# Technological investigations and efficiency analysis of a steam heat exchange condenser: conceptual design of a hybrid steam condenser

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***Abstract***
*Most of the electricity being produced throughout the world today is from steam power plants. At the same time, many other competent means of generating electricity have been developed viz. electricity from natural gas, MHD generators, biogas, solar cells, etc. But steam power plants will continue to be competent because of the use of water as the main working fluid which is abundantly available and is also reusable. The condenser remains among one of the key components of a steam power plant. The efficiency of a thermal power plant depends upon the efficiency of the condenser. In this paper, a theoretical investigation about thermal analysis and design considerations of a steam condenser has been undertaken. A hybrid steam condenser using a higher surface area to diameter ratio of cooling a water tube has been analyzed. The use of a hybrid steam condenser enables higher efficiency of the steam power plant by lowering condenser steam pressure and increasing the vacuum inside the condenser. The latent/sensible heat of steam is used to preheat the feed water supply to the boiler. A conceptual technological design aspect of a super vacuum hybrid surface steam condenser has been theoretically analyzed.*

*Keywords: heat transfer rate, heat exchanger, steam, vacuum, jet-pump-nozzle, hybrid, jet and surface condenser, LMTD*

## Introduction

The Rankine cycle is standard for steam power plants around the world. The basic Rankine cycle used in a steam power plant consists of the following main components: 1. Steam generator; 2. Turbine; 3. Steam condenser; and 4. Pump.

Figure 1 represents the key components of a thermal power plant working on a Rankine cycle and the pressure volume relation of condensing fluid i.e. steam. The actual Rankine cycle used in a modern steam power plant has many more components, but the above components are common to all power plants. In this cycle, water is heated in the steam generator to produce a high temperature and high pressure steam.

This steam is expanded in a turbine connected to an electricity generator. The exit steam from the turbine is condensed back to water in the condenser. The pump then returns the water to the steam generator. Thus, the main purpose of the condenser is to condense the exhaust steam from the turbine for reuse in the cycle, and to maximize turbine efficiency by maintaining a proper vacuum.

## Working principal of condenser

Basically, a condenser is a device where steam condenses and latent heat of evaporation released by the steam is absorbed by cooling water. Thermodynamically, it serves the following purposes with reference to the P-v diagram shown in Figure 1. Firstly, it maintains a very low back pressure on the exhaust side of the turbine. As a result, the steam expands to a greater extent and consequently results in an increase in available heat energy. The shaded area shown in the P-v diagram exhibits the increase in the work obtained by fitting a condenser unit to a non-condensing unit for the same available steam properties. In the P-v dia-

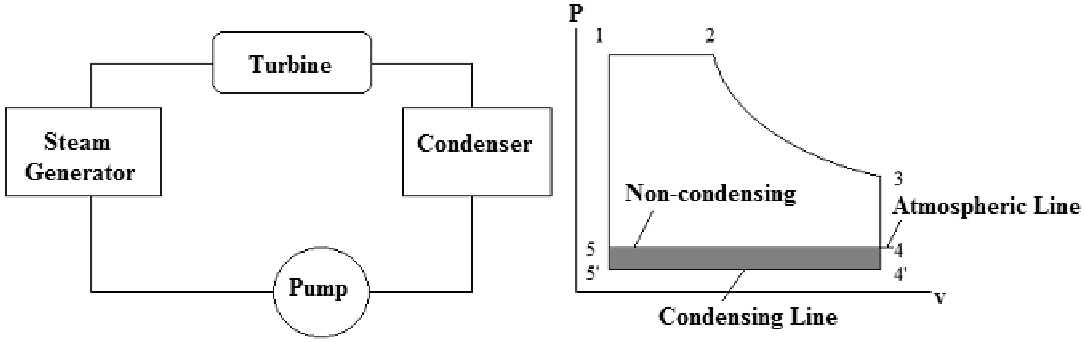
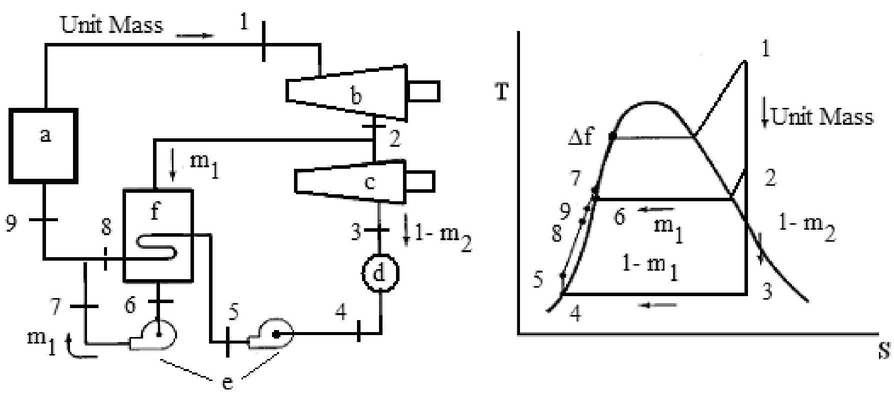



