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Determination of Length of a Triple Concentric Tube Heat Exchanger, Fabrication and Experimental Investigation on Double Tube Heat Exchanger

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Abstract: **-- A triple concentric tube heat exchanger when compared to a double tube heat exchanger has improved heat transfer characteristics. The third tube increases the effective area through which heat is transferred. A detailed MATLAB code for the determination of length of a triple concentric tube heat exchanger has been developed. The governing equations are solved using spatial discretization technique. The code can be used to design a triple concentric tube heat exchanger for different mass flow rates and temperature conditions. ANSYS FLUENT analysis has also been carried out for 3m long triple concentric tube heat exchanger. The triple tube heat exchanger is fabricated for experimental analysis**

Keywords: Triple tube, Double tube, Heat exchanger, Experimental analysis

NOMENCLATURE

Abbreviation	
DTHX	Double Tube Heat Exchanger
TTHX	Triple Tube Heat Exchanger
List of symbols	
d	Diameter of pipe, m
h	Convective heat transfer coefficient, W/m²K
k	Thermal conductivity, W/mK
L	Length of heat exchanger, m
$\dot{m}$	Mass flow rate, kg/s
Nu	Nusselt number
P	Perimeter, m
Pr	Prandtl number
T	Temperature of fluid, °C
U	Overall heat transfer coefficient, W/m²K
Subscripts	
c	Cold fluid
h	Hot fluid
i	Inlet
o	Outlet
1	Inner pipe
2	Middle pipe
3	Outer pipe

I. INTRODUCTION

Studies relating to compact heat exchangers have been gaining momentum since last few years. Researchers are looking for effective methods to miniaturize heat exchangers without affecting the productivity. Many improved heat exchanger designs were able to bring down the size of heat exchangers but they proved less cost effective. Double tube heat exchangers (DTHX) are being used in different industries like pharmaceutical, food, beverage and dairy. Double tube heat exchangers can be modified to improve the productivity per unit time. Addition of a third tube over the existing two provides a larger heat transfer area per unit length. This new version of concentric heat exchanger can be called Triple concentric Tube Heat Exchanger (TTHX).

Ünal[1] developed set of differential equations for fluid temperatures. Ünal[2] using computer program conducted the study on the effect of diameter on the performance of the heat exchanger. Ünal[3] developed the effectiveness-NTU relationships for a triple concentric heat exchanger.

Quadric et al.[4] conducted experimental investigation on the performance of the exchanger. But the experiment was limited to co-current flow and one volume flow rate. Quadric et al.[5] also analyzed the performance numerically using finite element method under steady state conditions.

The present study is performed to simplify the design of a TTHX and quickly evaluate the length and effect of mass flow rate on the length of heat exchanger.

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II. MODELLING METHODOLOGY

The analysis is done for the cooling of a hot fluid to a lower temperature. The cold fluids are taken in the inner pipe and outer annulus and hot fluid in the middle annulus. Counter flow system is being analysed in the current study. The cold fluid enters the inner pipe and outer annulus at Tc1,i and Tc2,i respectively and leaves at Tc1,o and Tc2,o in the inner pipe and outer annulus respectively. Hot fluid enters the middle annulus at Th,i and leaves at Th,o

By applying energy balance between different fluids, the following equations are obtained:

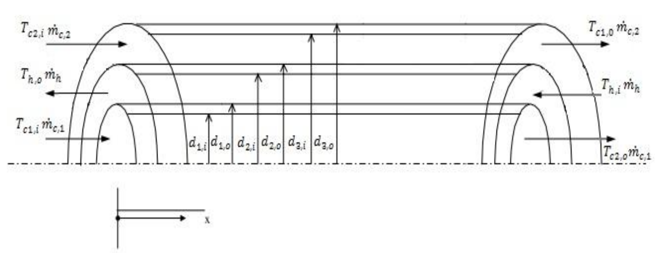

Fig. 1: Schematic of TTHX

By applying energy balance between different fluids, the following equations are obtained:

$$\left(\dot{m}_h c_{p,h}\right)\frac{dT_h}{dx} = U_1P_1(T_h - T_{c1}) + U_2P_2(T_h - T_{c2}) \qquad (1)$$

$$\left(\dot{m}_{c1} c_{p,c1}\right)\frac{dT_{c1}}{dx} = U_1P_1(T_h - T_{c1}) \qquad (2)$$

$$\left(\dot{m}_{c2} c_{p,c2}\right)\frac{dT_{c2}}{dx} = U_2P_2(T_h - T_{c2}) \qquad (3)$$

