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Optimization of a Shell and Tube Condenser using Numerical Method

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Abstract
The purpose of this study was to investigate the effect of installation of the tube external surfaces, their parameter and variable in a shell-and-tube condenser. Variation of heat transfer coefficient with each variable of shell and tube condenser was measured each test. The optimization tube outside diameter size was analyzed and use extended surface area attached tube with tube material and tube layout and arrangement (Number of tube a triangular or hexagonal arrangement) on shell-and tube condenser. The computer programming was used to get faster output in less time. Results suggest that mean heat transfer coefficient in variable condition were mainly at velocity is fixed. And also average additional surfaces and tube layout and the arrangement comparison with the quantity of the heat transfer.
Keyworld:- Tube outside surfaces, tube material, shell-and-tube condenser.etc

I. INTRODUCTION

Heat exchangers in which there is intermittent heat transform between the hot and cold fluids—via thermal energy or enthalpy accept and produce through the exchanger surface or matrix. Heat exchanger generally classified into two categories one is the regenerator and another is the recuperator. Common examples of heat exchangers are shell-and tube exchangers, automobile radiators, condensers, evaporators, air pre-heaters, and cooling towers. If no phase change occurs in any of the fluids in the exchanger, it is sometimes referred to as a sensible heat exchanger and another if their is phase change occurs in any fluid in the exchanger it is latent heat exchanger. There could be internal thermal energy sources in the exchangers, such as in electric heaters and nuclear fuel elements. Two important process are Combustion and chemical reaction may take place within the exchanger, such as in boilers, fired heaters, and fluidized-bed exchangers. Mechanical devices may be used in some exchangers such as in scraped surface exchangers, agitated vessels, and stirred tank reactors. Heat transfer in the separating wall of a recuperation generally takes place by conduction.[01] However, in a heat pipe heat exchanger, the heat pipe not only acts as a separating wall, but also facilitates the transfer of heat by condensation, evaporation, and conduction of the working fluid inside the heat pipe. In general, if the fluids are immiscible, the interface between the fluids replaces a heat transfer surface, as in a direct-contact heat exchanger. Not only are heat exchangers often used in the process, power Manufacturing industries, they also serve as key components of many industrial products available in the market place[2]. Two streams of fresh and return fluid have been connected with heat pipes heat exchanger to investigate the thermal performance and effectiveness of heat separating wall may be eliminated and the petroleum transportation, air conditioning refrigeration, cryogenic, heat recovery alternative fuel and fuel recovery system.[03]. The heat pipes for heat recovery equipment are aimed for recovering sensible heat and they are recommended for system in which inlet and return fluid should not be mixed such as chemical and biological industry

Q- The amount of heat flow(watt)
di - inner and inside diameter, m
do- outer and outside diameter, m
k- Thermal conductivity w/m k
ms - shell side fluid flow rate(Kg/m3)
hfg -latent heat of condensation.(KJ/Kg).
hi - inside heat transfer coefficient, w / m^2 k.
ho- outside heat transfer coefficient, w/ m^2 k
Rfi- internal fouling resistances, m^2 k/w
Um -Overall mean heat transfer coefficient, w/ m^2 k
U1- Outside heat transfer coefficient, w/ m^2 k
U2 - inside heat transfer coefficient ,w/ m^2 k
NTU-Number of transfer unit.
mh- hot fluid flow rate(kg/m3)
kl- thermal conductivity of liquid(w/mk)
ΔTlm -Log mean temp diff, k
ΔTc2 -Cold fluid outlet temp, k
d2- outside or outer side diameter, m
Ati- Tube inside or inner area, m^2

Cmin-((Mc*cpc))((Mh*cph))
Rt -Thermal resistances
tw -tube wall, m
mt- tube side fliud flow rate(Kg/m3)
Dm -Mean diameter, m
C1- tube layout constant
Re - Reynolds number
Pr -Predict number
Rfo -outside fouling Resis, m^2 k/w
Pt - Tube pitch
ΔTh - Steam temperature, k
f - friction factor.
mc- cold fliud flow rate (Kg/m3)
cp-specific heat(j/kg k)
ks-thermal cond of steam(w/mk)
Nt- Number of tubes.
ΔTc1-Cold fluid inlet temp, k
d1-tube extended surface diameter, m
Ato-Tube outside or outer area, m^2