**Figure 1: Key components of a thermal power plant working on a Rankine Cycle**

gram, line 4-5 is non-condensing line when the condenser unit is not applied and line 4'-5' is a condensing line when the condenser is used. Secondly, the exhaust steam condensate is free from impurities. Thermal efficiency of a condensing unit is higher than that of a non-condensing unit for the same available steam properties. In a reciprocating steam engine, the condenser pressure can be reduced to about 12 to 15 cm. of Hg. The thermodynamic analysis of condensate application is discussed in a thermal power plant using regenerative Rankine cycle with a closed feed water heater and pumped condensate as shown in the configuration of Figure 2. Condensate is pumped from the condenser through the Feed Water Heater (FWH) directly to the steam generator and to the turbine along the path 4-5-8-9-1. Ideally, $P_5 = P_1$ assuming no pressure drop occurs in the feed water heater and steam generator. As the operating pressure of the condenser is low due to an increased vacuum, the enthalpy drop of the expanding steam in the turbine will increase. This increases the amount of available work from the turbine. The low condenser operating pressure enables higher turbine output, an increase in plant efficiency and reduced steam flow for a given plant output. It is, therefore, advantageous to operate the condenser at the lowest possible pressure (highest vacuum).

The condenser provides a closed space into which the steam enters from the turbine and is forced to give up its latent heat of vaporization to the cooling water. It becomes a necessary component of the steam cycle as it converts the used steam into water for boiler feed water and reduces the operational cost of the plant. Also, efficiency of the cycle increases as it operates with the largest possible delta-T and delta-P between the source (boiler) and the heat sink (condenser). As the steam condenses, the saturated liquid continues to transfer heat to the cooling water as it falls to the bottom of the condenser, or *hot-well*. This is called sub-cooling, which is desirable up to a certain extent. The difference between the saturation temperature for the existing condenser vacuum and the temperature of the condensate is termed *condensate depression*. This is expressed as a number of degrees condensate depression or degrees sub-cooled. However, the pump is designed according to the available net-positive-suction-head (NPSH) which is given as: NPSH is = Static head + surface pressure head – the vapour pressure of product – the friction losses in the piping, valves and fittings.




(a)- Steam Generator, (b)- High Pressure Turbine, (c)- Low Pressure Turbine, (d)- Condenser
(e)- Pump, (f)- Closed FWH

**Figure 2: Regenerative Rankine Cycle feed-water-heater and pumped condensate**

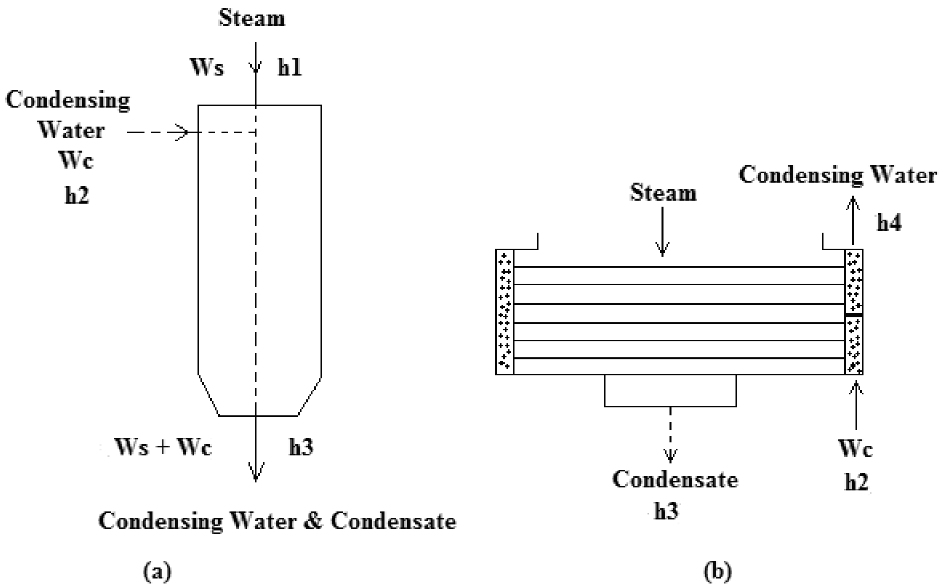



**Figure 3: Energy exchange in a condenser**

There are two primary types of condensers that can be used in a power plant: 1. direct contact or jet condenser 2. surface condenser 3. direct Dry Air-cooled Condenser.

Direct contact condensers condense the turbine exhaust steam by mixing it directly with cooling water. The older type Barometric and Jet-Type condensers operate on similar principles. The direct dry Air-cooled Condenser is beyond the scope of this paper. In a jet condenser, steam escapes with cooling water and this mixture inhabits recovery of condensate to be reused as boiler feed water. In this case, the cooling water should be fresh and free from harmful impurities. However, with moderate size turbine units the jet condensers can be used if enough supply of good quality cooling water is available.

Steam surface condensers are the most commonly used condensers in modern power plants. The exhaust steam from the turbine flows in the shell (under vacuum) of the condenser, while the circulating water flows in the tubes. The source of the circulating water can be a river, lake, pond, ocean or cooling tower. Energy exchange in a condenser is analyzed by using the following steady state equations (see Figure 3):

$$Ws \,.\, h_1 + W_c \,.\, h_2 = (W_s + W_c)\, h_3 \qquad (1)$$

(Direct / Jet condenser)

$$Ws\,(h_i - h_3) = W_c\,(h_4 - h_2) \qquad (2)$$

(Surface condenser)

