*IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*
*e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 1 Ver. VI (Jan- Feb. 2015), PP 15-20*
*www.iosrjournals.org*

# Optimization Of Parallel Condensing In Steam Power Plant

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***Abstract:*** *The spurt in the growth of water consumption for industrial, residential and power generation purposes has encouraged engineers to devise technologies that minimize water use. In addition, drought conditions have made the government to bring in regulations that encourage water conservation. Majority of power plants use water for cooling steam from the turbine which is beneficial for sites with plenty of water. An alternative is to use air as the cooling medium but their performance drops in hot weather conditions. Maximization of overall efficiency is as vital as the cost and availability of water. Therefore there is a need to integrate the technologies of air cooled and water cooled condensers. This project will focus on parallel condensing where steam from the turbine is ducted in parallel to both air cooled and water cooled condensers. To optimize the parallel condensing capacities of air cooled and water cooled condensers considering parameters such as ambient temperature, pressure, availability of water, fan power, pumping costs.*

***Keywords:*** *Optimization; Parallel Condensers; Steam Power Plant;*

## I. Introduction

### 1.1 Steam Power Cycle

A power cycle continuously converts heat energy released by burning of fuel into shaft work. A steam power plant works on the basis of Rankine cycle. A schematic diagram of this cycle is shown in Fig 1

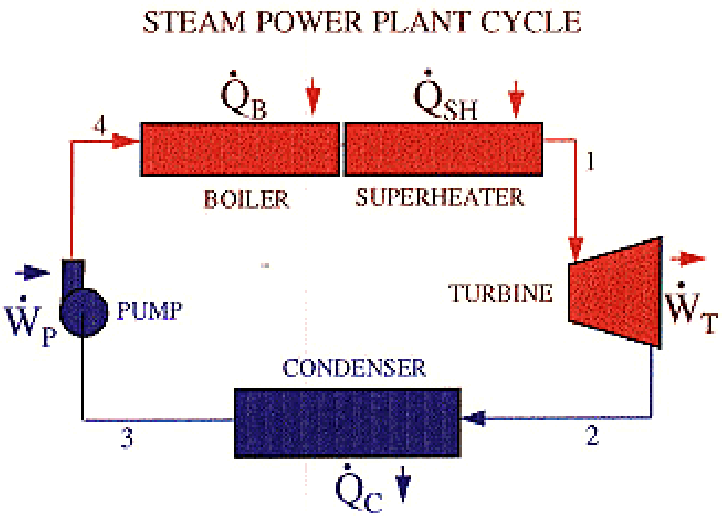



**Fig 1**

Heat is first transferred to water in the boiler from an external source to raise steam. This steam is at a very high pressure and temperature and it is made to expand in the turbine to produce shaft work. The steam leaving the turbine condenses into water in the condenser and then this water is pumped back into the boiler.

### 1.2 Condenser

Condenser is an important component in a power plant where the latent heat of the turbine exhaust steam is transferred to cooling medium which is eventually dissipated to the atmosphere. This waste heat limits the thermal efficiency of modern steam power plants to 40%.

The condenser is designed to maintain an economical condenser pressure determined by the cooling medium temperature. The work done in the turbine varies depending on the turbine back pressure which in turn depends on the temperature of the cooling medium. Fig.2 shows the Rankine cycle on T-s diagram.

