UNIT-3 ELECTRICAL MOTOR AND COMPRESSED AIR SYSTEM

Electric Motors

Motors convert electrical energy into mechanical energy by the interaction between the magnetic fields set up in the stator and rotor windings. Industrial electric motors can be broadly classified as induction motors, direct current motors or synchronous motors. All motor types have the same four operating components: stator (stationary windings), rotor (rotating windings), bearings, and frame (enclosure).

Electric Motor Types

1. Induction Motors

Induction motors are the most commonly used prime mover for various equipments in industrial applications. In induction motors, the induced magnetic field of the stator winding induces a current in the rotor. This induced rotor current produces a second magnetic field, which tries to oppose the stator magnetic field, and this causes the rotor to rotate.

The 3-phase squirrel cage motor is the workhorse of industry; it is rugged and reliable, and is by far the most common motor type used in industry. These motors drive pumps, blowers and fans, compressors, conveyers and production lines. The 3-phase induction motor has three windings each connected to a separate phase of the power supply.

2.Direct-Current Motors

Direct-Current motors, as the name implies, use direct-unidirectional, current. Direct current motors are used in special applications- where high torque starting or where smooth acceleration over a broad speed range is required

3. Synchronous Motors

AC power is fed to the stator of the synchronous motor. The rotor is fed by DC from a separate source. The rotor magnetic field locks onto the stator rotating magnetic field and rotates at the same speed. The speed of the rotor is a function of the supply frequency and the number of magnetic poles in the stator. While induction motors rotate with a slip, i.e., rpm is less than the synchronous speed, the synchronous motor rotate with no slip, i.e., the RPM is same as the synchronous speed governed by supply frequency and number of poles. The slip energy is provided by the D.C. excitation power.

Losses in Induction Motors

Stator and Rotor I_2R Losses

These losses are major losses and typically account for 55% to 60% of the total losses. I^2R losses are heating losses resulting from current passing through stator and rotor conductors. I^2R losses are the function of a conductor resistance, the square of current. Resistance of conductor is a function of conductor material, length and cross sectional area.

The suitable selection of copper conductor size will reduce the resistance. Reducing the motor current is most readily accomplished by decreasing the magnetizing component of current. This involves lowering the operating flux density and possible shortening of air gap.

Rotor I^2R losses are a function of the rotor conductors (usually aluminium) and the rotor slip. Utilisation of copper conductors will reduce the winding resistance. Motor operation closer to synchronous speed will also reduce rotor losses.

Core Losses

Core losses are those found in the stator-rotor magnetic steel and are due to hysterisis effect and eddy current effect during 50 Hz magnetization of the core material. These losses are independent of load and account for 20 – 25 % of the total losses.

The hysterisis losses which are a function of flux density, are be reduced by utilizing low loss grade of silicon steel laminations. The reduction of flux density is achieved by suitable increase in the core length of stator and rotor. Eddy current losses are generated by circulating current within the core steel laminations. These are reduced by using thinner laminations.

Friction and Windage Losses

Friction and windage losses results from bearing friction, windage and circulating air through the motor and account for 8 – 12 % of total losses. These losses are independent of load. The reduction in heat generated by stator and rotor losses permit the use of smaller fan. The windage losses also reduce with the diameter of fan leading to reduction in windage losses

Stray Load-Losses

These losses vary according to square of the load current and are caused by leakage flux induced by load currents in the laminations and account for 4 to 5 % of total losses. These losses are reduced by careful selection of slot numbers, tooth/slot geometry and air gap.

Motor Efficiency

Two important attributes relating to efficiency of electricity use by A.C. Induction motors are efficiency , defined as the ratio of the mechanical energy delivered at the rotating shaft to the electrical energy input at its terminals, and power factor (PF). Motors, like other inductive loads, are characterized by power factors less than one. As a result, the total current draw needed to deliver the same real power is higher than for a load characterized by a higher PF. An important effect of operating with a PF less than one is that resistance losses in wiring upstream of the motor will be higher, since these are proportional to the square of the current. Thus, both a high value for efficiency and a PF close to unity are desired for efficient overall operation in a plant.

Squirrel cage motors are normally more efficient than slip-ring motors, and higher-speed motors are normally more efficient than lower-speed motors. Efficiency is also a function of motor temperature. Totally-enclosed, fan-cooled (TEFC) motors are more efficient than screen protected, drip-proof (SPDP) motors. Also, as with most equipment, motor efficiency increases with the rated capacity.

Energy-Efficient Motors

Energy-efficient motors (EEM) are the ones in which, design improvements are incorporated specifically to increase operating efficiency over motors of standard design. Design improvements focus on reducing intrinsic motor losses. Improvements include the use of lower- loss silicon steel, a longer core (to increase active material), thicker wires (to reduce resistance), thinner laminations, smaller air gap between stator and rotor, copper instead of aluminum bars in the rotor, superior bearings and a smaller fan, etc.

Energy-efficient motors now available in India operate with efficiencies that are typically 3 to 4 percentage points higher than standard motors. In keeping with the stipulations of the BIS, energy-efficient motors are designed to operate without loss in efficiency at loads between 75 % and 100 % of rated capacity. This may result in major benefits in varying load applications. The power factor is about the same or may be higher than for standard motors. Furthermore, energy- efficient motors have lower operating temperatures and noise levels, greater ability to accelerate higher-inertia loads, and are less affected by supply voltage fluctuations

Factors Affecting Energy Efficiency & Minimizing Motor Losses in Operation

Motor performance is affected considerably by the quality of input power, that is the actual volts and frequency available at motor terminals vis-à-vis rated values as well as voltage and frequency variations and voltage unbalance across the three phases. Motors in India must comply with standards set by the Bureau of Indian Standards (BIS) for tolerance to variations in input power quality. The BIS standards specify that a motor should be capable of delivering its rated output with a voltage variation of +/- 6 % and frequency variation of +/- 3 %. Fluctuations much larger than these are quite common in utility-supplied electricity in India. Voltage fluctuations can have detrimental impacts on motor performance.

Voltage unbalance, the condition where the voltages in the three phases are not equal, can be still more detrimental to motor performance and motor life. Unbalance typically occurs as a result of supplying single-phase loads disproportionately from one of the phases. It can also result from the use of different sizes of cables in the distribution system.

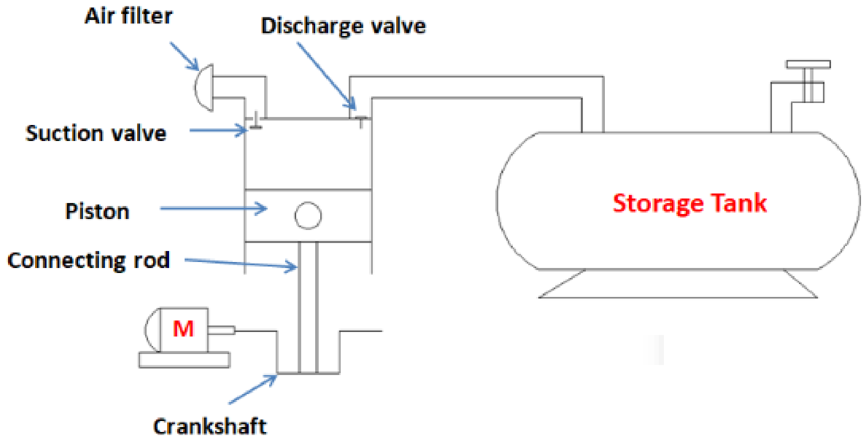
Compressed air system

An **air compressor** is a device that converts power (using an electric motor, diesel or gasoline engine, etc.) into potential energy stored in pressurized **air** (i.e., compressed**air**). By one of several methods, an air compressor forces more and more **air** into a storage tank, increasing the pressure

Reciprocating Air Compressor is a positive displacement air compressor in which air is sucked in a chamber and compressed with the help of a reciprocating piston. It is called as positive displacement compressor because air is first sucked in a chamber and then compression is achieved by decreasing area of the chamber. The area is decreased by a piston which does reciprocating motion.