Also, the exhaust steam enthalpy can be found from the turbine conditions line corrected for exhaust loss or by the energy relations as given below:

$$h_1 = h_i - W - Q - \Sigma\, mh \,/\, 1- \Sigma\, m \;\ldots\; (3)$$

Where,

$h_1$ = Exhaust-steam enthalpy, kJ/kg
$h_i$ = Prime-mover inlet steam enthalpy, kJ/kg
$h_2$ = Inlet cooling water enthalpy, kJ/kg
$h_3$ = Steam-condensate enthalpy, kJ/kg
$h_4$ = Exit cooling water enthalpy, kJ/kg
$W_s$ = Exhaust steam flow rate, kg per hrs
$W_c$ = Cooling water flow rate, kg per hrs
W = Work output to turbine blades, kJ/kg per kg steam
Q = Radiation or other heat loss, kJ/kg per kg inlet steam
$\Sigma$ mh = Enthalpy of turbine extraction steam, kJ/kg per kg inlet steam
$\Sigma$ m = Total extracted steam, kg per kg entering steam

In a surface condenser 'Terminal Temperature Difference (TTD)' is given as:

TTD = (Steam temperature) –
(Cooling water exit temperature)

This is usually 2K or more. A low cooling water temperature rise helps to keep condensing steam pressure at low.

## Elements of surface condenser

The basic components of a surface condenser are shown in Figure 3. The heat transfer mechanism is the condensation of saturated steam outside the tubes and the heating of the circulating water inside the tubes. Thus, for a given circulating water flow rate, the water inlet temperature to the condenser determines the operating pressure of the condenser. As this temperature is decreased, the condenser pressure will also decrease. As described above, this

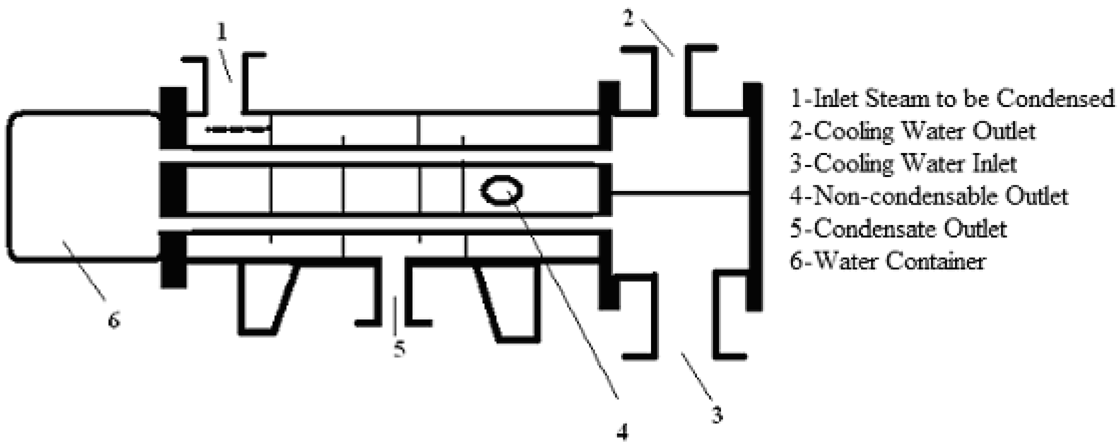



**Figure 4: Surface condenser**

decrease in the pressure will increase the plant output and efficiency. Steam condensation enables a vacuum and non-condensable gases will migrate towards the condenser.

The non-condensable gases consist of mostly air that has leaked into the cycle from components that are operating below atmospheric pressure. These gases are also formed by the decomposition of water into oxygen and hydrogen. These gases must be vented from the condenser for the following reasons:

(a) The gases will increase the operating pressure of the condenser. This rise in pressure will decrease the turbine output and efficiency.
(b) The gases will blanket the outer surface of the tubes. This will severely decrease the heat transfer rates of the steam to the circulating water, and pressure in the condenser will increase.
(c) The corrosiveness of the condensate in the condenser increases as the oxygen content increases. Thus, these gases must be removed in order to enhance the life of components.

### *Air removal*

The two main devices that are used to vent the non-condensable gases are Steam Jet Air Ejectors and Liquid Ring Vacuum Pumps. Steam Jet Air Ejectors (SJAE) use high-pressure motive steam to evacuate the non-condensable from the condenser (Jet Pump). Liquid Ring Vacuum Pumps use liquid to compress the evacuated non-condensable gases and then these are discharged into the atmosphere. Condensers are equipped with an Air-Cooler section for the removal of non-condensable gases. The Air-Cooler section of the condenser consists of a number of tubes that are baffled to collect the non-condensable. Cooling of the non-condensable gases reduces the volume and size of the air removal equipment.

Air removal equipment must operate in two modes: hogging and holding. Prior to admitting exhaust steam to a condenser, all the non-condensable gases must be removed. In hogging mode, large volumes of air are quickly removed from the condenser in order to reduce the condenser pressure from atmospheric to a predetermined level. Once the desired pressure is achieved, the air removal system can be operated in the holding mode to remove all non-condensable gases.

## Types of surface condenser

The heat transfer rate Q between the cooling water and steam vapour is the key parameter of thermal analysis of the heat exchange steam condenser. Practically, the condensers can be classified in various categories on the basis of the relative direction of the flow of hot and cold fluids. There are three basic categories i.e. parallel flow, counter flow and cross flow. Condensation takes place at essentially constant temperature, therefore, the mean temperature difference between these configurations will be marginal or negligible, but mode of heat transfer varies as:

In parallel flow condensers (Figure 5a) – both hot and cold fluid, flow in the same direction, parallel to each other. Both fluids enter the condenser at a common end with high temperature difference. The heat exchange occurs between the hottest hot fluid i.e. steam vapour and coldest cold fluid i.e. cooling water at the common entrance point of the condenser. The hottest cold-fluid temperature is always less than the coldest hot-fluid temperature.

