EXPERIMENTAL AND THEORETICAL ANALYSIS OF TRIPLE CONCENTRIC TUBE HEAT EXCHANGER

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ABSTRACT

The experimental study deals with advancements in double tube heat exchanger (DTHE). An intermediate tube is added in DTHE for better performance, known as Triple Concentric Tube Heat Exchanger (TCTHE). The Design of TCTHE consists of three concentric tubes of diameter 38.1 mm, 25.4 mm, 12.7 mm and length of tubes are 1098 mm, 1148 mm and 1198 mm from outer to inner respectively. Thickness of tubes are 2.0 mm, 1.5 mm1.0 mm respectively. Out of the three tubes, inner two tubes are of copper and outermost tube is of cast iron. The Objective of this experimental study is to increase heat flow rate and overall heat transfer coefficient. Use of TCTHE also gives instant cooling.

Keywords- *Heat exchanger, Triple concentric tube, Double tube, Overall heat transfer coefficients.*

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1. INTRODUCTION:

Heat exchanger is a heat transferring device. In Heat exchanger heat is transferred in between two fluids. There are two methods of heat transfer. In direct method, both fluids are in direct contact. While in indirect method, there is no any contact between fluids. In concentric tube heat exchanger, fluid flows through concentric tubes in same direction (Parallel flow) or in opposite direction (Counter flow). In the TCTHE, there are three sections**:** central tube, inner annular space and outer annular space. Heat transfer mediums are passed through the central tube and outer annular space and a thermal fluid is passed through an inner annular space. In DTHE there are two sections, outer and inner tubes.

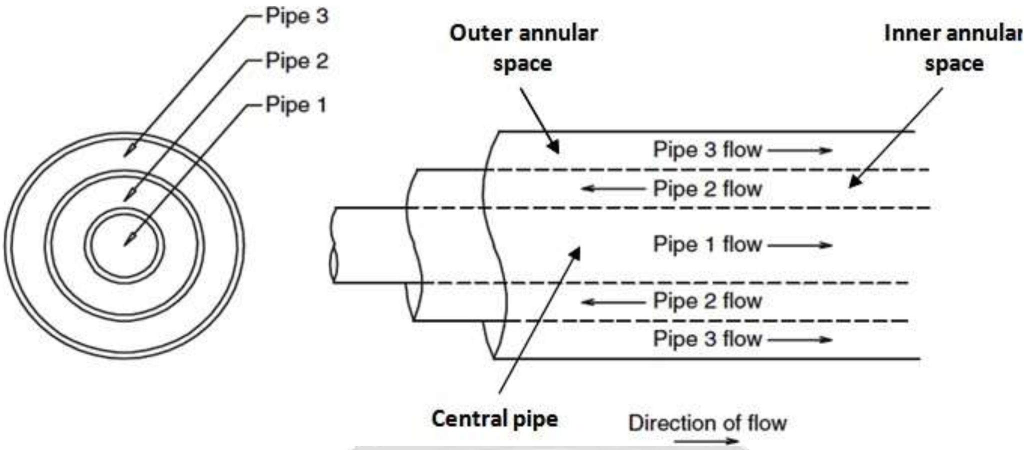

Figure 1. schematic diagram of TCTHE

2. LITERATURE REVIEW:

S Radulescu established an algorithm for the calculation of partial coefficient of heat transfer for a fluid which flows through an inner annular space of a triple concentric-tube heat exchanger in transition regime based on experimental results. He developed a new correlation for design purposes on heat transfer devices, such as triple concentric pipe heat exchanger. The correlation obtained is:

$$Nu_h=2.718*Re_h^{0.597}*Pr_h^{1/3}*(d_{h2}/L_1)^{2/3}$$

It molds the heat exchange for Reynolds values that go from 2264 to 7893 and for the velocities values between 0.11 and 0.36 m/s. The practical applicability of the obtained correlation in the study applies for Prandtl values between 3.30 and 3.70.

O. García-Valladares developed a numerical model for analyzing the behavior of triple concentric tube heat exchangers by means of a transient one-dimensional analysis of the fluid flow governing equations and the heat conduction in solids. He concluded that, the model developed can be an excellent tool to optimize the efficiency of triple concentric-tube heat exchangers, and consequently the energy consumption.

Ahmet Unal in his second part conducted several case studies for counter-flow arrangement in his second part based on the solution obtained in the first part. It has been demonstrated that demonstrates that: 1) the relative sizes of the tubes (the tube radii) play a very important role on the exchanger performance and/or on the exchanger length. 2) Optimizing triple tube heat exchanger effectiveness provides a considerable amount of increase in the exchanger performance.

D. P. Sekulic et al. offered in detail a review on thermal design theory of three fluid heat exchanger, where they have allowed for third fluid temperature to vary according to main thermal communication while neglecting interaction with ambient. He used effectiveness- NTU (number of heat transfer units) approach and corresponding rating and sizing problems for the determination of the effectiveness or NTU for a three-fluid heat exchanger

3.PROBLEM STATEMENT:

To increase the heat flow rate and overall heat transfer coefficient in DTHE.

