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# OPTIMIZATION IN THERMAL DESIGN OF SURFACE CONDENSER BY CHANGING TUBE MATERIAL

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## ABSTRACT

Owing to the wide utilization of heat exchangers in industrial processes, their cost minimization is an important target for both designers and users. Traditional design approaches are based on iterative procedures which gradually change design parameters until a satisfying solution, which meets the design specifications, is reached. However, such methods, besides being time consuming, do not guarantee the reach of an economically optimal solution. In this paper a procedure for optimal design of shell and tube heat exchangers is proposed, which utilizes a aspen plus software to minimize the total cost of the equipment including capital investment and the sum of discounted annual energy expenditures related to pumping. With changes of different parameters like thermal conductivity, Heat transfer rate, flow rate, Inlet and outlet of cooling water required for cooling purpose, we can optimise the thermal design by reducing area of surface condenser. Owing to the wide utilization of heat exchangers in industrial processes, their cost minimization is an important target for both designers and users: journal article [1]

**Keywords:** Tube Materials, Thermal Conductivity, Heat Transfer Rate, Design of Condensers and Aspen Tech Software

## 1. Introduction

Condenser is a type of heat exchanger in which hot fluid becomes cold fluid. Surface condenser is a commonly used term for a water-cooled shell and tube heat exchanger installed on the exhaust steam from a steam turbine in thermal power stations. These condensers are heat exchangers which convert steam from its gaseous to its liquid state at a pressure below atmospheric pressure. Where cooling water is in short supply, an air-cooled condenser is often used. An air-cooled condenser is however significantly more expensive and cannot achieve as low a steam turbine exhaust pressure as a water-cooled surface condenser.

The condensation can occur on the outside or inside of the tubes. Each setup requires different Considerations as well as different heat transfer correlations. (See recommended readings from HEI standards).HEI means heat exchanger institute. The shell of condenser is made by carbon steel and tube material made by different higher thermal conductivity material. Physically, the steam will flow from top to bottom inside the shell while the Water will move counter currently in the tube area.

There are many types of software available for condenser design like as Aspen plus, Compress, PVElite etc. Design on Aspen plus software is very similar to that of boiling design. Hand calculations will be needed again since Aspen has difficulty estimating condensation heat transfer coefficients accurately. On the other hand, the hand calculations can become very tedious steam from a steam turbine to obtain maximum efficiency and also to convert the turbine exhaust steam into pure water so that it may be reused in the steam generator or boiler as boiler feed water: journal article [2]

### 1.1 Purpose

In thermal power plants, the primary purpose of a surface condenser is to condense the exhaust steam from a steam turbine to obtain maximum efficiency and also to convert the turbine exhaust steam into pure water (referred to as steam condensate) so that it may be reused in the steam generator or boiler as boiler feed water: journal article [2]

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## 2. Design of Surface Condenser

For design of surface condenser following datas are required.
- Ambient Pressure & Temperature
- Relative Humidity
- Design Conditions at different Gas Turbine Load Steam inlet (kg/s)
- Steam inlet (kg/s)
- Condensate Outlet Temperature (0C)

### 2.1 Thermal Design

It's a primary design of heat exchanger in which we optimize the design by changing flow rate, material thermal conductivity etc. Also we optimized in process by changing design of two or three pass system. Turbine Condensers are designed as per HEI-standards for steam condensers (HEI means Heat Exchange Institute) Since 1933 - HEI is a non profit trade association committed to the technical advancement, promotion, understanding and education of industrial heat exchanger, vacuum system etc. HEI has developed and published Standard: journal article [3]

### 2.2 Mechanical Design

Mechanical design is a secondary design. The Following are the Mechanical Design & Construction Code:
1) ASME
2) Sec VIII Div I, II, III
3) Sec III
4) Sec I
5) TEMA
6) IBR
7) IS 2825