According to literature shell and tube condenser concept generated from shell and tube heat exchanger and shell and tube condenser sre generated doublepipe and heat exchanger is generated from the mass transfer techniques. The history starts in (1960s) which, apart from being when the author started his heat-transfer career, is an important decade in the development of process heat transfer[08]. Shell and tube heat exchanger are build from of round tube mount in a cylindrical shell with the tube parallel to the shell. One fluid flow inside the tubes, while the other fluid across along the exchanger. shell and tube heat exchanger typically includes the number of tubes, tube length and diameter, tube layout, number of shell and tube passes, type of heat exchanger (fixed tube sheet, removable tube bundle etc), tube pitch number of baffles, its type and size, shell and tube side pressure drop etc.[05]

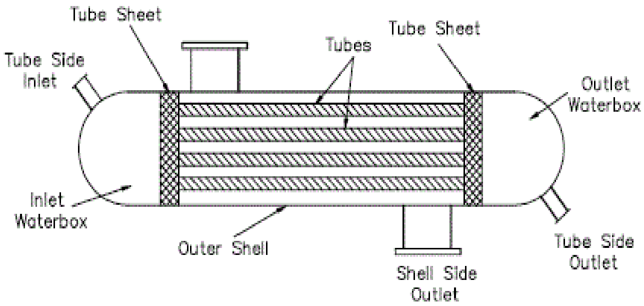


Fig 02 A horizontal type shell and tube heat exchanger

This paper reports the numerical investigation heat transfer from the convection from a add extended half circular surface to the mounted on the inner wall of the circular tube fig 02. Initially the investigation started from the matching circular surfaces over all heat transfer coefficient with add extended half circular surface tube surfaces with their comparatative study. Then numerical analysis has been performed to determine overall heat transfer coefficient with the tube wall, thermal conductivity of the tube material, and determine average heat transfer coefficient for add extended half circular surface by using numerical method. then investigation is carried forward by changing the tube layout tube arrangement, number of tube pass, and tube diameter.[04]

II. Design parameters and performance conditions:-

The optimization procedure for the design parameter are to be consider the number of tube ,tube material, number of the tube pass, the arrangement of the tube inner and outer diameter. Some limitation for the shell diameter should be selected less than 7m and tube length should be selected less than15m. As follows some performance condition are the.

Hot fluid temperature Th	318 K
Inlet cold fluid temperature Tc1	293K
Cold fluid mass flow rate Mc	10717.15 Kg/sec
Hot fluid mass flow rate Mh	218.15 Kg/sec

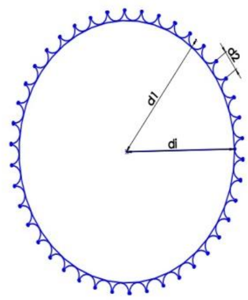


Fig 02. extended surface area added tube this tube used to replace simple tube.

For extended surfaces calculation
Πd1= (outside circumference)
Πd1= (number of half circle *circumferences)

$$\Pi d1=(42*\frac{\Pi d_2}{2})$$

for calculation heat duties of extended surface do is replaced by d1.

III. MATHEMATICAL MODELLING

The following specific case study selected for designing of new condenser.
The some following assumption of the condenser.

- ♣ Condensing flow is in the shell direction.
- ♣ Cooling fluid is considered in tube side.
- ♣ The shell pressure loss is negligible.

- The condenser changes the water state from saturated steam to liquid.[09]

The heat transfer between hot and cold fluid is calculated based of the following relation

Q=Um Ato Δ Tlm ………. (1)

where

Q- rate of heat flow (w)

Ato-Tube outside Heat transfer area (m^2)

Um-overall mean heat transfer coefficient (w/ m^2 k).

Δ Tlm is the logarithmic mean temperature difference.

Is defined as

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{Ln\frac{\Delta T_1}{\Delta T_2}}$$

ΔT1=Ts –Tt1

ΔT2=Ts –Tt2.

