flow meter. They are suitable for operation in hazardous areas.
4. Scaling Deposits. Special care should be taken for fluids having a property to deposit scales since scaling can block pressure lines and ducts.
5. Other properties. The fluid properties like compressibility, abrasiveness, transparency, electrical conductivity, magnetic properties and lubricity should be noted before selection of flow meter is made.

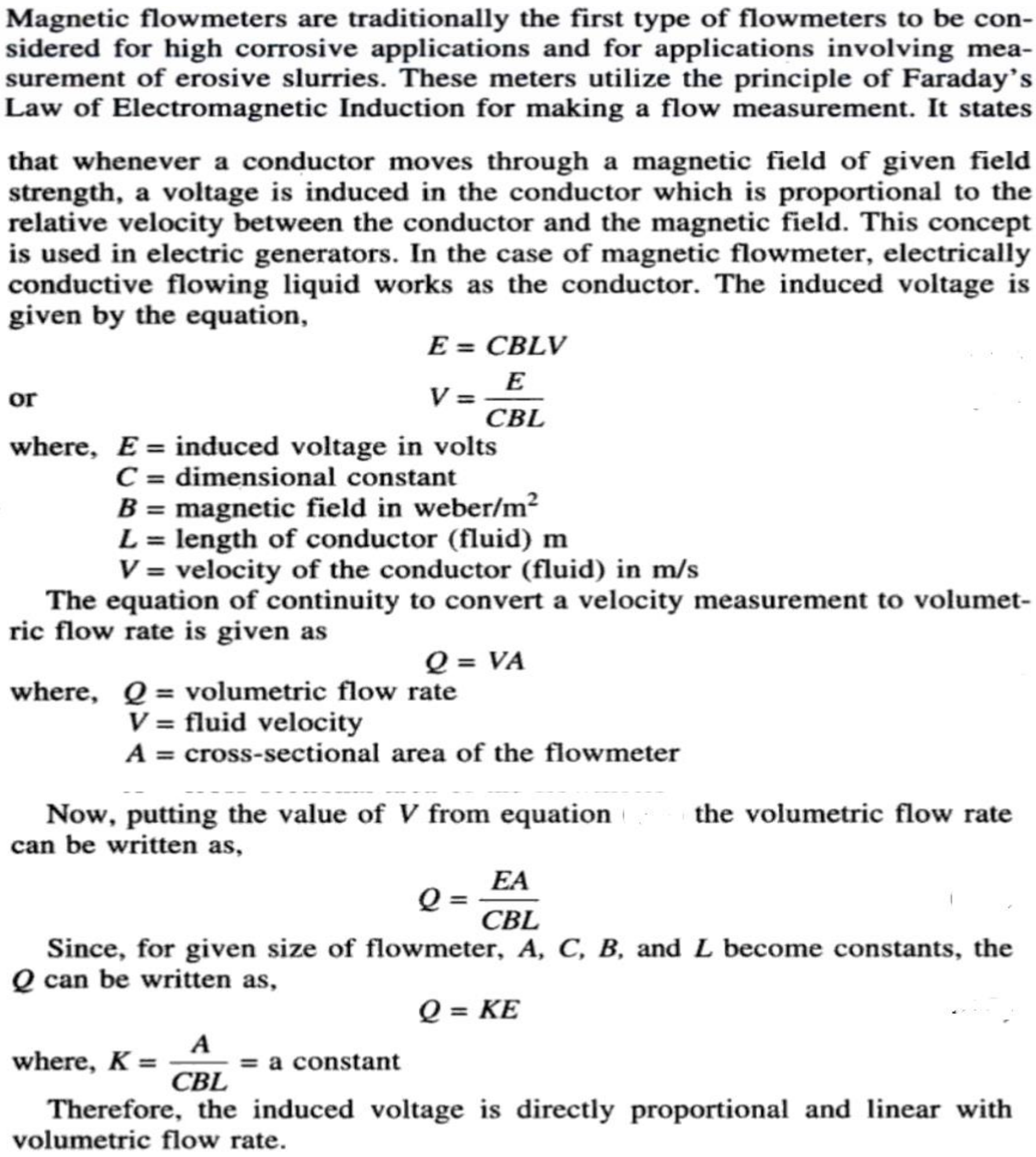
5.Installation and accessories

1. Valves and manifolds for equalizing, draining, venting and isolation.
2. Sumps, gas vents, poles and drains.
3. Cooling chambers when measuring condensable vapours.
4. Straighteners for improving velocity profile.
5. Piezometer rings for averaging the flow velocity profile for orifice plates.
6. Separators to prevent contaminating fluids like water in oil from entering the flow meter.
7. Gas detectors to provide a warning if the flow meter is not running full.

6. Cost consideration

- Any decision on the purchase or selection of flow meter will certainly take the economic factors into consideration.
- But that should not be given the top priority.
- When computing the cost of flow meters, the cost of accessories, transmitters etc.
- if needed, the maintenance cost for a period should also be taken into consideration.

2.9.1Electromagnetic flowmeter:



Magnetic flowmeters are traditionally the first type of flowmeters to be considered for high corrosive applications and for applications involving measurement of erosive slurries. These meters utilize the principle of Faraday's Law of Electromagnetic Induction for making a flow measurement. It states

that whenever a conductor moves through a magnetic field of given field strength, a voltage is induced in the conductor which is proportional to the relative velocity between the conductor and the magnetic field. This concept is used in electric generators. In the case of magnetic flowmeter, electrically conductive flowing liquid works as the conductor. The induced voltage is given by the equation,

$$E = CBLV$$

or

$$V = \frac{E}{CBL}$$

where, E = induced voltage in volts
C = dimensional constant
B = magnetic field in weber/m^2
L = length of conductor (fluid) m
V = velocity of the conductor (fluid) in m/s

The equation of continuity to convert a velocity measurement to volumetric flow rate is given as

$$Q = VA$$

where, Q = volumetric flow rate
V = fluid velocity
A = cross-sectional area of the flowmeter

Now, putting the value of V from equation the volumetric flow rate can be written as,

$$Q = \frac{EA}{CBL}$$

Since, for given size of flowmeter, A, C, B, and L become constants, the Q can be written as,

$$Q = KE$$

where, $K = \frac{A}{CBL}$ = a constant

Therefore, the induced voltage is directly proportional and linear with volumetric flow rate.

Construction and Working The magnetic flowmeter consists of an electrically insulated or non-conducting pipe such as fiber glass, with a pair of electrodes mounted opposite to each other and flush with the inside walls of its pipe and with magnetic coil mounted around the pipe so that a magnetic field is generated in a plane mutually perpendicular to the axis of the flowmeter body and to the plane of the electrodes. If a metal pipe is used, an electrically insulating liner is provided to the inside of the pipe. A cut way view of the magnetic flowmeter is shown in Fig. (a).

Figure (b) illustrates the basic operating principle of a magnetic flowmeter in which the flowing liquid acts as the conductor, the length *L* of which is the distance between the electrodes and equals the pipe diameter. As the liquid passes through the pipe section, it also passes through the magnetic field set up by the magnet coils, thus inducing the voltage in the liquid which is detected by the pair of electrodes mounted in the pipe wall.

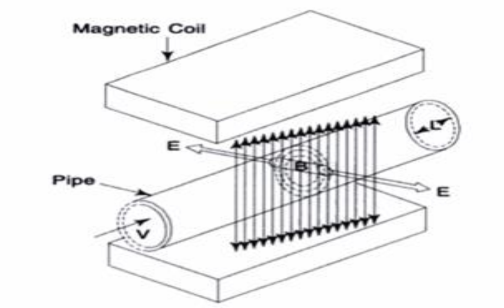


Figure:2.5 Working principle of magnetic flowmeter

The amplitude of the induced voltage is proportional to the velocity of the flowing liquid. The magnetic coils may energized either by AC or DC voltage, but the recent development is the pulsed DC-type in which the magnetic coils are periodically energized.

In a new design of magnetic flowmeter, it can be inserted into the line through couplings. It consists of electrodes mounted on each side of a probe and magnetic coils which are also integral to the probe. The probe can be mounted on pipes of any size, and can easily be mounted for open channel flow.

Advantages The advantages of a magnetic flowmeter are:

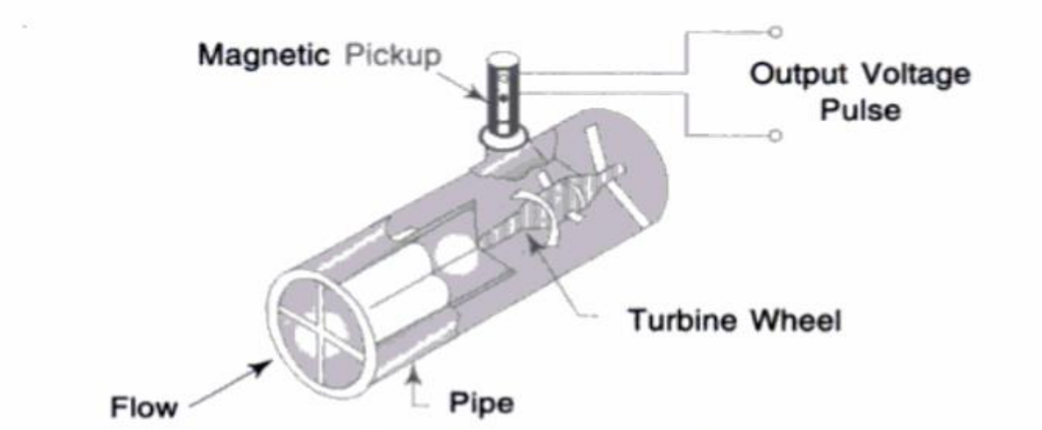
(i) It can handle slurries and greasy materials.
(ii) It can handle corrosive fluids.
(iii) It has very low pressure drop.
(iv) It is totally obstructionless.
(v) It is available in several construction materials.
(vi) It is available in large pipe sizes and capacities.
(vii) It is capable of handling extremely low flows (with minimum size, less than 3.175 mm inside diameter) and very high volume flow rate (with sizes as large as 3.04 meter offered).
(viii) It can be used as bi-directional meter.
(ix) Measurements are unaffected by viscosity, density, temperature and pressure.

Disadvantages and Limitations The disadvantages and limitations of magnetic flowmeter are:

(i) It is relatively expensive.
(ii) It works only with fluids which are adequate electrical conductors.
(iii) It is relatively heavy, especially in larger sizes.
(iv) It must be full at all times.
(v) It must be explosion proof when installed in hazardous electrical areas.

2.9.2 Turbine flowmeter

The turbine flowmeter is used for the measurement of liquid, gas and very low flow rates. It works on the basic principle of turbine. It consists of a multi-bladed rotor (turbine wheel) which is mounted at right angles to the axis of the flowing liquid, as shown in Fig. The rotor is supported by ball or sleeve bearings on a shaft which is retained in the flowmeter housing by a shaft-support section. The rotor is free to rotate about its axis.



Turbine Flowmeter.

Figure:2.6 Turbine flowmeter

The flowing fluid impinges on the turbine blades (rotor), imparting a force to the blade surface which causes the rotation of the rotor. The speed of the rotor is directly proportional to the fluid velocity, and hence to volumetric flow rate when it is at a steady rotational speed. The speed of rotation is monitored in most of the meters by a magnetic-pickup coil, which is fitted to the outside of the meter housing. The magnetic-pickup coil consists of a permanent magnet with coil windings which is mounted in close proximity to the rotor but internal to the fluid channel. As each rotor blade passes the magnetic-pickup coil, it generates a voltage pulse which is a measure of the flow rate, and the total number of pulses give a measure of the total flow. The electrical voltage pulses can be totalled; subtracted and manipulated by digital techniques so that a zero error characteristic of digital handling is provided from the pulse generator to the final read out. The K factor (i.e. the number of pulses generated per gallon of flow) is given as,

$$K = \frac{T_K f}{Q}$$

where, K = pulses per volume unit
T_K = a time constant in min.
Q = a volumetric flow rate in gpm.
f = frequency in Hz

Advantages The advantages of turbine flowmeter are:

(i) Its accuracy is good.
(ii) It provides excellent repeatability and rangeability.
(iii) It allows fairly low pressure drop.
(iv) It is easy to install and maintain.
(v) It gives good temperature and pressure ratings.
(vi) It can be compensated for viscosity variations.

Disadvantages The disadvantages of turbine flowmeter are:

(i) Its cost is high.
(ii) Its use is limited for slurry applications.
(iii) It faces problems caused by non-lubricating fluids.

2.9.3Target flowmeters

The target meter measures flow by measuring the force on a target (or disc), centred in the pipe at right angles to the direction of fluid flow. The fluid flow develops a force on the target which is proportional to the square of the flow.

A target meter consists of a target (or disc) which is mounted on a force bar (or beam) passing through a flexible seal, and is positioned in the centre of and perpendicular to the flowing stream, as shown in Fig. The device may be installed directly in the flow line, thus eliminating the need for pressure-tap connections. The flowing fluid while passing through the pipe, develops a force on the target which is proportional to velocity head (the square of the flow). The force bar transmits this force to a force transducer (either electronic or pneumatic) to measure the force which is proportional to the square of the flow. The relationship between the flow rate and force is expressed by the equation.

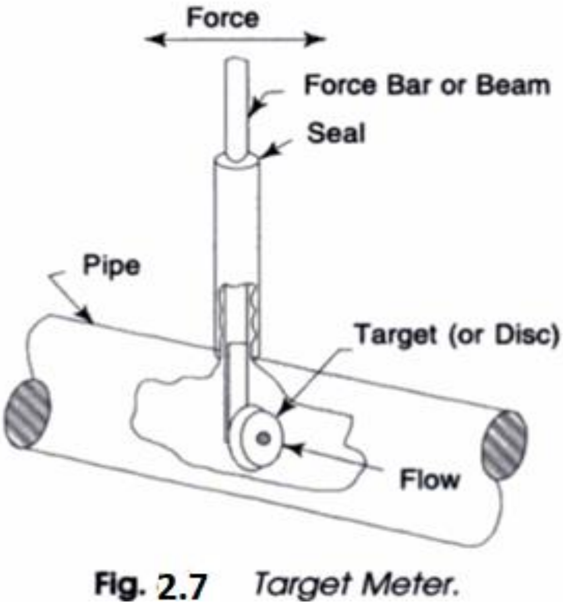


Fig. 2.7 *Target Meter.*

$$Q = K\sqrt{F}$$

where, Q = flow rate
K = a known coefficient
F = force

Another variation of target meter is also available which is known as drag body flow meter, as shown in Fig. It also uses the same operating principle where the force is given by the equation,

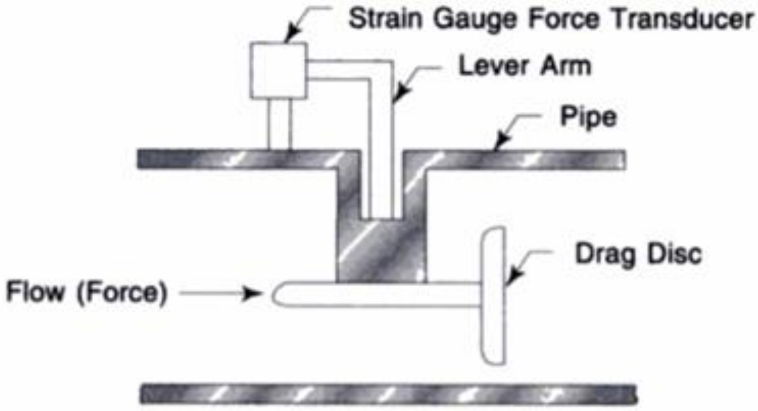


Fig. 2.8 *The Drag Body Flowmeter.*

$$F = C_d A \rho (V^2/2g)$$

where, F = force
C_d = drag coefficient
A = sensor area
ρ = fluid density
$V^2/2g$ = velocity head

This force is detected and transmitted by a strain gauge bridge circuitry, into a voltage signal which is proportional to the square of the flow rate. The accuracy of this device ranges from ±1/2 to ±3% depending on the calibration used.

Target meters are applied in a number of fields for measurement of liquids, vapours and gases. They are especially useful for measuring heavy viscous, dirty or corrosive fluids. The force-balance type (i.e. target type) can handle pressures upto 1,500 psig and temperatures to 398 °C, and the strain gauge type (i.e. drag body type) can handle pressures upto 5,000 psig and temperature to 315 °C.

Advantages The advantages of target flowmeters are:

(i) They are useful for difficult measurements such as slurries, polymer-bearing and sediment-bearing materials corrosive mixtures, etc.
(ii) They provide good accuracy when calibrated for specific streams.
(iii) Their repeatability is good.
(iv) They are good for relatively high temperatures and pressures.

Disadvantages The disadvantages of the target flowmeters are:

(i) In-line mounting required in these flowmeters.
(ii) They have a limited calibration data.
(iii) In case of target flowmeters no-flow conditions must exist for zeroing the scale.

2.9.4 Ultrasonic flowmeter

In ultrasonic flowmeters, the measurement of flow rate is determined by the variation in parameters of ultrasonic oscillations. There are two types of ultrasonic flowmeters currently in use:

Time Difference Type These devices measure flow by measuring the time taken for ultrasonic wave to transverse a pipe section, both with and against the flow of liquid within the pipe. It consists of two transducers, *A* and *B*, inserted into a pipe line, and working both as transmitter and receiver, as shown in Fig. (a). The ultrasonic waves are transmitted from transducer *A* to transducer *B* and vice versa. An electronic oscillator is connected to supply ultrasonic waves alternately to *A* or *B* which is working as transmitter through a changeover switch, when the detector is connected simultaneously to *B* or *A* which is working as receiver. The detector measures the transit time from upstream to downstream transducers and vice versa.

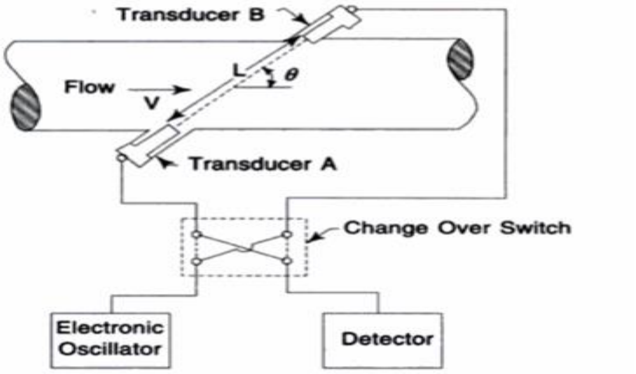


Fig. 2.9 (a) *Time-difference Type Ultrasonic Flowmeter.*

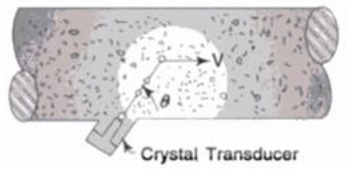


Fig. 2.9 (b) *Doppler-type Ultrasonic Flowmeter*

The time T_{AB} for ultrasonic wave to travel from transducer *A* to transducer *B* is given by the expression:

$$T_{AB} = \frac{L}{(C + V\cos\theta)}$$

and, the time (T_{BA}) to travel from *B* to *A* is given as,

$$T_{BA} = \frac{L}{(C - V\cos\theta)}$$

where, L = the acoustic path length between A and B
C = velocity of sound in the fluid
θ = angle of path with respect to the pipe axis
V = velocity of fluid in pipe

The time difference between T_{AB} and T_{BA} can be calculated as,

$$\Delta T = T_{AB} - T_{BA} = \frac{2\,LV\cos\theta}{C}$$

or, $$V = \frac{\Delta T\, C}{2\, L \cos \theta}$$

Since, this type of flowmeter relies upon an ultrasonic signal traversing across the pipe, the liquid must be relatively free of solids and air bubbles.

Doppler Flowmeters In doppler flowmeter, an ultrasonic wave is projected at an angle through the pipe wall into the liquid by a transmitting crystal in a transducer mounted outside the pipe, as shown in Fig. (b). Part of the ultrasonic wave is reflected by bubbles or particles in the liquid and is returned through the pipe wall to a receiving crystal. Since the reflectors (bubbles) are travelling at the fluid velocity, the frequency of the reflected wave is shifted according to the Dopple principle. The velocity of the fluid is given by the equation:

$$V = \frac{\Delta f\, C_t}{2 f_0 \cos \theta} = \Delta f\, K$$

where Δf = difference between transmitted and received frequency
C_t = velocity of sound in the transducer
f_0 = frequency of transmission
θ = angle of transmitter and receiver crystal with respect to the pipe axis.
K = constant

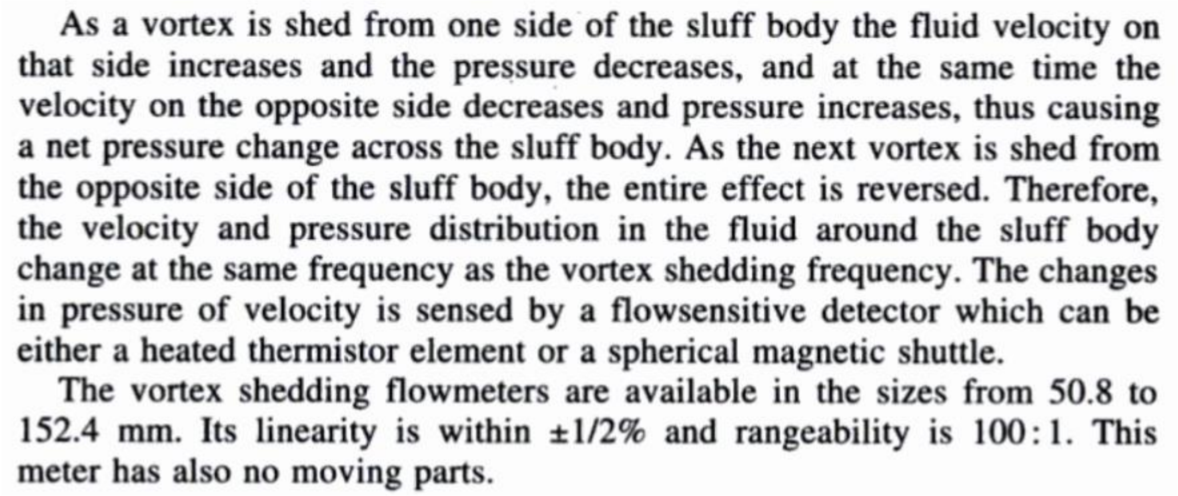
Advantages of Ultrasonic Flowmeters The advantages of ultrasonic flowmeters are:

(i) It does not impose additional resistance to the flow or disturb the flow pattern as the transducers are inserted in the wall of pipe.
(ii) Its velocity/output relationship is linear.
(iii) It has no moving parts.
(iv) Its repeatability is in the order of 0.01%.

2.9.5Vortex shedding flowmeter

The operation of the vortex shedding flowmeter is based on the phenomenon known as vortex shedding which occurs when a gas or liquid flows around a non-stream lined (or blunt) object known as sluff body. When a fluid flows past an obstacle, boundary layers of slow moving fluid are formed along the outer surfaces of the obstacle and the flow is unable to follow contours of the obstacle on its downstream side. Thus the flow layers are separated from the surface of the object, and a low pressure area is formed behind the object which causes the separated layers to get detached from the main stream of the fluid and roll themselves into eddies or vortices in the low pressure area, as shown in Fig. Each eddy on vortex first grows and gets detached or shed from alternate sides of the object. The frequency at which the vortices are formed is directly proportional to the fluid velocity.

Fig. 2.10 *Vortex Shedding Flowmeter.*



As a vortex is shed from one side of the sluff body the fluid velocity on that side increases and the pressure decreases, and at the same time the velocity on the opposite side decreases and pressure increases, thus causing a net pressure change across the sluff body. As the next vortex is shed from the opposite side of the sluff body, the entire effect is reversed. Therefore, the velocity and pressure distribution in the fluid around the sluff body change at the same frequency as the vortex shedding frequency. The changes in pressure of velocity is sensed by a flowsensitive detector which can be either a heated thermistor element or a spherical magnetic shuttle.

The vortex shedding flowmeters are available in the sizes from 50.8 to 152.4 mm. Its linearity is within ±1/2% and rangeability is 100 : 1. This meter has also no moving parts.

2.9.6 Laser doppler anemometer systems:

Anemometers are used to measure air and gas flows in a variety of applications.

Principle of Operation

When sound or light is beamed into the atmosphere, the inhomogeneities in the air will reflect these beams. The resulting Doppler shift in the returning frequencies can be interpreted as an indication of wind velocity.

Working

When laser-based Doppler anemometers are used, the intensity of the light scattered by the particles in the air is a function of their refractive index and the size of the reflecting particles. The Laser Doppler anemometer (LDA) is based on the Doppler effect. The Doppler shift of frequency occurs as light is dispersed on the surface of moving particles. The shift in the frequency of the light source (laser beam) is proportional to the velocity of the particles. The frequency shift is very small (from 1 KHz upto a tenth of a MHz) in comparison with the light frequency and thus it can be directly measured. Therefore, the arrangement using the interference of the original and refracted lights is used. This is called as 'differential mode' of LDA. Fig. illustrates the LDA Principle. The frequency '*f*' of electrical signals produced by a particle moving with velocity 'V' is given by

$$f = \frac{2V \sin \theta / 2}{\lambda} = \left[\frac{2 \sin \theta / 2}{\lambda} \right] V$$

$$\mathbf{f = KV}$$

where λ = Laser wavelength and θ = angle of the beam.

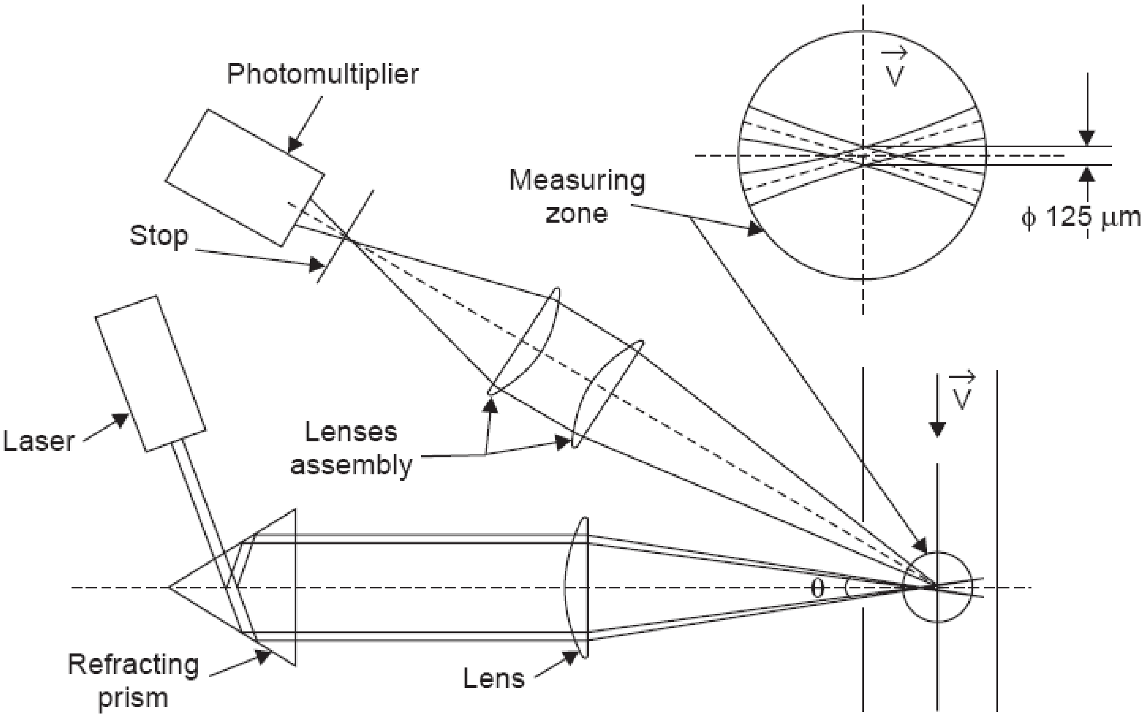


Figure:2.11 Laser doppler annemometer

Beams from the laser source intersect each other in the measurement zone, where a set of interference plates are formed. When particles pass through these, they generate optical signals with flash frequencies which equal the Doppler frequency. This signal is canned by the photo multiplier and is analysed. The signal has several cycles, variable amplitude, and high frequency and background noise.

Applications

The use of this non contact measurement method is suitable for nearly all hydro dynamical and aero dynamical velocity measurement applications.