## 3. Material for Construction of Heat Exchanger

The following materials are widely used for heat exchanger design.
1) CS (Plain CS & Micro Alloy Steels)
2) C-Mn, C-Mo, Cr.-Mo, Cr.-Mo. Ni. - Cr. - Mo, Ni- Steel
3) Stainless Steel.
4) Austenitic, Ferrite, Martensitic, Duplex, Super Duplex
5) Al, Cu, Brass, Bronze, Monel, Cupronickel, Titanium

## 4. Software used for Condenser Design

The following softwares used for condenser design.
1) Condenser Design on Aspen-Plus Software
2) Compress Software
3) PVElite
4) LMTD Calculator.
5) Condenser Design (Cnd)
6) Double Pipe Heat Exchanger Design(DHex)

**Table 1: Materials used for Surface Condenser Tubes and its Thermal Conductivity**

| Sr. no. | Tube Material | Thermal Conductivity (W/m$^0$C) |
|---|---|---|
| 1 | Titanium | 21.9 |
| 2 | Pure Nickel | 90.7 |
| 3 | Copper | 401 |
| 4 | 70%Cu-30%Ni | 110 |
| 5 | 90%Cu-10% Al | 52 |
| 6 | Carbon steel | 60.5 |
| 7 | Carbon steel - 1010 | 63.9 |
| 8 | Tantalum | 57.5 |
| 9 | Zirconium | 22.7 |
| 10 | Stainless steels 302 | 15.1 |
| 11 | stainless steels 304 | 14.9 |
| 12 | stainless steels 316 | 13.4 |

The thermal conductivity for different tube materials are shown in table.1

## 5. Optimisation of Area by Thermal Analysis of Heat Exchanger on ASPEN Tech Software

The following datas are taken taken from Sikalbaha 225 MW ± 10% Combined Cycle (Dual Fuel) Power Plant Project Bangladesh: journal article [5]
1) Ambient Pressure & Temperature
2) Relative Humidity
3) Design Conditions at different Gas Turbine Load
4) Steam inlet (kg/s)
5) Cooling Water Inlet, Condensate Outlet Temperature and fouling factor.

 

**Table 2: Result Table Produced by Aspen Plus Software**

| Stem Flow (kg/s) | Pressure (bar) | Steam I/O Temp. ($^0C$) | Water Inlet Temp ($^0C$) | Water Outlet Temp ($^0C$) | Different Tube Material & It's surface condenser area ($m^2$) | | | | LMTD |
|---|---|---|---|---|---|---|---|---|---|
| 41.1 | 0.093 | 44.3 | 37.5 | 42.2 | 307.5 | 301.02 | 280.09 | 289.4 | 2.68 |
| 43.3 | 0.095 | 44.8 | 37.7 | 42.6 | 4819 | 468.9 | 441.9 | 458.7 | 2.78 |
| 51.8 | 0.103 | 46.5 | 38 | 43.9 | 468.5 | 457.1 | 430.56 | 446.4 | 3.5 |
| 53 | 0.105 | 46.7 | 38.1 | 44.1 | 346.3 | 314.07 | 292.01 | 284.4 | 3.7 |
| 60.2 | 0.165 | 56 | 46.2 | 53.1 | 580.2 | 604.53 | 531.16 | 553.2 | 4.25 |
| 63 | 0.115 | 48.6 | 38.5 | 45.5 | 307.5 | 320.61 | 280.09 | 289.4 | 4.52 |
| 63.2 | 0.044 | 30.7 | 20.1 | 27 | 565.1 | 549.3 | 517.49 | 490.6 | 4.52 |
| 93.2 | 0.215 | 61.6 | 46.7 | 57.2 | 889.9 | 858.5 | 811.9 | 857.6 | 7.24 |
| 96 | 0.078 | 41 | 24.5 | 35.6 | 933.1 | 899.47 | 850.19 | 893.5 | 8.6 |
| 98.8 | 0.165 | 55.5 | 39.8 | 50.7 | 817.8 | 760.37 | 719.4 | 749.7 | 7.81 |

Table-2 shows the relation between heat transfer area, Thermal conductivity and inlet temperature of water. When thermal conductivity increases surface area decreases. Also surface area depends on inlet temperate of water. When temperature difference between two fluids is maximum then heat transfer surface area required is less.

