UNIT-2

STEAM GENERATION AND ITS APPLICATION IN CHEMICAL PLANT

Introduction Steam has been a popular mode of conveying energy since the industrial revolution. Steam is used for generating power and also used in process industries such as sugar, paper, fertilizer, refineries, petrochemicals, chemical, food, synthetic fibre and textiles The following characteristics of steam make it so popular and useful to the industry:

- Highest specific heat and latent heat
- Highest heat transfer coefficient
- Easy to control and distribute
- Cheap and inert

Properties of Steam

Water can exist in the form of solid, liquid and gas as ice, water and steam respectively. If heat energy is added to water, its temperature rises until a value is reached at which the water can no longer exist as a liquid. We call this the "saturation" point and with any further addition of energy, some of the water will boil off as steam. This evaporation requires relatively large amounts of energy, and while it is being added, the water and the steam released are both at the same temperature. Equally, if steam is made to release the energy that was added to evaporate it, then the steam will condense and water at same temperature will be formed.

Liquid Enthalpy

Liquid enthalpy is the "Enthalpy" (heat energy) in the water when it has been raised to its boiling point to produce steam, and is measured in kCal/kg, its symbol is h_f. (also known as "Sensible Heat") The heat required to change the temperature of a substance is called its **sensible heat**.

Enthalpy of Evaporation (Heat Content of Steam)

The Enthalpy of evaporation is the heat energy to be added to the water (when it has been raised to its boiling point) in order to change it into steam. There is no change in temperature, the steam produced is at the same temperature as the water from which it is produced, but the heat energy added to the water changes its state from water into steam at the same temperature.

When the steam condenses back into water, it gives up its enthalpy of evaporation, which it had acquired on changing from water to steam. The enthalpy of evaporation is measured in kCal/kg. Its symbol is h_{fg}. Enthalpy of evaporation is also known as latent heat.

The temperature at which water boils, also called as boiling point or **saturation temperature** increases as the pressure increases. When water under pressure is heated its saturation temperature rises above 100 ^{o}C. From this it is evident that as the steam pressure increases, the usable heat energy in the steam (enthalpy of evaporation), which is given up when the steam condenses, actually decreases. The total heat of dry saturated steam or enthalpy of saturated steam is given by sum of the two enthalpies $h_f + h_{fg}$ When the steam contains moisture the total heat of steam will be $h_g = h_f + q\, h_{fg}$ where q is the dryness fraction.

The temperature of saturated steam is the same as the water from which it is generated, and corresponds to a fixed and known pressure. Superheat is the addition of heat to dry saturated steam without increase in pressure. The temperature of superheated steam, expressed as degrees above saturation corresponding to the pressure, is referred to as the degrees of **superheat**.

To change the water to steam an additional 540 kcal would be required. This quantity of heat required to change a chemical from the liquid to the gaseous state is called **latent heat**.

Steam Piping:

Features General layout and location of steam consuming equipment is of great importance in efficient distribution of steam. Steam pipes should be laid by the shortest possible distance rather than to follow a building layout or road etc. However, this may come in the way of aesthetic design and architect's plans and a compromise may be necessary while laying new pipes. Apart from proper sizing of pipe lines, provision must be made for proper draining of condensate which is bound to form as steam travels along the pipe. For example, a 100mm well lagged pipe of 30-meter length carrying steam at 7 Kg/cm2 pressure can condense nearly 10 Kg. of water in the pipe in one hour unless it is removed from the pipe through traps. The pipes should run with a fall of not less than 12.5 mm in 3 meter in the direction of flow. There should also be large pockets in the pipes to enable water to collect otherwise water will be carried along with steam. These drain pockets should be provided at every 30 to 50 meters and at any low point in the pipe network. The pocket should be fitted with a trap to discharge the condensate. Necessary expansion loops are required to take care of the expansion of pipes when they get heated up. Automatic air vents should be fixed at the dead end of steam mains, which will allow removal of air which will tend to accumulate.

Steam Pipe Sizing and Design

Any modification and alteration (see box) in the existing steam piping, for supplying higher quality steam at right pressure and quantity must consider the following points: Pipe Sizing Proper sizing of steam pipelines help in minimizing pressure drop. The velocities for various types of steam are: Superheated 50-70 m/sec Saturated 30-40 m/sec Wet or Exhaust 20-30 m/sec The steam piping should be sized, based on permissible velocity and the available pressure drop in the line. Selecting a higher pipe size will reduce the pressure drop and thus the energy cost. However, higher pipe size will increase the initial installation cost. By use of smaller pipe size, even though the installation cost can be reduced, the energy cost will increase due to higher-pressure drop. It is to be noted that the pressure drop change will be inversely proportional to the 5th power of diameter change. Hence, care should be taken in selecting the optimum pipe size.