In counter flow condenser (Figure 5b) – the two fluids i.e. steam vapour and cooling water flow in opposite direction to each other. The flow of each fluid occurs at opposite ends of the steam condenser. The cooling fluid i.e. cold water exits the counter flow steam condenser at the point where hot fluid i.e. steam enters the steam condenser. In this case, the cooling water will meet the inlet temperature of the hot steam. Consequently, the counter flow steam condenser can have the hottest cold fluid temperature greater than the coldest hot fluid temperature. This is the basic reason for the highest effi-

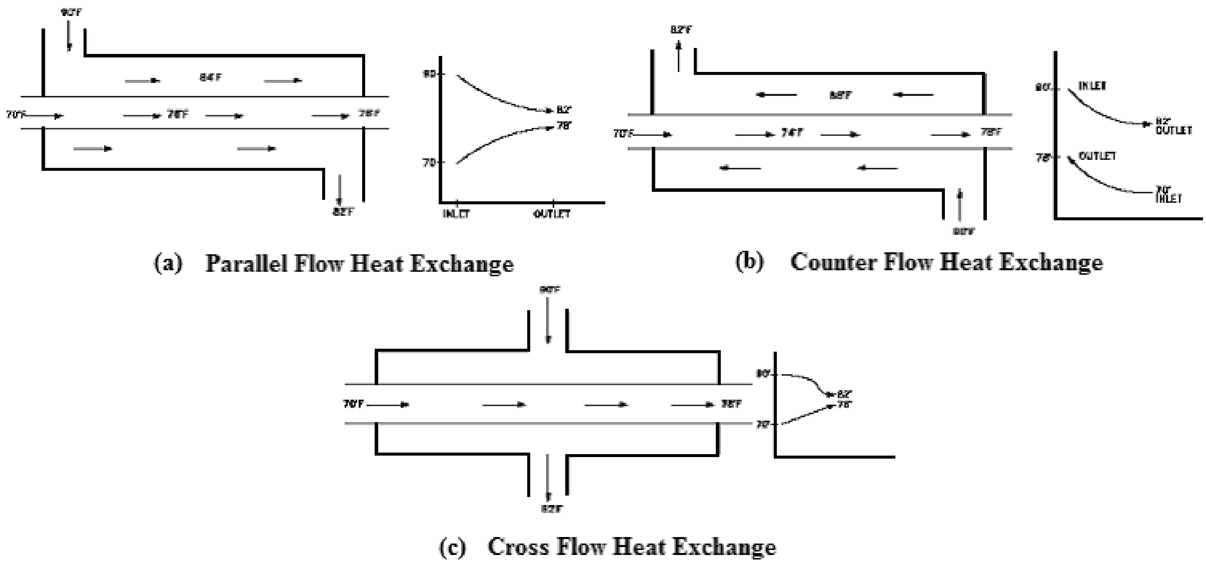



**Figure 5: Nature of hot and cold fluid flow in (a), (b) and (c) and the types of heat exchange devices**

ciency of the counter flow steam condenser. In comparison to the parallel flow steam condenser, the counter flow condensers can have the higher hottest cold fluid temperature than the coldest hot fluid temperature.

In cross flow condensers (Figure 5c) – fluids flow perpendicular to each other. Cooling water flows through the tubes and steam flows around these tubes at an angle of 90°. Basically a single type of steam condenser is not suitable in most of the thermal power plants, rather a combination of two or all the types among parallel, counter and cross flow is preferred. The reason for the combination of the various types is to maximize the efficiency of the heat exchanger within the restrictions placed on the design. That is, size, cost, weight, required efficiency, type of fluids, operating pressures, and temperatures. All these factors help in determining the complexity of a specific heat exchanger.

## Heat transfer analysis

It is theoretically analyzed that the counter flow heat exchange steam condenser design is the most efficient when the heat transfer rate per unit surface area is considered. It is because of the average temperature difference ($\Delta T$) between the two fluids over the length that the heat exchange processing is maximized. Therefore, the log mean temperature difference for a counter flow heat exchange steam condenser is larger than the log mean temperature for a similar parallel or cross flow heat exchange steam condenser (see Figures 4, 5 and 6). It can be demonstrated how the higher log mean temperature difference of the counter flow heat exchange steam condenser results in a larger heat transfer rate. The log mean temperature difference for a heat exchange unit is calculated using the following equation:

$$\Delta T_{lm} = (\Delta T_2 - \Delta T_1) / \ln (\Delta T_2 / \Delta T_1) \quad (4)$$

Where $T_1$ = Hot fluid temperature and $T_2$ = Cold fluid temperature

Heat transfer in a heat exchange condenser is assumed to occur by conduction and convection. The rate of heat transfer, 'Q', in a heat exchange steam condenser is calculated by using the following equation:

$$Q = U_o A_o \Delta T_{1m} \quad (5)$$

$$Q = U_o A_o F \Delta T_{1m} \quad (6)$$

Where:
Q = Heat transfer rate, W
Uo = Overall heat transfer coefficient, $W/m^2 K$
Ao = Cross sectional heat transfer area, $m^2$
$\Delta T_{lm}$ = Log mean temperature difference, $\Delta$
F = Correction factor for counter flow and cross flow conditions is taken as 1 for both the cases.