4. OBJECTIVE:

- To reduce effective cooling time.
- Increase overall heat transfer coefficient
- Increase heat flow rate.

5. EXPERIMENTAL SETUP:

TCTHE experimental model contains outer tube of Cast Iron (Diameter = 38.1mm), intermediate tube of copper (Diameter=25.4mm), inner tube of copper (Diameter=12.7mm). Assume effective length of all three pipes is same and is equal to 1098mm. Thickness of tubes are 2.0mm, 1.5mm and 1.0mm respectively. Digital thermometer used for measuring temperature. 1000 w heater is used for rise the temperature of water in order to prepare the process water. Three control valves were used at inlet of three heat exchanger tubes. So that flow rate through the different tubes can be easily controlled.

Figure 2. EXPERIMENTAL SET UP

6. METHODOLOGY:

- Make an experimental setup of heat exchanger as shown in figure.
- Perform experiment and take readings.
- Calculate heat transfer rate and overall heat transfer coefficient for 'Double Tube Heat Exchanger'.
- Calculate same for 'Triple Concentric Tube Heat Exchanger'.
- Compare results.

7. CALCULATION:

7.1 Calculation for DTHE:

- **Mass flow rate in inner tube of DTHE:**

$m=(\rho * v) / t$

For TCTHE tube,

$m_H=(989.8*150*10^{-3}) / t = 0.4124$

t=3600 sec.

V_H is increases in DCTHE due to increases in cross-sectional area of inner tube.

Volume flow rate is,

V_H=v/t

150*1*3600=v=150 lit.

$V=150*10^{-3}\ m^3$

Same for inner tube of TCTHE,

$m_{c1}=(\rho*v)/t$

$V_{c1}=100*10^{-3}$

Total volume flow rate ,

$V_H=150*10^{-3}+100*10^{-3}$

$V_H=250*10^{-3}\ m^3$

$m_{c1(DTHE)}=(996.3*.0025)/3600$

$m_{c1(DTHE)}$=0.06918 kg/s.

7.2 inner tube heat transfer coefficient(α_c):-

1. Bulk mean temp.:

$T_b=(T_{Hi}-T_{He})/2$
T_b=319K

2. Linear Velocity of Hot Water:

$W_H=(m_H*4)/\rho_H*\pi*(d_{in2}^2-d_{out1}^2)$

$=(0.06918*4)/989.8*\pi(0.036)^2$
=0.1316m/s.

To obtain Reynolds number of hot water ,

Hydraulic diameter is,

d_h=0.026m.

Reynolds number for hot water is ,

$R_{eH}=(\rho_H*w_H*d_{h2})/\mu_H$

$=(989.8*0.1316*0.026)/5.859*10^{-4}$

=5780.33

Then in the inner tube there is **turbulent flow.**

The following correlation is used for calculation of Nusselt number for hot water circulated through the inner tube.

$N_{uH}=2.718*R_{eH}^{0.597}*P_{rH}^{1/3}(d_{h2}/1.193)^{2/3}$

$=2.718*5780.33^{0.597}*3.916^{1/3}(0.026/1.193)^{2/3}$

$= 58.93$

Now, convective heat transfer in inner tube is,

$\boldsymbol{\alpha_H = N_{uH} * k_H / d_{h1}}$

$=58.93*0.6257/0.026$

$=1418.17\ w/m^2k$

And we have, heat transfer coefficient for outer tube is,

$\boldsymbol{\alpha_c = 1144 w/m^2 k.}$

Overall heat transfer coefficient for DTHE:

$\boldsymbol{(1/U_0)=(1/\alpha_H)+d_{in2}*\ln(d_{out2}/d_{in2})/2k_{copper}+(d_{in2}/d_{out2}*\alpha_{c1})}$

$U_o=681.5\ _{w/m}{}^2K$

Now, LMTD, for parallel flow,

$\Delta T_{lm}=(50-42)-(36.9-25)/\ln(8/36.9-25)$

$=12.51^o c$

For counter flow,

$\Delta T_{lm}=(50-36.9)-(42-25)/\ln(50-36.9/42-25)$

$=14.96^o c$

Now,

$\boldsymbol{Q=U_o*A*\Delta T_{lm}}$

$=681.5*0.09641*14.96$

$=982.92W$

7.3 Calculation for TCTHE:

In the present work, at first a TCTHE is designed by LMTD method by considering a known set of input values as a given table.