Guide for proper drainage and layout of steam lines:

1. The steam mains should be run with a falling slope of not less that 125 mm for every 30 metres length in the direction of the steam flow.

2. Drain points should be provided at intervals of 30-45 metres along the main.

3. Drain points should also be provided at low points in the mains and where the steam main rises. Ideal locations are the bottom of expansion joints and before reduction and stop valves.

4. Drain points in the main lines should be through an equal tee connection only.

5. It is preferable to choose open bucket or TD traps on account of their resilience.

6. The branch lines from the mains should always be connected at the top. Otherwise, the branch line itself will act as a drain for the condensate.

7. Insecure supports as well as an alteration in level can lead to formation of water pockets in steam,leading to wet steam delivery. Providing proper vertical and support hangers helps overcome such eventualities.

8. Expansion loops are required to accommodate the expansion of steam lines while starting from cold.

9. To ensure dry steam in the process equipment and in branch lines, steam separators can be installed as required.

Pipe Redundancy

All redundant pipelines must be eliminated, which could be, at times, upto 10-15 % of total length. This could reduce steam distribution loses significantly. The pipe routing shall be made for transmission of steam in the shortest possible way, so as to reduce the pressure drop in the system, thus saving the energy. However, care should be taken that, the pipe routing shall be flexible enough to take thermal expansion and to keep the terminal point loads, within the allowable limit.

Drain Points

These points help in removing water in the pipes due to condensation of steam. The presence of water causes water hammering. A steam trap must be provided at the drain points to avoid leakage of steam.

Proper Selection, Operation and Maintenance of Steam Traps

The purpose of installing the steam traps is to obtain fast heating of the product and equipment by keeping the steam lines and equipment free of condensate, air and non condensable gases. A steam trap is a valve device that discharges condensate and air from the line or piece of equipment without discharging the steam.

Types of Steam Traps

• The steam traps are classified as follows:

Functions of Steam Traps

The three important functions of steam traps are:

Group	Principle	Sub-group
Mechanical trap	Difference in density between steam and condensate.	Bucket type a) Open bucket b) Inverted bucket, with lever, without lever c) Float type d) Float with lever e) Free float
Thermodynamic trap	Difference in thermodynamic properties between steam and condensate	a) Disc type b) Orifice type
Thermostatic trap	Difference in temperature between steam and condensate	a) Bimetallic type b) Metal expansion type.

Some of the important traps in industrial use are explained as follows:

Inverted Bucket

The inverted bucket trap is a mechanically actuated model that uses an upside down bucket as a float. The bucket, connected to an outlet valve through a mechanical linkage, sinks when condensate fills the steam trap, opening the outlet valve. The bucket floats when steam enters the trap, closing the valve

• To discharge condensate as soon as it is formed

• Not to allow steam to escape.

• To be capable of discharging air and other incondensable gases.

Inverted bucket traps, as a group, are capable of handling a wide range of steam pressures and condensate capacities. However, each specific steam trap handles a very narrow range. An inverted bucket trap designed for 8.5 Kg/cm2 service operates at pressures below this; however, its capacity is so diminished that it may "back up" a system with unwanted condensate.

It is important to correlate the pressure rating and size with a specific application. For example, an inverted bucket trap designed for up to 1 kg/cm2 service fails to operate at pressures above 1 kg/cm2 . The inverted bucket trap can be a very economical solution for low-to-medium pressures and medium capacity applications such as plant heating and light-duty processes. When handling high pressures and capacities, these traps become large, expensive, and difficult for personnel to handle.

Float and Thermostatic

The float and thermostatic (F&T) trap is a hybrid. As condensate collects, it lifts a float which opens a valve as much as required. A built-in thermostatic element purges air and other non condensable gases and closes off when steam enters the trap. This type of trap continuously drains the condensate as it forms . However, this type of trap is vulnerable to dirt in the system

Similar to the inverted bucket trap, the F&T design handles a wide range of steam pressures and condensate loads. However, each individual trap can only handle a very narrow range of pressures and capacities, making it critical to exactly correlate the pressure rating and size to the application.

The F&T trap is able to purge the system of air and other non condensable gases, allowing for quick system startups. One disadvantage is the sensitivity of the float ball to damage by water hammer. F&T traps are an economical solution for light-to-medium condensate loads and lower pressures.