## 6. Results

The values of Thermal Conductivity for different materials used for surface condenser tubes are shown in table-3.

**Table: 3 Effect of Thermal Conductivity on Surface Area at 41.1kg/s Flow Rate**

| Material | Thermal conductivity (W/m $^0C$) | Surface Area Area ($m^2$) |
|---|---|---|
| Titanium | 21.9 | 307.59 |
| SS 304 | 14.9 | 301.02 |
| Nickel 200 | 90.7 | 280.09 |
| Copper | 401 | 289.4 |

In Figure-1 & Figure-3 also show that when the value of Thermal conductivity increases then Surface area decreases. This is because of heat transfer depends on Thermal conductivity.

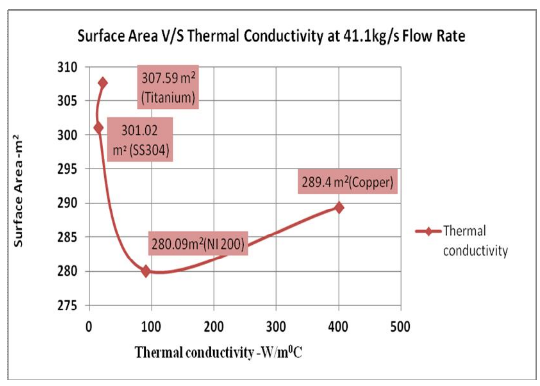


**Fig. 1 Surface area v/s Thermal Conductivity of Tube Material at 41.1kg/s Flow Rate**

**Table: 4 Effect of Heat Transfer Rate on surface Area at 41.1kg/s Flow Rate**

| Material | Surface Area ($m^2$) | Clean ($W/m^2$ K) | Dirty ($W/m^2$ K) |
|---|---|---|---|
| Titanium | 307.59 | 1328 | 1172.3 |
| SS 304 | 301.02 | 1208.6 | 1124.7 |
| Ni 200 | 280.09 | 1477.6 | 1287.4 |
| Copper | 28940% | 1418.1 | 1241.9 |

 

Table-4 show the Releation of surface area and dirty condition heat transfer rate.Heat transfer also depends on Heat transfer rate.This rate is different for different materials.At starting of the operation of Heat exchanger, It should be in clean condition.But after some time of operation period the fouling effect should be start.The fouling factor depen on different cooling water.Either it should be pure water,river water,Sea water etc.The fouling factor should be considered at starting of the design when we calculate surface area at that consider the value of Fouling factor as per standard for different fluid.

The also shows the relation that described that heat transfer surface area depends on not only Thermal conductivity.It also depends on Heat transfer rate in dirty condition. Figure 2 & 4 Shows that the thermal conductivity of copper is higher then Nickel inspite of that its surface area is less means its heat transfer rate in dirty condition for Nickel is Higher then copper.Because copper is highly corrosive then Nickel with Sea water.