To determine U_1 and U_2:

$$U_1 = \frac{1}{\frac{d_{1,o}}{h_1 d_{1,i}} + \frac{\ln\left(\frac{d_{1,o}}{d_{1,i}}\right)}{2k} \times d_{1,o} + \frac{1}{h_2}} \qquad (4)$$

$$U_2 = \frac{1}{\frac{d_{2,i}}{h_3 d_{2,o}} + \frac{\ln\left(\frac{d_{2,o}}{d_{2,i}}\right)}{2k} \times d_{2,i} + \frac{1}{h_2}} \qquad (5)$$

where U_1 is defined for inner cold fluid and hot fluid and U_2 is defined for hot fluid and outer cold fluid.

h_1, h_2 and h_3 are convective heat transfer coefficients of inner, middle and outer fluid respectively and it can be determined by:

$$h = Nu \times \frac{k}{D_h} \qquad (6)$$

Where, D_H is the hydraulic diameter and defined as:

D_h = $d_{1,i}$ for inner fluid
D_h = $d_{2,i} - d_{1,o}$ for outer fluid
D_h = $d_{3,i} - d_{2,o}$ for outer fluid

The Nusselt number can be determined by

$Nu = 0.0023Re^{0.8}Pr^n$ (7)

For Re ≥10,000, 0.7 ≤ Pr ≤ 160 and n=0.4 for heating and n=0.3 for cooling.

For $3x10^3 < Re < 5x10^6$, $0.5 \leq Pr \leq 2000$, modified equation by Gnielinski is used:

$$Nu = \frac{\left(\frac{f}{8}\right)(Re - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr^{\frac{2}{3}} - 1\right)} \qquad (8)$$

Where, $f = (0.79lnRe - 1.64)^{-2}$

Kays and Perkins formulation can be used fully developed laminar flow in an annulus.

III. DESIGN PROBLEM

The TTHX is designed for cooling hot water from 80°C to 50°C. A temperature drop of 30°C is to be achieved with the prescribed boundary conditions. The hot water flow rate is fixed to be 0.2kg/s, for cooling normal water at room temperature (say 25°C) is to be used. The diameters of the pipes to be used are 1", 2" and 3". The length of the TTHX is to be determined and performance is to be compared with that of a DTHX.

Table 1: Effect on temperature and mass flow rate on length

$T_{h,i}$ (°C)	$T_{h,o}$ (°C)	$\dot{m}_h$(kg/s)	$T_{c1,i}$ (°C)	$T_{c2,i}$ (°C)	$\dot{m}_{c,1}$(kg/s)	$\dot{m}_{c,2}$(kg/s)	L(m)
80	50	0.2	30	30	0.4	0.4	2.575
					0.4	0.5	2.426
					0.5	0.4	2.480
			30	25	0.4	0.4	2.360
					0.4	0.5	2.217
					0.5	0.4	2.280
			25	25	0.4	0.4	2.239
					0.4	0.5	2.111
					0.5	0.4	2.157
			25	30	0.4	0.4	2.430
					0.4	0.5	2.298
					0.5	0.4	2.333

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IV. MATLAB RESULTS

A MATLAB code has been developed to determine the length. The governing equations were solved using spatial discretization technique. The code can be modified for other diameters and also flow rates.

Counter flow is selected for effective heat transfer. The analysis is also extended beyond the problem for other flow rates and temperature conditions also. The same experimental setup can be used for testing the TTHX with other flow rates and also with other temperature fluids. For the simplicity to maintain the cold water, flow rate of both the streams are fixed at 0.4kg/s. The effect of mass flow rates and temperature of the cold fluid is detailed in Table 1.

For $T_{h,i} = 80°C, T_{h,0} = 50°C, T_{c1,i} = T_{c2,i} = 25°C$, $\dot{m}_h = 0.2$ kg/s , $\dot{m}_{c1}$= 0.4 kg/s, $\dot{m}_{c2}$= 0.4 kg/s, the length is found to be 2.239 m.