Working Principle

In reciprocating air compressor, as the piston moves towards the BDC, the air is sucked into the cylinder from the atmosphere and when it moves towards the TDC, the compression of the air starts and keeps on going and pressure increases. When the pressure increases upto its design limit it pushes the discharge valve to open and the compressed air is delivered to the storage tank.



1. **Piston:** It does reciprocating motion in the cylinder and responsible for the compression of the air.
2. **Cylinder:** It is a chamber in which air is compressed.
3. **Connection Rod:** It connects the piston and crankshaft.
4. **Crankshaft:** It is connected to the shaft of electric motor. And transfers its rotary motion to the piston.
5. **Suction valve:** The air is sucked through suction valve when piston moves to BDC.
6. **Discharge valve:** The compressed air is discharged through the discharge valve to the storage tank.

Working:

As power is On, the electric motor starts rotating and also rotates the crankshaft attached to it. The piston starts doing to and fro motion inside the cylinder.
As the piston moves downward (towards BDC), the air from the atmosphere enters into the chamber of the cylinder.
Now the piston after reaching at BDC, starts moving upward (i.e. towards TDC), the compression of the air starts and its pressure begins to increase.
When the pressure inside the cylinder increases above the pressure of the discharge valve, the discharge valve opens and the compressed air is delivered to an air storage tank from where it is utilized for the work.

Energy Efficiency / Saving Measures in Compressed Air System

- Ensure air intake to compressor is not warm and humid by locating compressors in well ventilated area or by drawing cold air from outside. Every 4°C rise in air inlet temperature will increase power consumption by 1 percent.
- Clean air-inlet filters regularly. Compressor efficiency will be reduced by 2 percent for every 250 mm WC pressure drop across the filter.
- Keep compressor valves in good condition by removing and inspecting once every six months.Worn-out valves can reduce compressor efficiency by as much as 50 percent.
- Minimize low-load compressor operation; if air demand is less than 50 percent of compressorcapacity, consider change over to a smaller compressor or reduce compressor speed appropriately(by reducing motor pulley size) in case of belt driven compressors.
- Consider the use of regenerative air dryers, which uses the heat of compressed air to remove moisture.

- If more than one compressor is feeding to a common header, compressors must be operated in such a way that only one small compressor should handle the load variations whereas othercompressors will operate at full load.
- The possibility of heat recovery from hot compressed air to generate hot air or water for process application must be economically analyzed in case of large compressors.
- Consideration should be given to two-stage or multistage compressor as it consumes less power for the same air output than a single stage compressor.
- Keep the minimum possible range between load and unload pressure settings. Automatic timer controlled drain traps wastes compressed air every time the valve opens. Sofrequency of drainage should be optimized.
- Present energy prices justify liberal designs of pipeline sizes to reduce pressure drops.
- Compressed air piping layout should be made preferably as a ring main to provide desiredpressures for all users.
- A smaller dedicated compressor can be installed at load point, located far off from the centralcompressor house, instead of supplying air through lengthy pipelines.
- All pneumatic equipment should be properly lubricated, which will reduce friction, prevent wear of seals and other rubber parts thus preventing energy wastage due to excessive air consumption or leakage.

Boilers

These are used to increase the efficiency of the plant. These are developed because of rising cost of fuel and restrictions on air pollution. Modern power generation plants generally use high pressure boilers. These high pressure boilers have pressures above 140 bar and the temperature may be up to 540 – 610°C.

Types of High Pressure Boilers:

1. LaMont Boiler: 2. Benson Boiler: 3.Loeffler Boiler:4.Velox Boiler:

Lamont boiler

This boiler works on basic principle of forced convection. If the water is circulate by a pump inside the tube, the heat transfer rate from gas to the water is increases. It is the basic principle of it.

Construction:
This boiler is the first force circulation boiler. This boiler consist various part which are as follow.

Economizer:
Economizer use to preheat the water by using remaining heat of the combustion gases. It increases the boiler efficiency. The feed water first supplied to the economizer before entering to the boiler.

Centrifugal pump:
The Lamont boiler is a force convection boiler. So a centrifugal pump is used to circulate water inside the boiler. This pump is driven by a steam turbine. The steam for the turbine is taken by the boiler.

Evaporator tube:

The evaporator tube or can say water tubes are situated at furnace wall which increase the heating surface of boiler. This is also at the up side and down side of the furnace and other equipment. The main function of these tubes to evaporate water into steam. This also cools down the furnace wall.

Grate:
The space in the furnace where the fuel is burn is called grate. It is bottom side of furnace.

Furnace:
In the Lamont boiler vertical furnace is used. The main function of Furnace is to burn the fuel.

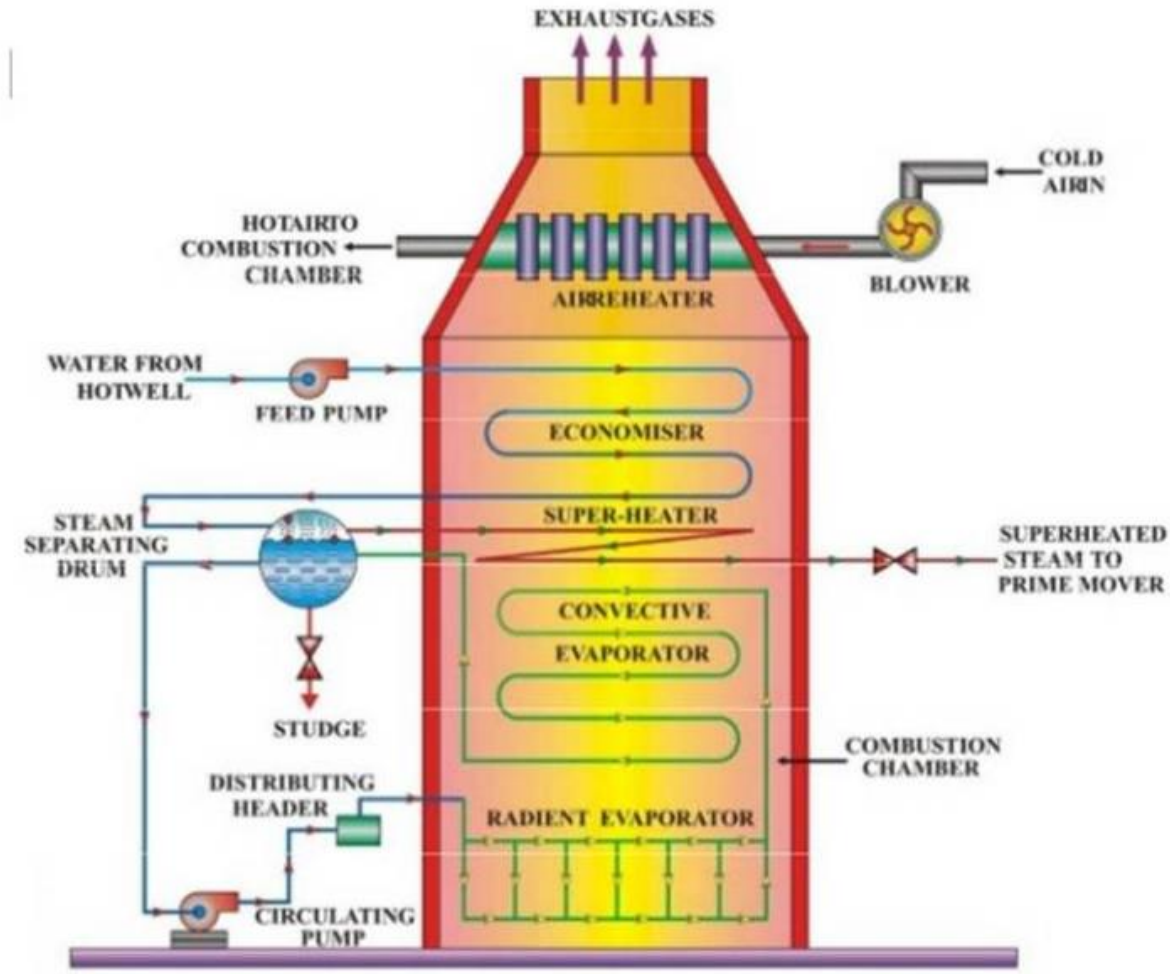
Super heater:
The steam generated by the evaporator tube is saturated steam. If it directly used in steam turbine can cause the corrosion. So the saturated steam sends to the super heater where it can increase the temperature of steam.