The results from the above equations for the same operating conditions will show that the heat transfer rate is greater in the case of a counter flow type of heat exchange condenser than the parallel flow type of heat exchange condenser.

## Simulation

In simulation, the heat exchanger is mathematically modelled to establish relations amongst condensing parameters. Prediction of outlet and inlet temperatures for different flow rates is simulated by using various equations for the heat transfer rate discussed below:

$$Q = C_h (T_{h,i} - T_{h,o}) \quad (7)$$

$$Q = C_c (T_{c,o} - T_{c,,i}) \quad (8)$$

$$Q = U A (T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i}) / \ln [(T_{h,i} - T_{c,o}) / (T_{h,o} - T_{c,i})] \quad (9)$$

These three equations contain three unknowns viz, Q, $T_{h,o}$ and $T_{c,o}$. The number of unknowns can be reduced to 2 by eliminating Q to give:

$$C_h (T_{h,i} - T_{h,o}) = C_c (T_{c,o} - T_{c,,i}) \quad (10)$$

$$C_h (T_{h,i} - T_{h,o}) = U A (T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i}) / \ln [(T_{h,i} - T_{c,o}) / (T_{h,o} - T_{c,i})] \quad (11)$$

Solving for $T_{c,o}$ in Eq. (IV) and substituting into Eq. (V) we get,

$$\ln \{ T_{h,i} - [T_{c,i} + (C_h / C_c) (T_{h,i} - T_{h,o})] / (T_{h,o} - T_{c,i}) \} = U A (1 / C_h - 1 / C_c)$$

Let $U A (1 / C_h - 1 / C_c) = x$
Then,

$$[T_{h,i} - T_{c,i} - (C_h / C_c) (T_{h,i} - T_{h,o})] / [(T_{h,o} - T_{c,i})] = e^x$$

Solving for $T_{h,o}$ enables,

$$T_{h,o} = T_{h,i} (C_h / C_c - 1) + T_{c,i} (1- e^x) / (C_h / C_c - e^x)$$

Or,

$$T_{h,o} = [T_{h,i} - (T_{h,i} - T_{c,i})] [(1- e^x) / (C_h / C_c - e^x)] \quad (12)$$

Equation 12 gives the outlet temperature of the hot fluid when $T_{h,i}$ and $T_{c,i}$ are known. The outlet temperature of the cold can be computed by using Equation 10. In the above simulation, the subscripts c and h indicate cold and hot fluids, whereas the subscripts i and o refer to the fluid inlet and outlet conditions, respectively.

## Surface condenser configurations

Steam surface condensers can be broadly categorized by the design of the orientation of the steam turbine exhaust into the condenser. Most common are side and down exhaust systems. In a side exhaust system condenser, the condenser and turbine are installed adjacent to each other, and the steam from the turbine enters from the side of the condenser. In a down exhaust condenser, the steam from the turbine enters from the top of the condenser and the turbine is mounted on a foundation above the condenser. Condensers can further be classified on the basis of:

a) Number of tube-side passes
b) Configuration of the tube bundle and water-boxes

Most steam surface condensers have either one or multiple tube-side passes as discussed above. There are many types of condenser designs based upon the specific use of requirements. However, in a large steam power plant a single-pass condenser illustrated in Figure 6 is widely accepted. The cooling water passes through straight tubes from the inlet water box on one end, and exits through the outlet water box on the other end. The separation between the water box area and the steam condensing area is accomplished by a tube sheet to which the cooling water tubes are attached. The cooling water tubes are supported within the condenser by the tube support sheets. Condensers normally have a series of baffles that redirect the steam to minimize direct impingement of steam on the cooling water tubes. The bottom area of the condenser is the hot-well. The condensate is collected at the hot-well and is sucked by the condensate pump.

The presence of non-condensable gasses decreases the vacuum of the condenser. This decrease in vacuum will result in an increase in the saturation temperature at which steam condenses. These non-condensable gases will make an envelope around the condenser tubes, which will reduce the overall heat transfer rate across the tubes surface.

The control of the condensate level is an important task in the design of condenser. Too high a level of condensate will cover the cooling water tubes and will prevent steam condensation, where steam comes in direct contact with the liquid which is at a higher temperature than cooling water. This will result in difficulty in maintaining a condenser vacuum under operating design capacity of the condenser. The temperature and flow rate of the cooling water through the condenser controls the temperature of the condensate. This, in turn, controls the saturation pressure (vacuum) of the condenser.

The maintenance of a proper hot-well level will enable the control of the condensate level effect on the cooling water tubes. The control on the condensate pump's suction and discharge flow rate is one of the methods that can be used to meet the hot-well level control. Overflow of the hot-well level is another method to maintain the water level below the cooling water tubes. The maximum wrathful expansion of steam occurs at the vacuum of nearly 29 inches of Mercury (Hg) and this results in the maximum work. Therefore, a condenser should be designed to maintain a vacuum of nearly 29 inches of Hg. The sudden reduction in steam volume as it condenses would generate a vacuum and very fast pumping of this condensate will further help in maintaining the vacuum.

