# a look into the design features of condensing plants in modern steam power station

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*The authors describe the condensing plants in modern Steam Stations,—their purpose, design & construction, operational features are also dealt with. The authors touch upon certain allied auxiliary equipment,—e.g. Air Ejectors. Sources of trouble and means to rectify are also indicated.*

The modern steam power stations consist of a Boiler House, a Turbine House, in which normally the condenser is located, and a Control Rood. In different stations, the boiler takes different forms depending on the type of fuel and firing equipment used. The turbines are also of different types :—the axial or radial flow, with characteristic governing systems; mechanical or hydrodynamic. But the main feature of any steam power station is its condensing plant (which is of the same type in all modern high capacity plants). Though this is generally delegated into the second place, its importance cannot be overemphasized.

**Purpose :**—All modern plants are generally of high generating capacity of 30 MW or more. Each plant may employ several boilers with a steaming rate ranging between 50,000 lbs./hr. to 2 million lbs./hr., depending on the generating capacity. This calls for large amounts of treated water. This is highly uneconomical if the cycle is open due to (i) cost of treatment, and (ii) the large quantity of heat wasted in the exhassted steam, which results in an extremely poor thermal efficiently for the plant. Hence in all modern plants, a steam loop is made a closed circuit, returning the exhaust steam back to the boiler after condensation. This requires only about 2—4% of make up water to cater for the lost steam in the plant due to leakages, blowdown etc.

Efficiency of a steam turbine increases with the lowering of the pressure and temperature of the exhaust steam, initial steam conditions remaining the same. So, steam coming out of the turbine has necessarily to be condensed to water and this condensate is pumped through feed heaters and economisers back into the boiler. This results in two advantages. It reduces the volume of the fluid to be handled (Water weighing one lb. at 1 p.s.i.a. occupies only 0.22 cft. occupied by the steam of equal weight). This considerably reduces the size and work of the pumps. Secondly, this enormous shrinkage in volume on condensation of steam creates vacuum in the condenser, that is, at the turbine exhaust. By maintaining a constant level of the condensate in the condenser, vacuum can be maintained at the turbine exhaust. Therefore, steam expands from the turbine inlet conditions to the sub-atmospheric condition at the exhaust and not to the atmospheric pressure. Thus, each lb. of steam in this case releases more energy in the turbine for conversion to mechanical work. In other words, more electrical energy can be produced with the same amount of fuel. Consequently, the output of the turbine and the efficiency of the plant also are considerably raised. In the actual case, as much as 50% of the energy produced is released in the sub-atmospheric stages of the turbine.—the tuibine output increasing with increasing values of vacuum.

**Primary Functions of a Condensing Plant :**—The primary functions of a condensing plant are :

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1. to completely condense the steam exhausted into it.
2. to reduce the exhaust steam pressure by the condensation of steam, thus creating a vacuum at the turbine exhaust.
3. to remove the condensed steam from condenser and return it to the boilers for evaporation.
4. to exhaust air and incondensable gases which enter the condenser with the exhaust steam and through tappings from evaporators and feed heaters.

In achieving these functions, the following features are desirable :

1. The plant must use the minimum quantity of cooling water.
2. The plant must have the minimum cooling surface per KW of installed capacity of the generating equipment.

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3. It must consume the minimum amount of auxiliary power.

4. Maximum amount of steam should be condensed per square feet of surface area.

5. The plant must be able to maintain a high vacuum for prolonged periods without trouble.

**Principles of condensation :**—When condensation takes place, the steam rejects its latent heat and becomes water. This latent heat specially at very low pressure is quite large (about 1100 BTU/lb.) Taking into consideration the steam passing through the turbine which finally enters the condenser, it can be said that several million BTU of heat will be liberated intthe condenser every hour. This must be continuously removed if the overheating of the condenser is to be avoided and if condensation is to take place in the condenser. Water is considered to be the best vehible for the heat transfer, and so cool water is circulated in the condenser.