Here Um is the mean value of total heat transfer coefficient and

$$\text{Um}=\frac{U1+U2}{2} \text{ .... (2)}$$

Where U1, U2 are the total heat transfer at the inlet and outlet parts of the condenser.

$$U_M = \frac{1}{U_1}\frac{\Delta T_M - \Delta T_2}{\Delta T_1 - \Delta T_2} + \frac{1}{U_2}\frac{\Delta T_1 - \Delta T_M}{\Delta T_1 - \Delta T_2} \text{....(3)}$$

By assuming that both1/ U and ΔT change linearly with Q, a useful relation for determining the mean value of total heat transfer is obtained as follows:

$$\frac{1}{U_1} = Rt + \frac{1}{h_o} \text{ .... (4)}$$

$$\frac{1}{U_2} = Rt + \frac{1}{h_i} \text{ .... (5)}$$

Where Rt is the thermal resistances

$$R_t = R_{f0} + \left[\frac{1}{h_i} + R_{fi}\right]\frac{d_0}{d_i} + \frac{t_w}{K_W}\frac{d_0}{D_m} \text{....(6)}$$

Then Dm is cal a $D_m = \frac{d_0 - d_i}{\ln d_0 / d_i}$

And tube wall tw=Dm- di

Having known the tube number as well as the mass flow rate in the pipe, the velocity in the pipe will be determined as: $V = \frac{4M_t}{\rho \Pi d_i^2 N_t}$

$$R_e = \frac{4M_t}{\Pi d_i u N} \text{.......... ....(7)}$$

Having known the Re number, Nu number at the tube side

will be defined as a Re number function (Kakac and Liu, 2000[01]):

$$N_u = \frac{0.5 f(\text{Re} - 100)\Pr}{1 + 12.7(f/2)^{0.5}(\Pr^{2/3} - 1)}$$

if(2300<Re<10^4)..............(8a)

$$N_u = \frac{0.5 f \text{ Re Pr}}{1.07 + 12.7(f/2)^{0.5}(\Pr^{2/3} - 1)}$$ (if10000<Re<5*10^6).............(8b)

f=(1.58(Re)-3.2 $^{-2}$ ………(1.9)

Therefore, knowing the Nu number, the convection heat transfer coefficient is determined as

$$h_i = \frac{N_u k}{d_i} \text{ …………………(9)}$$

Heat transfer coefficient for the condensate flow (ho) is obtained based on the following relation (Kakac and Liu, 2000[01])

$$h_0 = 0.728\left(\frac{\rho_l^2 g h_{fg} k^3{}_0}{u_1 \Delta T_w d_0}\right)^{0.25} \frac{1}{n^{1/6}} \text{ .(10)}$$

Here, n is the tube number in a column which may be predicted for each tube arrangement as follows:

- for arrangement angle between two tube 45,90

$$\text{n}= \frac{\sqrt{4C1Pt^2 N/\Pi}}{Pt + do} \text{ ...(11)}$$

- For arrangement 30, 60

$$\text{n}= \frac{\sqrt{4C1Pt^2 N/\Pi}}{do + \sqrt{3}Pt} \text{ ......(12)}$$

Pt=Pr*do

where pr is the pitch ratio and Cl is tube layout constant that is equal to 1 for 45, 90 and is 0.87 for 30, 60(Dentice and Vanoli, 2004[11]).
The shell and tube condenser effectiveness is evaluated as follow (Kakac and Liu, 2000):