Thermodynamic

Thermodynamic or disk traps are designed with a flat disk which moves between a cap and seat. On startup, condensate flow raises the disk and opens the discharge port. When steam or very hot condensate arrives, it closes the disk, which stays closed as long as pressure is maintained above the disk. Heat radiates out through the cap, which diminishes the pressure over the disk, opening the trap to discharge condensate.

Wear and dirt can be a problem with a disk trap because of the large, flat seating surfaces involved. If pressure is not maintained above the disk, the trap cycles frequently, wastes steam, and fails prematurely.

Thermodynamic traps are relatively small and compact for the amount of condensate they are capable of discharging. Their advantage is that one unit can handle a wide range of pressures. The primary disadvantage is difficulty in discharging air and other non condensable gases.

Thermostatic

Thermal-element thermostatic traps are temp element is in a contracted position with the other non condensable gases. As the system warms up, heat generates pressure in the thermal element, causing it to expand and throttle the flow of hot condensate through the discharge valve.

When steam follows the hot condensate into the trap, the thermal element fully expands, closing the trap. If condensate enters the trap during system operation, it cools the element, contracting it off the seat, and quickly discharging condensate.

Thermostatic traps are small, lightweight, and compact. One trap operates over extremely broad pressure and capacity ranges. Thermal elements can be selected to operate within a range of steam temperatures. In steam tracing applications it may be desirable to actually back up hot condensate in the lines to extract its thermal value.

Bimetallic Type

Bimetallic steam traps operate on the same principle as a heating thermostat. A bimetallic strip or wafer connected to a valve bends or distorts when subjected to a change in temperature. When properly calibrated, the valve closes off against a seat when steam is present, and opens when condensate, air, and other non condensable gases are present.

Advantages are their relatively small size for the condensate loads they handle and resistance to damage from water hammer. A disadvantage is that they must be set, generally at the plant, for a particular steam operating pressure. If the trap is used for a lower pressure, it may discharge live steam. If used at a higher steam pressure, it can back up condensate into the system

Bimetallic Disc Trap Thermostatic traps are often considered a universal steam trap; however, they are normally not recommended for extremely high condensate requirements (over 7000 kg/hr). For light-to-moderately high condensate loads, thermostatic steam traps offer advantages in terms of initial cost, long-term energy conservation, reduced inventory, and ease in application and maintenance.

Installation of Steam Traps

In most cases, trapping problems are caused by bad installation rather than by the choice of the wrong type or faulty manufacture. To ensure a trouble-free installation, careful consideration should be given to the drain point, pipe sizing, air venting, steam locking, group trapping vs. individual trapping, dirt, water hammer, lifting of the condensate, etc.

1) **Drain Point**

   The drain point should be so arranged that the condensate can easily flow into the trap. This is not always appreciated. For example, it is useless to provide a 15mm drain hole in the bottom of a 150 mm steam main, because most of the condensate will be carried away by the steam velocity. A proper pocket at the lowest part of the pipe line into which the condensate can drop of at least 100mm diameter is needed in such cases.

2) **Pipe Sizing**

   The pipes leading to and from steam traps should be of adequate size. This is particularly important in the case of thermodynamic traps, because their correct operation can be disturbed by excessive resistance to flow in the condensate pipe work. Pipe fittings such as valves, bends and tees close to the trap will also set up excessive backpressures in certain circumstances.

3) **Air Binding**

   When air is pumped into the trap space by the steam, the trap function ceases. Unless adequate provision is made for removing air either by way of the steam trap or a separate air vent, the plant may take a long time in warming up and may never give its full output.

4) **Steam Locking**

   This is similar to air binding except that the trap is locked shut by steam instead of air. The typical example is a drying cylinder. It is always advisable to use a float trap provided with a steam lock release arrangement.

5) **Group Trapping vs. Individual Trapping**

   It is tempting to try and save money by connecting several units to a common steam trap as This is known Group Trapping as group trapping. However, it is rarely successful, since it normally causes water-logging and loss of output. Figure 3.10 Individual Trapping The steam consumption of a number of units is never the same at a moment of time and therefore, the pressure in the various steam spaces will also be different. It follows that the pressure at the drain outlet of a heavily loaded unit will be less than in the case of one that is lightly or properly loaded. Now, if all these units are connected to a common steam trap, the condensate from the heavily loaded and therefore lower pressure steam space finds it difficult to reach the trap as against the higher pressure condensate produced by lightly or partly loaded unit. The only satisfactory arrangement, thus would be to drain each steam space with own trap and then connect the outlets of the various traps to the common condensate return main.