**Types of Condensers :**—There are mainly two types of condensers : 1. Contact type. 2. Surface condensing type.

In the contact type, the cooling water mixes with the condensing steam, extracts its heat and condenses the steam. This, however, cannot be used in bigger power stations because of the large amount of steam that is to be condensed, and under such circumstances also closed loop steam system cannot be achieved. In the surface condenser type, the steam enters the condenser and passes down across banks of tubes, through which cooling water is circulated. The steam rejecs its heat to the cooling water and condensate. In this type, there is no possibility for mixing of the condensate and the cooling water. This type is almost universally adopted.

When the steam condenses, the dissolved gases that enter the boiler through the feed water, separate out and collect in the condenser. Unless they are removed, the pressure at the turbine exhaust rises, thus limiting its output. Therefore, ejectors or vacuum pumps are essential installations to pump out these gases.

**Parts of Condensing Plant :—**

**General description.**—The surface condenser is an essential unit in any steam-turbine-powered power station. Together with the steam generator and turbo alternator, it forms the essential triumvirate of any vapour cycle system. The surface condenser is an air-tight shell enslosing a highly concentrated heat transfer surface in the form of a compact bundle of small diameter copper alloy tubes 10-25 ft. long. The other components of a condenser are those which enclose and support the heating surface, direct the condensing water flow, admit the steam and collect the condensate. The condenser is installed close up the turbine, frequently with its long axis trans-to that of the turbine. The shell is of welded plate steel construction, although formerly cast iron was the rule. Attached to or connected with the bottom of the shell is a collection chamber for the condensate, called "the Hotwell". This is generally arranged for deaerating and reheating the condensate. Steam lanes are left through the tube banks to provide direct steam flow to the reheating hotwell.

**Classification :**—Surface condensers are classified as horizontal or vertical by the position of their tubes. Common types have horizontal tubes. They are also classified as single pass or two pass, depending on the number of times the cooling water passes the length of the condenser. In the two pass, the water enters and leaves the same side of the water box, which is divided by a partition into two enclosures. Condensers are also classified by the shape of the shell-cylendrical, oval, u-shaped, rectangular etc.

**Condenser Tubes :**—Condenser tubes form the tubular heat transfer area. The tubes have high thermal conductivity and able to withstand the corrosive action of the fluids passing through them. The materials generally employed are arsenical admiralty, antimonial admiralty, auminum brass and cupro-nickel alloys.

During operation, the tubes are subjected to corrosion, dezincification, oxygen pitting and grooving. Under these adverse conditions, the tubes fail, and such failures should immediately be remedied, lest the condensate gets contaminated with the cooling water. The normal remedy for this is plugging of the tube at both ends. As many as 10% of the total number of tubes can be plugged in this fashion. The design takes this into consideration, and thus provides adequate condensing surface area even with this amount of plugging. During annual overhaul, these plugged tubes, which would have been worst effected, should be replaced.

**Dimensions and General Design Features.**—The diameter of the tubes ranges from $\frac{5}{8}''$ to $1''$. The length is the same for all the tubes. The tubes are arranged in such a way that steam lanes are created by omission of certain groups of tubes. The performances of the condensers depend upon the degree of effectiveness with which these lanes allow the steam to flow easily to all the tubes. Various designs of tube arrangements are available to serve the purpose. The length and diameter are determined by the design, taking into account the heat transfer area to be provided and the velocity of water inside the tubes. If the length determined by design is too large, then the condenser is made in "two pass", thus reducing the length of the condenser by half. But the same heat transfer area is assured by providing double the number of tubes as determined from the design.

Additional surface is provided to the extent of 5—20% of the calculated area with the purpose of reducing the temperature of the air-vapour mixture taken by the ejector system. This additional tubing is separated by means of a baffle from the condensing surface. This arrangement gives a longer time of contact between the air-vapour mixture and the cooling surface, thus improving the cooling effect. The absolute pressure under this baffle is the lowest anywhere in the condenser, and so all the non-condensable gases flow towards this region.

Tubes are fastened into tube sheets at their ends and are loosely supported by one or more intermediate plates. Since the material of the tubes is not steel but copper alloy, steam condensation results in differential thermal expansion. This is accommodated by :—

1. Rolling the tubes tightly into one tube sheet, and providing packing into the other.
2. Rolling the tubes into both sheets with a flexible joint between the sheet and the supporting shell,
3. Providing fixed tube ends, but using slightly bent tubes. The tubes are welded into the tube sheets in some cases, and
4. Packing both the ends.