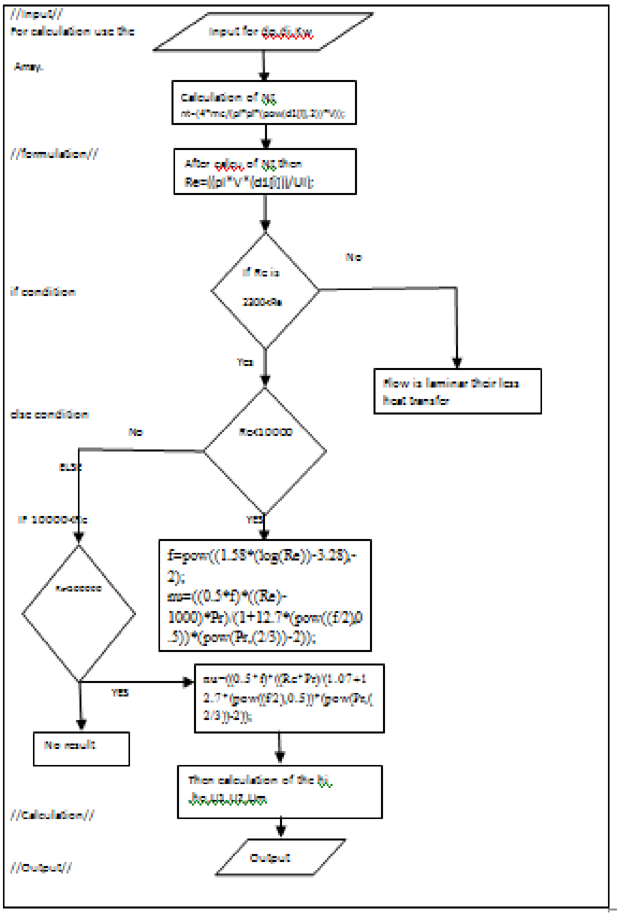
$$\varepsilon=1-e^{NTU} \quad ....(13)$$

NTU is the number of transfer unit.

NTU=Um Ato / Cmin.......(14)

IV. Numerical solution procedure

The finite volume model have been constructed using turbo (C++) programming and subsequent analysis have been done. The mathematical modelling equation solve by the programming by making the algorithm and the relationship. Once they analysed are completed, the resulting the data can be easilyevaluated and plot graph



V. Result and discussion

5.1 Matching With Analytical Solution

In this studies 5 parameter are considered to get output and each parameter compare with literature and that's new value change compare with the literature. For this optimization program 20 standard tube diameter used. In this graph the overall heat transfer coefficient compare with two parameter first is the simple tube that's (Um do) and another is extended surfaces Attachmate tube that's (Um d1). In this graph studies overall mean heat transfer coefficient increases with number of the tube. In this graph for extended surfaces overall heat transfer coefficient increases more in less tube as compare to the simple tube heat transfer coefficient. The number of the Tubes increase with cost of the shell and tube condenser is also increasing as show in fig 2.

Table 2 –The Range of change in design Parameters**.**

Variables	Lower range	Upper range
Tube Number	100	3000
Extended surfaces dia , m	0.105	0.600
Inner Tube diameter, m	0.059	0.490
Outer Tube diameter, m	0.070	0.392
Tube Arrangement	45^0	30^0
Thermal conductivity Kw (w/mk)	225 for aluminium	385 for copper

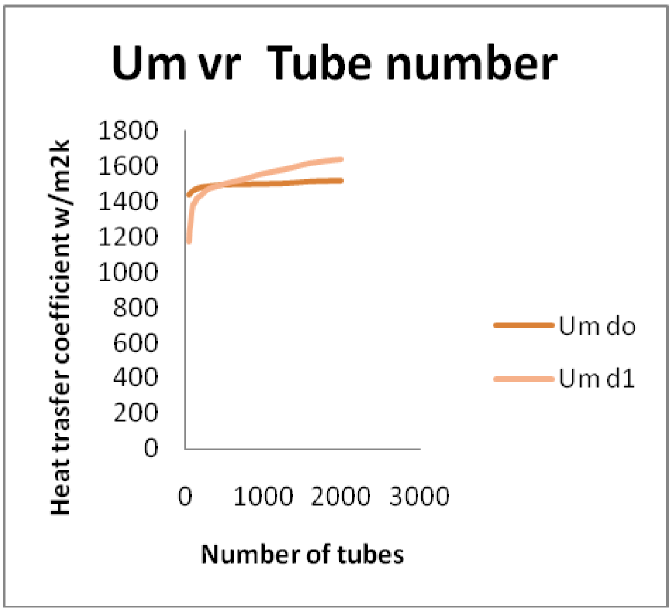


Fig 03. The variation mean heat transfer coefficient with tube number (Umdo) for simple tube and (Umd1) for extended surface tube