2.10 Solid flow measurement

Continuous determination of flow rate of dry materials such as coal, cement, powdered chemicals, paper and fruits is necessary in many industrial processes. Meters for measuring flow of dry materials are essentially of the weighing type, in that they determine the weight of material passing a given point. Belt feeders are compact factory—assembled devices utilizing belts to transport the material across a weight-sensing mechanism. In the case of meters, an uncontrolled solids flow passes across a constant speed belt and the belt load signal is thus a function of gravimetric flow rate.

The feeder in its most basic form consists of a meter to which a controller and volumetric solids flow regulator is added. The flow regulator is normally a simple gate, but may be in the form of a rotary gate, screw or other volumetric control device capable of being fitted with a suitable actuator.

2.10.1Belt Type Gravimetric Feeder

It incorporates a constant speed belt coupled with a gate to modulate the solids flow rate such that belt load is balanced by an adjustable poise weight. The feeder, which is still used in some industrial applications today, is unique in its simplicity but includes number of disadvantages relative to more modern designs as follows

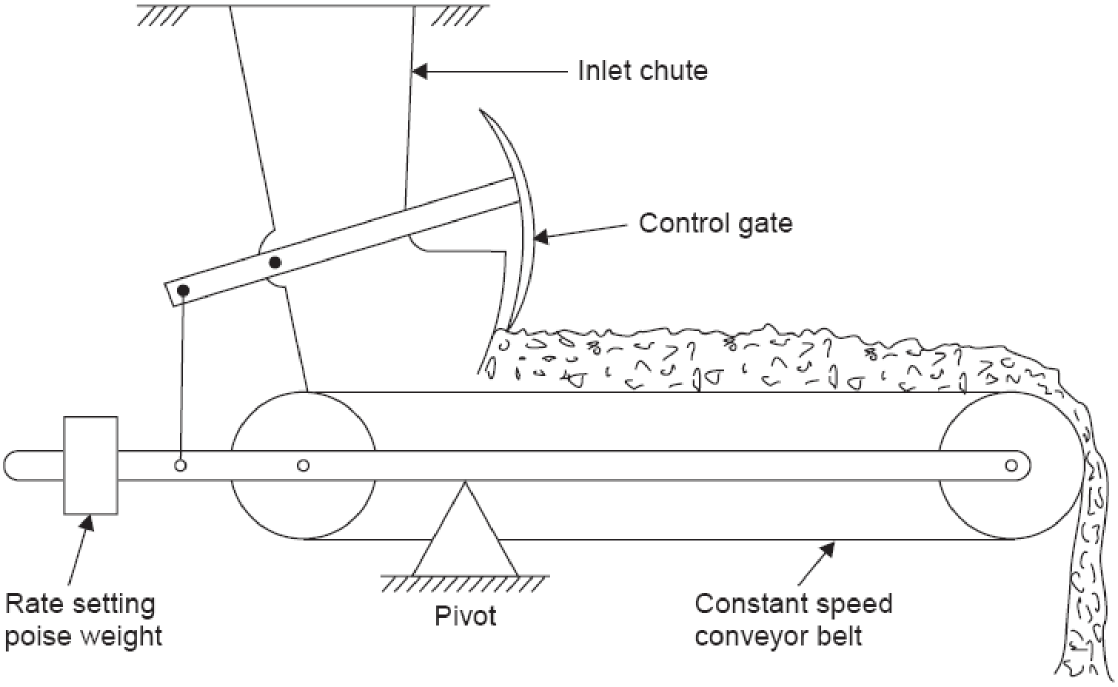


Figure:2.12 Belt type gravimetric feeder

1. The entire feeder is weighed rather than only a portion of the belt ; consequently, the low ratio of live load to tare coupled with mechanical friction in the linkage pivots results in relatively low sensitivity in the belt load detection system.
2. The position of the gate control element is proportional to the belt load error. In the same manner that a float-operated level control valve cannot maintain the level at set point if valve supply pressure vary, this feeder cannot maintain set gravimetric rate if the bulk density of the solids varies. It should be noted that the basic principle involving the weighing of the entire feeder has been applied in modern designs. Successful operation of these versions has

been achieved by adding belt load error detecting instrumentation and by actuating the control gate from an external power source. A controller with reset function eliminates the set point error.

2.10.2 Belt Type Electromechanical Gravimetric Feeder

Here the belt load is balanced by a mechanical beam and poise weight system which energizes one or other of two clutches via a pair of mercury switches energized by a magnet attached to the beam. These clutches actuate and establish the direction of travel of the gate-positioning mechanism.

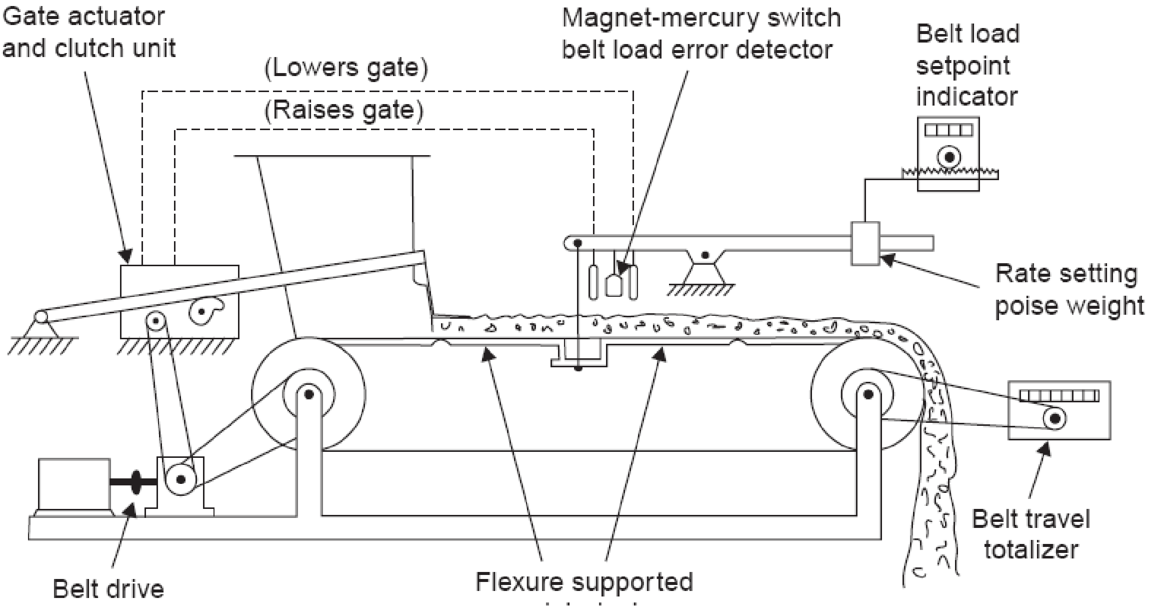


Figure:2.13 Belt type Electromechanical gravimetric feeder

The gate modulates as required to maintain the desired belt load as established by the position of the poise weight on the balance beam. It can be seen that this feeder will maintain belt load regardless of changes in material density, subject to the volumetric control limits of the gate. Belt load set point is indicated by a mechanical counter geared to the beam poise weight drive. A second counter geared to the belt drive totalizes the length of the belt travelled. By varying drive gears, these counters can be provided to read directly. Total weight fed can thus be calculated by multiplying the readings of the two counters. Remote belt load set point and readout functions are available as well as a belt travel contact switch may be used to operate a remote counter or to shut down the feeder via a predetermining counter after the desired total weight of material has been fed. Adjustable micro switches actuated by gate position may be utilized to activate alarms indicating either a stoppage of the material supply to the feeder or over travel of the control gate resulting from abnormal low material density.

The feed rate of all belt-type gravimetric feeders is a function of the belt speed and the belt load. Belt speed is normally expressed in terms of meter per minute , while belt load is defined as Kg per metre of belt.

Feed rate = Belt speed * Belt load

In the case of the constant speed belt feeders, rate is directly proportional to belt load. Rate set point is thus in terms of belt load, and the belt load signal generated by the device can be read out as rate.

2.11 Selection of suitable hardware for pressure:

- Pressure Range-This is the most important factor to consider because if a pressure transducer is operating in the wrong range, it will not function correctly for your application
- Medium and material compatibility-The external factors within the application will have an effect on what material you need to select for your pressure transducer. It is important to find a material strong enough to withstand the environment it is operating in. For example; can the material be exposed to elements such as seawater; tap water; nitrogen; compressed air or oxygen without corroding
- Temperature-The operating temperature range is another consideration to take into account when selecting a pressure sensor. Some pressure transducers are able to withstand high surrounding temperatures without their performance being affected whereas others may not be so durable in this area. Finding out the operating temperatures of the pressure transducers and comparing this with the expected temperatures of your given environment is an important process before purchasing the sensor.
- Environment conditions-The environment of the application must be examined closely before a pressure transducer is selected. Some working factors could have an effect on how the sensor operates. How much shock and vibration will the pressure sensor be exposed to? Is the space restricted in the environment?
- Accuracy -The level of accuracy you require will once again depend on your application. This will depend on the individual sensor.

2.11.1Pressure measurement:

2.11.2 Bourdon tube pressure gauge:

The Bourdon pressure gauge operates on the principle that, when pressurized, a flattened tube tends to straighten or regain its circular form in cross-section. The Bourdon tube comes in C, helical, and spiral shapes—although most gauges employ the C shape. One end is left free and the other end is fixed and is open for the pressure source to be applied. A tube of elliptical cross section has a smaller volume than a circular one of the same length and perimeter. When connected to the pressure source it is made to accommodate more of the fluid. Resultant of all reactions will produce maximum displacement at the free end. Within

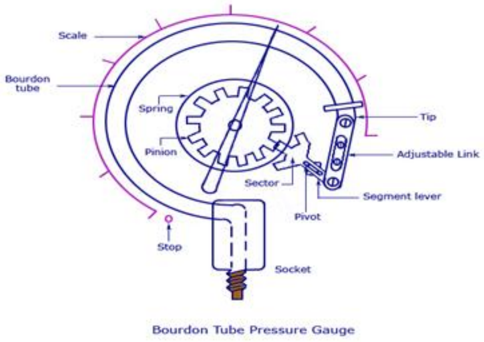


Figure:2.14 Bourdon tube pressure gauge

close limits, the change in angle subtended at the centre by a tube is proportional to the change of internal pressure and within the limits of proportionality of the material; the displacement of the free end is proportional to the applied pressure. The ratio between major and minor axes decides the sensitivity of the Bourdon tube. The larger is the higher is the sensitivity. Materials of the Bourdon tube is Phosphor bronze, Beryllium bronze or Beryllium Copper.

Bellows-Type Detectors

The need for a pressure sensing element that was extremely sensitive to low pressures and provided power for activating recording and indicating mechanisms resulted in the development of the metallic bellows pressure sensing element. The metallic bellows is most accurate when measuring pressures from 0.5 to 75 psig. However, when used in conjunction with a heavy range spring, some bellows can be used to measure pressures of over 1000 psig. Figure 1 shows a basic metallic bellows pressure sensing element.

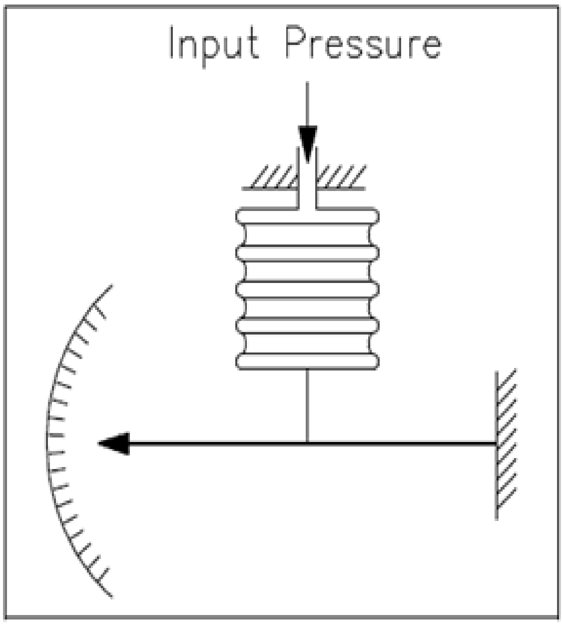


Figure:2.15 Bellow type detectors

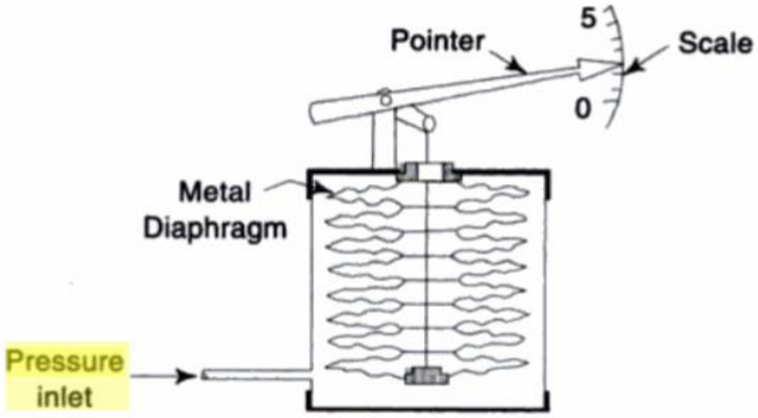
The bellows is a one-piece, collapsible, seamless metallic unit that has deep folds formed from very thin-walled tubing. The diameter of the bellows ranges from 0.5 to 12 in. and may have as many as 24 folds. System pressure is applied to the internal volume of the bellows. As the inlet pressure to the instrument varies, the bellows will expand or contract. The moving end of the bellows is connected to a mechanical linkage assembly. As the bellows and linkage assembly moves, either an electrical signal is generated or a direct pressure indication is provided. The flexibility of a metallic bellows is similar in character to that of a helical, coiled compression spring. Up to the elastic limit of the bellows, the relation between increments of load and deflection is linear. However, this relationship exists only when the bellows is under compression. It is necessary to construct the bellows such that all of the travel occurs on the compression side of the point of equilibrium. Therefore, in practice, the bellows must always be opposed by a spring, and the deflection characteristics will be the resulting force of the spring and bellows.

2.11.3 Diaphragm pressure gauge

Diaphragms are widely used for pressure (gauge pressure) and draft measurements, particularly in very low ranges. They can detect a pressure differential even in the range of 0 to 4 mm.

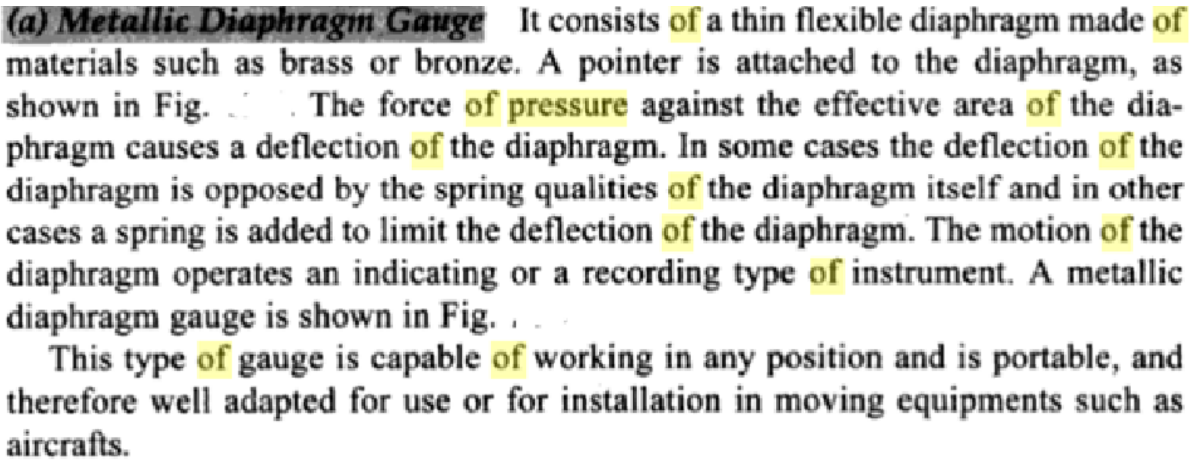
The diaphragms can be in the form of flat, corrugated or dished plates and the choice depends on the strength and amount of deflection desired. In high precision instruments the diaphragms are generally used in a pair, bak-to-back, to form an elastic capsule.

With suitable modification, diaphragm elements can be made to cause changes in electrical circuits, thus converting pressure movements to electrical signals which can be transmitted to an indicating or a recording system. Two types of diaphragms are generally used:



Metallic Diaphragm.

Figure:2.16 Metallic diaphragm



(a) Metallic Diaphragm Gauge It consists of a thin flexible diaphragm made of materials such as brass or bronze. A pointer is attached to the diaphragm, as shown in Fig. . The force of pressure against the effective area of the diaphragm causes a deflection of the diaphragm. In some cases the deflection of the diaphragm is opposed by the spring qualities of the diaphragm itself and in other cases a spring is added to limit the deflection of the diaphragm. The motion of the diaphragm operates an indicating or a recording type of instrument. A metallic diaphragm gauge is shown in Fig. .

This type of gauge is capable of working in any position and is portable, and therefore well adapted for use or for installation in moving equipments such as aircrafts.

2.12 Selection of suitable measurement of hardware for level

- Maximum Temperature
- Available as non contact
- Accuracy
- Cost
- Level range
- Applications for solids , liquids,slurries, viscous,powder, sticky, Nature of liquid,condition of liquid
- Operating conditions
- Consideration of durability, maintainability and consistency of performance are also very important during selecting the appropriate instrument.
- Range of measurement
- Type of response or output
- Tank size and shape
-

2.12.1Electrical Types Of Level Gauges Using Resistance

Electrical methods consist in converting liquid levels into electrical signals and measure by electrical or electronics means. The simplest of electrical types is the resistive method, a scheme of which is shown in fig. This is also known as the contact point type. A mercury column is operated by the liquid column so that the resistance R is measured. If R decreases with increasing level. A number of resistances of suitable values have their one end inserted in the column as shown in fig (Resistive level gauge)

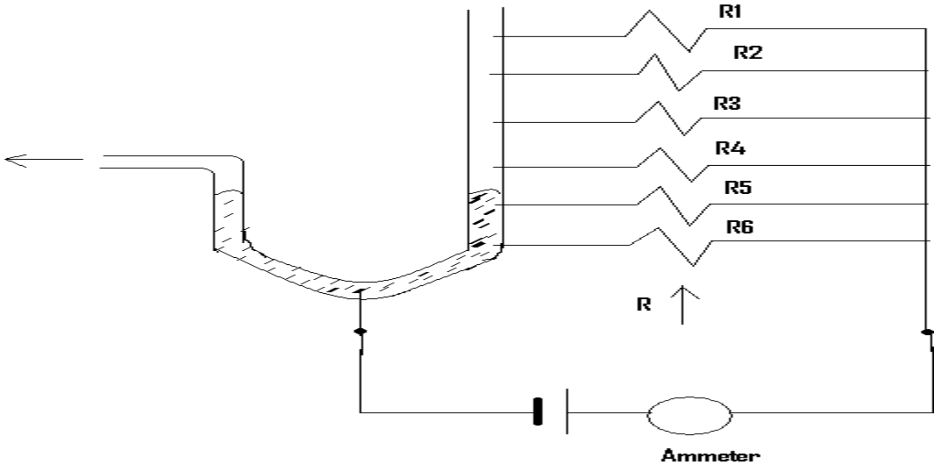
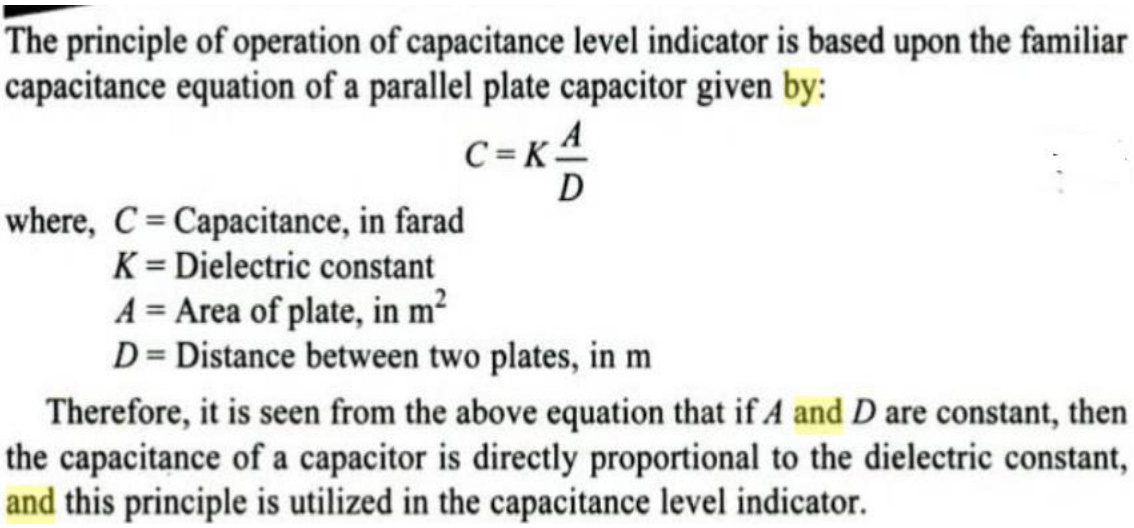


Figure:2.17 Resistance type level gauge

- Resistance is inversely proportional to current.
- ADV (linear output)(less maintenance)

Disadv(more resistors)

2.12.2 Capacitance type level indicator



The principle of operation of capacitance level indicator is based upon the familiar capacitance equation of a parallel plate capacitor given by:

$$C = K\frac{A}{D}$$

where, C = Capacitance, in farad
K = Dielectric constant
A = Area of plate, in m^2
D = Distance between two plates, in m

Therefore, it is seen from the above equation that if A and D are constant, then the capacitance of a capacitor is directly proportional to the dielectric constant, and this principle is utilized in the capacitance level indicator.

Construction and Working

Figure [illegible] shows a capacitance type liquid level indicator. It consists of an insulated capacitance probe (which is a metal eletrode) firmly fixed near and parallel to the metal wall of the tank. If liquid in the tank is non-inductive, the capacitance probe and the tank wall form the plates of a parallel plate capacitor and liquid in between them acts as the dielectric. If liquid is conductive, the capacitance probe and liquid form the plates of the capacitor and the insulation of the probe acts as the dielectric. A capacitance measuring device is connected with the probe and the tank wall, which is calibrated in terms of the level of liquid in the tank.

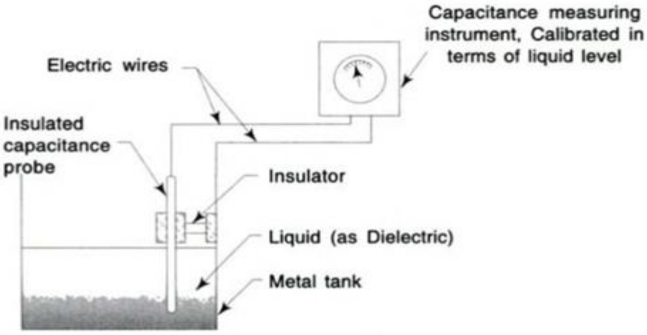


Figure:2.18 Capacitance type level gauge

When the level of liquid in the tank rises, the capacitance increases. When liquid level in the tank decreases, the capacitance also decreases. This increase and decrease in the capacitance is measured and is displayed on the indicator calibrated in terms of liquid level.

Advantages

Following are the advantages of a capacitance level indicator:

(i) It is very useful in a small system.
(ii) It is very sensitive.
(iii) There are no moving parts exposed to fluid.
(iv) It is suitable for continuous indication and/or control.
(v) Remote adjustment of span and zero is possible in this type of level indicator.
(vi) It is good for use with slurries.
(vii) Prob materials for most corrosive fluids are available.

Disadvantages

Following are the disadvantages of a capacitance level indicator:

(i) The performance of a capacitance level indicator is severely affected by dirt and other contaminants, because they change the dielectric constant.
(ii) Its sensitivity is adversely affected by changes in temperature.
(iii) Measured fluid must have proper dielectric qualities.
(iv) They usually require recalibration if measured material changes in comp osition or moisture content.
(v) Prob length and mounting must suit the tank.

2.12.3 Radiation level detector

Radiation level detectors are used where other electrical methods would not survive. Also, the most common reason for using a radiation level detector is that it does not need to come in contact with the liquid being measured.

Construction and Working

Figure shows a radiation level detector. It consists of gamma rays source holder on one side of the tank and a gamma detector on the other side of the tank. The gamma rays from the source are directed towards the detector in a thin band of radiation. When the gamma rays penetrate the thick wall of the tank, its energy level afterwards is greatly reduced. The radiation received at the gamma detector is inversely proportional to the thickness of the tank walls and the medium between the radiation source and the detector. That is, the thicker the medium between source and detector, the less radiation received by the detector and vice versa.

When the tank is empty, the gamma rays pass only through the two tank walls and the air or vapour in the empty tank. When liquid enters the tank and its level rises, the radiation beam passes through a path in the liquid, as well as the tank walls. The liquid in the tank reduces the radiation received by the detector.

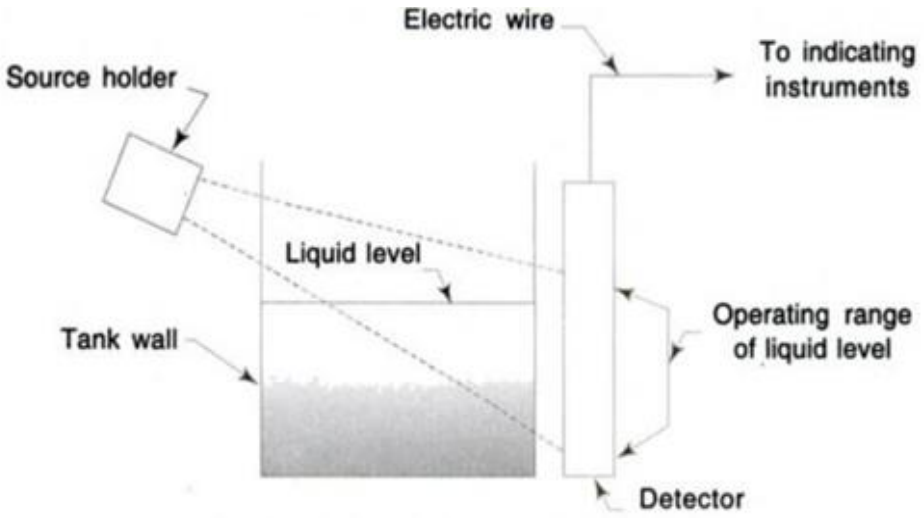


Fig. 2.19 *Radiation Type Level Indicator*

The amount of radiation received is inversely proportional to the amount of liquid between the radiation source and the detector. The difference in the amount of radiation received by the detector, corresponds to the liquid level in the tank. Thus, when liquid level rises, the amount of radiation received is reduced and vice versa. The radiation loss received by the tank walls is constant whether the tank is full or empty.

Advantages

Following are the advantages of radiation level indicators:

(i) There is no physical contact with the liquid.

(ii) They are suitable for molten metals as well as liquids of all types (corrosive, abrasive, highly viscous, adherent).

(iii) They are useful at very high temperatures/pressures.

(iv) They have good accuracy and response.

(v) They have no moving parts.

Disadvantages

Following are the disadvantages of radiation level indicators:

(i) The reading is affected by density change of liquid.

(ii) Radiation sourceholders may be heavy.

(iii) Their cost is relatively high.

2.12.4 Ultrasonic Level Indicators

Ultrasonic level detectors operate either by the absorption of acoustic energy as it travels from source to receiver or by the attenuation (frequency change) of a vibrating diaphragm face, oscillating at 35 to 40 KHz. It operates by generating an ultrasonic pulse and measuring the time it takes for the echo to return. When an ultrasonic transmitter is mounted at the top of the tank, the pulse travels in air at a speed of 331 meter/second at 0 °C. The time of travel is an indication of the depth of the vapour space above the liquid in the tank. If an ultrasonic transmitter is mounted on the bottom of the tank, the time of travel reflects the depth of liquid in the tank and the speed of travel is a function of what that liquid is. In case of water at 25 °C, an ultrasonic pulse travels at the speed of 1,496 meters/second. Figur illustrates the working of an ultrasonic level detector.

