# THE EFFECT OF TUBE DIAMETER AND NUMBER OF TUBES IN A CROSS FLOW STEAM CONDENSER ON PERFORMANCE

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**ABSTRACT**

Investigation of performance change of the heat transfer rate ($\dot{Q}$) when the tube diameter and the number of tubes are changed in a cross flow steam condenser is reported. A single pass horizontal tube condenser was studied by considering the convective heat transfer coefficients of inside and outside of the cross-flow tube bank and conductive heat transfer coefficient through the tube walls. A mathematical model was developed for simulations. The model was used to investigate the changes of efficiency by varying parameters: the number of longitudinal tubes (10 – 60) for three diameters (19 mm, 25 mm and 32 mm); The number of longitudinal tubes (10 – 60) while changing the number of transverse tubes (10, 20 and 30); The number of transverse tubes (5 – 55) for three diameters (19 mm, 25 mm and 32 mm). It was found that when the number of longitudinal tubes increases, $\dot{Q}$ increases and the rate of change of the $\dot{Q}$ decreases. It was also noticed that $\dot{Q}$ increases linearly when the number of transverse tubes increases while keeping the number of longitudinal tubes constant. It can be clearly observed that tube diameter does not have a significant effect on $\dot{Q}$ in both cases. It can be concluded that increasing the number of transverse tubes is more effective than increasing the number of longitudinal tubes.

**Keywords:** Heat Exchanger, Efficiency of Condenser, Cross Flow Steam Condenser, Effect of tubes in a condenser

## INTRODUCTION

Fresh water is one of the important substances for survival of human kind and fresh water resources are being depleted. Selective distillation is an efficient method of producing fresh water from polluted or sea water. Also, steam condensation is important step in steam power plants and other industries. Hence it is of a crucial importance to improve the efficiency of steam condensers. The shell and tube heat exchangers (STHE) are the most popular heat exchangers due to easiness of construction and maintenance at a low cost. There are three main types of STHE namely parallel flow, counter flow and cross flow (RAJPUT, 2003).

In parallel flow condensers both hot and cold fluids flow in the same direction and counter flow condensers fluids flow in opposite directions to each other. The cross flow condensers fluids flow perpendicular to each other. The main objective of this study is to mathematically model the heat exchange function of cross-flow shell and tube heat exchanger and identify the important parameters of the system in order to improve the efficiency.

## METHODOLOGY AND RESULTS

The modelling process was considered the steady state heat transfer rate from saturated steam (temperature - $T_{sat}$) to cooling water (temperature inlet - $T_{in}$ and temperature outlet - $T_o$). The intermediate layer temperatures were $T_x$ and $T_y$ as figure 1.

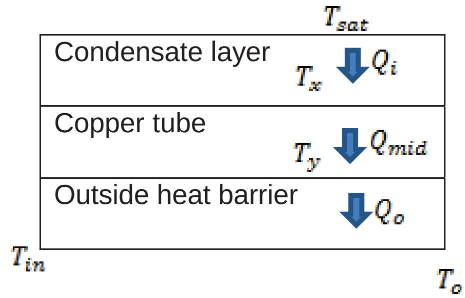


*Figure 1: Heat transfer through different layers with temperature differences*

Steady state heat transfer rate for each layer,

$$\dot{Q} = \dot{Q}_i = \dot{Q}_{mid} = \dot{Q}_o$$

For the heat transfer through the condensation layer,

$$\dot{Q}_i = h_i N \pi D_i L \left(T_{sat} - T_x\right) \qquad \text{(LI XU, et al., 2004)}$$

Where, $h_i$ is average heat transfer coefficient inside the tube [W/m$^2$K], N is total number of tubes in bank, $D_i$ is inner diameter of tube [m] and L is length of tubes [m].
For the heat transfer through the tube material,

$$\dot{Q}_{mid} = \frac{2\,\pi\,L\,k\,(T_y - T_x)}{\ln\left(D_o/D_i\right)} \qquad \text{(EASTOP \& MCCONKEY, 1993)}$$

Where, k is thermal conductivity of copper [W/m K] and $D_o$ is outer diameter of tube [m].

For the heat transfer through the outside heat barrier,

$$\dot{Q}_o = h_o (N \pi D_o L) \Delta T_{lm} \qquad \text{(KHAN, et al., 2006)}$$

$$\Delta T_{lm} = \frac{(T_y - T_{in}) - (T_y - T_o)}{\ln[(T_y - T_{in})/(T_y - T_o))]} \qquad \text{(KHAN, et al., 2006)}$$

Where, $h_o$ is average heat transfer coefficient outside the tube [W/m$^2$K].
The intermediate surface temperatures $T_x$ and $T_y$ are dependent on other variables. Above three equations for heat transfer rate, containing unknown parameters $\dot{Q}$, $T_x$ and $T_y$ for a given independent data set. Those equations with three unknown parameters could be used to find $\dot{Q}$.

The following equation was used to find the thermal conductivity for elevated temperatures (RAMIRES, et al., 1994)

$\lambda^* = -1.48445 + 4.12292(T^*) - 1.63866(T^*)^2$
where $T^* = T/298.15$ , $\lambda^* = \lambda(T)/\lambda(298.15)$
$\lambda$ is thermal conductivity of water, $T$ is temperature in Kelvin and $\lambda(298.15)$ = 0.6065 W/m K

All the parameters were considered within the practical ranges of values given in Table 1 to analyze an average sized heat exchanger.