6) **Dirt**

Dirt is the common enemy of steam traps and the causes of many failures. New steam systems contain scale, castings, weld metal, piece of packing and jointing materials, etc. When the system has been in use for a while, the inside of the pipe work and fittings, which is exposed to corrosive condensate can get rusted. Thus, rust in the form of a fine brown powder is also likely to be present. All this dirt will be carried through the system by the steam and condensate until it reaches the steam trap. Some of it may pass through the trap into the condensate system without doing any harm, but some dirt will eventually jam the trap mechanism. It is advisable to use a strainer positioned before the steam trap to prevent dirt from passing into the system.

7) **Water Hammer**

A water hammer in a steam system is caused by condensate collection in the plant or pipe work picked up by the fast moving steam and carried along with it. When this collection hits obstructions such as bends, valves, steam traps or some other pipe fittings, it is likely to cause severe damage to fittings and equipment and result in leaking pipe joints. The problem of water hammer can be eliminated by positioning the pipes so that there is a continuous slope in the direction of flow. A slope of at least 12mm in every 3 metres in necessary, as also an adequate number of drain points every 30 to 50 metres.

8) **Lifting the condensate**

In the interest of energy and treated water savings, every effort should be made to recover and re-use the condensate. Generally, this means lifting the condensate into a return main above the equipment. There may also be a case where the layout of the plant dictates that the steam traps be fitted above the equipment being drained. Wrong installation can lead to trouble. Because of the backpressures imposed upon the steam trap, it is often better not to lift the condensate directly from the trap, but to let it flow by gravity to a pump or a pumping trap, which can then do the lifting. However, if it is decided that the condensate has to be lifted by its own pressure at the trap, it is important to ensure that the installation is correctly arranged. The Figure 3.11 shows a desirable arrangement of condensate draining and lifting. The rising pipe coil is looped to form a water seal. A small bore pipe is then passed through a steam tight joint at the top of the rising pipe, and its end is pushed well into the loop seal. The trap is fitted as close to the top of this pipe as possible. The water seal now makes it near impossible for the steam to enter the pipe leading up to the trap, and the small bore of this pipe ensures that the water column rises steadily due to steam bubbles

Maintenance of steam traps

Dirt is one of the most common causes of steam traps blowing steam. Dirt and scale are normally found in all steam pipes. Bits of jointing material are also quite common. Since steam traps are connected to the lowest parts of the system, sooner or later this foreign matter finds its way to the trap. Once some of the dirt gets logged in the valve seat, it prevents the valve from shutting down tightly thus allowing steam to escape. The valve seal should therefore be quickly cleaned, to remove this obstruction and thus prevent steam loss.

In order to ensure proper working, steam traps should be kept free of pipe-scale and dirt. The best way to prevent the scale and dirt from getting into the trap is to fit a strainer. Strainer is a detachable, perforated or meshed screen enclosed in a metal body. It should be borne in mind that the strainer collects dirt in the course of time and will therefore need periodic cleaning. It is of course, much easier to clean a strainer than to overhaul a steam trap.

At this point, we might mention the usefulness of a sight glass fitted just after a steam trap. Sight glasses are useful in ascertaining the proper functioning of traps and in detecting leaking steam traps. In particular, they are of considerable advantage when a number of steam traps are discharging into a common return line. If it is suspected that one of the traps is blowing steam, it can be quickly identified by looking through the sight glass.

In most industries, maintenance of steam traps is not a routine job and is neglected unless it leads to some definite trouble in the plant. In view of their importance as steam savers and to monitor plant efficiency, the steam traps require considerably more care than is given. One may consider a periodic maintenance schedule to repair and replace defective traps in the shortest possible time, preferable during regular maintenance shut downs in preference to break down repairs.

Performance Assessment Methods for Steam Traps

Steam trap performance assessment is basically concerned with answering the following two questions:

- Is the trap working correctly or not?
- If not, has the trap failed in the open or closed position?

Traps that fail ‘open’ result in a loss of steam and its energy. Where condensate is not returned, the water is lost as well. The result is significant economic loss, directly via increased boiler plant costs, and potentially indirectly, via decreased steam heating capacity.

Traps that fail ‘closed’ do not result in energy or water losses, but can result in significantly reduced heating capacity and/or damage to steam heating equipment.

Sound Method

Mechanisms within steam traps and the flow of steam and condensate through steam traps generate sonic (audible to the human ear) and supersonic sounds. Proper listening equipment, coupled with the knowledge of normal and abnormal sounds, can yield reliable assessments of steam trap working condition. Listening devices range from a screwdriver or simple mechanic's stethoscope that allow listening to sonic sounds.