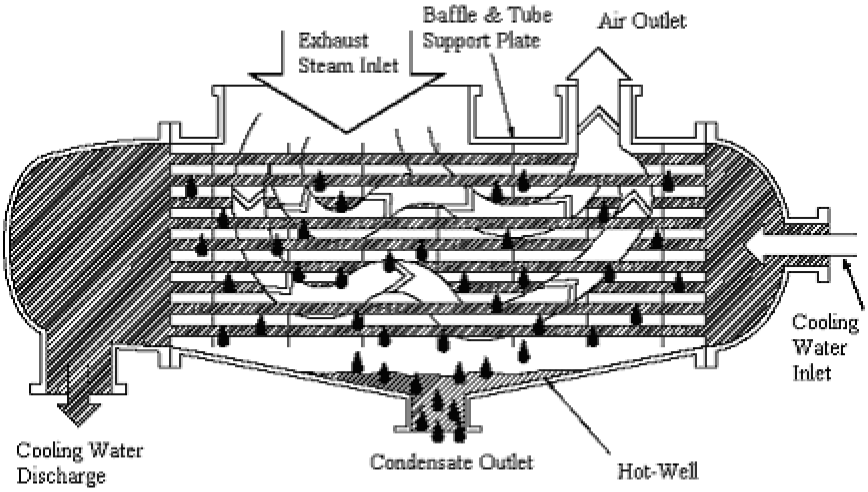



**Figure 6: Single pass condenser**

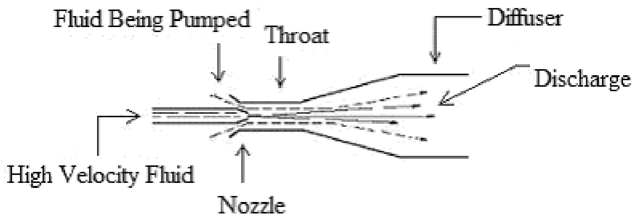



**Figure 7: Jet pump principle**

The presence of air and other non-condensing gasses cannot be avoided because of the leakage in the condenser body. This makes application of the air ejector or steam-jet ejector as a compulsory requirement to meet the standard efficiency of a steam condenser unit. The air ejector illustrated in Figure 7 is basically a jet pump which has two types of fluids. One fluid flows through the nozzle at a high pressure and the other fluid being pumped, flows around the nozzle into the throat of the diffuser. These two fluids collide in the diffuser where molecules of high velocity fluid strike with other fluid molecules.

Thus, at the diffuser end, low velocity molecules become part of a high velocity molecules stream as a result of entrainment, which in turn, creates a low pressure area around the mouth of the nozzle. This low pressure area will enable suction or pumping of more fluid from around the nozzle into the throat of the diffuser. As the fluid leaves the diffuser throat area, the diverging area converts the velocity back to the pressure. It has been observed that use of steam as a high pressure fluid from the source at a pressure between 200 psi and 300 psi enables a vacuum of about 26 inches of Hg by using a single stage air ejector.

Normally, air ejectors consist of two suction stages. The first stage suction is located on top of the condenser, while the second stage suction comes from the diffuser. The exhaust steam from the second stage must be condensed. This is normally accomplished by an air ejector condenser that is cooled by condensate. The air ejector condenser also preheats the condensate returning to the boiler. Two-stage air ejectors are capable of drawing vacuums to 29 inches Hg. A vacuum pump may be a motor-driven air compressor. Its suction is attached to the condenser, and it discharges to the atmosphere. A common type uses rotating vanes in an elliptical housing. Single-stage, rotary-vane units are used for vacuums up to 28 inches Hg. Two stage units can draw vacuums to 29.7 inches Hg. The vacuum pump has an advantage over the air ejector as it requires no source of steam for its operation. They are normally used as the initial source of vacuum for condenser start-up.

## Design of a super vacuum hybrid steam condenser

### *A. Cross flow type with plain tubes*

A hybrid super vacuum steam condenser is a heat exchanger with a combination of jet condensing and surface condensing systems. The exhaust steam at the inlet of the condenser is allowed to bifurcate into two streams. One stream of exhaust steam at high velocity and low pressure, is diverted into a chamber where mixing occurs with outlet cooling water as shown in Figure 8. The other