Water steam separator drum:
The steam separator is situated outside from the boiler. The mixture of water and steam from the evaporator tube send to the steam separator where it separate the steam and send it to super heater. The remaining water again sends to the economizer.

Air preheater:
It’s main function to preheat air before entering into furnace.

Working:

Lamont boiler is a forced circulation, internally fired water tube boiler. The fuel is burn inside the boiler and the water is circulating by a centrifugal pump through evaporator tubes. A feed pump forces the water into the economizer where the temperature of water increases. This water forced into the evaporator tube by using a centrifugal pump driven by steam turbine. Water passes 10 – 15 times into the evaporator tube. The mixture of saturated steam and water is formed inside the tube.



This mixture sends to the steam separator drum which is outside the boiler. Steam from the separator sends to the super heater, where the saturated steam converts into superheated steam. The water again sends to the economizer where it again passes by the evaporator tubes.

The air from the air preheater enter into the furnace where fuel burn. The flue gases first heat the evaporator tube then passes by the super heater. These gases from the super heater again use to preheat the air into air preheater before exhaust into atmosphere.

This working pressure of this boiler is above 170 bar and have the steam generation capacity of about 50000 kg/hour at temperature 773 K .

Advantages:

1. It can high pressure boiler.
2. It is flexible in design.
3. This boiler can reassemble in natural circulation boiler.
4. It can easily start.
5. It has high steam generation capacity of about 50 ton/ hour.
6. This boiler has higher heat transfer rate.

Efficiency computation of Boilers

Efficiency testing helps us to find out how far the boiler efficiency drifts away from the best efficiency. Any observed abnormal deviations could therefore be investigated to pinpoint the problem area for necessary corrective action. Hence it is necessary to find out the current level of efficiency for performance evaluation, which is a pre requisite for energy conservation action in industry

$$Boiler\ Efficiency = \frac{Heat\ Output}{Heat\ Input}$$

$$Boiler\ Efficiency = \frac{\text{Steam flow rate x (steam enthalpy} - \text{ feed water enthalpy)}}{\text{Fuel firing rate x Gross calorific value}}\ x\,100$$

Energy Conservation Opportunities in Boilers

1. Stack Temperature

The stack temperature (Temperature used to remove water vapor in the exhaust condenses on the stack walls) should be as low as possible. An estimated 1% efficiency loss occurs with every 22 °C increase in stack temperature.

2. Feed Water Preheating using Economizer

Feed Water Preheating using economizer would reduce the exit temperature to 65 °C, thereby increasing thermal efficiency by 5%.

3. Combustion Air Preheat

Combustion air preheating is an alternative to feed water pre-heating. In order to improve thermal efficiency by 1%, the combustion air temperature must be raised by 20 °C using pre-heater.

4. Incomplete Combustion

Incomplete combustion can arise from a shortage of air or surplus of fuel or poor distribution of fuel. It is usually obvious from the colour or smoke, and must be corrected immediately.

5. Excess Air Control

Controlling excess air to an optimum level always results in reduction in flue gas losses; for every 1% reduction in excess air there is approximately 0.6% rise in efficiency.

6. Radiation and Convection Heat Loss

Repairing or augmenting insulation can reduce heat loss through boiler walls and piping.

7. Automatic Blow down Control

Uncontrolled continuous blow down is very wasteful. Automatic blow down controls can be installed that sense and respond to boiler water conductivity and pH. A 10% blow down in a 15kg/cm2 boiler results in 3% efficiency loss.

8. **Variable Speed Control for Fans, Blowers and Pumps**

The possibility of replacing the dampers by a Variable speed should be improve the system efficiency.

9.Effect of Boiler Loading on Efficiency

The maximum efficiency of the boiler does not occur at full load, but at about two-thirds of the full load.

10. Proper Boiler Scheduling
Operate a fewer number of boilers at higher loads, than to operate a large number at low loads.
11. Boiler Replacement
The potential savings from replacing a boiler depend on the anticipated change in overall efficiency.

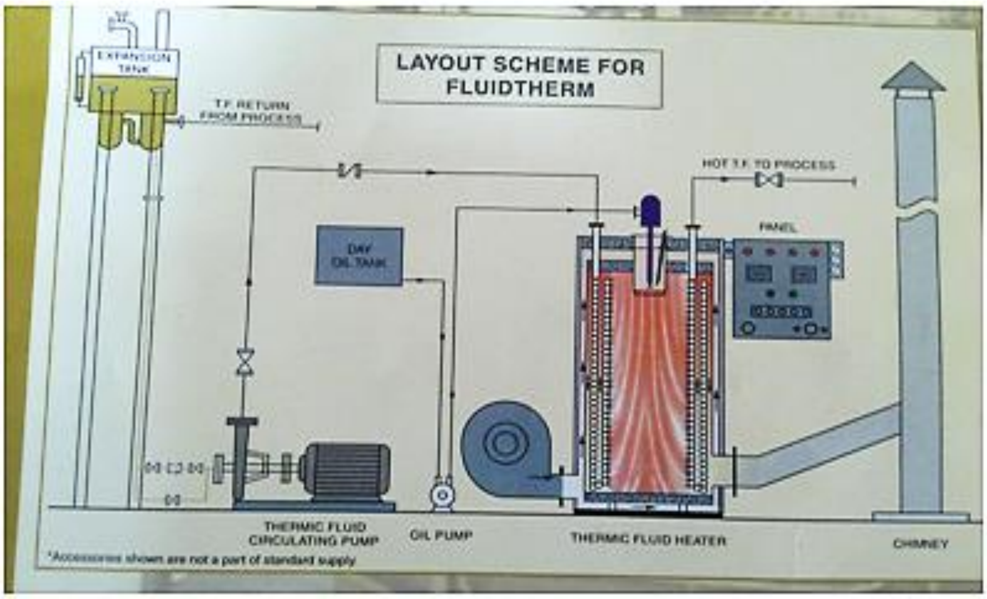
- Old and inefficient
- not capable of firing cheaper substitution fuel
- over or under-sized for present requirements
- not designed for ideal loading conditions

THERMIC FLUID HEATER (TFH)

A thermic fluid heater is a fully automatic highly efficient equipment that uses the thermic fluid as a heat transfer fluid which can be heated up to 300 degree Celsius at atmospheric pressure to cater needs of various industries i.e. chemical, textiles, plastic & rubber, metal finishing, food industry etc.,

thermic fluid heaterhot thermic fluid is circulated through which heat is transferred to the process using a heat exchanger at user’s end.