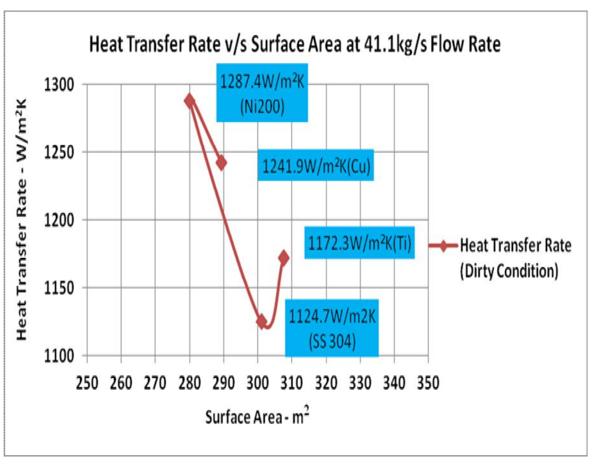


**Fig. 2 Heat Transfer Rate v/s Surface Area at 51.8kg/s flow rate**

**Table: 5 Effect of Thermal Conductivity on Surface Area at 51.8 kg/s Flow Rate**

| Material | Thermal conductivity (W/m $^0$C) | Surface Area (m$^2$) |
|---|---|---|
| Titanium | 21.9 | 468.5 |
| SS 304 | 14.9 | 457.1 |
| Nickel 200 | 90.7 | 430.56 |
| Copper | 401 | 446.42 |

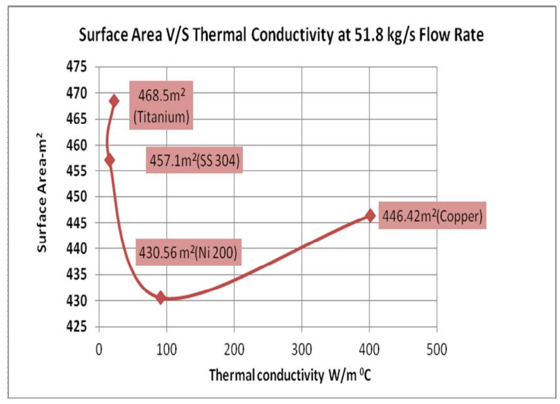


**Fig.3 Surface area v/s Thermal Conductivity of Tube Material at 51.8 kg/s Flow Rate**

**Table: 6 Effect of Heat Transfer Rate on Surface Area at 51.8 kg/s Flow Rate**

| Material | Surface Area (m$^2$) | Clean (W/m$^2$ K) | Dirty (W/m$^2$ K) |
|---|---|---|---|
| Titanium | 468.5 | 1068.5 | 965.3 |
| SS 304 | 457.1 | 1098.0 | 989.4 |
| Ni 200 | 430.56 | 1173.7 | 1050.4 |
| Copper | 446.42 | 1127.3 | 1013.1 |

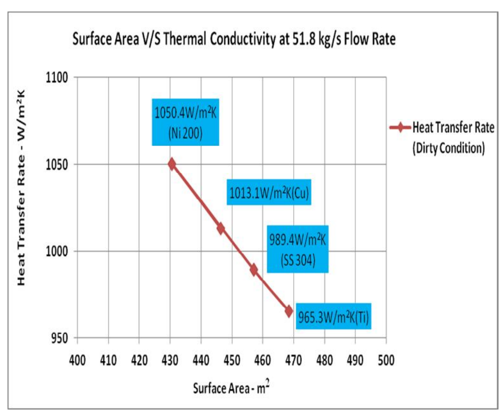


**Fig. 4 Heat Transfer Rate v/s Surface Area at 51.8 kg/s Flow Rate**

The figure-5&6 shows the relation between surface area required for heat transfer and thermal conductivity for different load condition on turbine in kg/s. Here the minimum surface area required for nickel inspite of its thermal conductivity value is (90.7 W/m $^0$C) as compared to thermal conductivity value for copper is higher (401 W/m $^0$C) but its heat transfer rate in dirty condition is higher than copper. Generally copper is highly corrosive with sea water so, its life duration of copper tube is less as compared to nickel and Titanium. Titanium is mostly used for tube material with sea water.