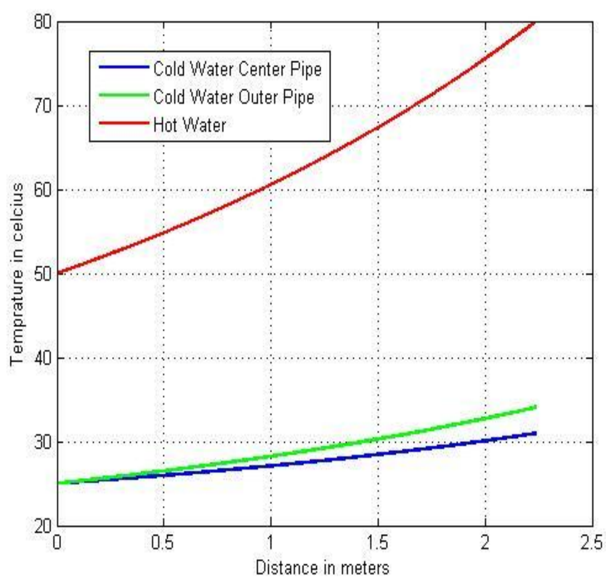

Fig. 2: Variation of temperatures along the length of TTHX for $T_{h,i} = 80°C, T_{h,0} = 50°C, T_{c1,i} = T_{c2,i} = 25°C$, $\dot{m}_h = 0.2$ kg/s , $\dot{m}_{c1}$= 0.4 kg/s, $\dot{m}_{c2}$= 0.4 kg/s

V. ANSYS FLUENT RESULS

To determine the temperature characteristics of all the three fluids, a TTHX is developed in ANSYS Fluent and same temperature and flow boundary conditions are employed as in MATLAB code. The TTHX is treated using k-ε RNG (renormalization group) turbulence model.

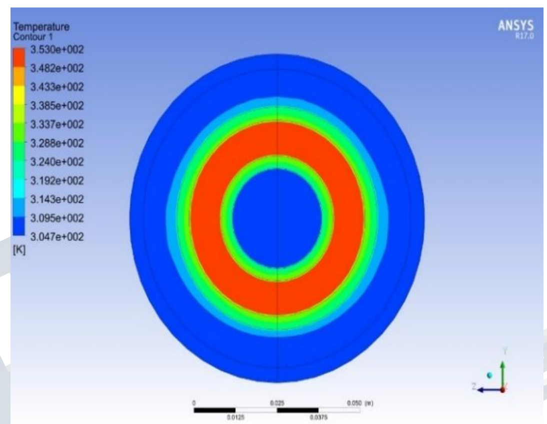

Fig 3: Temperature contour showing the hot fluid inlet and cold fluid exit

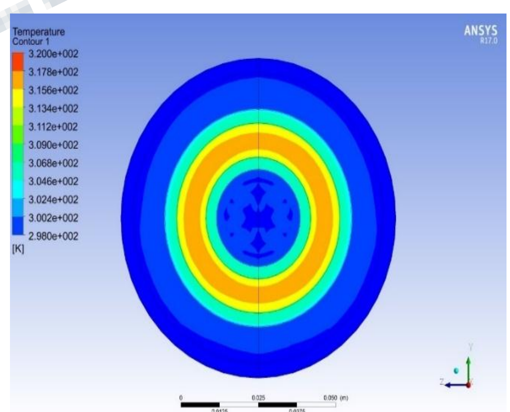

Fig 4: Temperature contour showing the hot fluid outlet and cold fluid inlet

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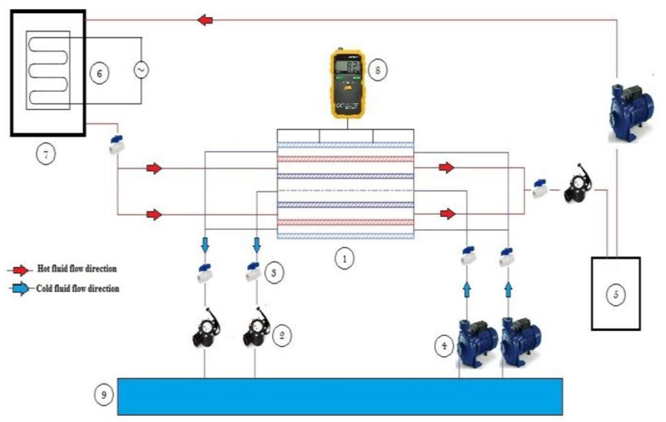

1- TTHX, 2-Flow sensor, 3-Control valve, 4-Centrifugal pump, 5-Collection tank, 6-Heating coil, 7-Tank for heating water 8-Temperature Display, 9-Cold water sump

Fig 5: Experimental setup

The area average temperature for both the hot fluid and the cold fluid are found at the respective outlets. The hot fluid was cooled to 44°C. While the temperature of the cold fluid in the inner tube increased to 31°C and outer tube increased to 34°C. The length of the TTHX for which the analysis was conducted is 3 m and the inlet temperature of the hot fluid and cold fluid are 80°C and 25°C respectively. Fig 3 and Fig 4 shows the inlet and outlet temperature contours it can be observed that the outer cold fluid absorbs more heat because of the larger heat transfer area available when compared with inner cold fluid.