The maximum temperature of 300°C of thermal fluid can be achieved in a Fluidtherm although the higher temperature of the thermal fluid can be achieved provided the temperature of fluid does not exceed the auto-ignition temperature



Operating principle:
• The combustion air enters the burner fan inlet, travels upward between the inner and outer layer, preheating the air before it enters the top mounted burner.

• Hot gases travel down the full length of the vessel creating the first (radiant) pass.

• The gases then travel back across the inner row of coils, creating the second (convection) pass.

• The third (convection) pass is created as the gases continue back down between the inner and outer coil

• The last pass is upward between the outer coil and inner jacket to the flue outlet, creating the fourth (convection) pass

Features Of Thermic Fluid Heater

- Fully Automatic Unit- Maintains the desired temperature of a thermic fluid
- High System Efficiency- Reduced operating cost
- High Flow Rate- the Higher life of thermic fluid & heater coil
- Minimum Site Work- Reduced Installation cost
- Rugged design & superior construction-Smooth operation for many years
- Failsafe design & dependable safety instruments
- Backed by prompt & efficient after sales service

INSULATORS

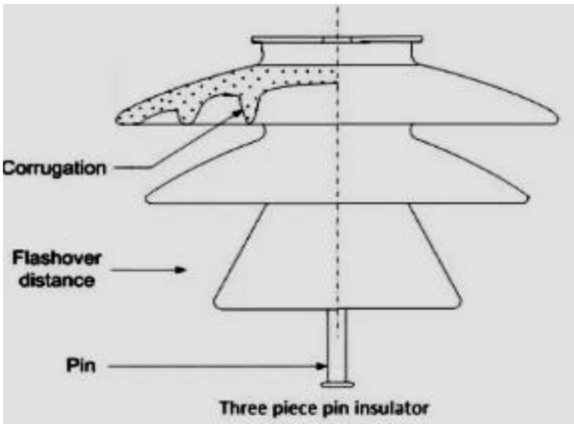
There are **5 types of insulators** used in transmission lines as overhead insulation:

1. Pin Insulator
2. Suspension Insulator
3. Strain Insulator
4. Stay Insulator
5. Shackle Insulator

Pin, Suspension, and Strain insulators are used in medium to high voltage systems. While Stay and Shackle Insulators are mainly used in low voltage applications.

1. Pin Insulator

Pin insulators are the earliest developed **overhead insulator,** but are still commonly used in power networks up to 33 kV system. Pin type insulator can be one part, two parts or three parts type, depending upon application voltage.



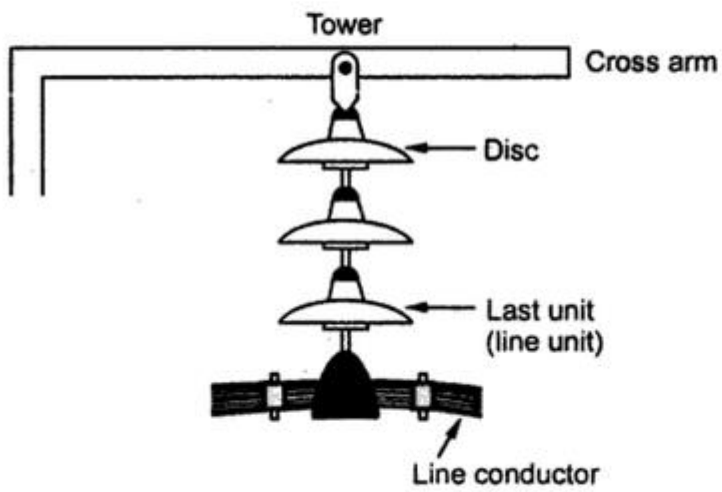
In a 11 kV system we generally use one part type insulator where whole pin insulator is one piece of properly shaped porcelain or glass.

As the leakage path of insulator is through its surface, it is desirable to increase the vertical length of the insulator surface area for lengthening leakage path. We provide one, two or more rain sheds or petticoats on the insulator body to obtain long leakage path.
In addition to that rain shed or petticoats on an insulator serve another purpose.

The live conductor attached to the top of the pin insulator which is at the live potential. We fix the bottom of the insulator to supporting structure of earth potential. The insulator has to withstand the potential stresses between conductor and earth. The shortest distance between conductor and earth, surrounding the insulator body, along which electrical discharge may take place through the air, is known as flashover distance.

2. Suspension Insulator

In higher voltage, beyond 33KV, it becomes uneconomical to use pin insulator because size, weight of the insulator become more. Handling and replacing bigger size single unit insulator are quite difficult task. For overcoming these difficulties, **suspension insulator** was developed.



String of suspension insulator with 3 units

In **suspension insulator** numbers of insulators are connected in series to form a string and the line conductor is carried by the bottom most insulator. Each insulator of a suspension string is called disc insulator because of their disc like shape.

Advantages of Suspension Insulator

1. Each suspension disc is designed for normal voltage rating 11KV (Higher voltage rating 15KV), so by using different numbers of discs, a suspension string can be made suitable for any voltage level.

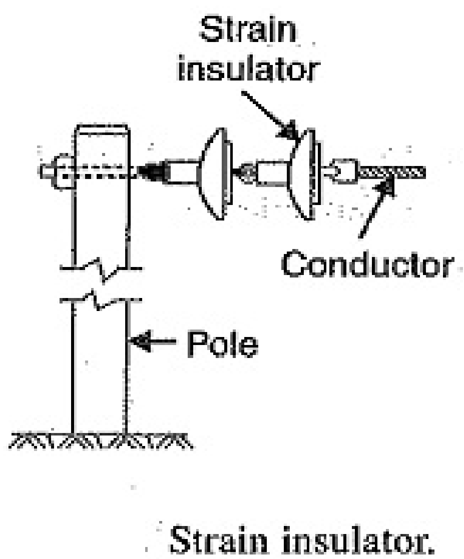
2. If any one of the disc insulators in a suspension string is damaged, it can be replaced much easily.
3. Mechanical stresses on the suspension insulator is less since the line hanged on a flexible suspension string.
4. As the current carrying conductors are suspended from supporting structure by suspension string, the height of the conductor position is always less than the total height of the supporting structure. Therefore, the conductors may be safe from lightening.

Disadvantages of Suspension Insulator

1. Suspension insulator string costlier than pin and post type insulator.
2. Suspension string requires more height of supporting structure than that for pin or post insulator to maintain same ground clearance of current conductor.
3. The amplitude of free swing of conductors is larger in suspension insulator system, hence, more spacing between conductors should be provided.

3. Strain Insulator

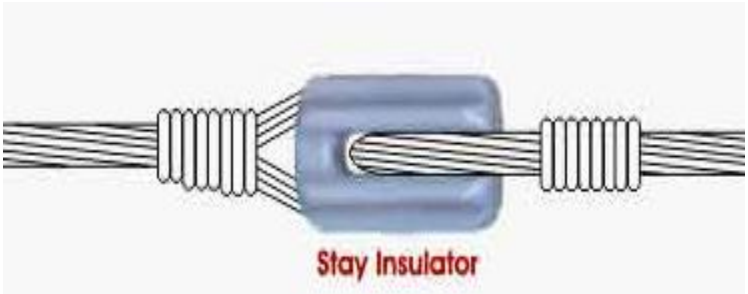
When suspension string is used to sustain extraordinary tensile load of conductor it is referred as **string insulator**. When there is a dead end or there is a sharp corner in transmission line, the line has to sustain a great tensile load of conductor or strain. A **strain insulator** must have considerable mechanical strength as well as the necessary electrical insulating properties.