**Tube sheets** :—Tube sheets are usually made of Muntz metal, but in some cases steel sheets are used. The steel sheets often get corroded, unless they are properly painted.

**Condenser shell** :—The Condenser shells were formerly made of cast iron. But with modern welding techniques, steel plate is considered to be the most suited, because it can be easily transported and welded at site. The shell should be so shaped as to enclose the tube bundle, and to support the tube sheets and 'support plates'. Water boxes are bolted on to the ends. Reinforcement in the form of stays should be provided to prevent the collapse of the shell, hotwell and the exhaust neck, due to the presence of atmospheric pressure outside the condenser. Safety release to atmosphere in case of a pressure built-up inside the condenser is also provided.

**Tube failures and possible simple remedies :**

Tube failures are mainly due to the following reasons :

1. In the case of a new unit, if the tubes are supported at points more than four feet apart, the tubes are subject to buffeting of high velocity exhaust steam, and so fail due to vibration fatigue. Additional tube supports or thin wood pieces may be provided between the top two rows of tubes to prevent the vibration.
2. Tubes get eroded on the external surface in the old plants because of the excessive water concentration in the exhaust steam or from some condensate return line or steam drain line which allows a high velocity jet to strike the tubes. Proper baffling inside the condenser prevents this trouble.
3. Tubes get internally eroded due to sand and great turbulence at the inlet. Belling of tube inlets, insertion of tube inlet sleeves or coating the inlet end for a few inches with a cement based or plastic paint are some good remedies.
4. Due to electrolytic cell action, the zinc in the tube material is lost, thus making the metal porous and brittle. This results in tube failure ; use of tubes free of zinc prevents this sort of failure.
5. If condenser is allowed to stand idle with dirty water in the tubes, corrosion sets in. In this case, tubes must be cleaned with fresh water.

Tube failures result in two types of leaks : (1) Heavy leaks and (2) Small leaks. A heavy leak is indicated by rapid rise in the conductivity of the condensate, and should be immediately attended to, whereas smaller leaks give more time before dangerous conditions develop.

**Condenser supports** :—There are mainly two types of supports : (1) Solid supports and (2) Spring mounted supports.

In the case of solid supports, one or more expansion joints should be provided in the exhaust neck connecting the condenser and the turbine to take care of the thermal expansion. If a solid connexion is made between the two, the condenser should be spring mounted, and all the connexions must be made flexible enough so as to permit free transverse movement.

**Condenser arrangement :**—Though various shapes of the condensers are in use, the modern trend is towards rectangular shells, as they utilise the space much better, providing the same amount of condensing surface in a less height than a circular condenser. This does considerably reduce the basement height also.

There are mainly two types of setting for a condenser with respect to the axis of a turbine ; perpendicular or parallel to the axis. In the case of parallel arrangements, oil tanks cannot be suitably located below the turbine. Besides, the free space between the bays in the transverse arrangement is normally more than in the longitudinal arrangement. The condenser may be set below the turbine, which is the normal practice or by the side of it. In the case of side exhaust turbines, working out of doors, the latter method is best suited. This arrangement reduces the turbine foundation height and is spedially suited in earthquake areas, besides resulting in economy. With multi-nozzle turbines, two condensers are placed parallel to each other and in a transverse direction with respect to the turbine. An alternative is to use a double inlet single shell condenser with long tubes placed parallel to the turbine axis. If long tubes are not feasible, two shells are provided end to end. In special circumstances, the condensers are placed opposite the turbine centre line, thereby reducing considerably the basement height. In some cases, the condenser foundation supports the turbine, which is the usual practice on the marine units. Where old units are replaced by new and modernised ones, the basement height is limited and in such cases the side mounting is most helpful.