In order to measure the time of travel of the echo of an ultrasonic pulse, it is essential that some of the sonic energy be reflected. Liquids and solids with large and hard particles are good reflectors. Loose dirt have poor reflecting

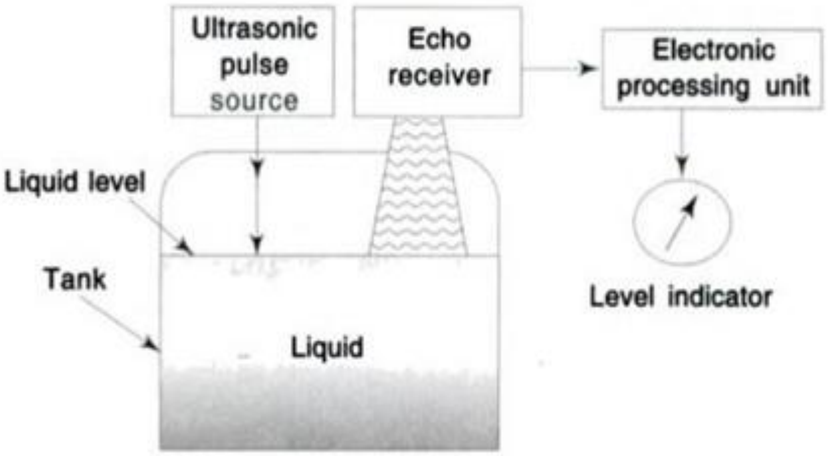
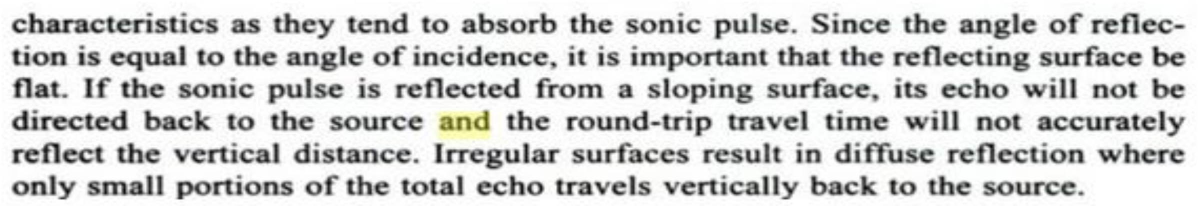


Fig. 2.20 *Ultrasonic Level Detector*



characteristics as they tend to absorb the sonic pulse. Since the angle of reflection is equal to the angle of incidence, it is important that the reflecting surface be flat. If the sonic pulse is reflected from a sloping surface, its echo will not be directed back to the source and the round-trip travel time will not accurately reflect the vertical distance. Irregular surfaces result in diffuse reflection where only small portions of the total echo travels vertically back to the source.

2.13 Selection of suitable hardware for temperature

- accuracy,
- response time,
- size
- temperature range
- installed cost (an important factor where many points of measurement are involved),
- sealing the detector from the process environment without significantly reducing response time,
- user's experience factor.
- Sensor location
- Choice between the various types of temperature measuring instruments for a given situation depends mainly on the type of medium to be measured.
- For the fluid temperatures can be measured by any of the instruments with the exception of radiation thermometers.
- The most commonly used devices in the industry for the temperature measurement is the base-metal thermocouple. The full scale over the temperature range -25 degreeC to +1200 degreeC.
- Noble metal thermocouples are much more expensive, but are chemically inert and can measure temperature up to 2300 degree.

2.13.1 Resistance Temperature detector (RTD)

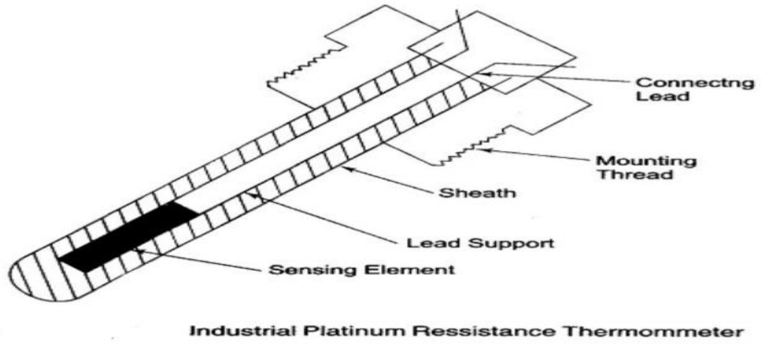
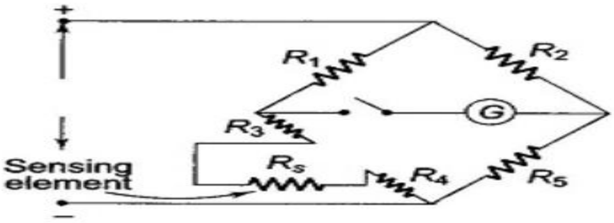


Figure 2.21: Resistance temperature detector

- The resistance of a conductor changes when its temperature is changed. This property is used for measurement of temperature.
- The Resistance Thermometer Connected in Bridge Circuit uses the change in electrical resistance of conductor to determine the temperature.
- Platinum, Nickel and Copper are the metals most commonly used to measure temperature.
- the temperature range over which Platinum has stability is 260 °C-1100 °C.

In normal practice, the sensing element is away from the indicator and the bridge, and its leads have a resistance, say R_3, R_{4}.

$$\frac{R_1}{R_2} = \frac{R_s + R_3 + R_4}{R_5}$$



Resistance Thermometer Connected in a Bridge Circuit

Advantages

High accuracy, fast response, small size

Disadv

1. High cost
2. Need for bridge and power source
3. Possibility of self heating.

2.13.2 Thermocouples

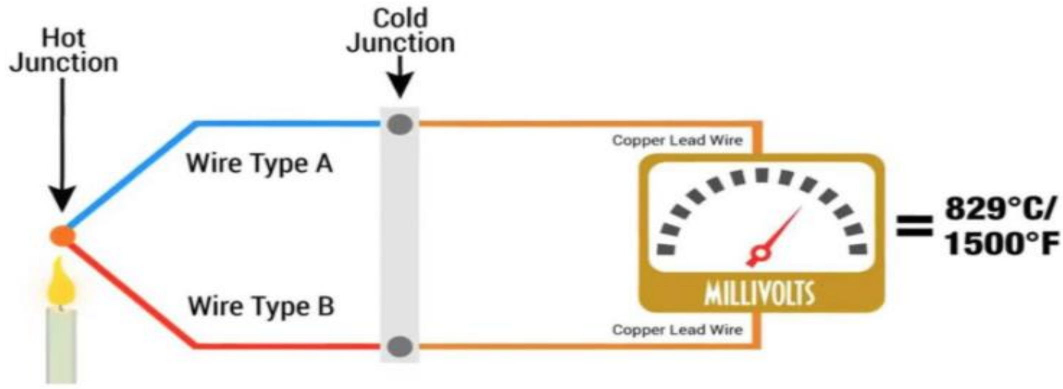
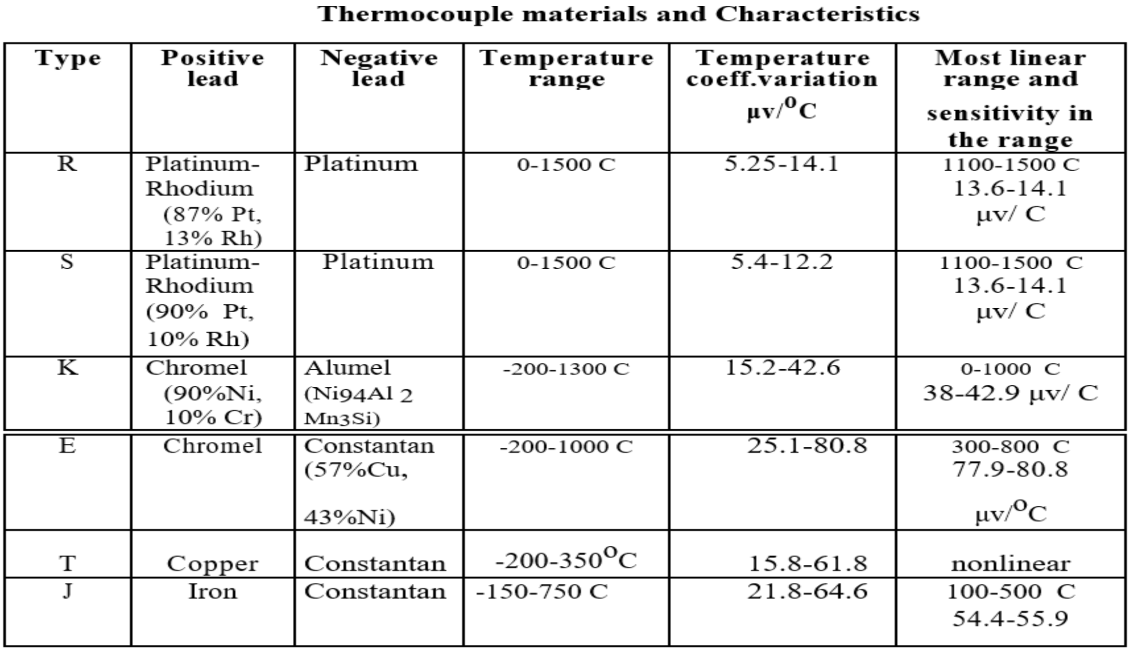


Figure 2.22: Thermocouple

- A thermocouple is a sensor that measures temperature.
- It consists of two different types of metals, joined together at one end.
- When the junction of the two metals is heated or cooled, a voltage is created that can be correlated back to the temperature.
- A thermocouple is a simple, robust and cost-effective temperature sensor used in a wide range of temperature measurement processes.
- Adv
- Inexpensive, no need of bridge circuit, good accuracy
- Disadv
- Temperature- voltage relationship non linear



Thermocouple materials and Characteristics

Type	Positive lead	Negative lead	Temperature range	Temperature coeff.variation μv/^{o}C	Most linear range and sensitivity in the range
R	Platinum-Rhodium (87% Pt, 13% Rh)	Platinum	0-1500 C	5.25-14.1	1100-1500 C 13.6-14.1 μv/ C
S	Platinum-Rhodium (90% Pt, 10% Rh)	Platinum	0-1500 C	5.4-12.2	1100-1500 C 13.6-14.1 μv/ C
K	Chromel (90%Ni, 10% Cr)	Alumel (Ni94Al 2 Mn3Si)	-200-1300 C	15.2-42.6	0-1000 C 38-42.9 μv/ C
E	Chromel	Constantan (57%Cu, 43%Ni)	-200-1000 C	25.1-80.8	300-800 C 77.9-80.8 μv/^{o}C
T	Copper	Constantan	-200-350^{o}C	15.8-61.8	nonlinear
J	Iron	Constantan	-150-750 C	21.8-64.6	100-500 C 54.4-55.9

2.14 Moisture measurement

- For paper producers, paper manufacturers, paper mills and others in the pulp and paper industry, moisture and humidity control is essential, especially during the production process, as excessive moisture can lead to warming of the paper rolls. A paper moisture meter can be used to detect moisture streaks during the paper production process as well as to identify optimal drying times.
- Regardless of whether paper is stored in paper rolls in paper converting plants or stacked in sheets and paper bales in commercial printing warehouses, the porous surface of paper gradually takes in moisture relative to the humidity of the surrounding environment. This moisture can be problematic, as too much moisture can cause curling, buckling or the formation of waves in otherwise flat paper products. Moisture also can prevent inks, dyes, paints and coatings from covering and saturating paper properly during printing and processing.
- Moisture analyzers utilize Loss On Drying (LOD) method to measure moisture.

- In this method, the moisture analyzer weighs a sample, heats it up to dry it, and weighs it again once it’s dry.
- The weight after drying is subtracted from the weight before, so the loss of moisture is determined using the loss of mass.
- **Oven Dry Method** – A paper sample is weighed and then exposed to a 221°F oven. When the samples are re-weighed after cooling, the gravimetric difference is calculated as “percent moisture.” This is the most accurate method and serves as the reference for any instrumental measurements.

2.14.1 Infrared Absorption Hygrometer

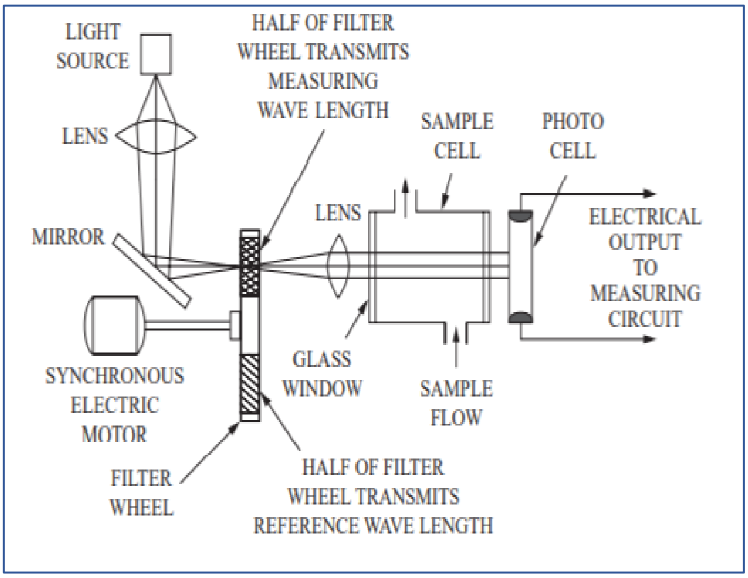


Figure 2.22: Infrared absorption hygrometer

- Water absorbs electromagnetic radiation in the infrared (IR) region of the spectrum.
- Specifically, infrared radiation of 1.4 and 1.93 µm wavelength is absorbed strongly by water.
- By measuring the attenuation (decrease of light intensity) of a beam of this wavelength as it passes through a sample, the moisture content of the sample can be determined.
- However, other factors such as reflection and dispersion of the radiant energy will contribute to the attenuation.
- The difference in the attenuation of the measurement and reference wavelength is then a function of moisture content only.
- The sensing element consists of three groups of components: an IR radiation source, sample cell, and radiation detector.
- The radiation source consists of a lamp, filters to pass the measuring and references wavelengths, and optics to direct the beam through the glass sample cell.

- The radiation pickup consists of optics to collect the transmitted radiation and a photocell to convert the electromagnetic energy to an electric current.
- The measuring and reference wavelengths are allowed to impinge alternately on the photocell so that two sets of current pulses are produced. These pulses are converted into two direct current (DC) signal levels whose ratio represents the moisture content of the sample .
- The higher the moisture content, the higher the amount of light absorbed. The instrument measures the light reflected back.

2.14.2 Nuclear Moisture Meter Method

- In this instrument, the neutron moderating characteristics of the hydrogen atoms; are used for moisture detection.
- Neutrons are subatomic particles that are emitted during the atomic decay of certain radioactive materials.
- These particles are electrically neutral and have a mass approximately equal to the mass of a hydrogen atom.
- The hydrogen atom, because it is most nearly equal in its mass to the neutron, is the most efficient energy absorber (or moderator) of neutrons.
- Therefore, the number of reflected or moderated neutrons can be used as a measure of the number of hydrogen atoms present in the sample, which relates to its moisture content. However, density also affects the amount of neutrons reflected.

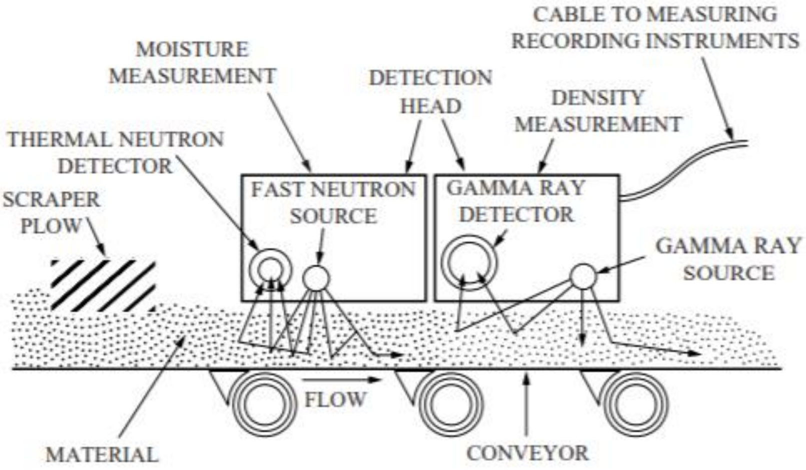


Figure 2.24: Nuclear moisture meter method

- The measuring system contains a high-energy neutron source of plutonium-beryllium or americium-beryllium and a low-energy neutron detector.
- The density measurement is made by a gamma-ray source and detector arranged to measure reflected or transmitted gamma rays.

- The moisture and density measurement signals are fed to an electronic chassis where they are scaled to engineering units and presented for readout as a compensated moisture concentration.

2.15 Consistency measurement

- Consistency is the term used to describe the solid content of a solid liquid mixture.
- consistency is expressed as a percentage by dividing the mass of solid material by the total mass of a wet sample, resulting in units of mass per unit mass.

  In order to have good control over the basis weight of the paper product, it is necessary to maintain the consistency of the feed constant

The weight of suspended solids per liter of liquid

$$\text{Total cons. (\%)} = \frac{\text{dry weight of sample}}{\text{total weight of sample}} \times 100$$

2.15.1 Mechanical consistency devices.

- These consistency-measuring instruments detect consistency of the process fluid as shear forces acting on the sensing element for consistencies greater than about 1%.
- In rotary devices, the shear force is reflected as the torque required to maintain the sensor at constant speed, as the imbalance of a strain-gauge resistance bridge, or as a turning moment.
- Stationary sensors depend on the process flow for measurement, and for such instruments, the output is affected by the velocity of the flow.

2.15.2 Blade Consistency Transmitter

- The consistency transmitter operates by measuring the shear force of the pulp as it passes the sensor.
- The sensor blade (located in the process stream) measures the sum of shearing forces created by pulp network shearing on the blade and dragging along the sides of the blade.
- The friction between the fiber network and the blade surface is converted into a output signal that varies as the consistency varies.
- These forces tilt the blade and move the diaphragm the blade is attached to on the transmitter body.
- The diaphragm actually acts as a spring and transfers the blade movement to the measuring arm. The displacement of the arm is measured by an electronic displacement sensor (eddy probe) which converts the distance in the gap between the arm and the sensor itself.
- The shear force value is transformed into gap measurement, which is converted to a consistency value by calibration based on laboratory verification.

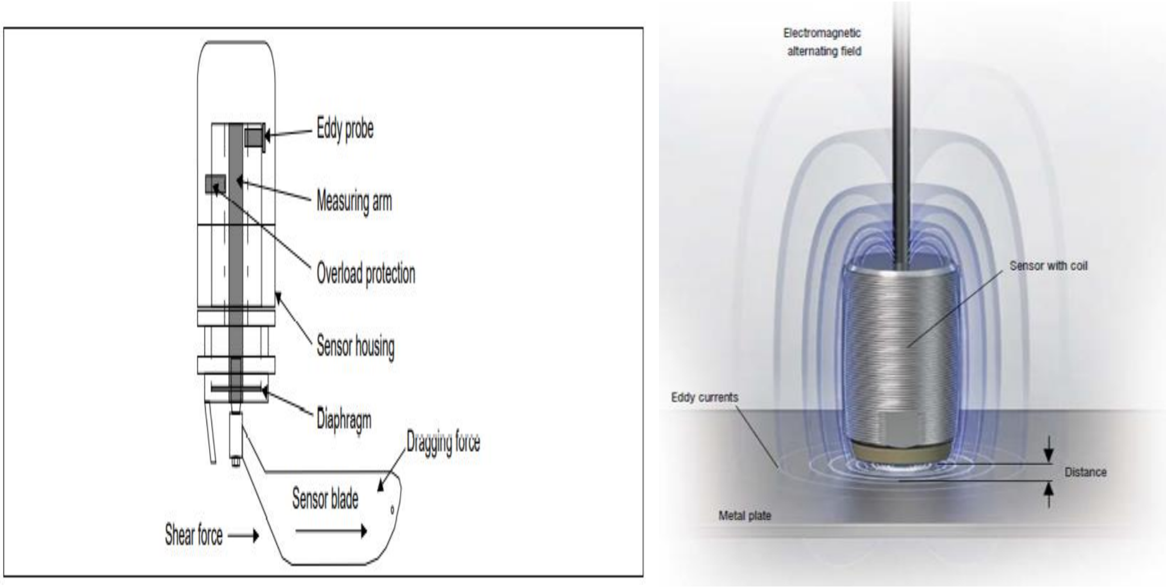


Figure 2.25: Blade consistency transmitter

- An analog 4 - 20 mA output signal is based on consistency signal
- A change in consistency affects shear force, which varies the deflection of the diaphragm thereby altering the displacement of measuring arm.
- This change in the arm position is sensed by the eddy probe and via the electronics is transformed to current signal (4 - 20 mA) which is proportional to consistency
- **Eddy current sensor**s uses the principle of eddy current formation to sense displacement.
- When the sensing coil is supplied with an alternating current, it causes a magnetic field to form around the coil.
- If an electrically conducting material is placed in this field, eddy current field is induced according to the Faraday's induction law.
- When the object moves, it causes the change in the impedance of the coil, which is proportional to the change in the distance between the sensor and the target.

2.15.3 Probe type

- This sensor transmitter functions as a resistance bridge strain gauge.
- The bridge elements are bonded to the inner wall of a hollow cylinder that is inserted into the process.
- The shear force acting in the cylinder, due to the consistency of the process fluid, causes an imbalance of the resistance bridge.
- The amount of imbalance is proportional to the shear force and the consistency of the process fluid.

2.15.4 Rotating sensors

- This unit consists of a motor-driven, ribbed disk immersed in the process fluid.

- The disk is rotated at constant speed, and variations in torque output by the motor are sensed by a torque arm.
- The motor is suspended by flexure bearings and anchored to the torque arm, which senses motor reaction torque.
- The detection of the torque force in the earlier designs were done pneumatically, today’s version are electrical.

Rotating sensors

2.15.5 Optical consistency sensors

Accordingly, optical devices, either in transmission or scatter mode, are the sensors of choice for low consistencies, relying on the fiber’s interaction with light, as shown in Figure for three types of sensors.

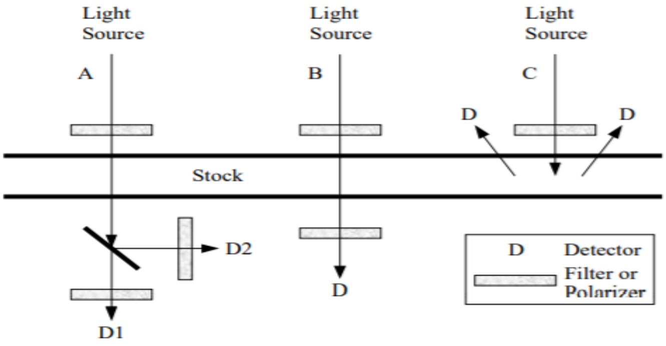


Figure 2.26: optical consistency sensors

- Sensor A uses linearly polarized light from either a halogen bulb or a semiconductor laser, which is passed through the measurement cell.
- The transmitted light is split into two beams, one passing through a second transverse-plane polarizing filter, the other passing through a third in-plane polarizing filter.
- The beams are detected by photodiodes and combined to produce a relative depolarization signal, which is a function of the total fiber and filler.
- The signal is insensitive to brightness, color, freeness, or soluble additives

2.15.6 Measuring Woodfree Pulp

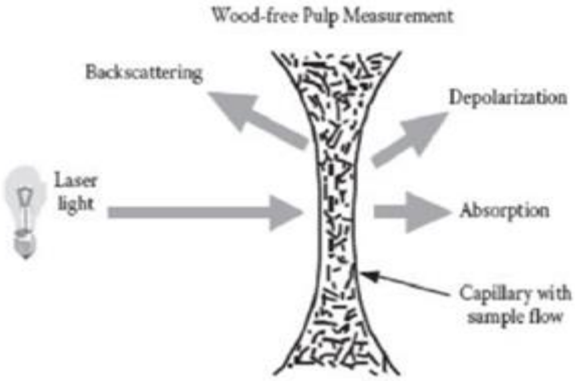


FIG. 2.27

Consistency measurement used to control retention on paper machines. (Courtesy of Metso Automation.)

This device is similar to sensor A in Figure in that a polarized light beam is directed through a glass capillary cell, where the sample continuously flows. The transmitted light is directed through a special aperture disk for scattering measurements, and then through a second polarizer, which splits the light into cross-polarized and parallel-polarized components that are detected by photodiodes. The depolarization signal mainly indicates the total consistency of the sample, and the attenuation of light is affected by the total consistency and filler consistency. Attenuation is strongly affected by scattering and light absorption. Since backscattering and attenuation are influenced by small particles, filler consistency is calculated from these signals.

Pulp containing wood

Pulp Containing Wood For pulp containing a considerable amount of fibers, and thus a large fraction of lignin, the depolarization scheme loses effectiveness. Another sensor has been developed that uses two light sources and a combination of optical measurement principles, including depolarization, absorption, and scattering at several wavelengths from the ultraviolet (UV) to the near infrared (NIR). An outline of this sensor is shown in Figure

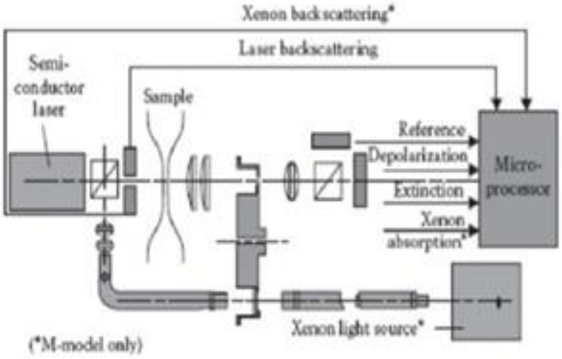


FIG. 2:28

Consistency measurement with two light sources used on wood-based pulp. (Courtesy of Metso Automation.)

- The near-IR semiconductor laser light is polarized, passed through the cell, and then depolarized, as before, in Figure 8.18e.
- UV light from the xenon lamp is directed through the cell via a filter and polarizing prism.
- The forward scattered light is directed through the lens and aperture disk to photodiodes.

- Backward scattering is also measured for both the UV and IR lights by detection with a photodiode before the cell.
- Light extinction, as well as backward and forward scattering, is measured at several different wavelengths
- . The signals are processed to monitor total solids and filler consistencies.

Wet end consistency analyser

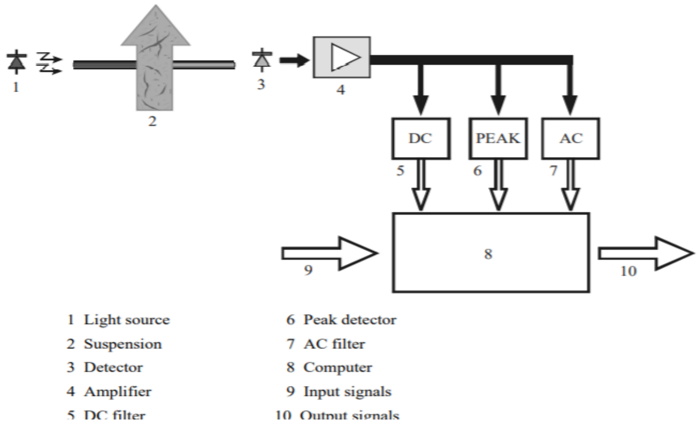


Figure 2.29: Wet end consistency analyser

- A light beam is directed at the suspension, and a photo detector senses the transmitted light.
- Three independent filters process the detector signal. The first filter determines the mean value VDC of the transmitted light; the second determines the peak value VP; and the third extracts the AC component VAC of the signal.
- The large particle content (LPC) is the difference between VP and VDC, while the fine particle content (FPC) is the difference betweenVCW and VP. The total consistency is obtained by summing lpc and FPC.
- VCW is the detector signal for clear water and is used as a reference value. The AC signal, VAC, is plotted along with VCW, VP, and VDC.