Strain insulator.

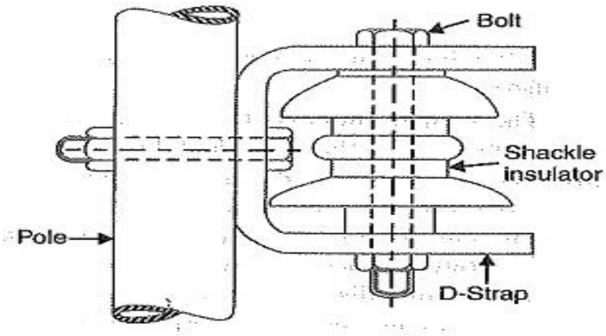
4. Stay Insulator

For low voltage lines, the stays are to be insulated from ground at a height. The insulator used in the stay wire is called as the **stay insulator** and is usually of porcelain and is so designed that in case of breakage of the insulator the guy-wire will not fall to the ground.



5. Shackle Insulator

The shackle insulator (also known as a spool insulator) is usually used in low voltage distribution network. It can be used in both the horizontal or vertical positions. The use of such insulator has decreased recently after increasing the using of underground cable for distribution purpose.



The tapered hole of the spool insulator distributes the load more evenly and minimizes the possibility of breakage when heavily loaded. The conductor in the groove of shackle insulator is fixed with the help of soft binding

FURNACE:

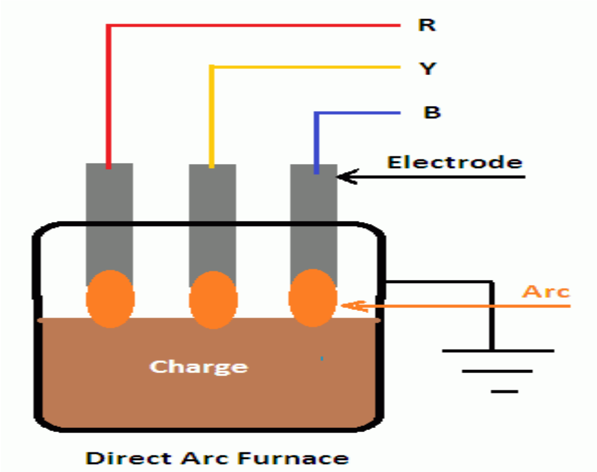
An enclosed structure in which material can be heated to very high temperatures, e.g. for smelting metals.

TYPES:

- central warm-air furnaces
- steam or hot-water systems (generally called "boilers")
- heat pumps (both air-source and geothermal)
- floor, wall, or pipeless furnaces
- built-in electric units
- heating stoves (which burn wood, coal or pellets)
- room heaters (which burns gas, oil or kerosene)
- fireplaces
- portable heater

WORKING OF FURNACE

- Furnaces are among the oldest of all residential heating systems. In their earliest days, they were fueled with coal and wood. Newer models use electricity, gas, or propane, and can run at high efficiency levels. Some have AFUE (annual fuel utilization efficiency) ratings of 98%, which means they turn 98% of the fuel they consume into heat.



- Whatever fuel a furnace uses, it operates on the principle of forced air heating. The furnace transfers heat to air, which blower fans then send through the ductwork of a house and out vents. Furnaces often share the duct system with an air conditioner so homeowners don't need to take up additional space for their cooling system.

Central Warm-Air Furnace: A type of space-heating equipment in which a central combustor or resistance unit--generally using gas, fuel oil, or electricity--provides warm air that circulates through ducts leading to the various rooms. Heat pumps are not included in this category. A forced-air furnace is one in which a fan is used to force the air through the ducts. In a gravity furnace, air is circulated by gravity, relying on the natural flow of warm air up and cold air down; the warm air rises through ducts and the cold air falls through ducts that return it to the furnace to be reheated, thus completing the circulation cycle.

Steam or Hot-Water System: Either of two types of a central space-heating system that supplies steam or hot water to radiators, convectors, or pipes.

The more common type supplies either steam or hot water to conventional radiators, baseboard radiators, convectors, heating pipes embedded in the walls or ceilings, or heating coils or equipment that are part of a combined heating/ventilating or heating/air-conditioning system.

The other type supplies radiant heat through pipes that carry hot water and are inlaid in a concrete slab floor.

Heat Pump (Reverse-Cycle System): A year-round heating and air-conditioning system in which refrigeration equipment supplies both heating and cooling through ducts leading to individual rooms. A heat pump generally consists of a compressor, both indoor and outdoor coils, and a thermostat.

Pipeless Furnace: Space-heating equipment consisting of a ductless combustor or resistance unit, having an enclosed chamber where fuel is burned or where electrical-resistance heat is generated to warm the rooms of a building. A floor furnace is located below the floor and delivers heated air to the room immediately above or (if under a partition) to the room on each side. A wall furnace is installed in a partition or in an outside wall and delivers heated air to the rooms on one or both sides of the wall.

Wood and Pellet Stoves: heating stoves can burn logs, wood pellets and other biofuels (such as corn). They can be configured as stove inserts (which fit into an existing fireplace and vent up a chimney -- often retrofitted with a liner), or as stand-alone units, which vent out of specially installed stainless steel flue.

Efficiency computation of Furnaces

A furnace is an equipment to melt metals for casting or heat materials for change of shape (rolling, forging etc) or change of properties (heat treatment).

The efficiency of furnace can be judged by measuring the amount of fuel needed per unit weight of material

Energy Conservation measures in Furnaces

1) Complete combustion with minimum excess air
2) Correct heat distribution
3) Operate furnace at the desired temperature
4) Reduce heat losses from furnace openings
5) Maintain correct amount of furnace draught
6) Optimum capacity utilization of furnace will give maximum thermal efficiency
7) Waste heat recovery from the flue gases improves system efficiency
8) Minimum refractory losses