VI. EXPERIMENTAL ANALYSIS

For the experimental analysis, GI pipes of 3 different diameters were used. The diameters of the pipes chosen for the fabrication of the TTHX are as follows:

Nominal Diameter	Inside Diameter	Outside Diameter
D = 1”	$d_{1,i} = 0.0273m$	$d_{1,o} = 0.0338m$
D = 2”	$d_{2,i} = 0.0530m$	$d_{2,o} = 0.0603m$
D = 3”	$d_{3,i} = 0.0808m$	$d_{3,o} = 0.0889m$

For measuring temperature, 12 K type thermocouples, 4 in each pipe were installed along the length of the TTHX. The TTHX was insulated using asbestos rope and plaster of paris coating. The flow rates are maintained using flow sensor and ball valves. The cooled hot water is recirculated from a collection tank. The temperature in the heating tank is maintained using a thermostat.

Experimental analysis was conducted for DTHX, on the same experimental test rig without passing water through the outermost tube. The hot fluid flow rates were kept constant and the cold fluid flow rates were varied for the experiment on DTHX. This is done to compare the values obtained with that of TTHX.

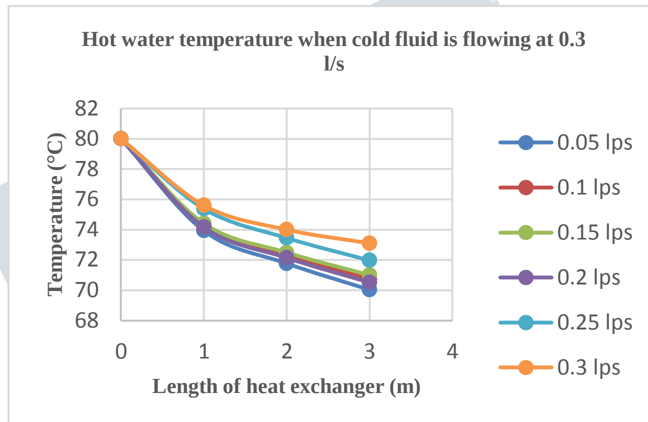

Fig 6: Variation of temperature along the length of DTHX when cold fluid is flowing at 0.3 lps

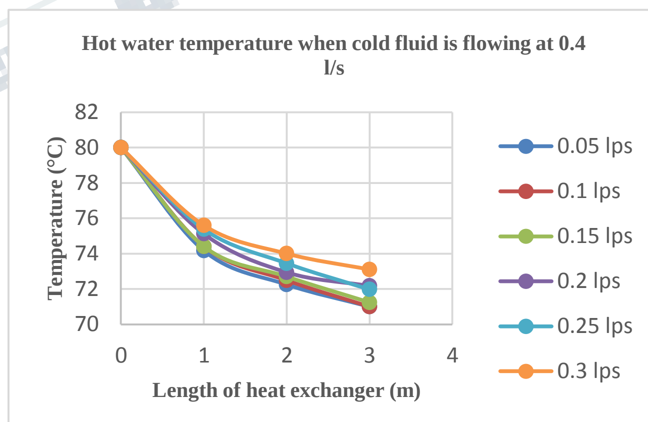

Fig 7: Variation of temperature along the length of DTHX when cold fluid is flowing at 0.3 lps

VII. CONCLUSIONS

The assumptions in the governing equations are the reason for the deviation in the results of the ANSYS FLUENT analysis and MATLAB results. ANSYS FLUENT analysis shows a temperature drop of 36 ºC for 3 m length of TTHX.

The experimental analysis on DTHX showed a maximum of 9.97 ºC temperature drop. The experiment has showed that higher temperature drop is obtained when the cold water is flowing at 0.3 l/s rather than 0.4 l/s. It is also noted that temperature drop is maximum when the hot water is flowing at a lower flow rate.

REFERENCES

1. Ahmet Ünal, "Theoretical analysis of triple concentric - tube heat exchangers: mathematical modelling", Int. Comm. Heat Mass Transfer, Vol. 25, No. 7, 1998
2. Ahmet Ünal, "Theoretical analysis of triple concentric - tube heat exchangers: case studies", Int. Comm. Heat Mass Transfer, Vol. 28, No. 2, 2001
3. Ahmet Ünal, "Effectiveness NTU Relations For Triple Concentric Tube Heat Exchangers", Int. Comm. Heat Mass Transfer, Vol. 30, No. 2, 2003.
4. Quadir, G.A. Jarallah, S.S, et al., "Experimental Investigation Of The Performance Of A Triple Concentric Pipe Heat Exchanger", International Journal of Heat and Mass Transfer, Vol. 62, 2013
5. Quadir, G.A. Jarallah, S.S, et al., "Numerical Investigation Of The Performance Of A Triple Concentric Pipe Heat Exchanger", International Journal of Heat and Mass Transfer, Vol. 75, 2014