2.16 pH Meter

pH Value-The number of gram ions of hydrogen ion present in one litre of the solution is called the hydrogen ion concentration of the solution.The acidity or basicity of the solution is expressed in terms of hydrogen ion concentarion

$pH = -\log_{10}\ [H^+]$

$pH = -\log_{10}\ [1/ H^+]$

$pOH=-\log_{10}\ [OH^-]$

$=-\log_{10}\ [1/ OH^-]$

pH is a convenient measure of the acidity/alkalinity of an aqueous solution at a specified temperature (usually 25°C). It is measured on a continuous scale from 0 to 14. If the pH **value** is 7, the solution is neutral, if it is less than 7, the solution is acidic and if it is greater than 7, it is alkaline (base)

2.16.1 Glass Electrode

An indicator electrode is also called as a working or measuring electrode which responds to changes in the activity of the analyte ion. It consists of ether sodium /calcium silicate or lithium silicates with lanthanum and barium ions added glass membrane. There is an internal reference electrode Ag/AgCl or calomel. The body of the glass tube is made up of non conducting glass tube.

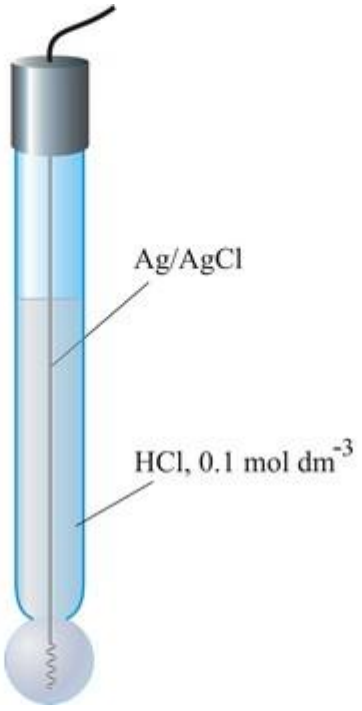


Figure 2.30: Glass electrode

Glass electrode is an ion selective electrode, sensitive, sensitive to H+ ions, so it is used to measure H+ ion concentrations. It is used with other reference electrodes to generate a potential difference.

Principle: When a glass surface is dipped in a solution containing hydrogen ions,it develops electro potential proportional to the conc.of hydrogen ion in the soln.

2.17 Oxidation reduction potential (ORP)

- Oxidation reduction potential (ORP), also known as REDOX, is a measurement that reflects the ability of a molecule to oxidize or reduce another molecule
- **Oxidation** is the loss of electrons, so **oxidizers** accept electrons from other molecules
- **Reduction** is the gain of electrons, so **reducers** donate electrons to other molecules
- Oxidation reduction potential is measured as a single voltage in millivolts (mV). Oxidizers have a positive ORP value, while reducers have a negative ORP value.

- Both oxidation and reduction can happen in the same reaction, which is why reactions involving oxidation and reduction are often called **redox** reactions.
- Chemicals (such as oxygen) that accept electrons from other compounds are called oxidizing agents, and substances (such as methane or hydrogen) that give up electrons are called reducing agents.
- The degree to which a fluid is oxidizing or reducing (represented by ORP) depends on the presence and strength of various oxidizing and reducing agents.
- ORP is expressed as an electrical potential (a voltage). Generally speaking, a reducing environment is indicated by a negative reading, and an oxidizing environment is indicated by a positive reading. The most common unit for expressing ORP is the millivolt (mV), and most meters can read values ranging from -1000 mV to +1000 mV.
- Oxidation-reduction potential (ORP) measurements are useful for the quantitative determination of ions, for monitoring chemical reactions, for determining the extent to which oxidizing or reducing reactions have taken place, and for determining the concentration of chemical species present.
- The measurement and control of oxidation-reduction potential (also called ORP or redox potential) is applied in many applications in both industrial processing and in wastewater treatment.
- In the pulp and paper industry, pulp is bleached with a variety of oxidants under ORP measurement and control
- The basic instrumentation used for ORP measurement closely parallels that used for pH measurement.
- In fact, many instrument suppliers use slightly modified pH analyzers for ORP detection, the main difference being changed sensitivity and a millivolt (mV) scale in place of a pH scale
- There are two major differences between an ORP system and a pH system.
- One is the sensing electrode, which in case of ORP measurement, is normally a noble metal (typically platinum or gold), although other metals and carbon have also been used on occasion. The second major difference is in temperature compensation. Process pH systems are typically temperature compensated, whereas ORP systems almost never.
- The detectors used for ORP measurement are very similar to that used for pH measurement. The reference electrode is identical to the pH reference electrode. The measuring electrode, however, consists of a noble metal instead of a glass bulb. The noble metal electrode is usually made from platinum, gold, or nickel, but carbon may also be used.

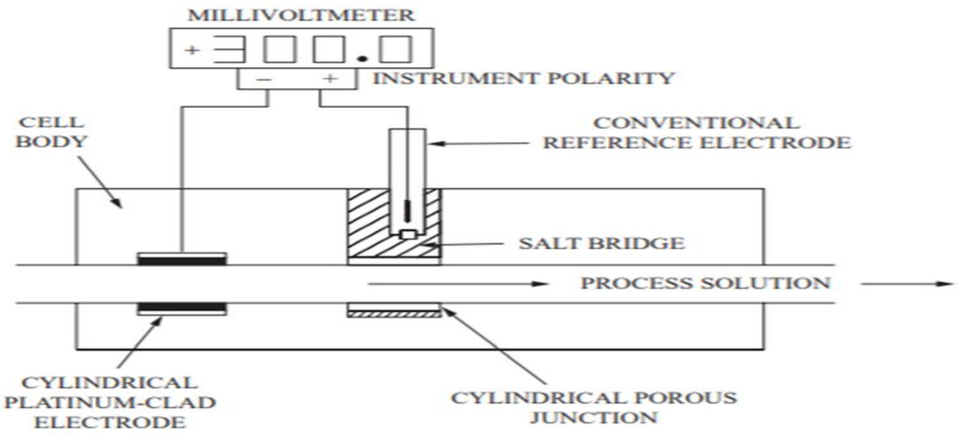


Figure 2.31: Measurement of Oxidation Reduction potential

- The object of the ORP control loop is to keep just enough excess reductant in the scrubbing fluid. The ORP set point would be in the reducing range, somewhere between –100 and –500 mV..
- In scrubbers that use white liquor or weak wash that contains sodium sulfide (Na_2S), pH must be maintained above 7, because otherwise sulfur compounds will tend to form and deposit in the scrubber, increasing chemical consumption, decreasing removal efficiency, and causing plugging.
- Further, for liquor or weak wash containing sodium hydrosulfide ($NaHS$), pH must be maintained above 8.5 to avoid the formation of hydrogen sulfide (H_2S) gas.
- Consequently, the control system shown in Figure includes a pH-based override controller. The output signal of this controller, through a high-signal selector (AY-1), overrides the ORP controller to ensure that enough white liquor or weak wash is added to keep the alkalinity at a pH of 9.0.
- Microbial Control in Cooling Towers Biocides are frequently used in cooling towers to control the growth of algae, bacteria, fungi, barnacles, and even clams and mussels in the water.
- Typical oxidizing microbiocides for this application are chlorine (Cl_2), bromine (Br_2), sodium hypochlorite ($NaOCl$), chlorine dioxide (ClO_2), and ozone (O_3). ORP-based continuous control of the addition of biocide helps to maintain effective treatment without wasting chemicals
- The desired range of ORP control is typically between 550 and 650 mV

TEXT / REFERENCE BOOKS

1.Liptak B G, “Instrumentation in the processing industries”, Chilton book Company, 1973.

2.Considine D. M., “Process/Industrial Instruments and control Handbook”, McGraw Hill, 5th edition 1999.

3. Hower P. Kallen, “Hand Book of Instrumentation and Control”, Tata McGraw Hill, 1961.

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SCHOOL OF ELECTRICAL AND ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION ENGINEERING

UNIT – III – Instrumentation in Industries – SIC1404

III. Instrumentation in Petrochemical Industries

P & I diagram of petroleum refinery, measurement and control of absolute pressure, density, conductivity, differential pressure and flow of evaporators. Measurement and control of column pressure, liquid distillate, vapour distillate

3.1 P&I diagram of petroleum refinery

- A piping and instrumentation diagram (P&ID) is a detailed diagram in the process industry which shows the piping and process equipment together with the instrumentation.
- A diagram which shows the interconnection of process equipment and the instrumentation used to control the process. In the process industry, a standard set of symbols is used to prepare drawings of processes and control devices.

3.1.1 Schematic flow diagram (P&I diagram) of a typical crude oil distillation unit as used in petroleum crude oil refineries.

- schematic flow diagram of a typical petroleum refinery that depicts the various refining processes and the flow of intermediate product streams that occurs between the inlet crude oil feedstock and the final end-products.
- Main Components of Distillation Columns
- schematic flow diagram of a typical petroleum refinery that depicts the various refining processes and the flow of intermediate product streams that occurs between the inlet crude oil feedstock and the final end-products.
- a vertical shell where the separation of liquid components is carried out
- column internals such as trays/plates and/or packings which are used to enhance component separations
- a reboiler to provide the necessary vaporization for the distillation process
- a condenser to cool and condense the vapour leaving the top of the column
- a reflux drum to hold the condensed vapour from the top of the column so that liquid (reflux) can be recycled back to the column
- Desalter unit washes out salt from the crude oil before it enters the atmospheric distillation unit.

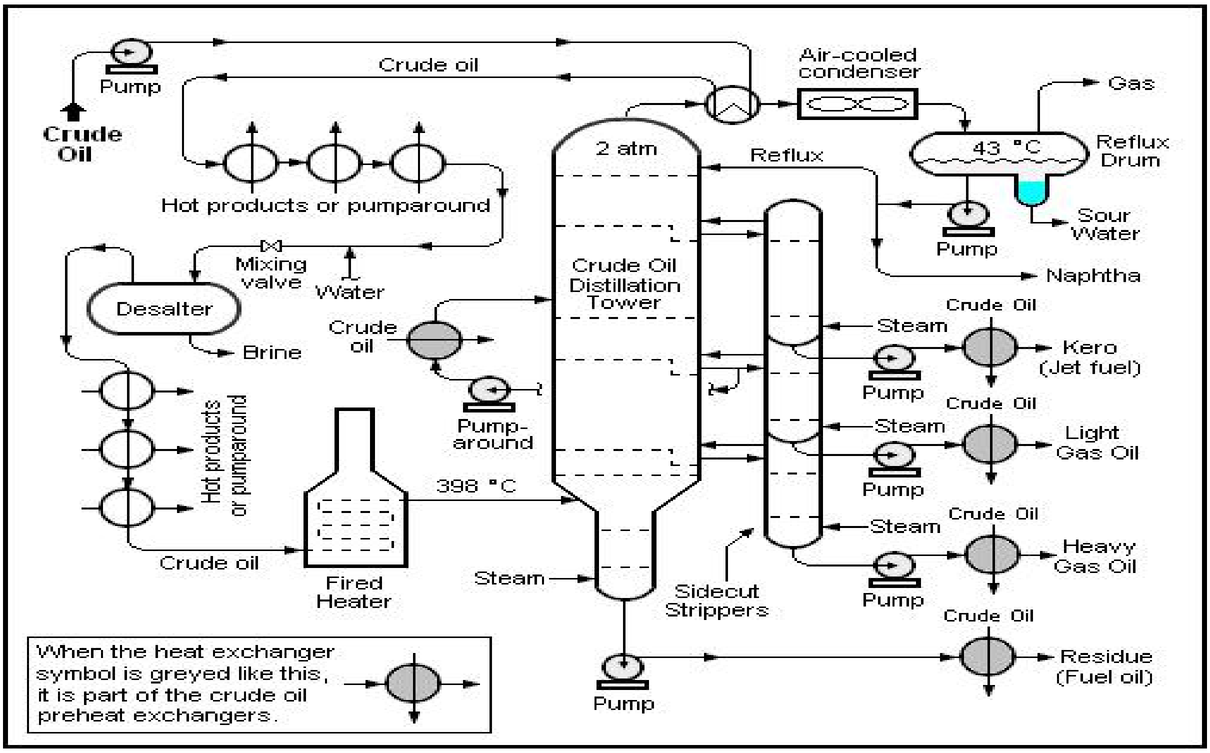


Figure 3.1 P&I diagram of petroleum refinery

3.2 Measurement and control of absolute pressure

- Absolute pressure is zero referenced against a perfect vacuum, so it is equal to gauge pressure plus atmospheric pressure. (or) actual total pressure (including atmospheric pressure) acting on a surface.
- Gauge pressure: A gauge that indicates zero at atmospheric pressure measures the difference between actual and atmospheric pressure.
- Differential pressure is the difference in pressure between two points. In differential pressure measurement, the gauge pressure is the difference between the absolute pressure of the fluid and atmospheric pressure.
- Static pressure: When the fluid is in equilibrium, the pressure at a particular point is identical in all directions and independent of orientation. This is called static pressure.
- Velocity pressure = Total pressure- static pressure.
- Pressure is measured by pressure sensors (PE) which are arranged to transmit pressure (PT) signals to pressure controllers (PIC).
- Pressure vessels and tanks are also usually provided with local pressure indicators (PI).
- Pressure in the petrochemical industry is frequently controlled by maintaining a constant pressure in the upper gas space of a vessel.
- The controller (PIC) adjusts the setting on a pressure control valve (PCV) that feeds gas forward to the next stage of the process.

- A rising pressure in the vessel results in the PCV opening to feed more gas forward.
- If the pressure continues to rise some controllers then act to open a second PCV that feeds excess gas to the flare system.
- The pressure transmitter is configured to provide warning alarms (PAL and PAH) if the pressure exceeds set high and low limits.
- If these limits are further exceeded an automatic shutdown of the system is initiated which includes closure of the inlet valves of the vessel.

3.2.1 Measurement of absolute pressure

Bellows:

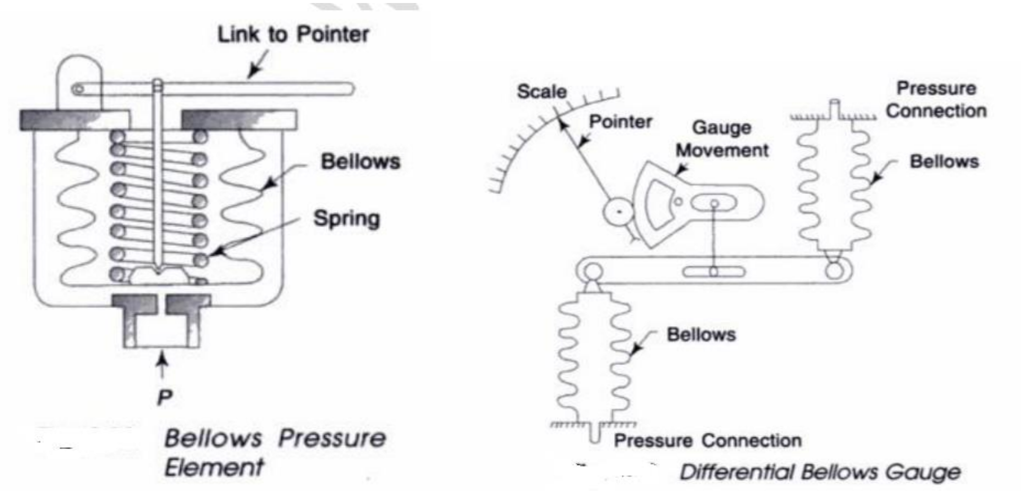


Figure 3.2: Bellows pressure gauge

• Principle: When an elastic pressure sensor (Bellow) is subjected to pressure, it deflects.

- The deflection is proportional to applied pressure when calibrated.
- The open end is used to receive applied pressure
- The closed end will expand due to pressure which is recorded or indicated.
- Rack & pinion arrangement.

Differential pressure measurement

- Just as differential pressure can be measured with a single bellows, dual bellows can also be used.
- The low process pressure is connected to the first bellows while the high process pressure is connected to the second bellows.
- Both of these process pressures will exert a force on the effective area of the bellows upon which they act. The resultant force rotates the pointer.

3.2.2 Diaphragm type pressure detectors

- **Metallic diaphragm gauge**
- Diaphragm –brass or bronze

- Force of pressure against the effective area of diaphragm causes defection
- Principle: the force (applied pressure) acts against the thin stretched diaphragm that causes a deflection, which is proportional to applied pressure.
- Diaphragm center deflects the most.

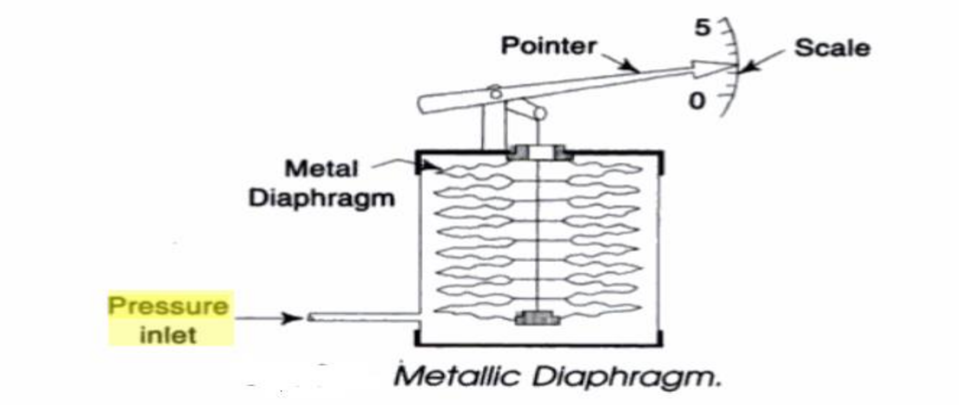


Figure 3.3: Metallic diaphragm pressure gauge

Slack diaphragm gauge

- Diaphragm –large area(made of rubber)
- Large change in force with small change in pressure A diaphragm with large change in force from small change in pressure. Similarly making the diaphragm slack (loose) rather than tight allows it to move a large distance in response to small pressure change.

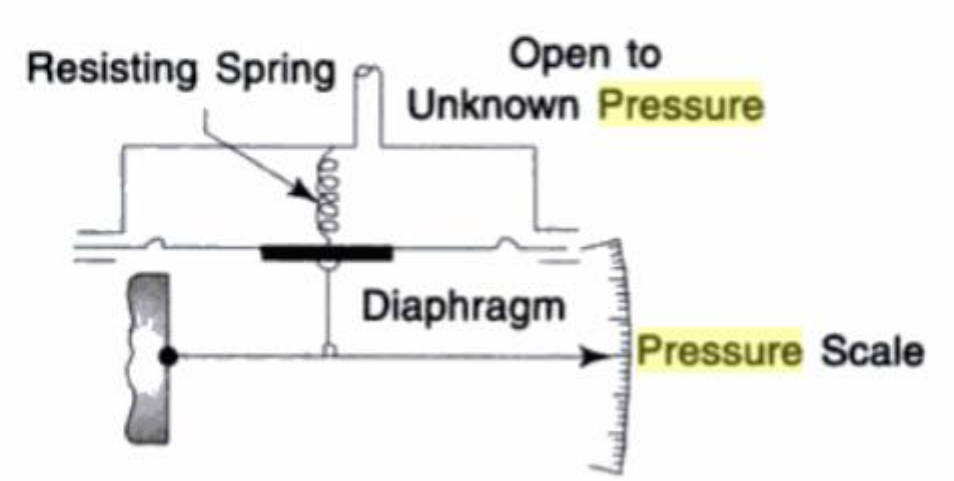


Figure 3.4: Slack diaphragm pressure gauge

Advantages

low cost, high range, good linearity

Disadvantages

difficult to repair

3.2.3 Piezoelectric type pressure detectors

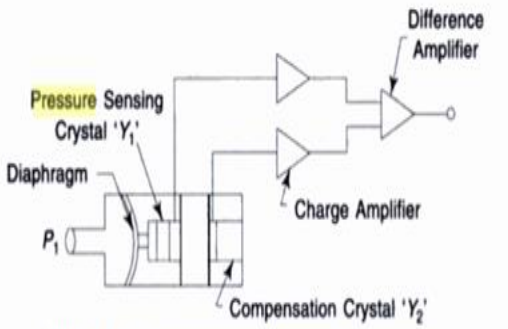


Figure 3.5 *Piezoelectric Pressure Transducer.*

- When pressure, force or acceleration is applied to a quartz crystal, a charge is developed across the crystal that is proportional to the force applied.
- Crystal of quartz, tourmaline, Rochelle salts
- It consists of a diaphragm by which pressure is transmitted to the piezoelectric crystal y1. this crystal generates an electrical signal which is amplified by a charge amplifier.
- A second piezoelectric crystal Y2 is included to compensate for any acceleration of the device during use.

Advantages

- no external power.
- Used to measure very high pressures that change very rapidly.

Disadvantages

- temperature compensation needed.

3.2.4 Capacitive pressure transducers

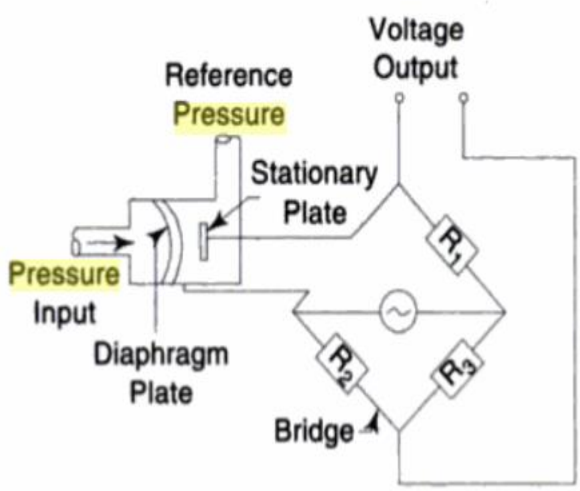


Figure 3.6: Capacitive pressure transducers

The capacitance C between the two plates of capacitive transducers is given by:

$$C = \varepsilon A/d$$

$$C = \varepsilon_r \varepsilon_0 A/d$$

Where A – overlapping area of plates in m^2

- d – the distance between two plates in m
- ε – permittivity of the medium in F/m
- ε_r – relative permittivity
- ε_0 – the permittivity of free space; $8.854*10^{-12}$ F/m.
- It consists of a fixed plate and a movable plate which is free to move as the pressure applied changes.
- According to the change in pressure the movable plate also change its position, due to which the distance d is changed.
- With an increase in pressure, d becomes less, capacitance c is increased.
- With a decrease in pressure, d increases, capacitance c is decreased.
- In place of a movable plate a diaphragm may be used, which expands and contracts due to change in pressure.
- The diaphragm acts as the movable plate of capacitor.
- A fixed plate is placed near the diaphragm.
- Any change in pressure causes a change in distance between the diaphragm and fixed plate, which unbalances the bridge.
- The voltage output of the bridge corresponds to the pressure applied.

3.2.5 Potentiometric pressure transducers

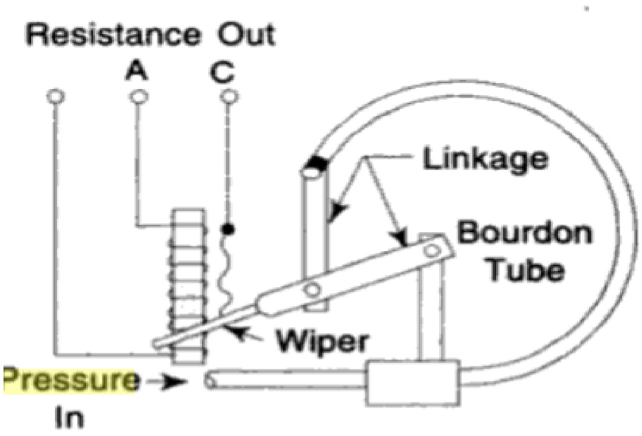


Figure 3.7: Potentiometric pressure transducers

- Potentiometer- made by winding resistance wire around an insulated cylinder.

- A movable electrical contact called a wiper alides along the cylinder, touching the wire at one point on each turn.
- The position of the wiper determines how much resistance is between the end of the wire and wiper.
- A mechanical linkage from the bourdon tube controls the position of the wiper on the potentiometer.
- An increase in pressure makes the bourdon tube straighten out partially.
- This motion causes the linkage to move the wiper across the winding on the potentiometer.
- As the wiper moves it increases the resistance between the terminals, which is equivalent to the pressure sensed by the bourdon tube.

3.2.6 LVDT pressure transducer

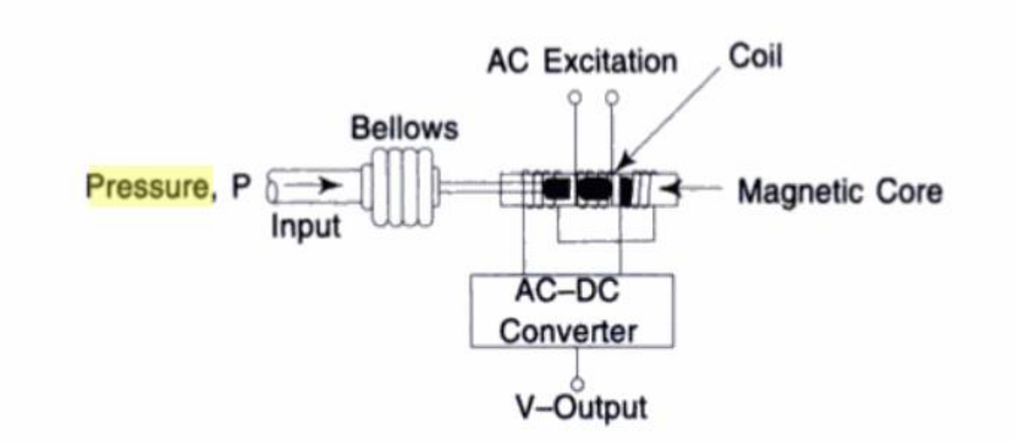


Figure 3.8: LVDT pressure transducers

- Linear variable Differential Transformer is the most inductive transducer to translate linear motion into electrical signal.
- It consists of a primary winding and two secondary windings.
- They are wound over a hollow bobbin which is usually a nonmagnetic and insulating material.
- A ferromagnetic core is attached to the bellows.
- A.c excitation is applied across the primary winding and the movable core varies the coupling between it and secondary windings.
- When the core is in the centre position, the coupling to the secondary coils is equal.

- As the core moves away from the centre position, the coupling to one secondary and hence its output voltage increases, while the coupling and the output of the other secondary decreases.
- Any change in pressure makes the bellows expand and contract.
- This motion moves the magnetic core inside the hollow portion of the bobbin.
- It causes the voltage of one secondary winding to increase while simultaneously reducing the voltage in the other secondary winding.
- The difference of the two voltages appears across the output terminals of the transducers and gives the measure of physical position of the core and hence the pressure.

3.2.7 Strain gauge pressure transducers

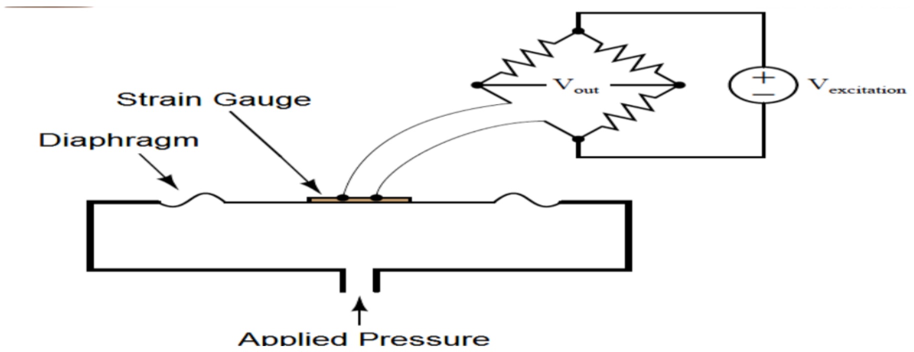


Figure 3.9: Strain gauge pressure transducers

- As the test specimen is stretched or compressed by the application of force, the conductors of the strain gauge are similarly deformed.
- Electrical resistance of any conductor is proportional to the ratio of length over cross-sectional area ($R \propto \{ l / A \}$), which means that tensile deformation (stretching) will increase electrical resistance by simultaneously increasing length and decreasing cross-sectional area while compressive deformation will decrease electrical resistance by simultaneously decreasing length and increasing cross-sectional area.
- Attaching a strain gauge to a diaphragm results in a device that changes resistance with applied pressure.
- Pressure forces the diaphragm to deform, which in turn causes the strain gauge to change resistance.
- By measuring this change in resistance, the amount of pressure applied to the diaphragm is known.
- As the diaphragm bows outward with applied fluid pressure, the strain gauge stretches to a greater length, causing its resistance to increase.