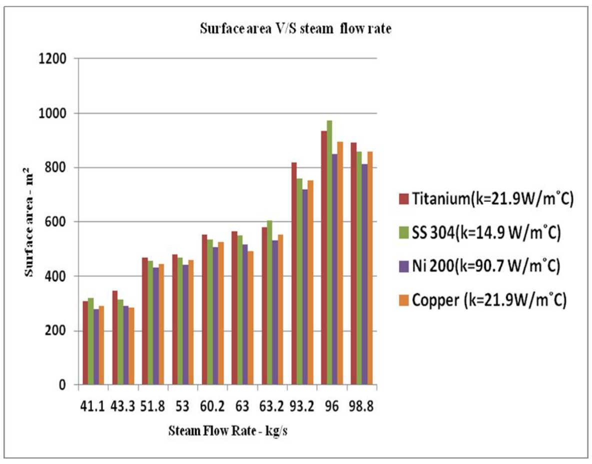


**Fig. 5 Surface area v/s Steam Flow Rate and Thermal Conductivity**

The heat transfer rate for Nickel is 1287.4 $W/m^2$ K is higher than copper 1241.9 $W/m^2$ K. So its surface area required for heat transfer is less as compared to copper. When designer will used copper with pure water at that time its fouling factor is approximate zero then surface area required for copper is less then Nickel.

Thus Heat transfer Surface area depends on many parameters like as inlet and outlet temperature of water, Thermal conductivity, fouling factor, Dirty condition heat transfer rate etc.

## 7. Conclusion

Surface area of condenser is depending on material thermal conductivity, overall heat transfer coefficient and logarithmic mean temperature difference. If we will use higher thermal conductivity material for designing of surface condenser then we can reduced the surface area of condenser.

While we design a surface condenser at that time its dirty condition Heat transfer rate is also consider because design based on dirty condition. At starting of operation on condenser it must be in clean condition but after some time it should be the effect of fouling on material. Fouling reduces the heat transfer rate so, more surface area required when we use sea water at that time Nickel is best material for maximum heat transfers over Copper in spite of them its thermal conductivity is higher than Nickel because nickel has high value of fouling resistance to protect against fouling effect. Also LMTD is more at that time also less surface area required. [10]

When we used specific thermal conductivity material for condenser tube at that time 08 to 10% surface area reduces. So, the final governing equation while we designing a surface condenser becomes
`$Q = F_f U_{dirty} A$ (LMTD)

## References

1. *Andre L H Costa and Eduardo M Queiroz (2008), "Design Optimization of Shell-and-Tube Heat Exchangers", Journal of Science direct Applied Thermal Engineering, Vol. 28 1798–1805*

2. *Antonio C Caputo and Pacifico M Pelagagge, (2008) "Heat Exchanger Design based on Economic Optimization", Journal of Science direct Applied Thermal Engineering, Vol. 28, 1151–1159*

3. *Standards of the tabular Exchanger Manufacturers Association (1999), Eighth Edition*

4. *Yunush A Cengel (2006), "Heat and Mass Transfer", 3rd edition, TATA McGraw HILL.*

5. *ABENER Project: Sikalbaha 225 MW ± 10% Combined Cycle (Dual Fuel) Power Plant Project data.*

6. *Jim Lang (2000), "Design Procedure for Heat Exchangers on Aspen Plus Software" Design Manual.*

7. *Aspen plus Simulator 10.0-1. User Interface (1998)*

8. *Ivan A Franson (1985), "Selection of Stainless Steel For Steam Surface Condenser Applications" Jt. ASME/IEEE Power Generation Conference, Milwaukee*

9. *HTRI design manual, Page D6.2.1 (Rev.1)*

10. *Rainer Greffrath (2002), "Effect of Scaling on Design and Operation of Thermal Seawater Desalination Plants".*

## Nomenclature

| Symbol | Meaning | Unit |
|---|---|---|
| A | Area | $m^2$ |
| k | Thermal conductivity | W/mK |
| Q | Heat exchange | kW |
| U | Overall Heat transfer coefficient | $W/m^2K$ |
| $F_f$ | Fouling factor | $m^2K/W$ |
| LMTD | Logarithmic Mean temperature difference | $^0C$ |
| IS | International Standards | - |
| HEI | Heat exchanger Institute | - |
| IBR | Indian boiler regulation | - |
| TEMA | Tabular exchanger manufactures Association | - |
| ASME | American Society for mechanical engineering | - |

 