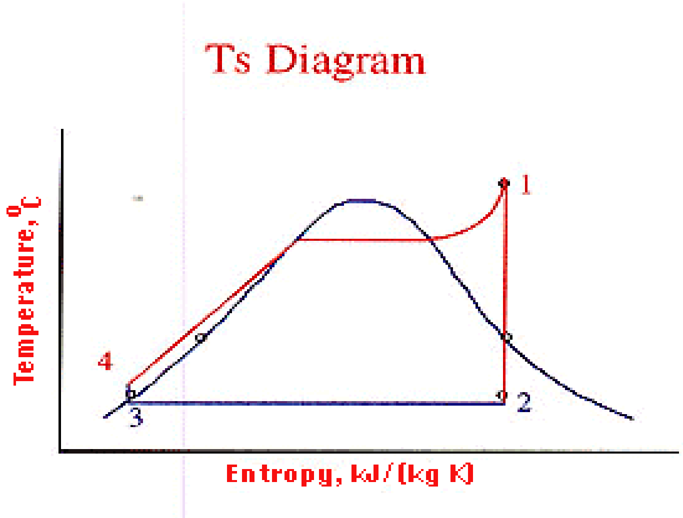



**Fig .2**

**1.3 Functions of condenser**

The main functions of a condenser are as follows:

1. To condense the steam exhausted from the turbine.
2. To maintain the desired vacuum.
3. To maintain condensate temperature, equal to the saturation temperature corresponding to condensing pressure of steam to avoid thermal losses.
4. To provide convenient point for make up water entry.
5. To facilitate extraction of non condensable gases.

For operation at optimum efficiency, the condenser is so designed that temperature of exhaust steam and condensate are nearly equal. Under such condition the cooling medium will carry only the latent heat of steam. The condenser is supported firmly on foundation and is connected to turbine through stainless steel expansion bellow, which allows for differential movements. An atmospheric relief valve and rupture disc is provided on the shell to prevent over pressure.

## II. Design Criteria

**3.1 For Water Cooled Condensers**

The design of a steam condenser depends on circumstances peculiar to the power plant in which it is to be installed. The temperature and availability of cooling water, pressure drop restrictions, purity of cooling water and a host of other parameters influence the choice of design parameters.

**Cooling water velocity**

Cooling water velocity to be used depends on the material selected and is based on the considerations of erosion and fouling. Since the principal barrier to heat transfer is the heat transfer coefficient on the water side, there is a strong incentive to increase the cooling water velocity. A high velocity results in erosion, wear and high pressure drop while low velocity promotes deposit accumulation and corrosion.

The heat exchange institute recommends a velocity ranging from 5 to 8 fps for a good compromise between heat transfer and pumping power requirements.

**Overall heat transfer coefficient**

The overall heat transfer coefficient is primarily a function of cooling water velocity, purity of water and temperature of cooling water. An increase in its value will decrease the size of the condenser required.

**Tube parameters**

The tube material to be used depends on the type of water and environment.

A smaller diameter tube and thickness gives lower surface area requirements as well as lower pressure drops for the same velocity compared to a larger sized tube or larger thickness. This is because, for a fully developed flow the Nusselt number is constant.

So, as the diameter of the tube increases, the heat transfer coefficient decreases to maintain the Nusselt number as a constant. Therefore the surface area required for heat transfer increases.

However higher water velocities cannot be used in a small tube. Hence, based on the above considerations a decision may be taken.

**Temperature of cooling water**

A lower temperature of cooling water allows the turbine to be operated at lower pressures due to which a higher turbine output may be obtained and also the surface area requirements of the condenser is decreased. A very low temperature may lead to subcooling. In such a case, the temperature rise in the condenser can be restricted.

**Pressure drop**

The pressure drop inside the tubes should be maintained small so as to reduce the pumping power required. Generally accepted value ranges from 2 to 7 psi.

**3.2 For Air Cooled Condensers**

The design of an air cooled condenser primarily depends on the dry bulb temperature at the plant location, air velocity, type of tube arrangement, pitch and space restrictions.