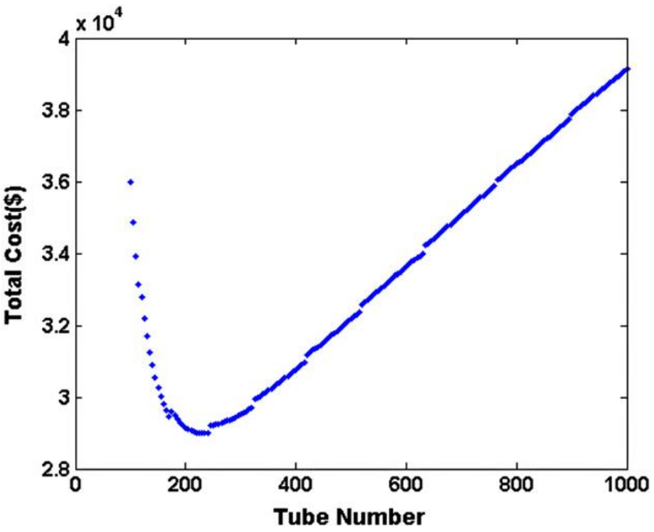


Fig 04.The variation Of mean total costs(₴) with tube number[09].

The next graph is comparison between the thermal conductivity of the material in mean heat transfer coefficient compare with the tube number. The heat transfer coefficient increasing with increasing number of the tube in the fig 05, first study the copper thermal conductivity is more. In this studies the number parameter varies with heat transfer coefficient such as tube diameter , number of the tube &their arrangement, Reynolds number and thermal conductivity of the material.

As we studies overall heat transfer coefficient increases with the no of tube increasing. In this graph studies overall than aluminium that's result showing the heat transfer coefficient for copper is more and due to thermal conductivity is high as compare to the aluminium. heat transfer coefficient decreasing with increasing the tube diameter. The (Um do) is simple tube diameter and the (UM d1) is the extended surfaces attached tube fig 06 ,the extended surfaces tube has mean heat transfer coefficient decreasing with increasing tube diameter has result than simple tube.

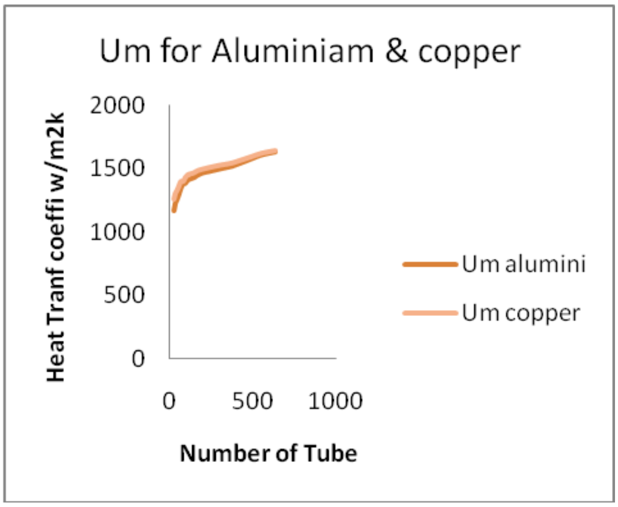


Fig 05 variation of mean heat transfer coefficient With number of tube for (Kw) aluminium and copper

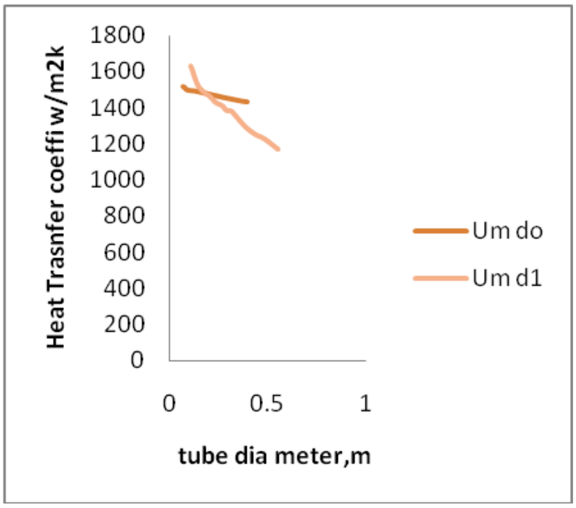


Fig 06 variation of mean heat transfer coefficient with outside diameter. (Umdo)for simple tube (Umd1) for Extendedtube.