- This change in resistance imbalances the bridge circuit, causing a voltage (Vout) proportional to the amount of applied pressure.

3.3 Measurement and control of density

- Density is mass per unit volume. Relative density (also called specific gravity) is the ratio of the density of a gas to that of air at the same temperature, pressure, and moisture content.
- Fluid Dynamic Densitometer
- Radiometric measurements for industrial processes

3.3.1 Fluid Dynamic Densitometer

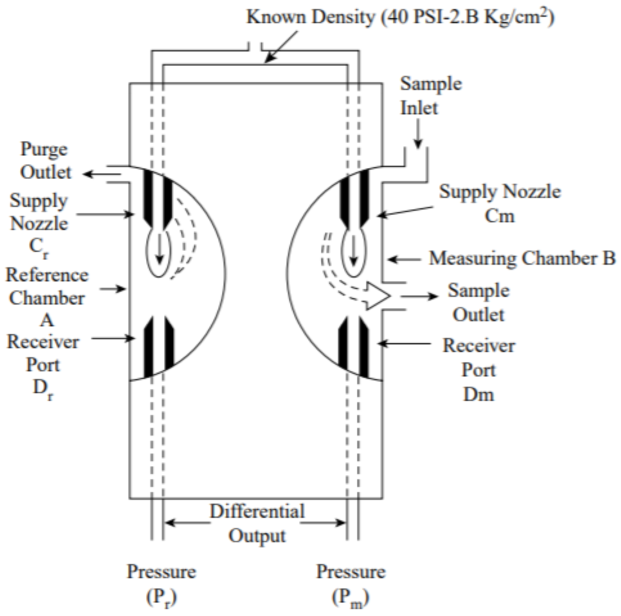


Figure 3.10: Fluid dynamic densitometer

- The fluid dynamic densitometer (is used to measure the densities of gases and liquids.
- It is composed of two chambers (A and B) each having a supply nozzle (Cr and Cm) and an opposing receiver port (Dr and Dm). One chamber is used as a reference chamber having only a small outlet port; it is filled with a suitable supply of nitrogen or other fluids (E) such that the dynamic pressure (Pr) of this jet on the receiver port (Dr) serves as a reference value.
- Directly adjacent to this reference chamber is a similar measuring chamber (B) that has large inlet and outlet ports through which the measured fluid is pumped by the action of the same supply fluid (E).
- The product whose density is to be measured, being entrained by this supply jet, affects the dynamic pressure (Pm) of this jet on the receiver port, which is inversely proportional to the density.
- A comparison of the pressure differential produced between the reference chamber and the measurement pressure is a measure of the density of the unknown product.

- It has no moving parts, a very high sensitivity, and a high rate of response, but it is not particularly suitable for non-Newtonian fluids.
- It can be made of a wide variety of materials and can be mounted directly in a body or stream of fluid to give precise point measurements.

3.3.2 Radiometric measurements

- The radiometric principle is based on the fact that isotopes – contained inside a source container – emit radiation that is damped as it penetrates a material (the medium).
- A detector mounted on the opposite side of a pipe containing this flowing medium converts the radiation it receives into an electric signal.
- The measuring effect as such derives from the absorption of radiation by the medium.
- This uses the received (attenuated) radiation to calculate density and also the concentration of the measured substance.
- The radiometric measurement of density is based on the Gamma transmission principle.
- Gamma radiation is attenuated as it passes through a pipeline. This attenuation is measured by a detector.
- The extent to which the radiation is attenuated is dependent on the density of the medium in the pipeline.
- The higher the density, the less radiation reaches the detector.
- In this way, density, concentration and solids content can be determined reliably in a non-contacting manner – regardless of pressure, temperature, viscosity, conductivity and chemical properties.
- This results in high reliability and low maintenance of the radiometric measuring systems, even under severe operating and environmental conditions.

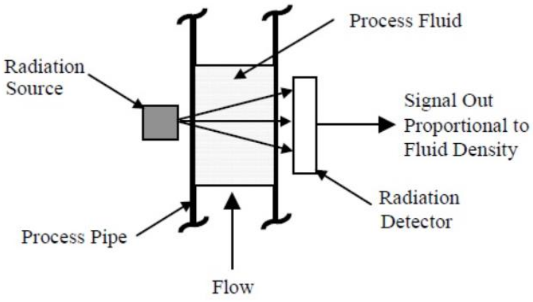


Figure 3.11: Radiometric densitometer

- They operate on the principle that the absorption of gamma radiation increases with the density of the material being measured.
- In the figure, a representative element for measuring the density of the radiation type is represented.
- It consists of a source of constant gamma radiation (which can be radio, cesium or cobalt), which is mounted on a wall of the pipe, and a radiation detector, which is mounted on the opposite side.

- The gamma rays are emitted from the source, through the pipe and the detector.
- The materials that flow through the pipe and between the source and the detector absorb radioactive energy in proportion to their densities.
- The radiation detector measures the radioactive energy that is not absorbed by the process material.
- The quantity that is measured varies inversely with the density of the process stream. The unit of the radiation detector converts this energy into an electrical signal, which is transmitted to an electronic module.

3.4 Measurement of Conductivity

- The unit of conductance, the reciprocal of the ohm, is the siemens (S).
- Conductance is a measure of how easily those charge particles move through a solution/material (measured in Siemens, S).
- Conductivity is the conductance (S) measured across a specified distance through a material/solution (measured in Siemens per centimetre, S/cm)
- In a metal wire it is electrons that are the charged particles moving through the material, in a solution it is ions.
- Concentration of ions: the more ions the greater the conductivity and so conductivity can be used as a measure of concentration.
- The Conductivity Probe is actually measuring *conductance*, defined as the reciprocal of resistance.
- When resistance is measured in ohms, conductance is measured using the SI unit, siemens (formerly known as a mho). Since the siemens is a very large unit, aqueous samples are commonly measured in microsiemens, or µS.
- Even though the Conductivity Probe is measuring conductance, we are often interested in finding conductivity of a solution. Conductivity, C, is found using the following formula:

$$C = G \bullet k_c$$

- where G is the conductance, and kc is the cell constant. The cell constant is determined for a probe using the following formula:

$$k_c = d / A$$

- where d is the distance between the two electrodes, and A is the area of the electrode surface.

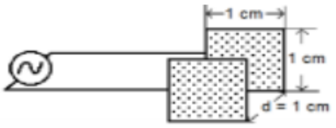


Figure 3.12: Measurement of conductivity

For example, the cell in Figure 1 has a cell constant:

$k_c = d / A = 1.0 \text{ cm} / 1.0 \text{ cm}^2 = 1.0 \text{ cm}^{-1}$

The conductivity value is found by multiplying conductance and the cell constant. Since the Vernier Conductivity Probe also has a cell constant of 1.0 cm^{-1}, its conductivity and conductance have the same numerical value. For a solution with a conductance value of 1000 µS, the conductivity, *C*, would be:

$C = G \cdot k_c = (1000 \ \mu\text{S}) \text{ X } (1.0 \text{ cm}^{-1}) = 1000 \ \mu\text{S/cm}$

3.4.1 Measuring conductivity

- The Conductivity Probe measures the ability of a solution to conduct an electric current between two electrodes. In solution, the current flows by ion transport. Therefore, an increasing concentration of ions in the solution will result in higher conductivity values.
- The most common method is using a conductivity probe as seen in Figure. These use two or more platinum electrodes and measure the conductivity directly.

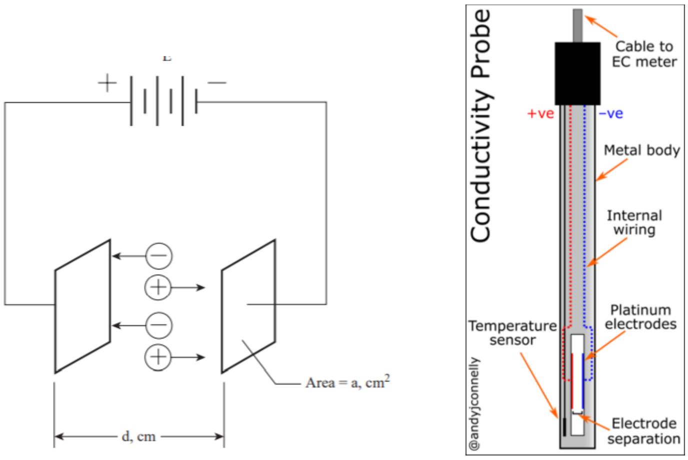


Figure 3.13: Measurement of conductivity

- A potential difference is applied to the two probe electrodes in the Conductivity Probe. The resulting current is proportional to the conductivity of the solution. This current is converted into a voltage.
- Alternating current is supplied to prevent the complete ion migration to the two electrodes. Each cycle of the alternating current, the polarity of the electrodes is reversed, which in turn reverses the direction of ion flow.
- In the simplest arrangement of a platinum electrode type probe (a 2-electrode cell), a voltage is applied to two flat plates immersed in the solution, and the resulting current is measured and then conductivity, G, can then be calculated using inverted Ohm’s law. Where R is the resistance, V = voltage and I = current:
- A more advanced conductivity cell uses four electrodes (see Figure 2). These probes use an alternating current through the outer electrodes and measures the voltage across the inner electrodes .The four electrode system gives a lower current and so has less charge transfer at the metal-liquid interface. This allows a much wider dynamic range to be measured than a two-electrode sensor. Such measurements are volume dependent

and the outer sheath of the probe ensures that the volume of sample solution remains constant for all analysis.

- Current is imposed across two drive electrodes, and the potential drop through the electrolyte is detected between two points in the cell using two sense electrodes .

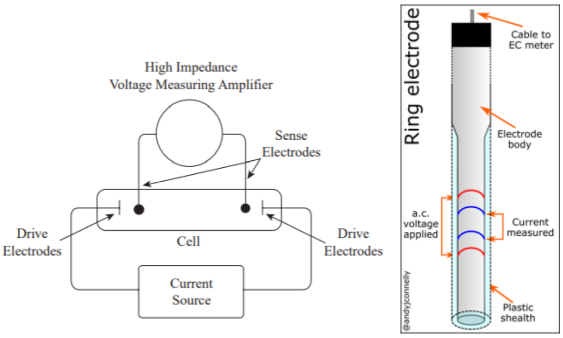


Figure 3.14: Measurement of conductivity

3.5 Evaporators

- Evaporation is an operation used to remove a liquid from a solution, suspension, or emulsion by boiling off some of the liquid.
- It is thus a thermal separation, or thermal concentration, process.
- The evaporation process starts with a liquid product and ends up with a more concentrated, but still liquid and still pumpable concentrate as the main product from the process.

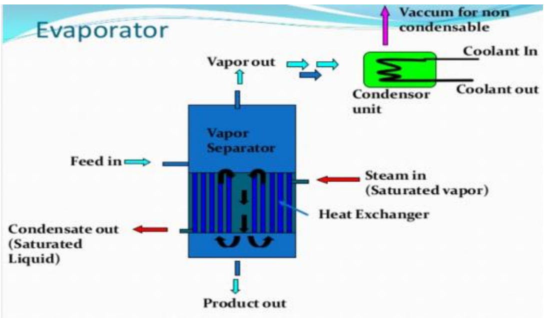


Figure 3.15: Evaporator

- The solution containing the desired product is fed into the evaporator and passes across a heat source.
- The applied heat converts the water in the solution into vapor.
- The vapor is removed from the rest of the solution and is condensed while the now-concentrated solution is either fed into a second evaporator or is removed.
- The heating section contains the heating medium, which can vary. Steam is fed into this section.
- The most common medium consists of parallel tubes but others have plates or coils typically made from copper or aluminium.

- The concentrating and separating section removes the vapor being produced from the solution.
- The condenser condenses the separated vapor, then the vacuum or pump provides pressure to increase circulation.
- A heat exchanger is a system used to transfer heat between two or more fluids. Heat exchangers are used in both cooling and heating processes.

most common types of evaporators.

- 1. Falling Film Evaporators
- 2. Rising Film Evaporators
- 3. Forced Circulation Evaporators
- 4. Plate Evaporators
- 5. Thermal and Mechanical Vapor Recompression (TVR &M VR)

1.Falling Film Evaporators

- In falling film evaporators, liquid and vapors flow downwards in parallel flow.
- The liquid to be concentrated is preheated to boiling temperature.
- Flows down tubes
- Hot vapour flows down also
- Vaporisation occurs
- Concentrate and vapours separated on exit from base
- Vapour condensate removed at base

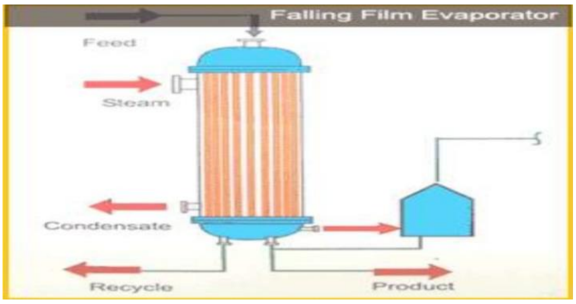


Figure 3.16: Falling Film Evaporator

- It consists of single large diameter tube with the material to be concentrated falling in a film down the inside where a mechanical wiper spreads the film over the inside surface of the tube.
- The feed material descends by gravity along the inside of the heated tubes.
- Falling film evaporators can be operated with very low temperature differences between the heating media and the boiling liquid.

- These characteristics make the falling film evaporator particularly suitable for heat-sensitive products, and it is today the most frequently used type of evaporator.
- If the heating surfaces are not wetted sufficiently, dry patches and incrustations will occur; at worst, the heating tubes will be completely clogged.
- In critical cases extending or dividing the evaporator effects, keeping the advantages of single pass operation, can increase the wetting rate.

2.Rising Film Evaporators(or) long-tube vertical evaporator

- The LTV evaporator is frequently called a rising or climbing film evaporator.
- Feed enters the bottom of the heating tubes and as it heats, steam begins to form.
- The ascending force of this steam produced during the boiling causes liquid and vapors to flow upwards in parallel flow.
- At the same time the production of vapor increases and the product is pressed as a thin film on the walls of the tubes, and the liquid rises upwards.
- This co-current upward movement against gravity has the advantageous effect of creating a high degree of turbulence in the liquid.
- This is useful during evaporation of highly viscous and fouling solutions.
- The length of the boiling tubes will typically not exceed 23 ft .

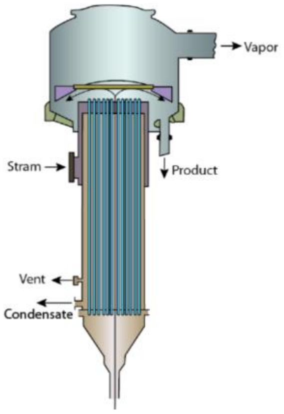


Figure 3.17: Rising Film Evaporator

3.Forced Circulation Evaporator

- The liquid is circulated at high velocity through the heat exchanger tubes to enhance the heat transfer rate and inhibit particle deposition.
- Any evaporator that uses pump to ensure higher circulation velocity is called a forced circulation evaporator.
- The main components of a forced circulation evaporator are a tubular shell and tube heat exchanger (either horizontal or vertical), a flash chamber (separator) mounted above the heat exchanger and a circulating pump.

- The circulating liquid is heated when it flows through the heat exchanger and then partially evaporated when the pressure is reduced in the separator, cooling the liquid to the boiling temperature corresponding to this pressure.
- The solution is heated in the heat exchanger without boiling and the superheated solution flashes off (partially evaporated) at a lower pressure are reduced in the flash chamber.
- The pump pumps feed and liquor from the flash chamber and forces it through the heat exchanger tubes back to the the flash chamber.
- Forced circulation evaporator is commonly used for concentration of caustic and brine solutions and also in evaporation of corrosive solution.

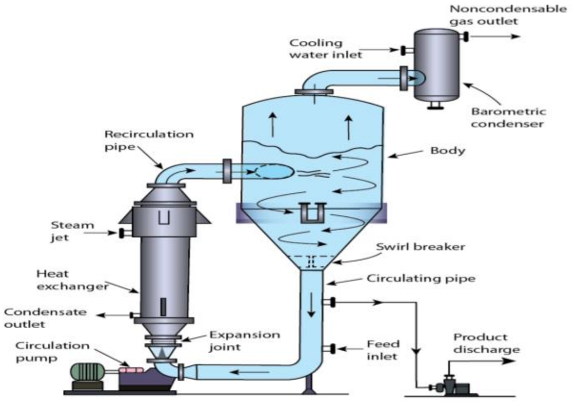


Figure 3.18: Forced Circulation Evaporator

3.5.1 Methods Of Feeding Of Evaporators

- Evaporators are classified by the number of effects.
- In case of a single-effect evaporator, the vapor from the boiling liquor is condensed and the concentrated product is withdrawn from the bottom of the evaporator.
- Although the operation is simple, the device does not use steam efficiently.
- Typically 1.1 to 1.3 kg of steam is required to evaporate 1 kg of water.
- The steam consumption per unit mass of water evaporated can be increased by putting more than one evaporator in series such that the vapor from one evaporator is used in the second evaporator for heating.
- The vapor from the second evaporator is condensed and the arrangement is called double-effect evaporators.
- The heat from the vapor generated in the first evaporator is used in the second evaporator.
- Evaporation of water is nearly doubled in double effect evaporation system compared to single effect per unit mass of steam used.

- Additional effects can be added in series in the same way to get a triple-effect evaporator, quadruple-effect evaporator and so on. There are several configurations based on feeding arrangement.

Forward feed

- The typical feeding method of multi-effect evaporators is forward.
- Both feed and steam are introduced in the first effect and the feed passed from effect to effect parallel to the vapor from the earlier effect.
- Concentration increases from the first effect to the last.
- Forward feeding operation is helpful when the concentrated product may degenerate if exposed to high temperature.
- The product is withdrawn from the last effect.
- It requires a pump for feeding of dilute solution to the first effect. A pump removes thick liquor from the last effect. The liquid from one effect to the next effect also can be transferred without a pump as the flow occurs in the direction of decreasing pressure.

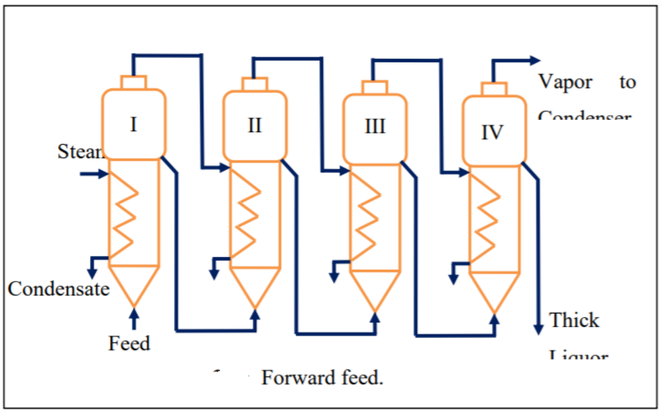


Figure 3.19: Forward Feed

Backward feed

- In backward feed configuration, the feed enters at the last effect (coldest effect) and is pumped through the successive effects.
- The product is withdrawn from the first effect (hottest) where the steam is introduced .
- This method of feeding requires a pump between each pair of effects to transfer liquid from lower pressure effects to higher pressure effects.
- It is advantageous when cold feed entering needs to be heated to a lower temperature than in forward feed operation.
- Backward feed is commonly used when products are viscous and exposure to higher temperature increases the rate of heat transfer due to reduction in viscosity of the liquid**.**

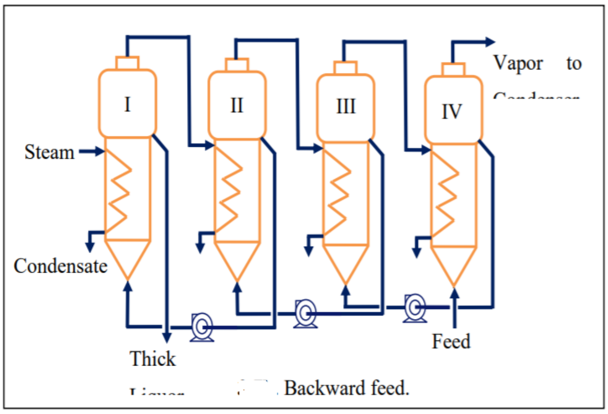


Figure 3.20: Backward Feed

Mixed feed

- In the mixed feed operation, the dilute feed liquid enters at an intermediate effect and flows in the next higher effect till it reaches the last effect of the series.
- In this section, liquid flows in the forward feed mode. Partly concentrated liquor is then pumped back to the effect before the one to which the fresh feed was introduced for further concentration.
- Mixed feed arrangement eliminates some of the pumps needed in backward configuration as flow occurs due to pressure difference whenever applicable.

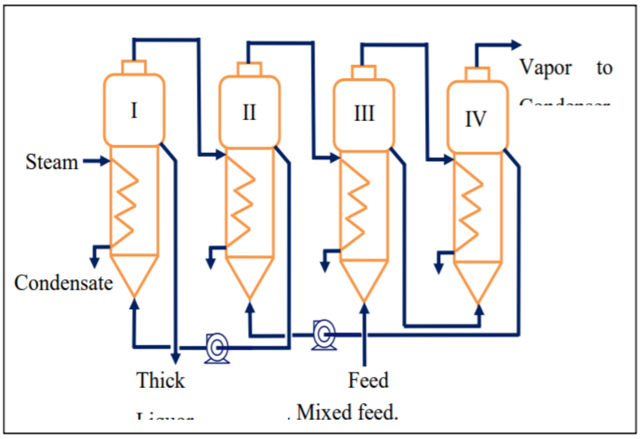
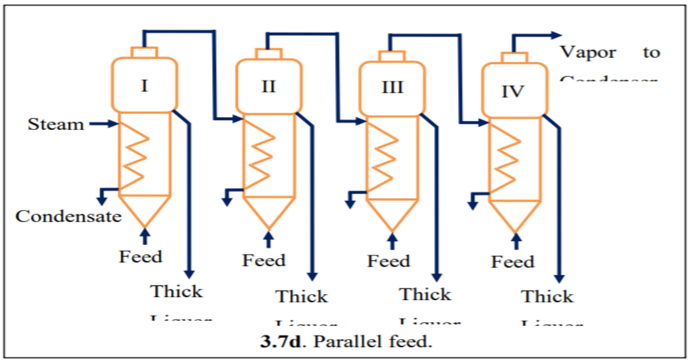


Figure 3.21: Mixed Feed

Parallel feed

- The fresh feed is introduced to each effect and in this configuration the product is withdrawn of from the same effect in parallel feed operation .
- In parallel feeding, there is no transfer of liquid from one effect to another effect.
- It is used primarily when the feed is saturated and the product is solid containing slurry.
- This is most common in crystallizing evaporators



3.7d. Parallel feed.

Figure 3.22: Parallel Feed

3.6 Measurement and control of column pressure

- Most distillation columns are operated under constant pressure.
- However, floating-pressure operation can have advantages in many processes.
- The primary advantage of floating-pressure control is the ability to operate at the minimum column pressure within the constraints of the system.
- Lower pressure reduces the volatility of distillation components.

thereby reducing the heat input required to effect a given separation

- floating-pressure control strategies will be described for the following conditions:

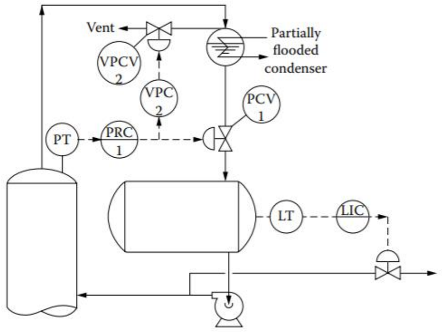
(1) liquid distillate withdrawn when noncondensables are present,

(2) vapor distillate withdrawn when noncondensables are present, and

(3) liquid distillate withdrawn when the amount of noncondensables is negligible.

3.6.1 Liquid Distillate and Inerts

- In some separation processes the problem of pressure control is complicated by the presence of large percentages of inert gases.
- The noncondensables must be removed, or they will accumulate and blanket off the condensing surface, thereby causing loss of column pressure control.



Column pressure control with inerts present.

Figure 3.23: Column pressure control with inerts present

- As the noncondensables build up in the condenser, the pressure controller will tend to open the control valve (PCV-1 in to maintain the proper rate of condensation and increase the rate of condensation
- When PCV-1 is nearly fully open (say 95%), the valve position controller (VPC-2) starts to remove the inerts by opening control valve (VPCV-2).

3.6.2 Vapor Distillate and Inerts

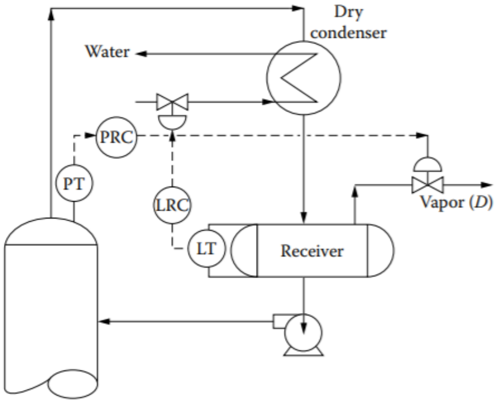


Figure 3.24: Vapour distillate and inerts

- In this case where the distillate is in the vapor phase and inerts are present, the overhead product is removed under pressure control.
- In this control system a level controller is installed on the overhead receiver to regulate the cooling water to the condenser, so that it will condense only enough condensate to provide the column with reflux.
- This control system will give acceptable performance only if the condenser residence time on the coolant side is short.

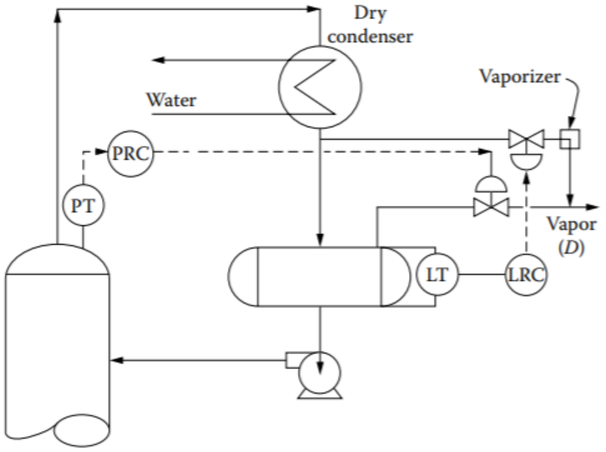


Figure 3.25: Vapour distillate and inerts

- If this is not the case, the cooling water flow should be maintained at a constant rate.
- In this case the level controller can regulate the flow of condensate through a small vaporizer and mix it with the vapor from the pressure control valve.

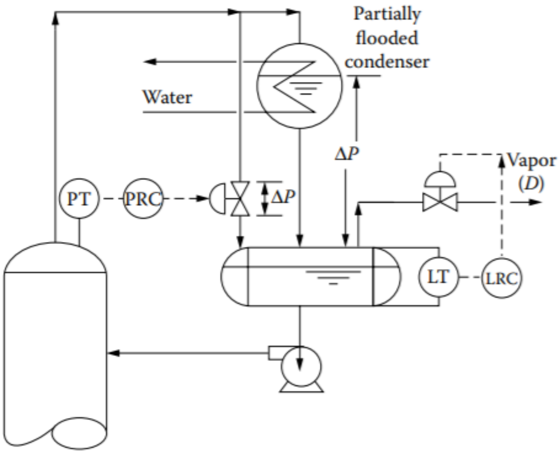
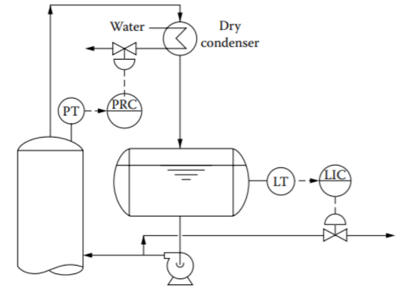


Figure 3.26: Vapour distillate and inerts

- If the cooling water can cause fouling, or if the use of a vaporizer represents a substantial waste of energy, instead of revaporizing the condensate, part of the overhead vapor stream is sent to a vapor bypass valve around the condenser .
- This allows the condensate flow to stay constant.

3.6.3 Liquid Distillate with Negligible Inerts



Column pressure control by throttling condenser water.