**Dry bulb temperature**

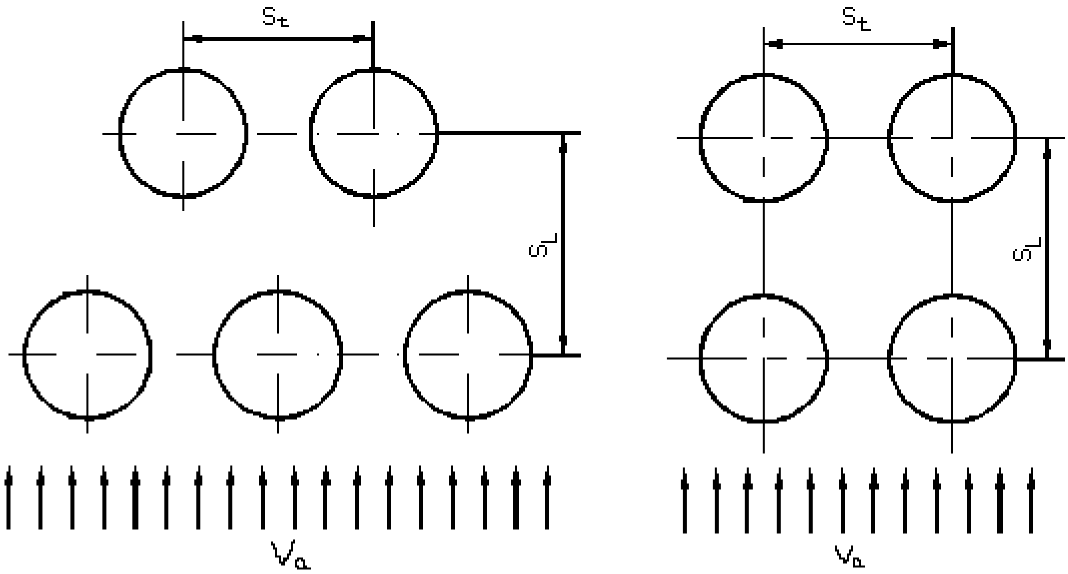
Since the cooling medium for steam is air, a higher ambient temperature results in a lower heat transfer coefficient and hence a larger size condenser is required. At lower temperatures a smaller condenser is sufficient. An air cooled condenser is generally designed for a temperature that is 2 to 5% higher than the highest ambient temperature at that location.

**Air velocity**

A higher air velocity implies a larger heat transfer coefficient and hence a smaller condenser size. But we need to supply more fan power in such conditions and the pressure drop across the tubes increases. So a compromise must be made between fan power requirements and overall heat transfer coefficient.

**Tube arrangement:**

The tubes may be arranged in an inline or staggered fashion as shown in the Fig.3. The inline tubes tend to give a lower pressure drop and poorer heat transfer because the flow tends to be channeled into high velocity regions in the centre of the lanes between the tube rows. Staggered tubes, on the other hand produce good mixing of the flow over the tube banks but give a higher pressure drop.




Staggered arrangement                Inline arrangement

**Fig .3**

**Pitch**

As the distance between the successive tubes increases the pressure drop on the fin side decreases due to less obstruction. But a higher pitch occupies more space. So, a balance between space restrictions and pressure drop must be made.

## III. Design Procedure For Water Cooled Condenser

In the design of condensers calculation of heat transfer co-efficient are the most significant and should be determined with reasonable accuracy. When the cooling medium has a reasonably high heat transfer co-efficient such as water, the heat transfer co-efficient inside and outside the tubes compares well. A significant error in estimating this would affect the overall size of the equipment.

The heat exchanger is designed to heat or cool a steam for which the flow rate, an acceptable pressure drop, and inlet and outlet temperatures are defined. The LMTD will depend only in the flow configuration.

Practical considerations such as fabrication and maintenance determine the tube diameter and geometric arrangement. Once the geometric pattern is fixed, the relations between the fluid mass flow rate outside the tubes and both the pressure drop and heat transfer coefficient are then defined.

Assumptions made in the design calculation:

1. Assuming shell and tube heat exchanger
2. No. of tube passes, n = 1
3. Velocity of cooling water, V =5.5fps (5 to 10 fps)
4. Condenser purity factor for water with chemical treatment, ß= 0.8
5. Tube size 0.5 inch, 18 BWG.