After comparison of the heat transfer coefficient with tube number and tube diameter, then next the comparison tube arrangement is the triangular surfaces and the hexagonal surfaces. In the studies of the tube arrangement triangular arrangement is giving more output than hexagonal surfaces fig 07 is ploted as simple tube that's doesn't has extended tube surfaces and fig 08 is ploted for for extended surfacese area attachated tube

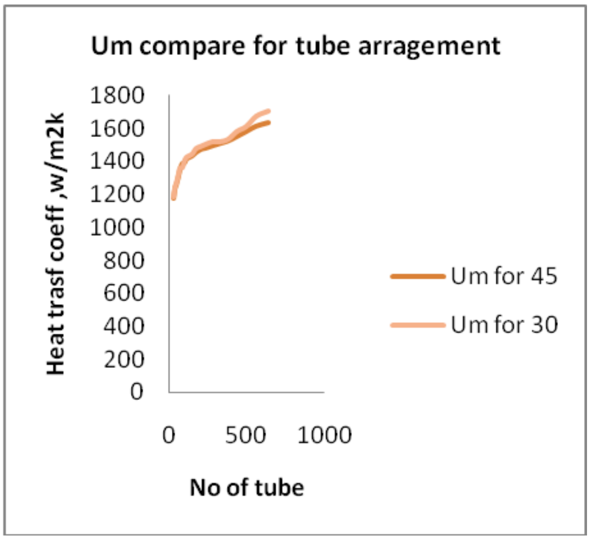


Fig 07 varaition of mean heat transfer Tube number for tube arrangement triangular And hexagonal for simple tube.

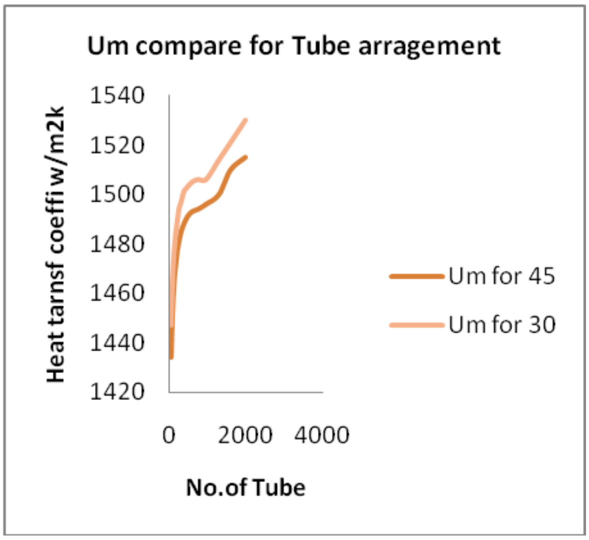


Fig 8 Varation of mean heat transfer coefficent with tube number for tube arrangement Triangular and hexagonal for extended extented Tube.

VI. Conclusion

In this studies the optimization of the shell and tube condenser using numerical method. The output value of the mean heat transfer coefficient is increased as tube extended surfaces compare with the simple tube with the reducing the Number of tube. The number of tube decreasing with cost of the shell and tube condenser decreasing and also quantity of heat transfer is increasing as discussed. The study of the tube external surfaces is attached some half arc outside tube that increasing tube inside diameter and thermal resistances. And the in the arrangement of the tube triangular arrangement is better than other.

One disadvantage of this technique is due tube outside attached outer circle that's at condensation their influences of liquid collect and that will increase the fouling, for avoid increasing the fouling the shell and tube condenser always take inclined or the used vertical condenser.

The numerical method is used to point to point variation as the quantities of the heat transfer

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