*Table 2 : The paractical ranges of parameters*

| Parameter | Range |
|---|---|
| **Number of longitudinal tubes** | $10 \leq N_L \leq 60$ |
| **Number of transverse tubes** | $5 \leq N_T \leq 55$ |
| **Diameter of the tube (inch)** | $3/4" \leq \emptyset \leq 1\ \ 1/4"$ |
| **Ratio between longitudinal distance and outer diameter** | $1.1 \leq \frac{S_L}{D_O} \leq 3.5$ |
| **Ratio between transverse distance and outer diameter** | $1.1 \leq \frac{S_T}{D_O} \leq 3.5$ |
| **Input temperature ($^0$C)** | $0 \leq T_i \leq 100$ |
| **Velocity of the outflow of steam (m s$^{-1}$)** | $0.1 \leq V_{so} \leq 2$ |
| **Length of the tube (m)** | $0.1 \leq L \leq 10$ |
| **Flow rate of cold fluid (m$^3$/h)** | $1 \leq \dot{V} \leq 50$ |

The behaviour of heat transfer rate when the number of longitudinal tubes changes was analyzed for the tubes of diameters 19 mm, 25 mm and 32 mm, and plotted in Figure 2 for constant parameters of an inline arrangement of tube length of 2.5 m, 20 transverse tubes, input temperature of the cool water of 30 $^0$C, water flow rate of 3 m$^3$/h, tail velocity of steam 1.5 m/s, both transverse and longitudinal pitches as 2.

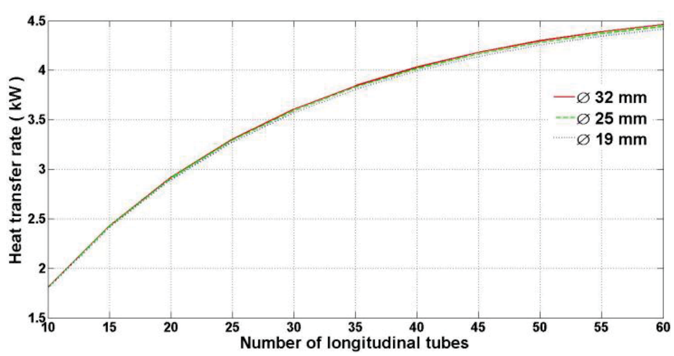


*Figure 2: Heat transfer rate vs. number of longitudinal tubes for different tube diameters*

The graph plotted Figure 3 was studying the behaviour of heat transfer rate with the number of longitudinal tubes for a 25 mm diameter by varying the number of transverse tubes ($N_T$). Other constant parameters are same in the previous study. The variation of heat transfer rate was drafted with the number of transverse tubes by changing the tube diameter in figure 4 for the same constant parameters used for the above studies.

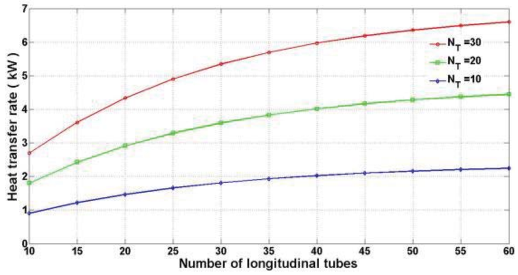


*Figure 3: Heat transfer rate vs. number of longitudinal tubes for different transverse*

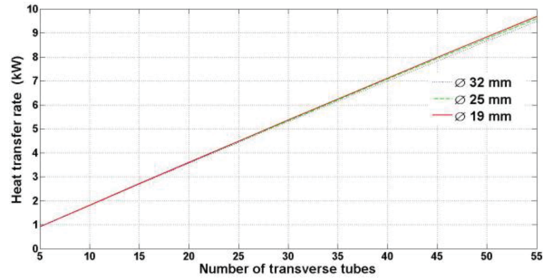


*Figure 4: Heat transfer rate vs. number of transverse tubes for different tube diameters*

## CONCLUSION

The rate of change of heat transfer rate is decreasing when the number of longitudinal tubes increases. It can be observed that heat transfer rate increases linearly, when the number of transverse tubes are increased while keeping the number of longitudinal tubes fixed. Moreover, those are evident that tube diameter does not affect significantly on the heat transfer rate. It can be concluded that increasing the number of transverse tubes is more effective than increasing the number of longitudinal tubes. The root cause of this result is due to increment of the temperature of cooling water by absorbing heat from the tubes in the initial rows.

### Acknowledgement

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### REFERENCES

EASTOP, T. & MCCONKEY, A., 1993. *Applied Thermodynamics for Engineering Technologists.* 5th Edition ed. s.l.:Pearson Education Ltd.

KHAN, W., CULHM, J. & YOVANOVICH, M., 2006. Convection heat transfer from tube bank in crossflow. *International journal of heat and mass transfer,* Volume 49, pp. 4831-4838.

LI XU, WANG., S., WANG., S. & WANG, Y., 2004. Studies on heat-transfer film coefficients inside a horizontal tube in falling film evaporators. *Desalination,* Volume 166, pp. 215-222.

RAJPUT, R., 2003. *Heat and mass transfer in SI units.* 2nd Edition ed. New Delhi: S Chand & Company Limited.

RAMIRES, M. et al., 1994. Standard referance data for the thermal conductivity of water.