The steps for designing a water cooled condenser are as follows:

**Step 1:** Find the heat duty of condenser

$$\mathbf{Q = w_s\,(x)\,h_{fg}} \tag{1}$$

**Step 2:** Find mass flow rate of cooling water

$$\mathbf{w_c = Q/\,C_p\,(t_{wo}-t_{wi})}$$

**Step 3:** Find overall heat transfer co-efficient

$$\mathbf{U = 4070.5\,\beta[0.51V]^x\,[1\text{-}(0.42\sqrt{\beta}\,(35\text{-}t_{wi})^2\,/1000)]}$$

**Step 4:** Calculation of cooling surface area

$$\mathbf{A = w_c\,\ln[(T\text{-}t_{wi})/(T\text{-}t_{wo})]\ \ [0.022/d_i]^{(x/4)}\ \ /\,(U\Phi)}$$

**Step 5:** Find number of tubes

This is found using the continuity equation.

$$\mathbf{N = (4w_c)/(\pi d_i^2 \rho v)}$$

**Step 6:** Find the approximate length of tube

$$\mathbf{L = ((900v\rho)/U)[\ln((T\text{-}t_{wi})/(T\text{-}t_{wo}))]((d_i)^2\,/nd)((0.022/d_i)^{(x/4)}/\Phi))}$$

**Step 7:** Find the accurate length of tube

This is based on the heat transfer area required.

$$\mathbf{N = A\,/\,\pi dL}$$

Initially assume length of the tube L as obtained in the previous step. Then iterate by varying L until the number of tubes N equals that obtained in **Step 5**. This value of L gives the accurate length of the tube.

**Step 8:** Determination of shell diameter

$$\mathbf{D_s = d(\sqrt{(N\,/k)})}$$

The occupancy factor k varies from 0.24 to 0.31

**Step 9:** Determination of pumping power

$$\mathbf{P_{pump} = Qh_p\,/\,(102\,\eta_p)}$$

**Step 10:** Determination of cooling tower fan power

$$\mathbf{P_{fan} = Qh_f\,/\,(102\,\eta_f)}$$

| | |
|---|---|
| Pressure of steam,p | 0.1ata |
| Steam condensed,$w_s$ | 27222 kg/h |
| Cooling water temp. inlet,$t_{wi}$<br>outlet,$t_{wo}$ | $32^0$C<br>$40^0$C |
| Cooling water flow rate, $w_c$ | 1855 $m^3$ /h |
| Cooling water velocity, V | 5.5 fps (1.6764 m/s) |
| Number of tubes, N | 1323 |
| Tube size | 0.75in, 20 BWG |
| Number of passes,n | 1 |
| Surface area required,A | 681.05 $m^2$ |
| Length of tubes,L | 8.6 m |
| Shell diameter,$D_s$ | 133.2 cm |
| Overall HT coefficient,U | 2973.6 W/m2 K |