The hotwell provides a place for accumulating the condensed steam dripping off the condenser tubes and is normally situated directly below the condenser. This is designed to hold a 5-10 minute condensate accumulation at full load. Guage glasses and high and low level alarms are normally provided. Water level is normally kept at a point, well up in the hotwell so as to provide a reserve of condensate. If the water level is too high, then the space available for condensate build up, in the case of the failure of the extraction pump is restricted. The water might get high enough to seal off the connection to the ejector resulting in rapid loss of valuum. Also the condensing surface may be submerged partially thereby affecting condensation. If water gets low, cavitation may occur in the extraction pump but this is not so detrimental as the loss of vacuum.

**AIR EJECTOR SYSTEM :**

**Purpose :**—The non-condensable gases separating out of steam on condensation form a blanket on the condensing surfaces and prevent condensation unless they are removed continuously. The air or gas removal, also results in reduced pressure. But, however, it is negligible. The pressure in the condenser, is thus mainly due to the water vapour alone. As pointed out earlier, the air is cooled before it is removed so that any vapour passing with it is condensed. This increases the air handling capacity of the pumps, besides saving the condensate.

The source of these gases may be traced to the following :—

1. Boiler steam,
2. Leak in the turbine packing glands and exhaust nozzle connections, condenser shell, vents, low pressure heaters etc.,
3. Condensing water leakage past tube packings (The raw water releases the dissolved gases under vacuum).

Air infiltration should be eliminated to the maximum possible extent and any air that will be leaked should be removed.

**Methods of air removal :**—Air pumps or ejectors are used to draw out the gases. They compress the air upto atmospheric pressure and then expell. The air pumps used are :

1. A reciprocating Pump,
2. A Rotary Pump and
3. Air ejector.

Large volumes of air are to be handled when starting up a unit or when the unit is operated under high vacuum. Hence large displacement volumes are to be provided in the case of reciprocating and rotary pumps. This is very uneconomical. The air ejectors are stationary devices and also require little maintenance, besides handling large volumes of air. Due to this, the jet pumps or air ejectors are almost universally used for condenser air-removal.

**Operation of the air ejector :**—All ejectors, normally, use steam except in very small plants. When the steam is expanded through nozzle, very high vacuum is produced at the end of the nozzle. This part is surrounded by a box connected to the condenser and so the air and other non-condensable gases flow towards this high vacuum region and get entrapped in the high velocity steam. The mixture of steam, gases and air then enters a diffuser, where the kinetic energy is converted to pressure energy. The outlet of the diffuser can be connected to one or more ejectors in series, thereby raising the pressure to that of atmosphere at which the gases are discharged. In the second and subsequent stages of the ejector system, increasing quantities of water vapour will be handled and this steam has to condense and so they are condensers, leaving the subsequent stages to handle only the air non-condensable gases. The condensed steam may be saved for return to the main condensate system.

The steam jets have to be arranged in pairs for each stage. This gives extra capacity for dealing with high leakage conditions and provides a reserve jet for normal leakage operation. A reducing valve is required to provide a supply of steam at design pressure to the jets, as pressures above and below the optimum value will adversly affect the jet performance. The pressure at inlet is not to exceed 400 psig normally. Individual shut-off valves are provided for each jet on the steam supply, jet suction and discharge. A relief valve protects against over-pressure, in case steam is turned on with the discharge valve closed.

If the cooling water to the ejector condensers is not cool enough or plentiful enough, the jets, in the later stage, get overloaded. During such moments the main condenser has to be under for the ejector condensers for cooling purposes. In such cases a re-circulating line has to be provided to the main condenser to increase the flow through the ejector condensers at low loads. The re-circulated water can be sprayed over a portion of the main condenser tubes and is thus cooled. As load increases an automatic control valve shuts off the recirculating line. The temperature difference between the inlet and outlet of ejectors should not exceed 10°C.

**Care and Maintenance :**

Steam to the air jet must be turned on first before the jet suction valve is opened and should not be turned off until suction valve is closed, when taking a jet out of service.

Steam jet nozzles are usually constructed of erosion resistant material to prevent wear. Carry over in the steam sometimes deposits on the jet thus altering the steam flow. Occasional inspection with cleaning will ensure against this trouble.

Adequate water seals must be provided on the drains to prevent leakage of air into the ejector system.

The water jet system also operates on the same principle and in a similar fashion. The main difficulties in this system are plugging, erosion and deposits on the ejector nozzle surface.