Figure 3.27: Liquid distillate with negligible inerts

- In distillation processes where the distillate is in the liquid phase and the amount of inerts is negligible, the column pressure is usually controlled by modulating the rate of condensation in the condenser.
- a control configuration where the column pressure is controlled by throttling the cooling water flow from the condenser.
- This method of control is recommended only when the cooling water is treated with chemicals that prevent the fouling of the tubes in the event of high temperature rise across the condenser tubes.

- In such configuration, the maintenance costs are low, because the control valve is on the water side and the control performance is acceptable, provided the condenser is properly designed.

TEXT / REFERENCE BOOKS

1 Liptak B G, “Instrumentation in the processing industries”, Chilton book Company, 1973.

2. Considine D. M., “Process/Industrial Instruments and control Handbook”, McGraw Hill, 5th edition 1999

3. BaskaraRao, “Petrochemicals”, Khanna Publishers, New Delhi, 1987.

4. Liptak B.G, “Process Measurement and Analysis”, Third Edition, Chilton Book Co., 2003

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DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION ENGINEERING

UNIT – IV – Instrumentation in Industries – SIC1404

IV. Instrumentation in Iron & Steel and Mining Industries

Iron and steel: Selection of suitable measurement hardware for temperature, pressure, level, flow, weighing and proportioning - special gauges for measurement of thickness and shape Mining Industry: Weighing - conveyor belts - metal detectors - level sensors - nuclear density detectors - flow meters, Coal analyzer - thermogravimetri - gross calorific value - total sulphur analysis - ash analyser - online monitor- air quality monitoring- Sampling of ambient air - general air sampling system - Flue gas oxygen analyzer - analysis of impurities in feed water and steam - dissolved oxygen analyzer - chromatography - pH Meter - pollution monitoring instruments

4.1 Iron and steel: Selection of suitable measurement hardware for temperature

- Temperature is one of the most important process variables in the steel industry.
- Almost every process has some thermal requirement and the acceptable range is usually restrictive.
- Temperature is frequently used in determining other variables such as level.
- Another application is the carbon analysis of a molten sample of raw steel**.**
- A few cubic inches of molten sample of raw steel prepared at the furnace is poured into a specially designed insulated cup containing a rugged thermocouple, and the time –temperature relationship is recorded on a strip chart.
- Usually the temperature during solidification is relatively flat, preceded and followed by steeper slopes.
- The level of temperature during solidification is direct measurement if the present carbon in the sample .
- Thermocouple and pyrometers are used for process measurement as well as for maintenance and equipment protection.

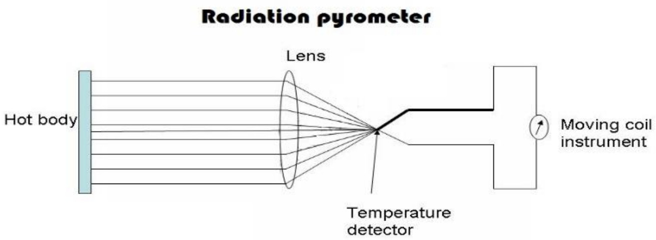


Figure 4.1 : Radiation pyrometer

4.2 Selection of suitable measurement hardware for pressure

- It is used in almost all chemical and heating process with ranges from a few inches of water for fume withdrawal from a BOF to 10-25PSIG for the top pressure of an iron making blast furnace.
- Hydraulic systems commonly operate at 950 to 1000 PSIG and are regulated at that level.
- An interesting use of pressure measurement is in the hot or cold rolling mill.
- To impart the required force to product being rolled the top roll is forced down against the bottom one by an electromechanical system which turns a pair of large screws(one at each end of the roll)synchronously.

- The force acting on the rolls is of course needed to push the rolls together.
- A stiff solid pressure sensor capable of withstanding the force of several thousand tons without deflection senses this important parameter.
- The magnetostrictive effect utilized by this sensor is best described .
- A series of electrical steel laminations are stacked and glued together. Four holes 90º from each other punched or bored in the stack, a primary winding is wound through two holes at 180º and a secondary is wound the other two .
- When the primary is excited by an AC voltage, the flux pattern in the steel is as shown IN FIG.
- Since the coils are a right angles to each other ,no voltage is induced into the secondary.
- However, when a compressive force is place on the lamination stack, the unloaded flux pattern is distorted because the magnetic permeability is reduced in the direction of applied force.
- Part of the flux now links the secondary winding, inducing a voltage in the secondary.
- The effect is linear over a range of compressive forces, An actual load cell based on this custom designed with the total load cell arranged so that the force would be evenly distributed across all sensor laminations.
- This is also provides a suitable bearing surface for forces from 2 to 3 million pounds.

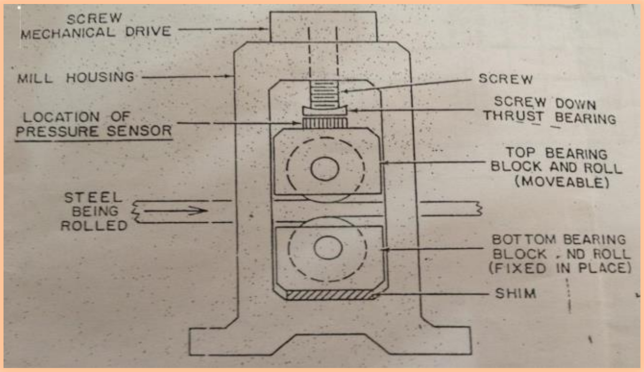


Figure 4.2 : Rolling mill

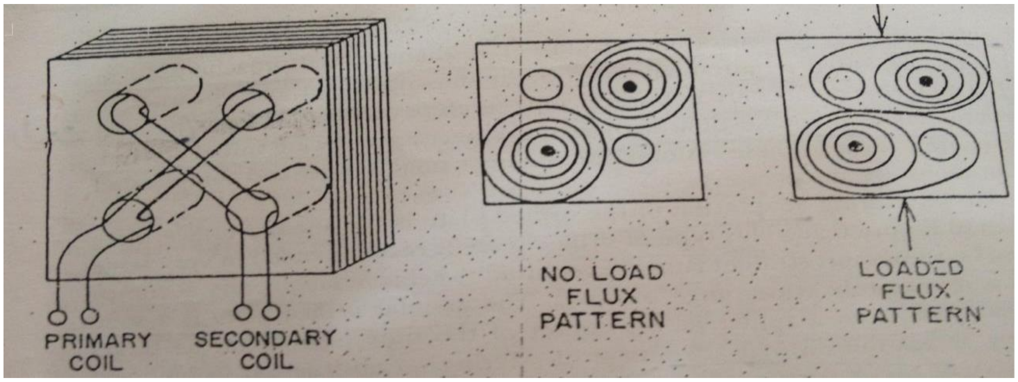


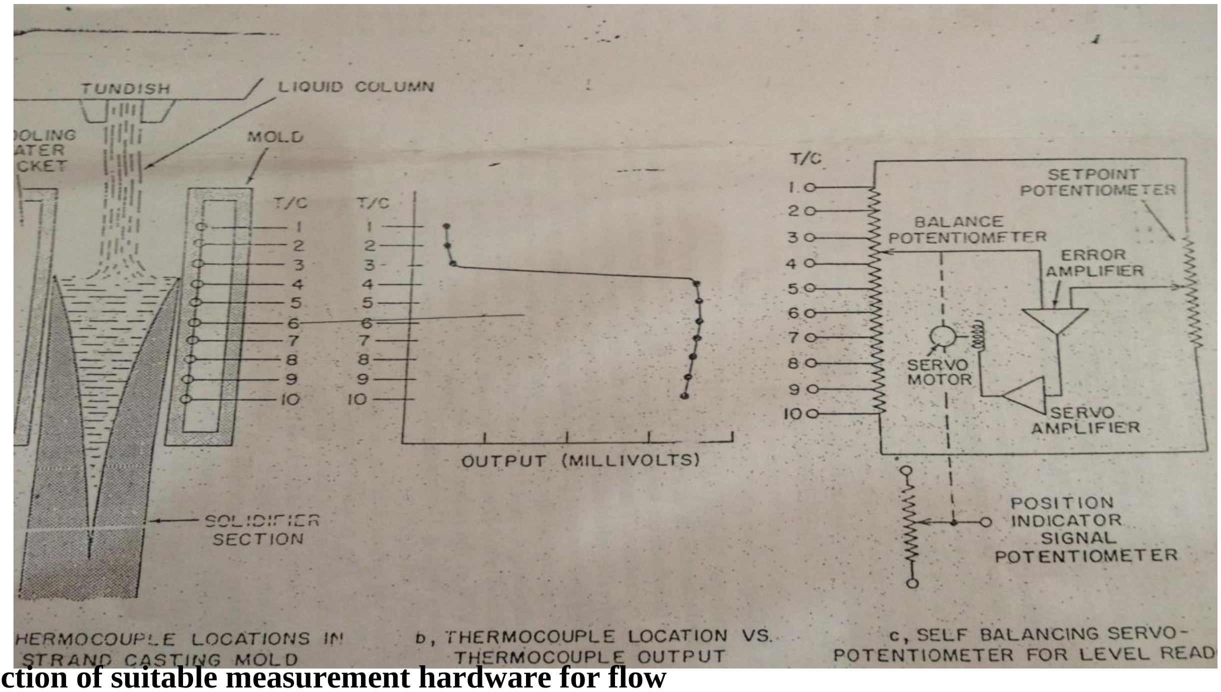
Figure 4.3 : Magneto-Stirctive Effect In Load Detection

4.3 Selection of suitable measurement hardware for level

The measurement of level in the steel industry is critical to the operation of utilities. Most fluid tanks, whether used for fuel ,chemicals or other storage settling basins, flocculator separators or cooling water supply basins must have their levels either monitored or controlled. Naturally the hardware must be compatible with the material being monitored and for that reason many level sensors are made of glass or inert plastics, stainless steel or ceramics. A unique method for measuring level utilizes thermocouples to measure the height of molten metal in the mold of a continuous casting machine.

During continuous casting. It is important that the solidifying shape be withdrawn from the mold bottom as rapidly as molten metal is poured into the top of the mold. If this is done, the level of the liquid meniscus has to be held constant. A sensor monitors this level and supplies an output signal which can control withdrawal rate .Radiation type detectors may be used although safety cost and licensing pose certain problems,.

A patented thermocouple system represents unique and reliable solution to measurement problems. The thermocouple are mounted in a vertical row in the wall of a water jacketed mold. If thermocouples are connected in a self balancing, potentiometer circuit, the temperature gradient output is proportional to the height of the meniscus in the mold. The output may be used as a feedback signal for control.



HERMOCOUPLE LOCATIONS IN STRAND CASTING MOLD

b, THERMOCOUPLE LOCATION VS. THERMOCOUPLE OUTPUT

c, SELF BALANCING SERVO-POTENTIOMETER FOR LEVEL READ

4.4 Selection of suitable measurement hardware for flow

The measurement and control of process gas flow rates are generally restricted to orifice plates, venture tubes and pilot tubes because, the volumes are very high. Blast furnace gas flow rate of 40,000SCFM to the stoves are common. The waste gas from a BOF steel making vessel during the blow period can be from 600 to 700000SCFM.These volumes occur at relatively low pressure and require pipe diameters approaching 10 to 14 feet. The usual requirement of straight runs upstream and downstream of metering devices is not practical. Therefore, calibrations using indirect methods, such as combustion analyzers are necessary during initial startup. Fortunately, most of these systems operate over small ranges and complicated calibrations are unnecessary.

An interesting adaption of the orifice plate is the annular orifice plate .This type of orifice plate is recommended in very large pipes because short straight runs are required to achieve satisfactory accuracy over a moderately wide range of flows .The annular orifice plate is solid disk supported on a spider in the center of the pipe .It has a distinct advantage of offering no obstruction to sediment or heavy material .Also it may be used freely with 90° elbows three diameters ahead of the plate .It has disadvantage of requiring precise filed fabrication and of being subject to wear from erosion, corrosion and abrasion.

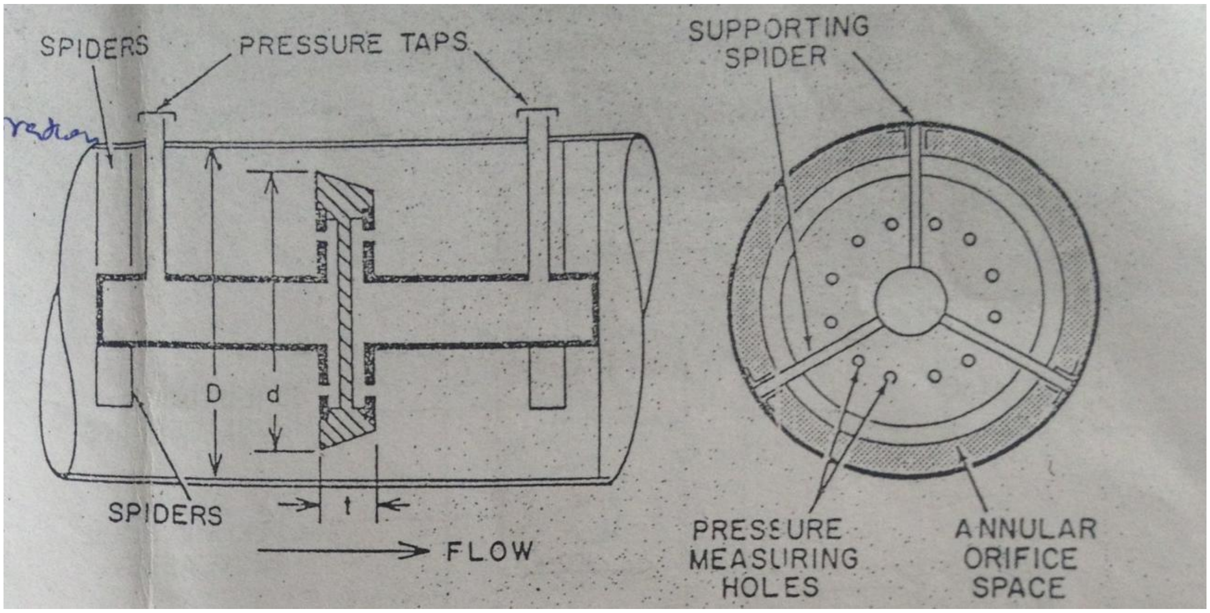


Figure 4.4 Annular Orifice Plate Installation

4.5 Selection of suitable measurement hardware for weighing and proportioning

Measurement of accurate weights in the processing of iron and steel is of primary importance because the product not only is solid by weight ,but is processed in very step by batches according to weight and volume .In the finished products such as structural shapes, coils of sheet and strip the major problem is accommodating the physical shapes .coils of sheet and strip the major problem is accommodating the physical shapes .The weight of coils of sheet product is as high a 90,000lbs:large rolled structural items may weigh up to 350lbs per foot and be 50 or more feet long. Conversely some spools of high quality wire may weigh less than 50lbs.All types of weight measurement elements are utilized in the iron and steel industry. Electronic scale systems are becoming more popular owing to their high level of accuracy, capacity and safety, features that offset the disadvantage of complexity.

4.6 Shape and thickness measurement

The two most important parameters of flat rolled sheet products are thickness and shape. Because sheet is processed in die-forming lines and is subject to appearance type criteria (automobile bodies and refrigerator cases) shape and thickness must be controlled closely in all rolling operations. Thickness, often referred to as gauge, is monitored most frequently by non contacting radiation type gauges. X-ray and beta ray devices are both common, with the x-ray absorption gauge being the more popular. The gauges are made with the source of radiation located below the strip and the measurement chamber above it (fig 6.2f). this allows the thickness to be monitored at any given point along the length of the strip, usually a fixed distance from the centre line

Shape may best be defined as the variation of thickness of sheet strip from edge to edge. Both acceptable and unacceptable (this sheet not lying flat on a flat surface)

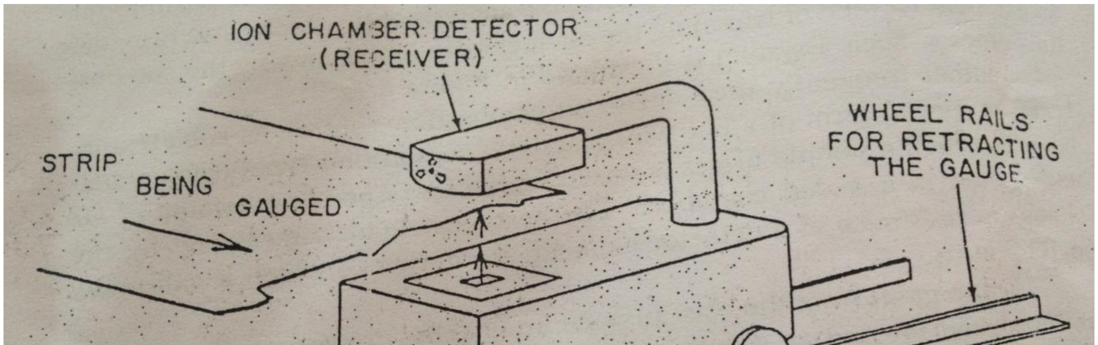


Figure 4.5 Non contacting Radiation type gauges

shape is the result of the rolling process. The strip tends to accept the cross section of the opening between the rolls as it exits from them. When bending stresses or thermal effects, or both cause the roll opening to be distorted, the cross section will be similarly distorted. This distortion, if detected can be controlled by the rolling mill mechanisms, but distortions may often not be visible.

A shapes sensors for the monitoring of high speed rolling mill products must be non contacting and very rugged. It is well known that the tension distribution across a strip perpendicular to its rolling direction bears a direct relationship to the quality of the shape. Thus the magnetic permeability of the steel which varies the tension may be measured and used to describe the shape (fig 6.2g). The unit consist of a four legged magnetic core, two legs being the primary and two the secondary core. The impedance of this devise is a function of several constant factors as well as of the strip permeability and of the air gap.

Because the primary leg flux is divided between each secondary leg-one in the rolling direction, one in the transverse direction-the sum of the secondary voltages is a direct measurement of the stress concentration in the strip at the point where the sensor is mounted. The actual shape gauge consist of a series of these devises, encapsulated in epoxy, mounted side by side across the width of the mill and scan at a high frequency. A circuitry stores and displays the pattern of an entire scan on the face of an oscilloscope. Thus the operator is given a visual portrait that can be correlated to the strip shape.

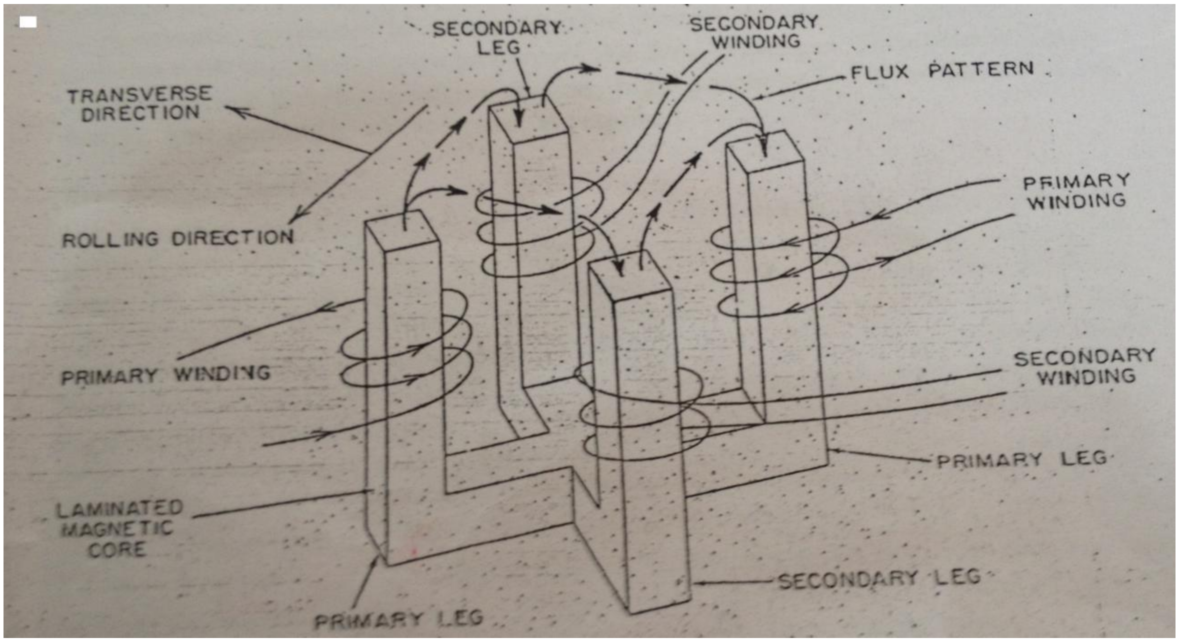


Figure 4.6 magnetic detector for shape gauge

4.7 Mining Industry: Weighing

- Modern mineral processing plants utilize weighing systems in every area of operation.

- In underground mining, the ore trains and trackless load-haul-dump units utilize electronic weigh scales.
- Time and load are printed out remotely on the surface to indicate number of loads, net tonnage and the frequency of loads, and the information is used to calculate tonnage of ore remaining in the mine.
- To optimise skip loading to underground mines, automatic loading systems based on weight are being used.
- On the surface, track scales and conveyor scales weigh the open pit ore going to the crushing plant.
- Conveyor scales, critical instruments in the ore beneficiation plant, weigh crude ore in and dried concentrate out of the plant.
- They control feeds to crushers and to grinding mill circuits.
- The equipment must be rugged and protected from wind, dust and the corrosive atmosphere.
- Accuracy must be maintained high.
- Conveyor scales often measure and control the amount of finished product being loaded onto ships, rail cars and trucks.

4.8 Conveyor belts

- Stoppage of the conveyor will shut down the equipment feeding it.
- For personnel safety, good practice is to introduce a 30 second delay in starting the conveyor after the operator presses the start button, during which interval a horn or siren should sound to warn anyone working on or situated near the conveyor which is about to start operation.
- All belt conveyors should be equipped with subnormal speed switches driven from a separate pulley.
- If the belt breaks or the speed of the conveyor drops below a preset rate the switch causes a sequential stopping of the conveying system.
- Usually there are rope switches along the walkway side of the conveyor for emergency stopping, and the conveyor cannot be restarted until the rope switch is manually reset .
- Belt misalignment or slew detectors are common on longer conveyors for alarm and shutdown.
- Immediate detection of abnormal conveyor speed is Important because extensive belt damage can result in a very short time. Protection should be provided during conveyor startup as well as under normal running conditions.
- To protect the system during startup requires differential speed detectors to monitor the bead and tail pulley ends of the conveyor and respond to an excessive angular displacement between them as well as to a subnormal speed during normal running.
- Conveyors motor power load should at least be indicated in the controlroom.
- Television cameras are frequently positioned at feed transfer points and the operator can observe these points on monitors located in the control room and be altered to spills, blockages and other problems.
- On long conveyors, telemetry system may be necessary to transmit information to the central control room.

4.9 Metal detectors

- A tramp detector is often mounted on the conveyor to the crushing plant to alarm and stop the conveyor or operate a reject mechanism to prevent injurious magnetic material from entering and damaging a crusher.
- The detector uses an electric coil which creates a magnetic field across the conveyor belt.
- Any metallic object on the belt will cause a change in the field resulting in a power change in the coil to be sensed and indicated.

4.10 Level Sensors

- Ultrasonic level detectors
- Measurement of solids level in large bins has long been a problem.
- Most level measurement devices require that sensors be in contact with the process fluid.
- In the environment of an ore bin, however, the sensors are quickly worn out and destroyed.
- Ultrasonic level measurement offers a major breakthrough in this area became no probe or sensor is required to be in contact with the process material.
- A high intensity sound wave is generated in the detector at a frequency and time rate determined by the type of process material and distance to be measured.
- The time required for the signal to travel between the source and the receiver is proportional to the level in the bin.
- This method of continuous level measurement can also be applied to liquids.
- In difficult measurements especially, such as milk-of-lime mixing tanks, reagents mixing tanks and slurry sumps ultrasonic level sensors are very efficient.
- Two major problems in utilizing the sensor are surface quality and dust. In bins where dust is very thick, the ultrasonic signal may rflect from the dust and give an erroneous reading
- The signal performs well in reflecting from a smooth surface,but a jagged surface presented by a coarse ore pile climes extraneous return signals to be bounced around by the irregular but solid surfaces, causing erroneous level readings.

4.10.1 Differential pressure detectors

- Flat diaphragm or chemical seal type differential pressure transmitter, often measure viscous, corrosive or slurry liquid levels
- Level measurement in reagent tanks and slurry sumps is efficiently carried out by the differential pressure transmitter.
- Often the extended diaphragm type transmitter is utilised, the diaphragm face being placed flush with the inside of the tank.
- The diaphragm surface is then kept clean by the normal agitation of the liquid in the tank.

4.10.2 Nuclear level detectors

- This measurement is utilized in the hard to reach difficult areas.
- Under crushers, where high ore levels may cause damage nuclear level devices are effective.
- Other applications are in high and low alarm or shutdown levels in storage and feed bins.
- The high level point should alert the operators to stop feeding equipment ahead of the bin.

- Low level may be dangerous because if the bin is drawn empty,after which fresh ore is fed to it, it may fall directly down and strike and severely damage the feeder.

4.10.3 Conductivity level detectors

- This simple inexpensive device is useful to sound alarms and to pump start-stop circuits in intermittent service tanks and sumps
- When the level needs only to be held between limits, this two-position or on-off control system is applicable.
- Location of the electrodes is important because material may settle out and bridge between the electrodes (or ground), causing a short circuit.
- The use of insulated electrodes or wire suspension electrodes reduces the problem because the electrode is exposed to the fluid only in its active portion.

4.10.4 Tape Level Detectors

- This instrument, popularly known as a tank gauge, is normally used on the larger storage tanks.
- One or more large storage tanks for fresh or potable water, mill water and reclaimed water require level measurement and monitoring.
- The detector affords accurate, inexpensive measurement, sounding alarms for high and low levels in the tanks.
- With special wetted parts materials, the detector can be applied to level measurement in the large reagent storage or holding tanks.

4.10.5 Bubbler Level Detectors

- This sensor is a convenient, reliable and inexpensive instrument to measure slurry and flotation cell levels.
- Care in construction and location of the dip tube is necessary to prevent plugging.
- The tube is almost always located through the top of the sump or floatation cell. Ease of removal for cleaning-or replacing, (the agitated slurry will erode the tube) is necessary.

4.10.6 Diaphragm type

- This device is used when dry dust or fine ore is the medium measured.
- Vibration and stray pieces of ore can contact the sensor and the instrument can be damaged.
- In dust collecting systems, they are useful for high and low alarming or signaling devices to start and stop their cycles.

4.10.7 Displacer type

- As the need for more accurate level measurement increases, the displacer replaces bubbler type devices.
- Froth level detection in floatation cells is one example of the growing applications for the displacer.
- When a high degree of accuracy and steady signal transmission are required, the displacer detector is preferred to the air bubbler.

4.11 Nuclear density detectors

- Density control of slurry drawn from thickeners and fed to driers is important and is normally measured by a gamma ray density sensor.
- The signal may regulate a valve opening or pump speed in order to control the density of the slurry.
- Another important application is in grinding mill controls.
- The density is regulated by the federate to the mill.
- Massflow can be measured using an electromagnetic flowmeter with the density gauge.
- The design of sumps or vessels ahead of the density gauge should gurantee that no air is entrained or erroneous readings will result.
- The location chosen must be free of restrictions and the velocity should be high enough so that a buildup of slurry will not occur.

4.12 Flow meters

4.12.1 Magnetic flowmeter

- It measures slurry flows in floatation systems,concentrates.
- Combined with nuclear density gauge it can measure the mass flowrate.
- This is especially useful when the stream contains magnetic iron and it is desirable to know the amount**.**

4.12.2 Head type flow meter

- Orifice plate with a differential pressure transmitter meters water in small quantities whereas the venturi tubes are normally used on the larger water lines.
- Monitoring and control of large water additions to the process are important in balancing the material
- Excess water increases the load on the dewatering equipment downstream.

4.12.3 Area flow meter

- Measures reagent flows.
- It is inexpensive, has a wide range, can handle low flows and is reliable.
- When reagent feedrate is indicated only locally the ,glass tube rotameter is a good selection.
- With a flowrate alarm switch attachment, the meter can be interlocked to the pump circuit to prevent starting the pump if seal water flow is low.