Temperature Method

Saturated steam and condensate exist at the same temperature. So it's not possible to distinguish between the two based on temperature. Still, temperature measurement provides important information for evaluation purposes.

A cold trap (i.e., one that is significantly cooler than the expected saturated steam temperature) indicates that the trap is flooded with condensate, assuming the trap is in service. On the other hand, the temperature downstream of the trap will be nearly constant if significant steam is getting past the trap.

At the low-end, spitting on the trap and watching the sizzle provides a general indication of temperature. Alternatively, a glove-covered hand can provide a similar level of accuracy.

Finally, non-contact (i.e., infrared) temperature measuring devices provide the precision of thermometers and thermocouples without requiring physical contact. Non-contact temperature measurement makes it easier to evaluate traps that are relatively difficult or dangerous to access closely.

Energy Saving Opportunities

1. Monitoring Steam Traps

For testing a steam trap, there should be an isolating valve provided in the downstream of the trap and a test valve shall be provided in the trap discharge. When the test valve is opened, the following points have to be observed.

Condensate discharge-Inverted bucket and thermodynamic disc traps should have intermittent condensate discharge. Float and thermostatic traps should have a continuous condensate discharge. Thermostatic traps can have either continuous or intermittent discharge depending upon the load. If inverted bucket traps are used for extremely small load, it will have a continuous condensate discharge.

Flash steam-This shall not be mistaken for a steam leak through the trap. The users sometimes get confused between a flash steam and leaking steam. The flash steam and the leaking steam can be approximately identified as follows:

If steam blows out continuously in a blue stream, it is a leaking steam.

If a steam floats out intermittently in a whitish cloud, it is a flash steam.

Avoiding Steam Leakages Steam leakage is a visible indicator of waste and must be avoided. It has been estimated that a 3 mm diameter hole on a pipeline carrying 7kg/cm2 Steam would waste 33 KL of fuel oil per year. Steam leaks on high-pressure mains are prohibitively costlier than on low pressure mains.

Any steam leakage must be quickly attended to. In fact, the plant should consider a regular surveillance programmed for identifying leaks at pipelines, valves, flanges and joints. Indeed, by plugging all leakages, one may be surprised at the extent of fuel savings, which may reach up to 5% of the steam consumption in a small or medium scale industry or even higher in installations having several process departments.

To avoid leaks it may be worthwhile considering replacement of the flanged joints which are rarely opened in old plants by welded joints.

Flash Steam Recovery

Flash steam is produced when condensate at a high pressure is released to a lower pressure and can be used for low pressure heating. The higher the steam pressure and lower the flash steam pressure the greater the quantity of flash steam that can be generated. In many cases, flash steam from high pressure equipments is made use of directly on the low pressure equipments to reduce use of steam through pressure reducing valves.

The flash steam quantity can be calculated by the following formula with the help of a steam table:

Flash steam available % = S1—S2 /L2

Where: S1 is the sensible heat of higher pressure condensate.

S2 is the sensible heat of the steam at lower pressure (at which it has been flashed).

L2 is the latent heat of flash steam (at lower pressure).

Flash steam can be used on low pressure applications like direct injection and can replace an equal quantity of live steam that would be otherwise required. The demand for flash steam should exceed its supply, so that there is no build up of pressure in the flash vessel and the consequent loss of steam through the safety valve. Generally, the simplest method of using flash steam is to flash from a machine/equipment at a higher pressure to a machine/equipment at a lower pressure, thereby augmenting steam supply to the low pressure equipment.

In general, a flash system should run at the lowest possible pressure so that the maximum amount of flash is available and the backpressure on the high pressure systems is kept as low as possible.

Flash steam from the condensate can be separated in an equipment called the 'flash vessel'. This is a vertical vessel as shown in the. The diameter of the vessel is such that a considerable drop in velocity allows the condensate to fall to the bottom of the vessel from where it is drained out by a steam trap preferably a float trap. Flash steam itself rises to leave the vessel at the top. The height of the vessel should be sufficient enough to avoid water being carried over in the flash steam.

The condensate from the traps (A) along with some flash steam generated passes through vessel (B). The flash steam is let out through (C) and the residual condensate from (B) goes out through the steam trap (D). The flash vessel is usually fitted with a 'pressure gauge' to know the quality of flash steam leaving the vessel. A 'safety valve' is also provided to vent out the steam in case of high pressure build up in the vessel.