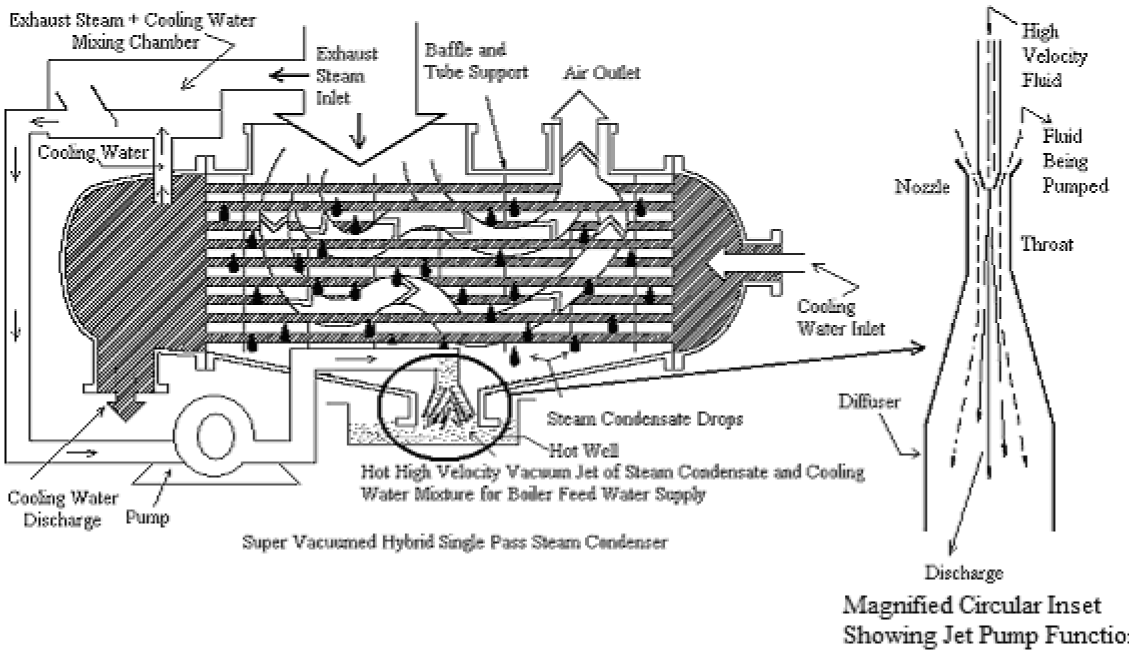



**Figure 8: A super vacuum hybrid pass steam condenser**

stream enters downwards onto the surface of the water cooling tubes of the condenser. The outlet cooling water should be clean or a filter is essential at the jet exit.

The fluid from the mixing chamber is sucked by a pump and is discharged through a nozzle as a high velocity jet. This nozzle is combined with the outlet of the condenser shell opening from where condensate is discharged to the hot-well. The hot-well discharge opening of the condenser shell is designed as the part of a diffuser throat where the nozzle discharges high velocity cooling water through a mixed condensate jet. This nozzle and diffuser throat position is shown by a magnified circular inset in Figure 8. This high velocity jet creates a low pressure area around the mouth of the nozzle which enables pulling of the tube surface condensate. Both the condensate i.e. jet condensate and tubes surface condensate meet at the diffuser throat expansion and gets mixed with hot-well fluid.

These are the following advantages in this condenser design:

1. A partial vacuum is created near the hot-well discharge opening of the main condenser body. This influences the vacuum efficiency of the condenser.
2. This enables uniform temperature of hot-well fluid, which is almost near saturation temperature of the steam, and a heat efficient boiler feed is ensured.
3. The temperature of mixing chamber fluid is near the saturation temperature of steam because of the loss of latent heat of steam only. There is no chance of under-cooling of condensate.
4. The hot-well fluid is the mixture of the two condensates and temperature remains uniform i.e. near the saturation temperature.

It is also important to note that the cooling water of the mixing chamber is taken from the exit of the condenser tubes where this fluid has already exchanged latent heat of steam and is at the temperature, which is somewhat closer to the saturation temperature of steam. In another design, the mixing chamber receives cooling water directly from the inlet cooling water supply line of the condenser where the temperature of the mixing chamber cooling water is same as of the supply line.

### *B. Dual counter and cross flow type with flat tubes*

This steam condenser has a combination of counter flow and cross flow mechanisms as illustrated in Figure 9. It is well known that the overall heat transfer rate is greater in counter flow than parallel flow.

The design and arrangement of condenser tubes is such that the condensation of the steam takes place at both the counter flow and cross flow. The cross flow pattern is desirable when the bulk volume of steam is to be condensed. The application of a hybrid super vacuumed condensing mechanism as discussed above is also used very effectively in this design.

### *C. Dual counter and cross flow type with corrugated tubes*

This is a steam condenser in which the cooling water carrying tubes are not a flat type. These tubes are a corrugated type, where both the length and average diameter of the tube can be varied. This is

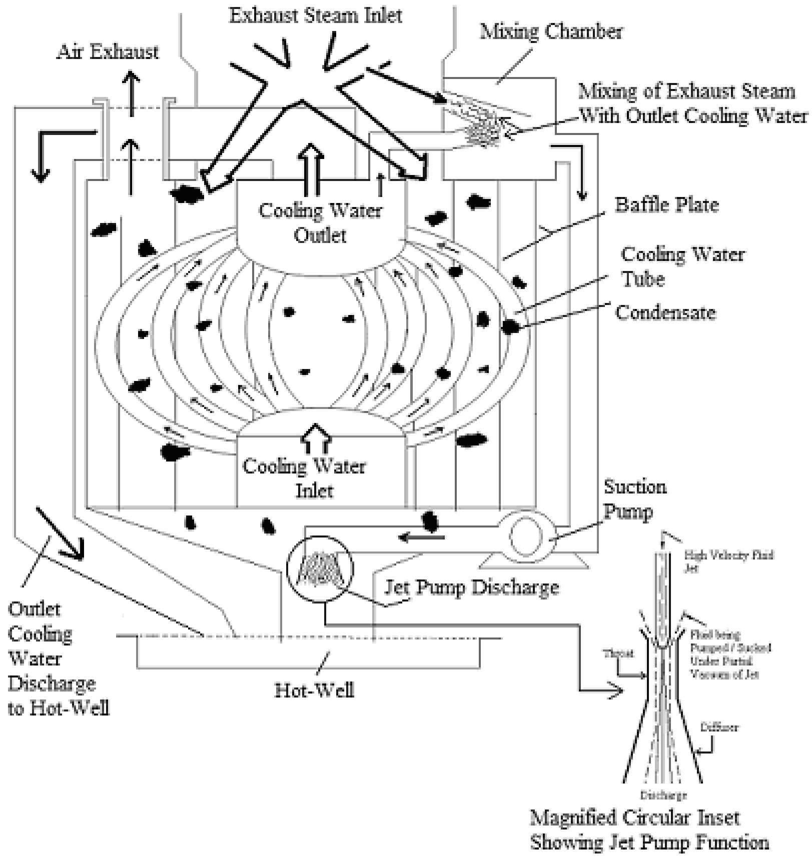



**Figure 9: Advanced super vacuum hybrid single pass steam condenser**

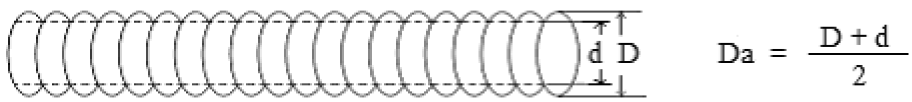



**Figure 10: Corrugated cooling water tube for a given length and average diameter**

illustrated in Figure 10.