4.13 Thermo Gravimetric analysis

- Thermogravimetric analysis is an evaluation technique that measures masses of different Substances at temperature change or at a constant temperature over a given time
- In thermogravimetric analysis, the sample is heated in a given environment (Air, N2 , CO2 , He, Ar etc.) at controlled rate.
- The change in the weight of the substance is recorded as a function of temperature or time.
- The temperature is increased at a constant rate for a known initial weight of the substance and the changes in weights are recorded as a function of temperature at different time interval.

- This plot of weight change against temperature is called thermogravimetric curve or thermogram.
- Modern TGA equipment has a sensitive balance, usually a microbalance, for continuously measuring sample weight, a furnace surrounding a sample holder, and a purge gas system for providing inert or reactive atmospheres.
- A computer generally controls the furnace and the data (weight vs. sample temperature) is collected and processed by computer.
- Several modern analytical microbalances are commercially available - torsion balances, spring balances, and electro balances.
- In general, the balance is designed so that a change in sample weight generates an electrical signal proportional to the weight change.
- The electrical signal is transformed into weight or weight loss by the data processing system and plotted on the y-axis of the thermal curve.

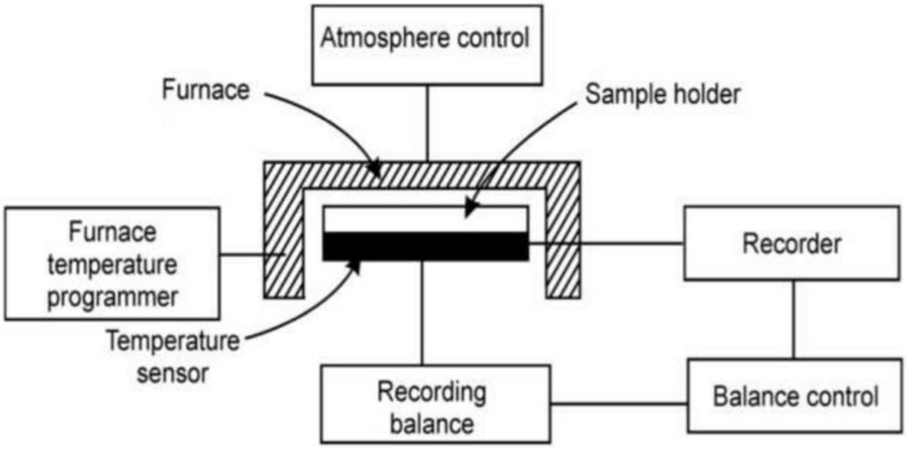


Figure 4.7 Block diagram of Thermo Gravimetric analysis

4.14 Gross calorific value

- Coal, as it is commonly known, is a solid fossil hydrocarbon fuel material.
- The gross calorific value of coal is frequently used when determining the total calorific value for a specific amount of coal for fuel value purposes or when establishing the rank of classification of the coal material.
- The sulfur value and gross calorific value of the coal material is also suitable for determining if the coal material complies to regulatory requirements for industrial fuel use or not.
- Gross Calorific Value: It is the total amount of heat generated when a unit quantity of fuel is completely burnt in oxygen and the products of combustion are cooled down to the room temperature.
- As the products of combustion are cooled down to room temperature, the steam gets condensed into water and latent heat is evolved.
- Thus in the determination of gross calorific value, the latent heat also gets included in the measured heat. Therefore gross calorific value is also called the higher calorific value.

- The calorific value which is determined by Bomb calorimeter gives the higher calorific value (HCV) .
- Calorific value of a fuel is "the total quantity of heat liberated, when a unit mass (or volume) of the fuel is burnt completely.“
- gross calorific value:
- Usually, all fuels contain some hydrogen and when the calorific value of hydrogen-containing fuel is determined experimentally, the hydrogen is converted into steam.
- If the products of combustion are condensed to the room temperature (15°C or 60°F), the latent heat of condensation of steam also gets included in the measured heat, which is then called "higher or gross calorific value".
- So, gross or higher calorific value (HCV) is "the total amount of heat produced, when unit mass/volume of the fuel has been burnt completely and the products of combustion have been cooled to room temperature"(i.e., 15°C or 60°F).
- **Dulong's formula** for calorific value from the chemical composition of fuel is :
- HCV = 1/100 [8,080 C + 34,500 (H – O/8)+ 2,240 S] kcal/kg
- where C, H, O, and S are the percentages of carbon, hydrogen, oxygen and sulphur in the fuel respectively.
- In this formula, oxygen is assumed to be present in combination with hydrogen as water

4.15 Total sulphur analysis

- Sulphur is determined from the washings obtained from the known mass of coal, used in a bomb calorimeter for determination of a calorific value.
- During this determination, Sulphur is converted into sulphate.
- The washings are treated with barium chloride solution, when barium sulphate is precipitated.
- This precipitate is filtered, washed and heated to constant weight.

$$\text{Percentage of S} = \frac{\text{Weight of } BaSO_4 \text{ obtained} \times 32 \times 100}{\text{Weight of coal sample taken in bomb} \times 233}$$

4.16 Ash Analyser

- The residual coal in the crucible is then heated without lid in a muffle furnace at 700 ± 50° C for 1/2 hour.
- The crucible is then taken out, cooled first in air, then in desiccator and weighed.
- Heating, cooling and weighing is repeated, till a constant weight is obtained. The residue is reported as ash on percentage-basis.
- Percentage of ash = $\frac{\text{Wt. of ash left}}{\text{Wt. of coal taken}} \times 100$

4.17 Online monitor

4.17.1 Air quality monitoring

- Monitoring is done to keep a track on quality of air with a view to collect information & improve it.

- The best indicators are – SO2, smoke & suspended particles.
- These are monitored on a daily basis and the results are collected by a central agency
- main reason for air pollution control programs is to protect public health - define air quality based on its effects on people and the environment
- Measurements of air quality generally fall into three classes: –
- Measurements of Emissions - also called source sampling - when a particular emission source is measured, generally by on the spot tests
- Meteorological Measurement - Measures meteorological factors that show how pollutants are transferred from source to recipient
- Ambient Air Quality - Measures the quality of all the air in a particular place. Almost all the evidence of health effects is based on these measurements

4.17.2 Sampling of ambient air

- ambient air is atmospheric air in its natural state, not contaminated by air-borne pollutants.
- Ambient air is typically 78% nitrogen and 21% oxygen.
- The extra 1% is made up of a combination of carbon, helium, methane, argon and hydrogen.
- The objective of ambient air sampling is determining the quality of ambient air as it relates to the presence and concentration of substances regarded as pollutants.
- Most air pollution monitoring equipment performs the act of sampling and analysis in one action = real time measurement**.**
- When obtaining a sample for air pollution analysis – should be sufficient sample for analysis.
- require gases or particles to be drawn to the surface of a collecting medium or a sensor
- sampling trains, which may include a vacuum pump, vacuum trap, a flow regulator and a collecting device or sensing unit
- Sampling trains for gases may also utilize filters to present particles from entering the collection unit
- Particulate matter in ambient air is measured by use of a “high-volume sampler,” which is an integrated filter holder-vacuum pump.
- A glass fiber filter is held in the filter holder, and a high flow rate of ambient air is drawn through it over a measured period of time.
- Calculations of particulate matter concentration in the ambient air are carried out using the weight of particulate matter collected on the filter and the flow rate (or total volume) of air drawn through the filter.
- The volume of air is measured against the amount of contaminant captured.
- This gives the concentration, which is expressed either as milligrams per cubic metre (mg/m3) or parts per million (ppm).
- The volume of air is calculated by multiplying the flow rate through the filter medium by the time in minutes.

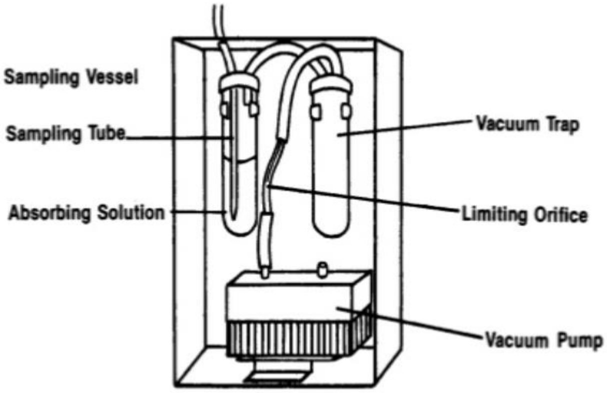


Figure 4.8 Sampling system

4.18 Flue gas oxygen analyser

- Exhaust gas generated through combustion process is called flue gas.
- To have proper control on combustion process, an idea about complete or complete combustion of fuel is made by the analysis of flue gas.
- Thus, (i) if the gases contain considerable amount of carbon monoxide, it indicates that incomplete combustion is occurring (i.e. considerable wastage of fuel is taking flue).
- Also indicates the short supply of oxygen for combustion (ii) if the flue gases contain a considerable amount of oxygen, it indicates the oxygen supply is in excess, though the combustion may be complete.
- The analysis of flue gases made with the help of Orsat's apparatus.

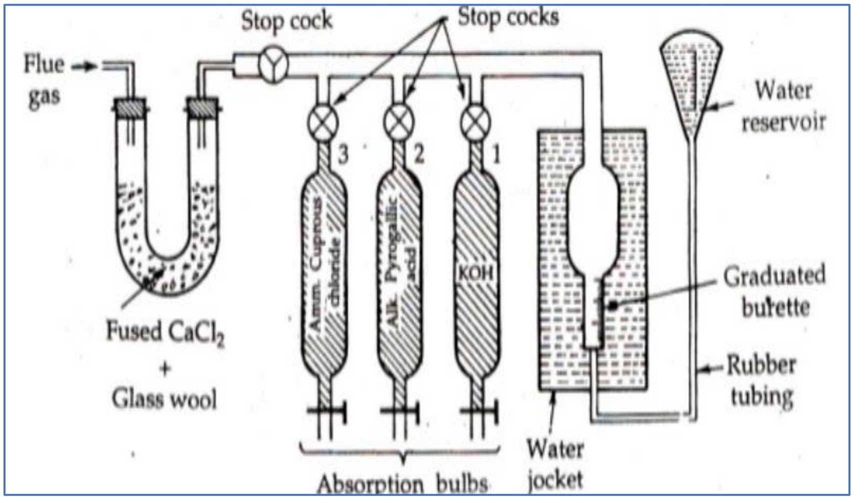


Figure 4.9 Orsat's apparatus

- It consists of a water-jacketed measuring burette, connected in series to a set of three absorption bulbs, each through a stop-cock.
- The other end is provided with a three-waystop-cock, the free end of which is further connected to a U-tube packed with glass wool (for avoiding the incoming of any smoke particles, etc.)
- The graduated burette is surrounded by a water-jacket to keep the temperature of the gas constant during the experiment.
- The lower end of the burette is connected to a water reservoir by means of a long rubber tubing.

- The absorption bulbs are usually filled with glass tubes, so that the surface area of contact between the gas and the solution is increased.
- The absorption bulbs have solutions for the absorption of CO2, O2 and CO respectively.
- First bulb has ‘potassium hydroxide’ solution (250g KOH in 500mL of boiled distilled water), and it absorbs only CO2. Second bulb has a solution of ‘alkaline pyrogallic acid’ (25g pyrogallic acid+200g KOH in 500 mL of distilled water) and it can absorb CO2 and O2.
- Third bulb contains ‘ammonical cuprous chloride’ (100g cuprous chloride + 125 mL liquor ammonia+375 mL of water) and it can absorb CO2, O2 and CO.
- Hence, it is necessary that the flue gas is passed first through potassium hydroxide bulb, where CO2 is absorbed, then through alkaline pyrogallic acid bulb, when only O2 will be absorbed (because CO2 has already been removed) and finally through ammonical cuprous chloride bulb, where only CO will be absorbed.

Working

- Flue gas is passed through fused Calcium Chloride which absorbs the water vapor present due to its hygroscopic properties.
- Three-way stopcock is opened and the flue gas is filled in the graduated burette.
- The whole set up is water jacketed to maintain a constant temperature.
- The stopcock of the KOH reservoir is opened and the water reservoir is moved up.
- Water inflows in the graduated burette and pushes the gas to flow in the KOH reservoir.
- In that reservoir carbon dioxide is absorbed. The whole CO2 in the sample is absorbed.
- The water reservoir is brought down so that the air again can rush to the burette.
- Again, the stopcock of the alkaline pyrogallic acid reservoir is opened and the water reservoir is moved up.
- Water inflows in the graduated burette and pushes the gas to flow in the alkaline pyrogallic acid reservoir where the absorption of Oxygen takes place.
- The same process is repeated with the ammonical cuprous chloride reservoir.
- The Volume increase of all the reservoir is measured and the amount of Carbon Dioxide, Carbon Monoxide and Oxygen are determined.

4.19 Analysis of impurities in feedwater and steam

The natural water contains solid, liquid and gaseous impurities and therefore, therefore this water cannot use for the generation of steam in boilers. The impurities present in the water should be removed before its use in steam generation. The necessity for reducing the corrosive nature and quality of dissolved and suspended solids in feed water has become increasingly important with the advent of high pressure, critical and supercritical boilers.

The impurities present in the boiler feed water are classified as given below

—Undissolved and suspended solids materials

—Dissolved salts and minerals

—Dissolved Gases

— Other material (as oil, acid) either in mixed or unmixed forms.

4.20 Dissolved Oxygen analyser

Oxygen analyzers are widely used in industries to detect the amount of oxygen present in the water in order to avoid corrosion in the metallic part of the boiler. The analyzer is based on the katharometer or thermal conductivity.

Principle:

The amount of oxygen in a closed space above water at a constant temperature depends upon the oxygen content present in the water only and does not depend on gas above the water.

Schematic of dissolved oxygen analyzer:

Construction:

The dissolved oxygen analyzer consists of

- Condensing section
- Transmitting section
- Analyzing section

The condensing section cools the sample water to be tested to 20 -25 0C. The sample water is made to flow in a coiled tube around which cooled water is passed. The Transmitting section consists of flow regulator, which regulates the cool water to be flowed into analyzing section. The heart of the analyzer is analyzing section. The analyzing section terminals are connected to the wheat stone bridge. The analyzing section consists of reference arm to which a platinum wire is connected. This platinum wire is exposed to inert hydrogen gas. The other platinum wire is made to expose to oxygen which is present above the water. This platinum wire is connected to the measuring arm.

Working:

(i) Balancing the Bridge: Initially the bridge would not be balanced. To balance the bridge the amount of hydrogen ions in the reference arm has to be adjusted. Until the balance is arrived, the sample should not enter the measuring arm. The arm is subjected to a standard solution which produces a constant oxygen rate. The sample is blocked from entering the contact tube by a water cock.

(ii) Measuring dissolved oxygen: Once the bridge is balanced, the water cock is opened and the sample water is allowed to flow through the measuring arm. The contact tube picks up the oxygen gas and it changes the temperature of the platinum wire placed in the contact tube and hence the current flows through the bridge. The amount of current flow gives the measure of dissolved oxygen present in the sample.

Dissolved oxygen refers to oxygen dissolved in water. Its concentration is expressed as the amount of oxygen per unit volume and the unit is mg/L. Biologically, oxygen is an essential element for respiration of underwater life and also acts as a chemical oxidizer. The solubility of oxygen in water is affected by water temperature, salinity, barometric pressure, etc. and decreases as water temperature rises.

Membrane electrode method

The membrane electrode method measures a diffusion current or reduction current generated by the concentration of dissolved oxygen or partial pressure of oxygen to obtain the concentration of dissolved oxygen. This method is not affected by the pH value of water being measured, oxidation and reduction substances, color, turbidity, etc. and the measurement method offers good reproducibility. If a sensor is inserted into water, an air layer forms on the membrane (Teflon membrane). The oxygen partial pressure (concentration) in the air layer is in equilibrium with the concentration of dissolved oxygen in the water. The membrane electrode method measures the oxygen concentration in the gas phase to indirectly obtain the concentration of dissolved oxygen in water.

There are two types of membrane electrode method: the galvanic cell method, and polarographic method. These methods differ only in the presence or absence of an external applied voltage and have the same performance, features, and usage method.

(1) Galvanic cell method

The membrane has high permeability to oxygen and is constructed so that the electrodes and electrolyte are isolated from the water being measured. The counter electrode is a base metal and the working electrode is a noble metal and potassium hydroxide is used as the electrolyte. Oxygen passes through the membrane and is reduced on the working electrode, and so the method measures the reduction current flowing between both electrodes, which is proportional to the concentration of dissolved oxygen.

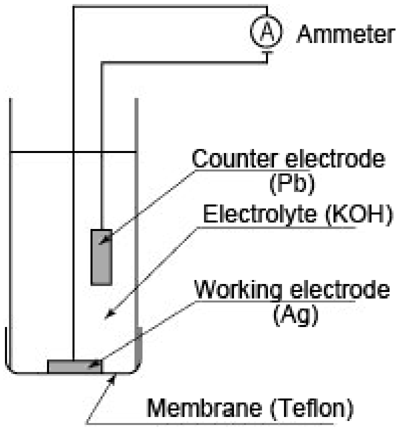


Figure 4.10 Galvanic cell method

(2) Polarographic method

The sensor construction is almost the same as that of the galvanic cell method. The counter electrode is silver-silver chloride and the working electrode is gold or platinum. When a voltage of 0.5–0.8 V is applied between both electrodes, oxygen that has permeated through the membrane initiates a reduction reaction on the working electrode, causing a polarographic limiting current to flow which is proportional to the oxygen concentration. This method measures the concentration of dissolved oxygen based on this current value.

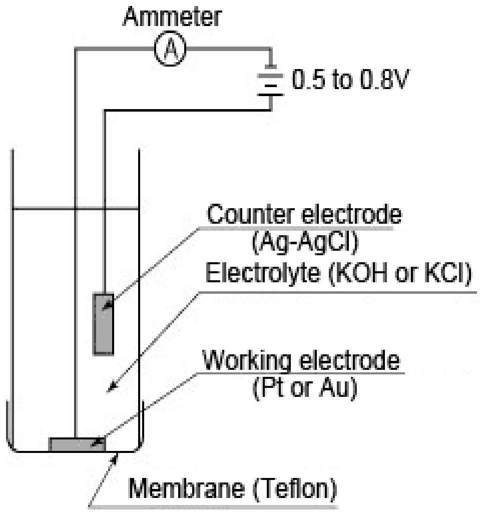


Figure 4.11 Polarographic method

4.21 Chromatography

It is a technique for separation of a mixture. The components of a mixture are basically of two types of phases, mobile phase and stationary phase. The constituents of the mixture travel at different speeds thus enabling the separation.

Principle of separation: The mobile phase flows through the stationary phase and carries the components of the mixture with it. The migration velocity of different components is different hence the molecules in the mixture can be isolated.

Definition: Chromatography is the ability to separate molecules based on partitioning characteristics of a molecule to remain in stationary or mobile phase.

4.21.1 Gas chromatography

Gas chromatography (GC) is an analytical technique used to separate the chemical components of a sample mixture and then detect them to determine their presence or absence and/or how much is present. These chemical components are usually organic molecules or gases.

As the name implies, GC uses a carrier gas in the separation, this plays the part of the mobile phase . The carrier gas transports the sample molecules through the GC system, ideally without reacting with the sample or damaging the instrument components.

The sample is first introduced into the gas chromatograph (GC), either with a syringe or transferred from an autosampler that may also extract the chemical components from solid or liquid sample matrices. The sample is injected into the GC inlet through a septum which enables the injection of the sample mixture without losing the mobile phase. Connected to the inlet is the analytical column , a long (10 – 150 m), narrow (0.1 – 0.53 mm internal diameter) fused silica or metal tube which contains the stationary phase coated on the inside walls. The analytical column is held in the column oven which is heated during the analysis to elute the less volatile components. The outlet of the column is inserted into the detector which responds to the chemical components eluting from the column to produce a signal. The signal is recorded by the acquisition software on a computer to produce a chromatogram .

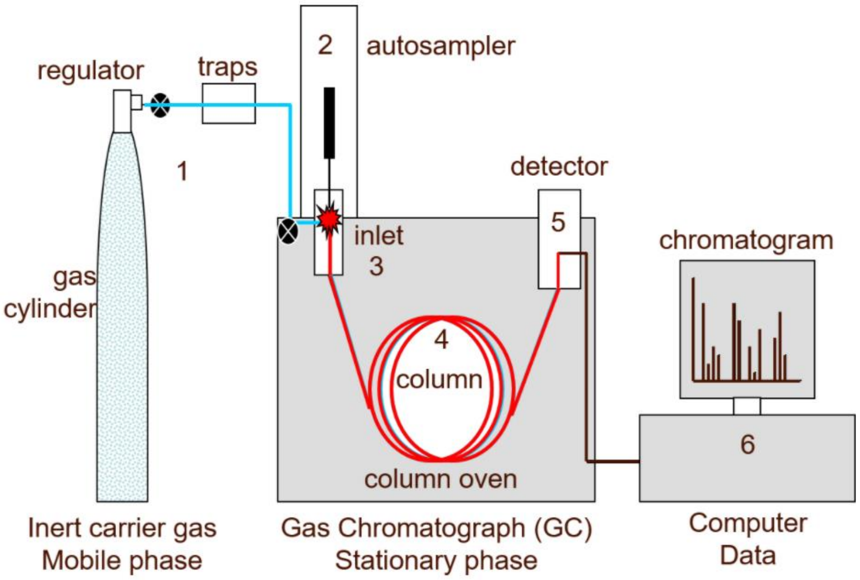


Figure 4.12 Gas Chromatograph

4.21.2 Liquid chromatography

Separation technique that involves: the placement (injection) of a small volume of liquid sample into a tube packed with porous particles (stationary phase) where individual components of the sample are transported along the packed tube (column) by a liquid moved by gravity.

The components of the sample are separated from one another by the column packing that involves various chemical and/or physical interactions between their molecules and the packing particles. The separated components are collected at the exit of this column and identified by an external measurement technique, such as a spectrophotometer that measures the intensity of the color, or by another device that can measure their amount.

4.21.3 HPLC (HIGH PERFORMANCE LIQUID CHROMATOGRAPHY)

Separation technique that involves: the injection of a small volume of liquid sample into a tube packed with tiny particles (3 to 5 micron (µm) in diameter called the stationary phase) where individual components of the sample are moved down the packed tube (column) with a liquid (mobile phase) forced through the column by high pressure delivered by a pump.

In principle, LC and HPLC work the same way except the speed, efficiency, sensitivity and ease of operation of HPLC is vastly superior. These components are separated from one another by the column packing that involves various chemical and/or physical interactions between their molecules and the packing particles. These separated components are detected at the exit of this tube (column) by a flow-through device (detector) that measures their amount. An output from this detector is called a “liquid chromatogram”.

Components of HPLC:

1.Pump:

The role of the pump is to force a liquid (called the mobile phase) through the liquid chromatograph at a specific flow rate, expressed in milliliters per min (mL/min). Normal flow rates in HPLC are in the 1-to 2-mL/min range. Typical pumps can reach pressures in the range of 6000-9000 psi (400-to 600-bar). During the chromatographic experiment, a pump can deliver a constant mobile phase composition (isocratic) or an increasing mobile phase composition (gradient).

2. Injector:

The injector serves to introduce the liquid sample into the flow stream of the mobile phase.

Typical sample volumes are 5-to 20-microliters (µL).

The injector must also be able to withstand the high pressures of the liquid system.

An auto sampler is the automatic version for when the user has many samples to analyze or when manual injection is not practical.

Manual Injector:

1.User manually loads sample into the injector using a syringe

2.Then turns the handle to inject sample into the flowing mobile phase, which transports the sample into the beginning (head) of the column, which is at high pressure

Autosampler:

User loads vials filled with sample solution into the auto sampler tray (100 samples) autosampler automatically

1.measures the appropriate sample volume,

2.injects the sample,

3.then flushes the injector to be ready for the next sample, etc., until all sample vials are processed

3.Column:

The column's stationary phase separates the sample components of interest using various physical and chemical parameters. The small particles inside the column are what cause the high backpressure at normal flow rates. The pump must push hard to move the mobile phase through the column and this resistance causes a high pressure within the chromatograph.Columns are packed with small diameter porous particles. The most popular sizes are: 5-µm, 3.5-µm and 1.8-µm.Columns are packed using high-pressure to ensure that they are stable during use, most users purchase pre-packed columns to use in their liquid chromatographs.These porous particles in the column usually have a chemically bonded phase on their surface which interacts with the sample components to separate them from one another , for example, C18 is a popular bonded phase. The process of retention of the sample components (often called analytes) is determined by the choice of column packing and the selection of the mobile phase to push the analytes through the packed column.

4. Detector:

The detector can see (detect) the individual molecules that come out (elute) from the column.

A detector serves to measure the amount of those molecules so that the chemist can quantitatively analyze the sample components. The detector provides an output to a recorder or computer that results in the liquid chromatogram (i.e., the graph of the detector response).

4.22 Pollution monitoring instruments

In power houses it is necessary to control the amount of dust into flue gases in order to comply with the requirements imposed by the municipal laws to control the pollution.

4.22.1 Dust monitoring instrument

Types of dust monitoring instrument

1. Optical type flow dust monitor
2. Electrical type flow dust monitor

3. Electrostatic type flow dust monitor

4. Reflected type dust monitor

1.Optical type flow dust monitor

It consists of light source, photo detector and a glass plate. Initially a clean glass plate is placed in the flow path of the dust laden gas. After a particular time, the plate is analyzed by measuring the obscuration caused by the deposition of dust on the glass plate. In the analysis process, the dust collected glass plate is placed in between the light source and the photo cell. The light beam is allowed to pass through the glass plate and it is received by a photocell. The output of photocell decreases with increase in the dust on the glass plate which is proportional to the amount dust present in the gas.

2.Electrical type flow dust monitor

It uses the principle of charging to measure the amount of dust present in the flue gas. The instrument gets a sample of dust laden gas at a constant velocity and charges the dust electrically and then measures this charge. This charge will be proportional to the amount of dust present in the flue gas.

3.Electrostatic type flow dust monitor

It uses a tube made from special materials for the measurement of dust. The instrument withdraws a sample of gas at a constant velocity and imparts swirl to the gas and passes it through the tube. The swirling dust gives an electrostatic charge to this tube by friction. The

measurement of this charge gives the measure of the dust in the flue gas.

4.Reflected type dust monitor

It measures the scattered light or reflected light. It consists of a lamp and a photocell both are mounted by side. The light from the lamp is allowed to pass into the duct through a small opening. While it passing through the duct laden gas some of the light will be reflected back on the photocell. Reflected light ray is directly proportional to the amount of dust present in the gas. The output from the photocell is amplified and is indicated by a indicator**.**

4.22.2 Smoke Measurement

There are two methods –

1.optical method

2.ionization method

1.Optical Method

In this method, a known volume of air is continuously drawn through a filter paper for a period of one hour. The properties of the sample are measured by the reduction of light transmission through the filter. This reduction in light transmitted is a measure of the smoke. This method does not measure the absolute concentration or the deposited mass of particulates, rather it is an indicator of particulate matter suspended in the air

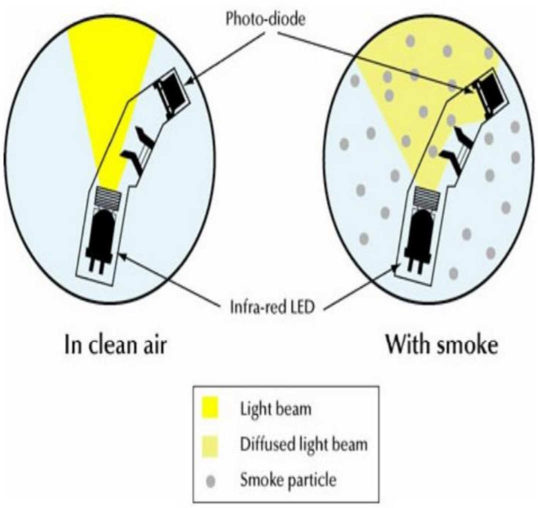


Figure 4.13 Optical method for smoke measurement

2.Ionization Method

It works on the principle of electrically charging the air within an open detector chamber. The charged air is a measure of the smoke. It is also called as fire alert ionization because it detects the outbreaks of fire at an earliest state. It consists of the ionization chamber, integrating timer, charge detector and alarm. The ionization chamber is having a small radioactive source which irradiates the space between the electrodes with alpha particles. This creates ions of both positive and negative signs and moves towards the respective electrodes. The movement of ions constitutes the current flow. When compared with normal air ionized current, air with smoke produce less ionization current. This reduction in the electric current is a measure of smoke.