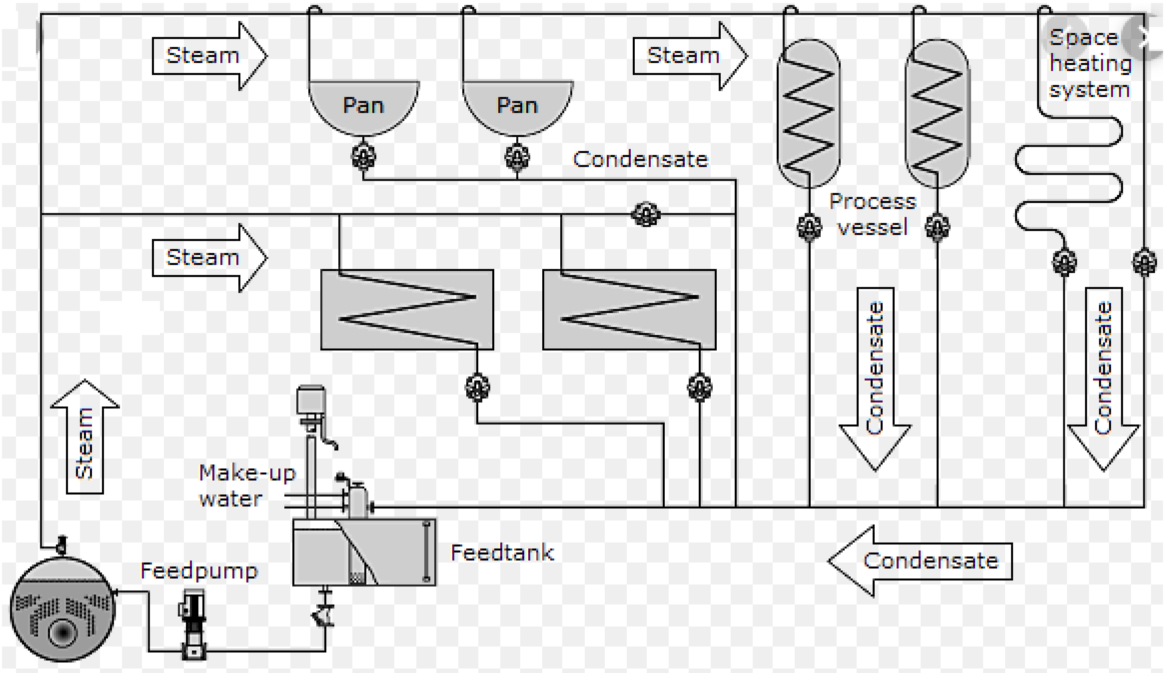
The appropriate choice of refractory and insulation materials goes a long way in achieving fairly high fuel savings in industrial furnaces

9) Use of Ceramic Coatings in furnace chamber promotes rapid and efficient transfer of heat, thereby extended life of refractories

STEAM DISTRIBUTION SYSTEM

An efficient steam distribution system is essential if steam of the right quality and pressure is to be supplied, in the right quantity, to the steam using equipment.

This page will look at methods of carrying steam from a central source to the point of use. The central source might be a boiler house or the discharge from a co-generation plant. The boilers may burn primary fuel, or be waste heat boilers using exhaust gases from high temperature processes, engines or even incinerators. Whatever the source, an efficient steam distribution system is essential if steam of the right quality and pressure is to be supplied, in the right quantity, to the steam using equipment. Installation and maintenance of the steam system are important issues, and must be considered at the design stage.



<u>Steam system basics</u>

From the outset, an understanding of the basic steam circuit, or 'steam and condensate loop' is required - see image below. As steam condenses in a process, flow is induced in the supply pipe. Condensate has a very small volume compared to the steam, and this causes a pressure drop, which causes the steam to flow through the pipes.

The steam generated in the boiler must be conveyed through pipework to the point where its heat energy is required. Initially there will be one or more main pipes, or 'steam mains', which carry steam from the boiler in the general direction of the steam using plant. Smaller branch pipes can then carry the steam to the individual pieces of equipment.

When the boiler main isolating Valve (commonly called the **CROWN** Valve) is opened, steam immediately passes from the boiler into and along the steam mains to the points at lower pressure. The pipework is initially cooler than the steam, so heat is transferred from the steam to the pipe. The air surrounding the pipes is also cooler than the steam, so the pipework will begin to transfer heat to the air.

Steam on contact with the cooler pipes will begin to condense immediately. On start-up of the system, the condensing rate will be at its maximum, as this is the time where there is maximum temperature difference between the steam and the pipework. This condensing rate is commonly called the **STARTING LOAD**

The resulting condensation (condensate) falls to the bottom of the pipe and is carried along by the steam flow and assisted by gravity, due to the gradient in the steam main that should be arranged to fall in the direction of steam flow. The condensate will then have to be drained from various strategic points in the steam main.

When the Valve on the steam pipe serving an item of steam using plant is opened, steam flowing from the distribution system enters the plant and again comes into contact with cooler surfaces. The steam then transfers its energy in warming up the equipment and product (starting load), and, when up to temperature, continues to transfer heat to the process (running load).

There is now a continuous supply of steam from the boiler to satisfy the connected load and to maintain this supply more steam must be generated. In order to do this, more water (and fuel to heat this water) is supplied to the boiler to make up for that water which has previously been evaporated into steam.

Generating and distributing steam at higher pressure offers three important advantages:

- The thermal storage capacity of the boiler is increased, helping it to cope more efficiently with fluctuating loads, minimising the risk of producing wet and dirty steam.
- Smaller bore steam mains are required, resulting in lower capital cost, for materials such as pipes, flanges, supports, insulation and labour.
- Smaller bore steam mains cost less to insulate.

STEAM TRAP:

A **steam trap** is a device used to discharge condensates and non-condensable gases with a negligible consumption or loss of live steam. Most steam traps are nothing more than automatic valves. They open, close or modulate automatically.[1] The three important functions of steam traps are:

1. Discharge condensate as soon as it is formed (unless it is desirable to use the sensible heat of the liquid condensate)
2. Have a negligible steam consumption (i.e. being energy efficient)
3. Have the capability of discharging air and other non-condensable gases.

Basic operation

The simplest form of steam trap is a disc or short solid pipe nipple with a small hole drilled through it installed at the lowest point of the equipment. Since steam condensate will collect at the lowest point and live steam is about 1200 times greater in volume than this hot liquid, condensate is effectively removed and steam is blocked. However, the vast majority of steam traps in current operation are of the mechanical or thermostatically operated design.

Mechanical and thermostatic steam traps basically open when condensate and inert gases need to be removed, and close when all the condensate is removed. The process repeats when new steam is condensed again and ready to be drained.

Steam traps work best when sized specifically for the application they are used on. Generally, it is better to oversize, as they will still discharge condensate when present and close or obstruct for live steam. However an oversized steam trap may wear quickly, waste energy (use steam), and if drastically oversized can cause process issues

Steam traps can be split into four major types:

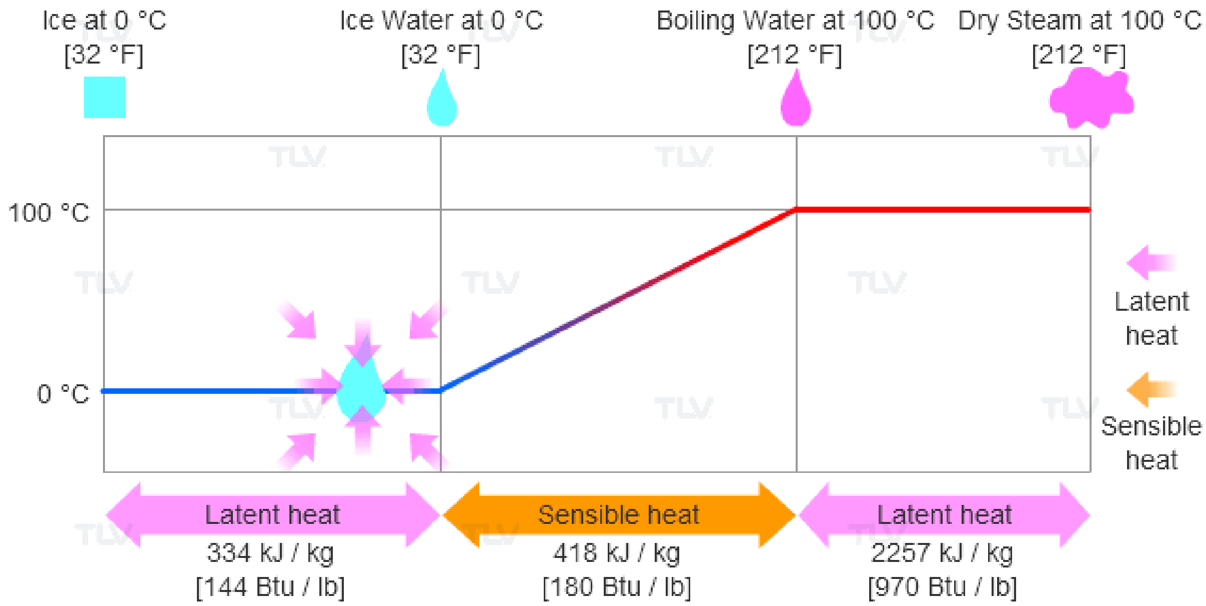
1. **Mechanical traps.**They have a float that rises and falls in relation to condensate level and this usually has a mechanical linkage attached that opens and closes the valve. Mechanical traps operate in direct relationship to condensate levels present in the body of the steam trap. Mechanical steam traps have a typical service of life of 3-4 years. Inverted bucket and float traps are examples of mechanical traps.Float traps are classified into "free ball float traps" and "lever ball float traps".
2. **Temperature traps**. They have a valve that is driven on / off the seat by either expansion / contraction caused by temperature differ from mechanical traps in that their design requires them to hold back some condensate waiting for it to cool sufficiently to allow the valve to open. In some exceptional circumstances this is not desirable if condensate needs to be removed as soon as it is formed. According to best practices to save energy and reduce CO_2 emissions, in most of applications (like tracing lines) it is universally accepted that condensate must be removed 40 °C (104 °F) below saturation temperature. This best practice is only possible by using temperature operated traps. Temperature Control (TB) traps, Thermostatic traps, Bi-Thermostatic traps and bimetallic traps are examples of temperature operated traps.
3. **Thermodynamic (TD) traps**. Thermodynamic traps work on the difference in dynamic response to velocity change in the flow of compressible and incompressible fluids. As steam enters, static pressure above the disk forces the disk against the valve seat. The static pressure over a large area overcomes the high inlet pressure of the steam. As the steam starts to condense, the pressure against the disk lessens and the trap cycles. This essentially makes a TD trap a "time cycle" device: it will open even if there is only steam present, this can cause premature wear. If non-condensable gas is trapped on top of the disc, it can cause the trap to be locked shut.

CONDENSATE RECOVERY

Condensate recovery is a process to reuse the water and sensible heat contained in the discharged**condensate**. **Recovering condensate** instead of throwing it away can lead to significant savings of energy, chemical treatment and make-up water.

Condensate is the liquid formed when steam passes from the vapor to the liquid state.

In a heating process, condensate is the result of steam transferring a portion of its heat energy, known as latent heat, to the product, line, or equipment being heated.



Latent Heat vs. Sensible Heat

In steam-using industries, Latent Heat refers to the energy required to transform water into steam, also known as the Enthalpy or Heat of Vaporization. By absorbing this Latent Heat, water becomes steam, and by releasing it, steam reverts to high temperature water (condensate).

When steam condenses, at the threshold or instant of phase change, the condensate temperature is the same as steam because only the latent heat has been lost, and the full amount of sensible heat remains. This condition is known as “Saturated Water”. Not wasting, but rather recovering and reusing as much of this sensible heat as possible is one of the main reasons behind condensate recovery.

Condensate can be reused in many different ways, for example:

- As heated feedwater, by sending hot condensate back to the boiler’s deaerator
- As pre-heat, for any applicable heating system
- As steam, by reusing flash steam
- As hot water, for cleaning equipment or other cleaning applications

Benefits of Condensate Recovery

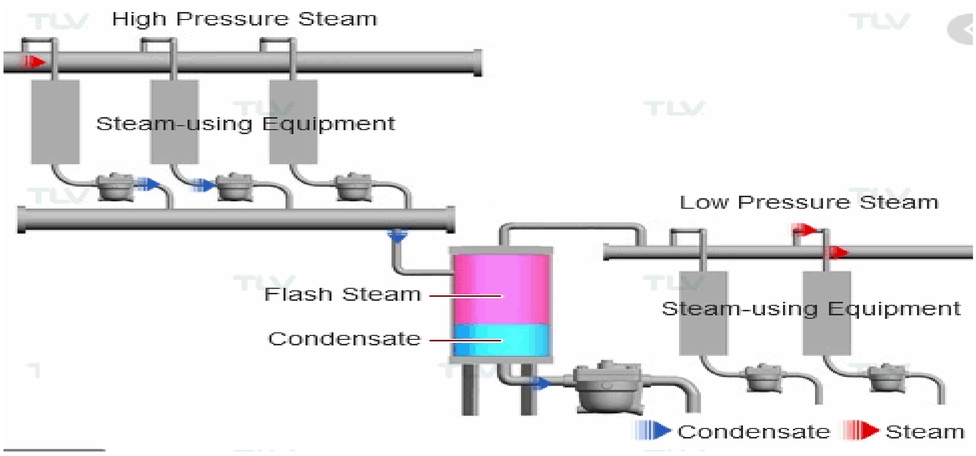
- **Condensate** is an excellent source of feed water as it is relatively pure (compared to most water supplies) being condensed water vapor.
- Boiler water cycles of concentration can be increased and blow down amounts can be reduced with its use.
- Improves energy efficiency.
- Reduces water treatment chemical cost.

FLASH STEAM RECOVERY:

The word 'flash' describes the way it is formed. At atmospheric pressure, water boils at 100 Deg. C. Inside steam piping or any pressurized vessel, steam is generally utilised at a pressure above the atmospheric pressure. This excess energy is used to convert a portion of this condensate into steam.

Flash steam is formed when high pressure/temperature condensate is suddenly decreased in pressure. (See Steam Basics for more information.)

A facility may have two steam operating pressures, such as a high pressure for process loads, and a low pressure for heating water and space heating equipment. If there is enough differential in the steam pressures, about 75 psi, flash steam from the high pressure condensate can be recovered to supply steam to the low pressure steam header.



If not recovered in a flash steam generator, high pressure condensate is either flashed to steam and vented (lost), or may be used in the deaerator to pre-heat boiler feed water..

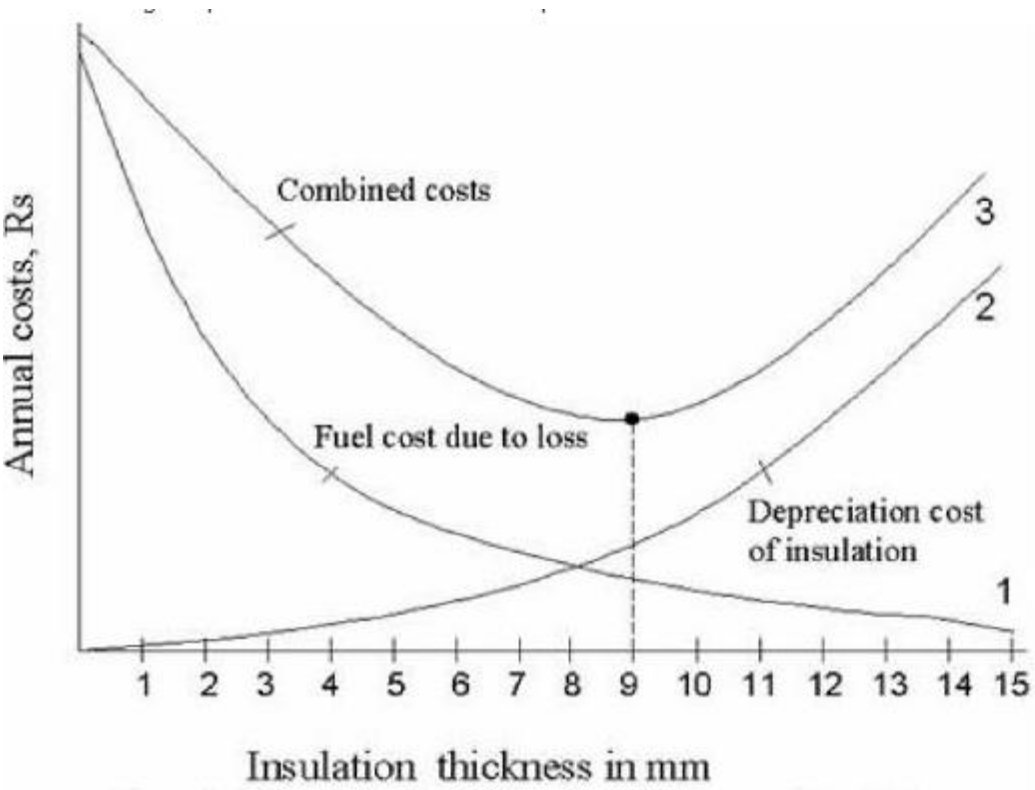
The economics of a flash steam recovery system will depend on the amount of flash steam available and how much can be used that is currently not used in applications such as the deaerator.