Here it is possible to get a higher surface area for a given length and an average diameter of a tube. In this design, the heat transfer rate is greater because of the increase in the surface area. It is well known that for a given length and average diameter, the heat transfer rate is greater in the case of a corrugated tubes condenser than the flat tubes condenser. Theoretically, this condenser design with a hybrid super vacuumed mechanism is most efficient than any other type for the following reasons:

a) The heat transfer rate is greater than any other type due to:
   i) Higher surface area of the corrugated tube.
   ii) Counter flow pattern of cooling water; and
b) Higher vacuum efficiency.

## Conclusions, suggestions and recommendations

The main function of a condenser is to only remove the latent heat of vaporization so that the temperature of condensate becomes equal to the saturation temperature of steam corresponding to the condenser pressure. It further theoretically elaborates complete absence of under cooling of condensate. Therefore, the maximum temperature to which cooling water can be raised is the condensate temperature at the minimum possible condenser pressure where only latent heat of vaporization is extracted without any under cooling. The condenser efficiency is given as the ratio of actual rise in the temperature of outlet cooling water to the maximum possible temperature rise in a saturated temperature at condenser pressure corresponding to the inlet cooling water temperature. Mathematically,

$$\text{Condenser efficiency} = \frac{\text{Actual tise in the cooling water temperature}}{\text{Saturation temperature at condenser pressure} - \text{inlet cooling water temperature}}$$

$$= \frac{T_2 - T_1}{T_3 - T_1}$$

$T_1$ and $T_2$ are inlet and outlet cooling water temperature, and $T_3$ is saturation temperature at condenser pressure.

Here in all A, B, and C Types of super vacuumed hybrid condenser designs discussed above, the saturation temperature corresponding to the condenser pressure is minimum in comparison to conventional surface condensers where a nozzle-diffuser system is absent across the hot-well discharge opening. This super vacuum does not allow any under-cooling of condensate because of the mixing of high velocity jet condensate (from mixing chamber) with tubes surface condensate.

The temperature of jet condensate remains equal to the saturation temperature because the removal of latent heat only. This enables uniform temperature distribution of condensate around the nozzle area of the hot-well discharge opening. The possibility of achieving a minimum value of $T_3$ is the basic source of higher condenser performance efficiency of these condenser designs. Theoretically, vacuum efficiency of these A, B, and C Types of condenser design is also higher than conventional types. The development of a vacuum basically occurs in following ways:

1. Vacuum due to a volume change during the condensation process.
2. Vacuum across the nozzle mouth due to high velocity of jet.

Hence, it is evident that there is one other source of vacuum from the nozzle jet which is generally absent in the case of conventional surface condensers. That is why this condenser design is named as a super vacuumed condenser. The increase in vacuum decreases the condenser pressure and lowers the saturation temperature $T_3$ which is a prime requisite for the high performance of the condenser.

Theoretically, all three types of condenser design have a higher heat transfer rate because of the counter flow and cross flow nature. A Type C design of condenser is more efficient than A and B Types because of the higher heat transfer rate due to increased surface area of cooling water carrying tubes of a corrugated nature. These tubes further improve the efficiency of heat transfer because of the increased surface area. It is also important to note that in all the three A, B, and C Types of condenser design two things are common, that is the flow of cooling water which is of counter-flow and cross-flow type. The other common feature is availability of a mixing chamber where jet condensation takes place with the mixing of exhaust steam with cooling water.

At the same time, it is possible to use inlet cooling water or outlet cooling water in a mixing chamber. The heat transfer rate in the former is higher than the latter because the temperature of the inlet cooling water is lower than the outlet cooling water. It is strongly recommended that the proportionate mixture of inlet and outlet cooling water should be used for mixing chamber jet condensation according to the steam mass to be cycled in the mixing chamber. This shall enable extraction of only latent heat of vaporization during condensation. Excessive condensate depression decreases the operating efficiency of the plant because the sub-cooled condensate must be reheated in the boiler, which in turn, requires more heat from the reactor, fossil fuel, or other heat source.

The cooling water should be of a good quality – free from impurities such as algae, salt etc. The capacity of the suction pump which is used to pull jet condensate from the mixing chamber and to deliver it to hot-well discharge should be higher. This enables higher speed of suction, which in turn, increases the velocity of the cooling water flow in tubes, and enables a higher heat transfer rate between the exhaust steam and tubes cooling water. The rate of heat transfer varies approximately with a square root of the cooling water flow velocity in the condenser tubes. It is also important to regulate speed of suction at an optimum level beyond this possibility of back pressure into the mixing chamber because it could harm the smooth flow of exhaust steam over the condenser tubes.

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