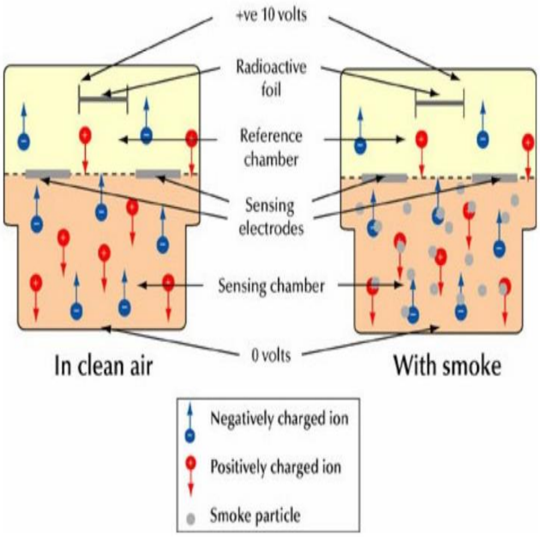


Figure 4.14 Ionization method for smoke measurement

TEXT / REFERENCE BOOKS

1.Considine D. M., “Process/Industrial Instruments and control Handbook”, McGraw Hill, 5th edition 1999

2.Liptak B G, “Instrument Engineer’s Handbook, Vol. 2: Process Control and Optimization”, CRC Press, 2006

3.Liptak B.G, “Process Measurement and Analysis”, Third Edition, Chilton Book Co., 2003

4.. Considine D. M, “Hand Book of Applied Instrumentation”, Tata McGraw Hill, 1984

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SCHOOL OF ELECTRICAL AND ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION ENGINEERING

UNIT – V – Instrumentation in Industries – SIC1404

V. Instrumentation in Pharmaceutical, nuclear and power plant Industries

Pharmaceutical Industries: Flow measurement - pressure measurement - smoke detector Nuclear Industries: Radiation detection instruments - Area monitors and in-place detectors - Temperature measuring devices - level sensors. Power Plant Industries: Metal temperature measurements, flow of feed water - fuel, air, steam with correction factor for temperature and pressure.

5.1 Pharmaceutical Industries: Flow measurement

The measurement of flow must be suitable for measuring low flowrates in streams containing solids, or corrosive materials or both. As a result frequent use is made of integral orifice meters, magnetic flowmeters, armored or metal tube rotameters, turbine meters and liquid displacement flowmeters. The orifice meter is frequently used in glass armored or plastic pipe with plastic orifice holding blocks. For measurement of liquid stream containing sediments, a float type sensor is employed. The float in flume transmitter transmits a signal that is dependant on the height of the liquid leaving the flume. The liquid height is detected by the “ski” type sensor. The nonlinear measurement is linearized by a characterized cam, and the maximum range of the transmitter is 20000 gallons per hour.

5.2 Pressure measurement

The special requirements in pressure measurement are associated prevention of contamination and plugging. Ordinarily the inline chemical and the full stream spool seal afford satisfactory service for pressures between 20 and 200 psig. For pressures below 20 psig, the extended diaphragm, differential pressure transmitter can be used by venting the low pressure side of the transmitter to the atmosphere.

5.3 Smoke detector

This unit utilizes a small radioactive source to make the air electrically conductive(ionized). A voltage applied across the ionization chamber causes a minute electrical current. When products of combustion enter the chamber, they also become ionized, but owing to their relatively large size they move more slowly, thereby reducing the current flow. The current is amplified by two ionization chambers and a special cold cathode tube connected in parallel with the chambers.

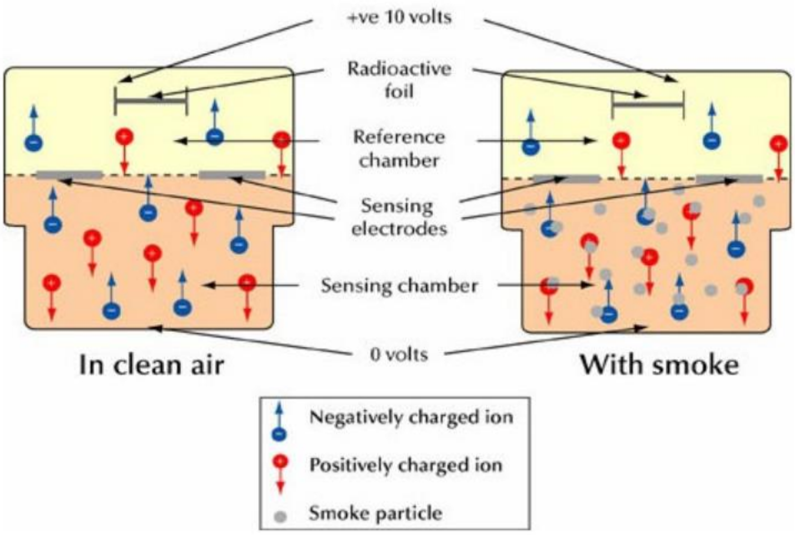

Figure 5.1 Smoke detector

With the outer chamber open to the air and the inner chamber sealed, a reduction of current in the measuring chamber will increase the voltage at the trigger electrode and activate an alarm relay. A minimum air velocity past the detector is required for proper operation.

5.4 Nuclear Industries:

Nuclear power is the use of sustained nuclear fission to generate heat and do useful work. Nuclear Electric Plants, Nuclear Ships and Submarines use controlled nuclear energy to heat water and produce steam, while in space, nuclear energy decays naturally in a radioisotope thermoelectric generator. Scientists are experimenting with fusion energy for future generation, but these experiments do not currently generate useful energy.

Nuclear power provides about 6% of the world's energy and 13–14% of the world's electricity, with the U.S., France, and Japan together accounting for about 50% of nuclear generated electricity. Also, more than 150 naval vessels using nuclear propulsion have been built. Just as many conventional thermal power stations generate electricity by harnessing the thermal energy released from burning fossil fuels, nuclear power plants convert the energy released from the nucleus of an atom, typically via nuclear fission.

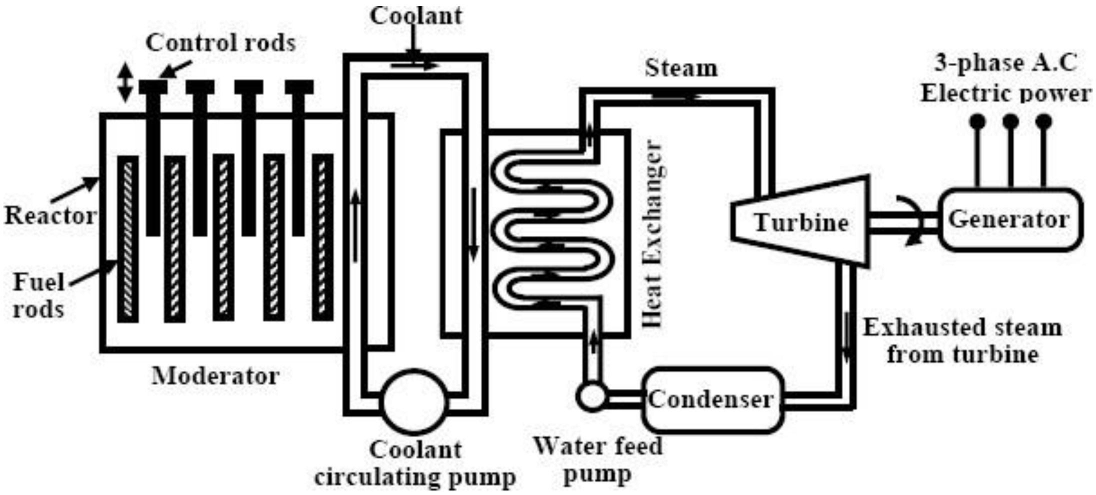

Figure 5.2: Nuclear power generation

5.4.1Nuclear reactor technology

When a relatively large fissile atomic nucleus (usually uranium-235 or plutonium-239) absorbs a neutron, a fission of the atom often results. Fission splits the atom into two or more smaller nuclei with kinetic energy (known as fission products) and also releases gamma radiation and free neutrons. A portion of these neutrons may later be absorbed by other fissile atoms and create more fissions, which release more neutrons, and so on.

This nuclear chain reaction can be controlled by using neutron poisons and neutron moderators to change the portion of neutrons that will go on to cause more fissions Nuclear reactors generally have automatic and manual systems to shut the fission reaction down if unsafe conditions are detected.There are many different reactor designs, utilizing different fuels and coolants and incorporating different control schemes. Some of these designs have been engineered to meet a specific need. Reactors for nuclear submarines and large naval ships, for example, commonly use highly enriched uranium as a fuel. This fuel choice increases the reactor's power density and extends the usable life of the nuclear fuel load, but is more expensive and a greater risk to nuclear proliferation than some of the other nuclear fuels.A number of new designs for nuclear power generation, collectively known as the Generation IV reactors, are the subject of active research and may be used for practical power generation in the future. Many of these new designs specifically attempt to make fission reactors cleaner, safer and/or less of a risk to the proliferation of nuclear weapons. Passively safe plants (such as the ESBWR) are available to be built and other designs that are believed to be nearly fool-proof are being pursued. Fusion reactors, which may be viable in the future, diminish or eliminate many of the risks associated with nuclear fission. There are trades to be made between safety, economic and technical properties of different reactor designs for particular applications. Historically these decisions were often made in private by scientists, regulators and engineers, but this may be considered problematic, and since Chernobyl and Three Mile Island, many involved now consider informed consent and morality should be primary considerations.

5.4.2 Cooling system

A cooling system removes heat from the reactor core and transports it to another area of the plant, where the thermal energy can be harnessed to produce electricity or to do other useful work. Typically the hot coolant will be used as a heat source for a boiler, and the pressurized steam from that boiler will power one or more steam turbine driven electrical generators.

5.4.3 Nuclear Fission

In nuclear physics and nuclear chemistry, **nuclear fission** is a nuclear reaction in which the nucleus of an atom splits into smaller parts (lighter nuclei), often producing free neutrons and photons (in the form of gamma rays). The two nuclei produced are most often of comparable size, typically with a mass ratio around 3:2 for common fissile isotopes. Most fissions are binary fissions, but occasionally (2 to 4 times per 1000 events), three positively-charged fragments are produced in a ternary fission. The smallest of these ranges in size from a proton to an argon nucleus.Fission is usually an energetic nuclear reaction induced by a neutron, although it is occasionally seen as a form of spontaneous radioactive decay, especially in very high-mass-number isotopes. The unpredictable composition of the products (which vary in a broad probabilistic and somewhat chaotic manner) distinguishes fission from purely quantum-tunnelling processes such as proton emission, alpha decay and cluster decay, which give the same products every time. Fission of heavy elements is an exothermic reaction which can release large amounts of energy both as electromagnetic radiation and as kinetic energy of the fragments (heating the bulk material where fission takes place). In order for fission to produce energy, the total binding energy of the resulting elements must be less than that of the starting element. Fission is a form of nuclear transmutation because the resulting fragments are not the same element as the original atom.

5.4.4 Nuclear fusion

In nuclear physics, nuclear chemistry and astrophysics **nuclear fusion** is the process by which two or more atomic nuclei join together, or "fuse", to form a single heavier nucleus. This is usually accompanied by the release or absorption of large quantities of energy. Large-scale thermonuclear fusion processes, involving many nuclei fusing at once, must occur in matter at very high densities and temperatures. The fusion of two nuclei with lower masses than iron (which, along with nickel, has the largest binding energy per nucleon) generally releases energy while the fusion of nuclei heavier than iron absorbs energy. The opposite is true for the reverse process, nuclear fission.

In the simplest case of hydrogen fusion, two protons must be brought close enough for the weak nuclear force to convert either of the identical protons into a neutron, thus forming the hydrogen isotope deuterium. In more complex cases of heavy ion fusion involving two or more nucleons, the reaction mechanism is different, but the same result occurs— smaller nuclei are combined into larger nuclei. Nuclear fusion occurs naturally in all active stars. Synthetic fusion as a result of human actions has also been achieved, although this has not yet been completely controlled as a source of nuclear power (see: fusion power). In the laboratory, successful nuclear physics experiments have been carried out that involve the fusion of many different varieties of nuclei, but the energy output has been negligible in these studies. In fact, the amount of energy put into the process has always exceeded the energy output. Uncontrolled nuclear fusion has been carried out many times in nuclear weapons testing, which results in a deliberate explosion.

5.4.5 Types Of Reactors

Pressurized water reactors (**PWR**s) constitute a majority of all western nuclear power plants and are one of two types of light water reactor (LWR), the other type being boiling water reactors (BWRs). In a PWR the primary coolant (water) is pumped under high pressure to the reactor core where it is heated by the energy generated by the fission of atoms. The heated water then flows to a steam generator where it transfers its thermal energy to a secondary system where steam is generated and flows to turbines which, in turn, spins an electric generator. In contrast to a boiling water reactor, pressure in the primary coolant loop prevents the water from boiling within the reactor. All LWRs use ordinary light water as both coolant and neutron moderator.

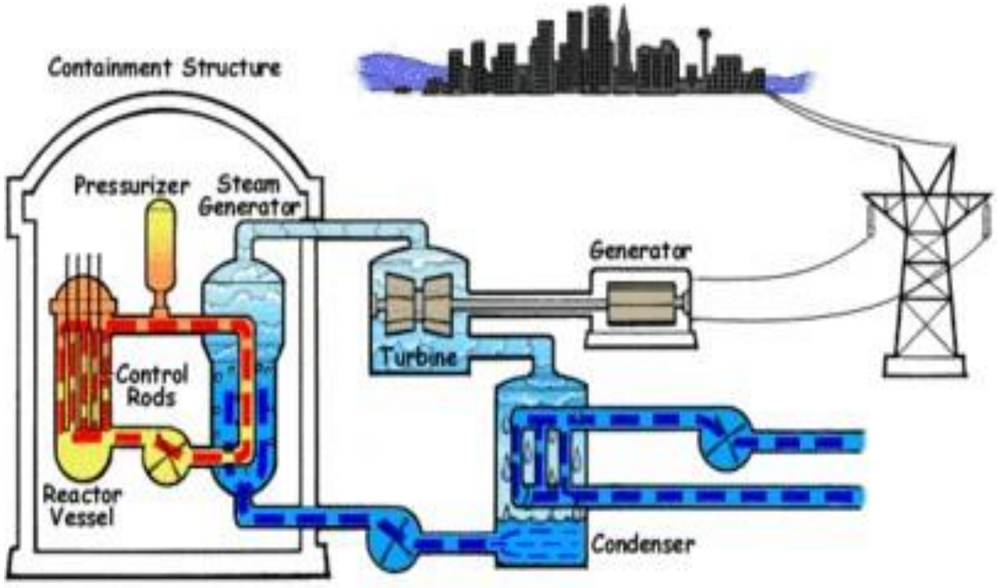

Figure 5.3: Pressurized water reactors

Primary coolant is in orange and the secondary coolant (steam and later feedwater) is in blue. Nuclear fuel in the reactor vessel is engaged in a fission chain reaction, which produces heat, heating the water in the primary coolant loop by thermal conduction through the fuel cladding. The hot primary coolant is pumped into a heat exchanger called the steam generator, where it flows through hundreds or thousands of tubes (usually 3/4 inch in diameter). Heat is transferred through the walls of these tubes to the lower pressure secondary coolant located on the sheet side of the exchanger where it evaporates to pressurized steam. The transfer of heat is accomplished without mixing the two fluids, which is desirable since the primary coolant might become radioactive. Some common steam generator arrangements are u-tubes or single pass heat exchangers. In a nuclear power station, the pressurized steam is fed through a steam turbine which drives an electrical generator connected to the electric grid for distribution. After passing through the turbine the secondary coolant (water-steam mixture) is cooled down and condensed in a condenser. The condenser converts the steam to a liquid so that it can be pumped back into the steam generator, and maintains a vacuum at the turbine outlet so that the pressure drop across the turbine, and hence the energy extracted from the steam, is maximized. Before being fed into the steam generator, the condensed steam (referred to as feedwater) is sometimes preheated in order to minimize thermal shock.

5.4.6 Boiling Water Reactor

The boiling water reactor (BWR) is a type of light water nuclear reactor used for the generation of electrical power. It is the second most common type of electricity generating nuclear reactor after the pressurized water reactor (PWR), also a type of light water nuclear reactor. The BWR was developed by the Idaho National Laboratory and General Electric in the mid-1950s. The main present manufacturer is GE Hitachi Nuclear Energy, which specializes in the design and construction of this type of reactor.

A newer design of BWR is known as the Advanced Boiling Water Reactor (ABWR). The ABWR was developed in the late 1980s and early 1990s, and has been further improved to the present day. The ABWR incorporates advanced technologies in the design, including computer control, plant automation, control rod removal, motion, and insertion, in-core pumping, and nuclear safety to deliver improvements over the original series of production BWRs, with a high power output (1350 Mwe per reactor), and a significantly lowered probability of core damage. Most significantly, the ABWR was a completely standardized design, that could be made for series production.

General Electric (GE) also developed a different concept for a new boiling water reactor (BWR) at the same time as the ABWR, known as the simplified boiling water reactor (SBWR). This smaller (600 megawatt electrical (Mwe) per reactor) was notable for its incorporation for the first time ever in a light water reactor of passive safety design principles. The concept of passive safety means that the reactor, rather than requiring the intervention of active systems, such as mergency injection pumps, to keep the reactor within safety margins, was instead designed to return to a safe state solely through operation of natural forces if a safety-related contingency developed.

5.5 Radiation detection instruments

Radiation always consists of charged particles (such as alpha and beta rays) and the detector materials are chosen so that charged particles (ions) are produced, as the radiation is absorbed or passes through the detector. The charged particles are collected on an electrode in the detector, resulting in a measurable electrical signal. Radiation detectors operate either in the pulsed mode or in the integrated (mean-level) mode. Nearly all of the detectors except the scintillation and semiconductor detectors operate on the bases of ion collection in a gas-filled chamber that uses a central electrode and the chamber wall at opposite electrical potentials. The applied potential determines the detection characteristics. Ionization chambers, operated at relatively low voltage produce pulses that are accurately proportional to the energy of the initiating radiation, or in the integrating mode, the output is accurately proportional to the total radiation detected.

The electrical capacitance of the ionization chamber and associated circuitry determines the operation mode—larger capacitance being used for the integrating mode. As the applied potential is increased, the ions created by the radiation are accelerated to sufficient velocities that they produce additional ions in the chamber fill gas. This gas multiplication improves the signal amplitude while still preserving the proportionality between initiating radiation energy and output pulse height. As the applied potential is increased, a point is reached at which the radiation induced ions (above some minimum threshold energy) produce an avalanche of ions essentially unrelated to the energy of the original radiation.

Scintillation detectors operate on the principle of light emission on the tax absorption of radiation by an atom and on its return to its unexcited state. The scintillating material is usually a zinc sulfide, sodium iodide or cesium iodide crystal, although liquid scintillators of organic materials such as naphthalene are also used. The light emitted by the passage of the radiation through the scintillator may be proportional to the energy of the radiation and is detected by a photomultiplier tube. The light emitted, and hence the pulse height at the output of the photomultiplier depend on the type of radiation as well as its energy, requiring different calibration factors for alpha, beta and gamma radiation.

Semiconductor detectors function on the principle of the creation of, electron-hole pairs, within the semiconductor diode junction by the ionizing radiation. Such detectors are becoming widely used in nuclear research, primarily for heavy particle detection, because of their relatively higher cost and their present state of development.

Personal radiation detectors are for monitoring the amount of low-level radiation that a nuclear industry employee may be exposed to or for warning him that he has been esposed to radiation in excess of some predetermined level. Pocket detectors, called pencil type meters, are about the size of a large fountain pen. A cylindrical Ion chamber,the detector has a plastic case coated on the inside with a conducting material serving as one electrode and an insulated wire cathode along the axis of the cylinder serving as the other electrode. The chamber is charged to about 150 volts prior to use, and for 500 to 1000 hours the charge leakage (if the insulator is efficient) is primarily related to ion pairs created by gamma or energetic beta radiation. An indication of the charge remaining on the ion chamber is obtained by inserting the pencil meter in an electrometer reading station. Similar in principle but designed for visual reading is the pocket quartz-fibcr electrometer. About the size of the pencil meter, it contains an insulated fiber which is physically displaced inside the ion chamber by the stored charge. The fiber projects a shadow on an etched scale, which is visible when the instrument is held up to the light. Although more popular for civil defense uses because it requires no reading station (only a charging device), it is not used in the nuclear industry in quantities as large as the pencil meter.

Thermoluminescent dosimeters depend for their operation on the absorption of radiation energy within lithium fluoride, calcium fluoride, calcium sulfate or lithium borate crystals. These crystals absorb neutron or gamma energy over long periods with only about 5% kiss (at room temperature) after 1 year. Read-out of the absorbed energy is done by warming the crystals, whereupon they emit light in proportion to the amount of radiation absorbed. A photomultiplier is required to detect the light output. Isotopic concentration (Li-6 vs Li-7) can be varied in the lithium compounds to effect discrimination of neutrons and gamma rays. The crystal compounds are available as powder or as extruded polycrystalline solids.

5.6 Area monitors and Inplace detectors

They are intended to ensure safe working conditions in nonradioactive areas, by sounding an alarm when unsafe conditions are detected. Because false alarms quickly negate the dependence that workers should place on safety instruments, they are often designed to accommodate power line transients without alarming, and use very conservative circuitry for reliability. Three typical uses include air monitoring for radioactive particulate matter; detection of inadvertent transport of radioactive material away from an area designated for work with radioactive materials; and detection of short bursts radiation may indicate a briefly unsafe or uncontrolled condition otherwise undetectable.

Air monitors concentrate minute quantities of particulate matter by continuously drawing air from the area being monitored and passing it through a filter on which the particulate matter is deposited. A scintillation counter detects alpha-emitting radionuclides by allowing the filter (in the form of a wide paper tape) to move periodically or continuously past the scintillator. Detection of hazardous alpha ray radioactivity is severely complicated by the possible presence of beta or gamma radiation and by the fact that radon at an alpha emitter, is continuously present in air at the earth's surface. The normal concentration of radon may pro6ice alpha disintegrations that may be 200 or more times the allowable number for Pu. Discrimination of the hazardous alpha-emitting radionuclides such as Pu is done by circuitry that analyzes the characteristic energy spectrum or decay half-life of the radiation detected. Several types of monitors detect the presence of radioactive material that may be picked up by shoes, hands or clothing of personnel working in radiochemical faciliities. To detect alpha radiation—because of the necessity of placing the detector in intimate contact with the possible source of contamination. The hand and foot counter saves time by automatically monitoring shoe soles and both sides of each hand for beta-emitting and gamma-emitting contamination. A monitr consisting of five or more G-M tubes mounted above and around doorways and connected to a single alarming instrument is often used to warn against unwitting transport of radioactive material.

5.7 Temperature measuring devices

Thermocouples in the nuclear industry are almost always the mineral-insulated metal-sheathed type, in which one or more measuring junctions are enclosed in a stainless steel, tantalum or in conel tube with tightly compacted insulation. Rigid specifications ensure high quality materials and construction that will enable the thermocouples to withstand nuclear environments with low failure rates. These thermocouples may be installed in wells or if speed of response must be high, the sheath can be inserted directly into the process. When penetrations into the vessels or piping must be held to a minimum, sheathed thermocouples may be fitted with a thin metal tab which is tack welded to the pipe. The thermocouples are then strapped to the pipe underneath the insulation. the time response of the grounded junction thermocouples is generally faster than that of the insulated junction types. Resistance thermometer devices (RTDs) for nuclear processes are becoming more widely available than heretofore for use at higher temperatures and they are less subject to drift, have greater sensitivity and are therefore more accurate than thermocouples. As yet they cannot be used much beyond 900 C, are more fragile and more expensive than thermocouples and must be used in a protective well in addition to having a slower time response than thermocouples. Furthermore, platinum RTD elements cannot be used with stainless steel materials above 400 C.

5.8 Level sensors

Nuclear processes require special applications of level measurement instruments primarily in radiochemical fuel reprocessing plants and in nuclear reactors. In radiochemical fuel reprocessing plants, to permit access for zeroing, callibration or replacement, the air bubbler type of level sensors are commonly used. The major disadvantages of the air bubbler system have been overcome by dip tube optimization, purge control and differential pressure cell system design. The measurement of liquid level in the hostile environment of high temperature and radiation is a great challenge. Sensors that work on the principle of liquid metal electrical conductively and succeed in detecting sodium level will not work for other fluids. A differential thermal conductivity level sensor has been successfully adapted to various applications in which there is a difference between the immersed and the unimmersed state. Such a change in thermal conductance results in a temperature difference which can be detected by a thermocouple because the heat generated by a small heater is easily transferred in the liquid immersed case but not in the unimmersed condition. Thermal level probes based on this principle have been made for single point level detection and for multiple point or semipropotional indication using a continuous length of heater (resistance wire) and several thermocouple junctions. The single point thermal level probe is a reliable alarm sensor or detecting leakage or spills in the cell slump of a nuclear processing plan or reactor.

5.9 Power plant industries

5.9.1 Metal temperature measurements

- Temperature is one of the most widely measured parameters in a power plant.
- No matter the type of plant, accurate and reliable temperature measurement is essential for operational excellence. Incorrect measurement because of electrical effects, nonlinearity or instability can result in damage to major equipment.
- Although some specialty temperature measurements involve infrared sensors, the vast majority of measurements in a power plant are made with resistance temperature detectors (RTDs) or thermocouples (T/Cs). Both are electrical sensors that produce a mV signal in response to temperature changes.
- RTDs consist of a length of wire wrapped around a ceramic or glass core placed inside a probe for protection. An RTD produces an electrical signal that changes resistance as the temperature changes. RTD sensing elements can be made from platinum, nickel, copper and other materials and can have two, three or four wires connecting them to a transmitter.
- RTDs are commonly used in applications where accuracy and repeatability are important. RTDs have excellent accuracy of about 0.1ºC and a stable output for a long period of time, but a limited temperature range. The maximum temperature for an RTD is about 800ºF.
- A thermocouple sensor consists of two dissimilar metals joined together at one end. When the junction is heated, it produces a voltage that corresponds to temperature. T/Cs can be made of different combinations of metals and calibrations for various

temperature ranges. The most common T/C type are J, K and N; for power industry applications, high-temperature versions include R and S.

- A thermocouple can be used for temperatures as high as 3100°F. T/Cs will respond faster to temperature changes than an RTD and are more durable, allowing use in high vibration and shock applications
- RTDs tend to be relatively fragile and generally not suitable for high temperatures or high vibration, so areas such as steam generators and pump monitoring tend to use thermocouples, but exceptions exist.
- Most temperature applications in power plants involve directly wiring a temperature sensor to the control system
- A transmitter converts the mV signal from an RTD or T/C to a 4-20mA signal or to a digital fieldbus output such as HART, Foundation Fieldbus or Profibus PA in the case of a smart transmitter. Either of these outputs can be transmitted over a twisted pair wire for a considerable distance. Smart transmitters incorporate remote calibration, advanced diagnostics and built-in control capabilities and some are capable of wireless operation.

5.9.2 Flow of feedwater

The power generation industry largely depends on feed water and hydrocarbon fuels to generate electricity. The flow of such liquids, gases, or a mixture of both must be accurately monitored to keep the entire system operating in an efficient manner. To achieve precise flow monitoring, power plants require reliable and responsive flow measurement systems to measure and verify liquid/gas flow.

To avoid corrosion, feed water used in power plants is purified to the highest level. The high purification level makes the feed water an electrical insulator. This makes it difficult for an electromagnetic meter to measure the flow of the feed water. However, there are ultrasonic flow measurement meters available in the market that accurately measure the flow of feed water regardless of their electrical conductivity.

TEXT / REFERENCE BOOKS

1. Considine D. M., “Process/Industrial Instruments and control Handbook”, McGraw Hill, 5th edition 1999.
2. Liptak B G, “Instrument Engineer’s Handbook, Vol. 2: Process Control and Optimization”, CRC Press, 2006.

3. Liptak B.G, “Process Measurement and Analysis”, Third Edition, Chilton Book Co., 2003
4. Considine D. M, “Hand Book of Applied Instrumentation”, Tata McGraw Hill, 1984