| | |
|---|---|
| Pump power | 155.05 KW |
| Cooling tower fan power | 36.1 KW |

## IV. Analysis Of Operating Parameters

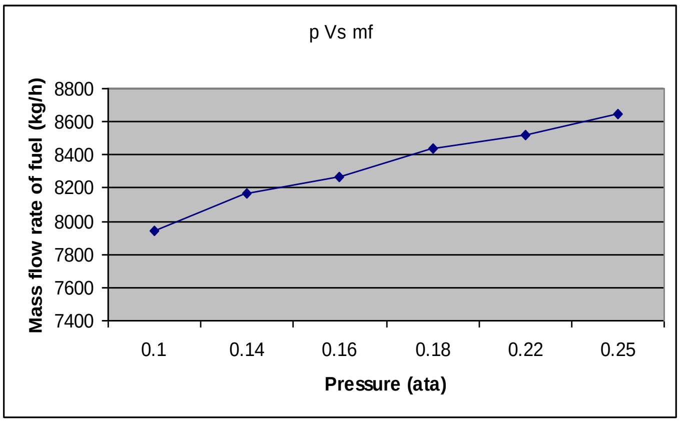



Fig.4 Effect of turbine exhaust pressure on mass flow rate of steam

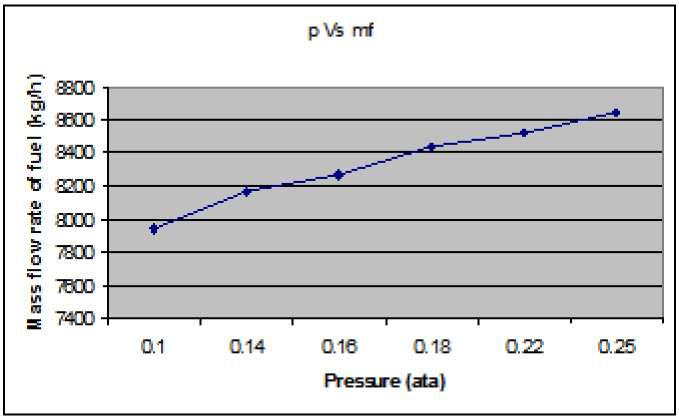



**Fig.5** Effect of air velocity on heat transfer area

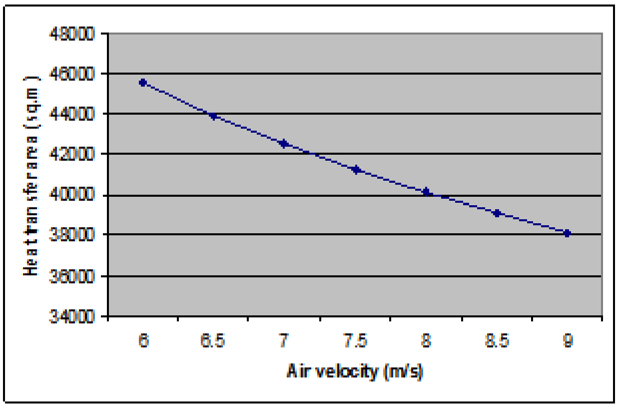



**Fig.6** Effect of transverse pitch on pressure drop

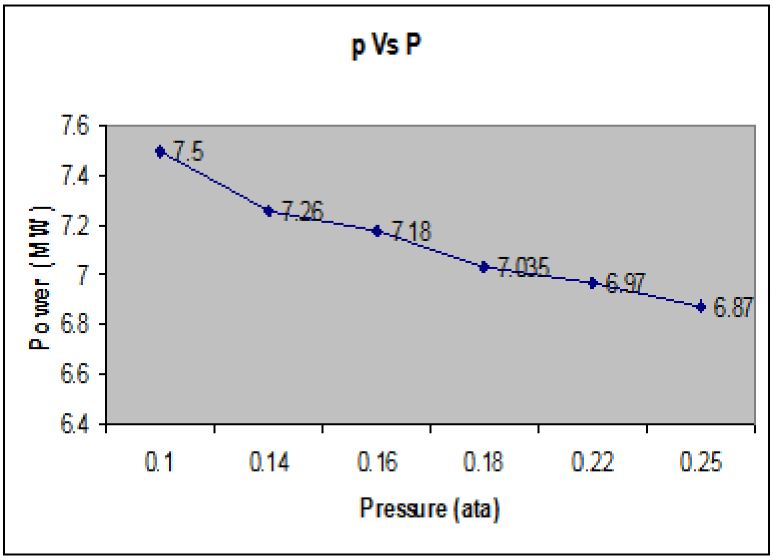



**Fig.7** Effect of turbine exhaust pressure on power output

## V. Conclusion

1. From the above methods of analysis it is clear that dry cooling is comparable to wet cooling at the assumed rates of water and power.
2. The cost of water and power will have a strong bearing on the analysis. If the water cost increases economics favour dry cooling.
3. If water is available in sufficient quantities at a cheaper rate, wet cooling is economical.
4. When water is available but only for certain months in the year we can opt for a parallel condensing system. In this case, the capital cost decreases and performance is improved compared to 100% dry cooling system.
5. The percentage of dry cooling and wet cooling in a parallel condensing system depends on the water availability.

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