Economic Thickness Insulation

Insulation of any system means capital expenditure. Hence the most important factor in any insulation system is to analyse the thermal insulation with respect to cost. The effectiveness of insulation follows the law of decreasing returns. Hence, there is a definite economic limit to the amount of insulation, which is justified.

An increased thickness is uneconomical and cannot be recovered through small heat savings. The determination of economic thickness requires the attention to the following factors.

i. Cost of fuel
ii. Annual hours of operation
iii. Heat content of fuel
iv. Boiler efficiency
v. Operating surface temperature
vi. Pipe diameter/thickness of surface
vii. Estimated cost of insulation.
viii. Average exposure ambient still air temperature



Procedure for calculating Economic thickness of insulation

To explain the concept of economic thickness of insulation, we will use an example. (Refer Table 5.3) Consider an 8 bar steam pipeline of 6" dia having 50-meter length. We will evaluate the cost of energy losses when we use 1", 2" and 3" insulation to find out the most economic thickness.

A step-by-step procedure is given below.

1. Establish the bare pipe surface temperature, by measurement.
2. Note the dimensions such as diameter, length & surface area of the pipe section under consideration.

3. Assume an average ambient temperature. Here, we have taken 30oC.
4. Since we are doing the calculations for commercially available insulation thickness, some trial and error calculations will be required for deciding the surface temperature after putting insulation. To begin with assume a value between 55 & 65 C, which is a safe, touch temperature.
5. Select an insulation material, with known thermal conductivity values in the mean insulation temperature range. Here the mean temperature is 111 C. and the value of k = 0.044 W/m2oC for mineral wool.
6. Calculate surface heat transfer coefficients of bare and insulated surfaces, using equations discussed previously. Calculate the thermal resistance and thickness of insulation.
7. Select r2 such that the equivalent thickness of insulation of pipe equals to the insulation thickness estimated in step 6. From this value, calculate the radial thickness of pipe insulation = r2-r1
8. Adjust the desired surface temperature values so that the thickness of insulation is close to the standard value of 1" (25.4 mm).
9. Estimate the surface area of the pipe with different insulation thickness and calculate the total heat loss from the surfaces using heat transfer coefficient, temperature difference between pipe surface and ambient.
10. Estimate the cost of energy losses in the 3 scenarios. Calculate the Net Present Value of the future energy costs during an insulation life of typically 5 years.
11. Find out the total cost of putting insulation on the pipe (material + labour cost)
12. Calculate the total cost of energy costs and insulation for 3 situations.
13. Insulation thickness corresponding to the lowest total cost will be the economic thickness of insulation.
14. Corresponding to the lowest total cost will be the economic thickness of insulation.

Table 5.3 Example for Economic Insulation Thickness

		Insulation thickness		
Description	Unit	1"	2"	3"
Length of pipe, L	m	50	50	50
Bare Pipe outer diameter, d1	mm	168	168	168
Bare pipe surface area, A	m^2	26.38	26.38	26.38
Ambient Temperature, Ta :	°C	30	30	30
Bare Pipe Wall Temperature, Th:	°C	160	160	160
Desired Wall Temperature With Insulation, Tc :	°C	62	48	43
Material of Insulation :		Mineral Wool		
Mean Temperature of Insulation, Tm = (Th+Tc)/2 :	°C	111	104	101.5
Sp.Conductivity of Insulation Material, k (from catalogue) :	W/m°C	0.044	0.042	0.04
Surface Emissivity of bare pipe:		0.95	0.95	0.95
Surface emissivity of insulation cladding(typically Al)		0.13	0.13	0.13

Calculations

Surface Heat Transfer Coefficient of Hot Bare Surface, h :(0.85+ 0.005 (Th – Ta)) x 10	W/m^2°C	15	15	15
Surface Heat Transfer Coefficient After Insulation, h' = (0.31+ 0.005 (Tc – Ta)) x 10	W/m^2°C	4.7	4	3.75
Thermal Resistance, R_{th} = (Th-Tc)/[h' x (Tc-Ta)] :	°C-m^2/W	0.7	1.6	2.4
Thickness of Insulation, t = k x R_{th} :(if surface was flat)	mm	28.7	65.3	96.0
r_1=outer diameter/2 =	mm	84	84	84
$t_{eq} = r_2 \times \ln(r_2/r_1)$ = (select r_2 so that t_{eq} = t)	mm	28.7	65.3	106.3
Outer radius of insulation , r_2=	mm	109.2	135.9	161.9
Thickness of insulation	mm	**25.2**	**51.9**	**77.9**
Insulated pipe Area , A :	m^2	34.29	42.66	50.85
Total Losses From Bare Surface, Q = h x A x (Th-Ta) :	kW	51.4	51.4	51.4
Total Loss From Insulated Surface, Q' = h' x A' x (Tc-Ta) :	kW	5.16	3.07	2.48
Power Saved by Providing Insulation, P = Q - Q' :	kW	46.3	48.4	49.0
Annual Working Hours, n :	Hrs	8000	8000	8000
Energy Saving After Providing Insulation, E = P x n :	kWh/year	370203	386892	391634

Economics

Steam cost,	Rs/kg	0.70	0.70	0.70
Heat Energy Cost, p :	Rs./kWh	1.11	1.11	1.11
Annual Monetary Saving, S = E x p :	Rs.	412708	431313	436599
Discount factor for calculating NPV of cost of energy loss	%	15%	15%	15%
Cost of insulation (material + labor)	Rs/m	450	700	1100
Total cost of insulation	Rs/m	22500	35000	55000
Annual Cost of energy loss	Rs/year	46000	27395	22109
NPV of annual cost of energy losses for 5 years	Rs	154198	91832	74112
Total cost (insulation & NPV of heat loss)	Rs	**176698**	**126832**	**129112**

Note that the total cost in lower when using 2" insulation, hence is the economic insulation thickness.

REFRACTORIES

Refractories are inorganic non-metallic material which can withstand high temperature without undergoing physico – chemical changes while remaining in contact with molten slag, metal and gases. It is necessary to produce range of**refractory** materials with different **properties** to meet range of processing condition.

- Materials that can withstand high temp without softening and deformation in their shape.Used for the construction of furnaces, converters, kilns, crucibles, ladles etc.