The step-by step design procedure as follows:

For steady state energy balance equation:

$Q\ H = Q\ c1 + Q\ c2$

Bulk mean temperature of water is determined by:

$$T_{b1} = \frac{Tc1i + Tc2e}{2}$$

$$T_{b2} = \frac{T_{Hi} + T_{He}}{2}$$

$$T_{b3} = \frac{T_{c2i} + T_{c2e}}{2}$$

Properties of hot and cold water corresponding to bulk mean temperature that are used for design calculation given in table

Input Parameter	Values
Hot water inlet temperature, T_{Hi}	60^oC
Hot water outlet temperature, T_{He}	43^o C
Cold water C1 inlet temperature, T_{c1i}	25^o C
Cold water C2 inlet temperature, T_{c2i}	25^o C
Mass flow rate of cold water, m_{c1}&m_{c2}	0.0278lit./sec
Mass flow rate of hot water, m_H	0.0417lit./sec
Diameter of central tube, d_{in1}	11mm
Diameter of intermediate tube, d_{in2}	23.5mm
Diameter of outer tube, d_{in3}	38.7mm
Specific heat of hot water, C_{ph}	4182J/kg K
Thermal conductivity of copper, K_{copper}	401W/m

Table 1: Known input parameters for sizing calculation

Properties	At31.35^{o}c	At 51.5^{0}c
Dencity,ρ(kg/m^3)	995.04	987.34
Thermal conductivity,k(W/m.k)	0.622	0.646
Specific heat ,C_p(J/kg.K)	4174.8	4176.35
Viscocity,μ (Pa.s)	$7.8*10^{-4}$	$5.39*10^{-4}$
Prandtl number,Pr	5.23	3.48

1. Calculate Exit temperature for cold tube:-

$\mathbf{Q_H=Q_{ci} +Q_{c2}}$

$\mathbf{m_H\ C_{pH}(T_{h1}-T_{he})=m_{c1}C_{ph}(T_{ele}-T_{cli})+m_{c2}C_{pc2}(T_{c2e}-T_{c2i})}$

$T_{c1e}=T_{c2}=30.9\ ^0c$

2. Inner tube heat transfer coefficient:

$$\boldsymbol{\alpha_{c1}=N_{uc1}k_{c1}\ /d_{in1}}$$

Calculate physical properties of water at bulk temp

Properties		Values
Density, Kg/m^3		996.3
Thermal conductivity		0.5997
Specific heat		4183

viscosity		8.33×10^{-4}
Prandlt number		5.813

,

$T_{b1}=(T_{ci}+T_{c1e})$ /2

T_{b1}=301.1k

Linear velocity:-

$W_{c1}=(m_{c1}*4)/\rho_{c1}\pi*d_{in1}^{2}$
W_{c1}=0.246 m/s

Reynolds number ,
$R_{ec1}=(\rho_{c1}*W_{c1}*d_{in1})/(\mu_{c1})$
R_{ec1}=3530 ....(Transition regime)

Nusselt Number:- (Gnieliski correlation)
$N_{uc1}=[(f/2)(R_{ec1}-1000)P_{rc1}]/[1+12.7\,(f/2)^{1/2}(P_{rc1}^{2/3}-1)]$
$f=[1.58\ln(R_{ec1})-3.28]^{-2}$
N_{uc1}=26.31

$\acute{\alpha}_{c1}=(N_{uc1}*k_{c1})/d_{in1}$
$\acute{\alpha}_{c1}$=1315 w/m^{2}k

3. Inner Annulus heat transfer coefficient :-

Bulk Mean Temp.:
$T_{bH}=(T_{Hi}+T_{He})/2$
T_{bH}=319.2 k

Follows thermo physical properties:

Properties		Values
Density, Kg/m^{3}		989.8
Thermal conductivity		0.6257
Specific heat		4182
viscosity		5.859×10^{-4}
Prandlt number		3.916

Linear Velocity:
$W_{H}=(m_{H}*4)/\rho_{H}*\pi*(d_{in2}^{2}-d_{out1}^{2})$
W_{H}=0.1105 m/s.

Hydraulic diameter:
$d_{h2}=d_{in2}-d_{out1}$
d_{h2}=0.012 m.

Reynolds number:
$R_{eH}=(\rho_{H}*W_{H}*d_{h2})/\mu_{H}$
R_{eH}=2241 (Transition Regime)

Nusselt number:-

$N_{uH}=2.718*R_{eH}^{0.597}P_{rH}^{1/3}(d_{in2}/1.193)^{2/3}$

$N_{uH}=19.97$

Convective heat transfer coefficient:

$\alpha_H=(N_{uH}-k_H)/d_{h1}$

$\alpha_H=1041$ w/m^{2}k

4. Outer annulus heat transfer coefficient:-

$T_{b3}=301.1$ k

Linear Velocity:

$W_{c2}=(m_{c2}*4)/\rho_{c2}*\pi*(d_{in3}^3-d_{out1}^2)$

Hydraulic diameter:

$d_{h3}=d_{in3}-d_{out2}$

$d_{h3}=0.012$ m

Reynolds number:

$R_{ec2}=(\rho_{c2}*W_{c2}*d_{h2})/\mu_{c2}$

$R_{ec2}=622.9$ .... (Laminar Flow)

Nusselt Number:

$N_{uc2}=0.51*R_{ec2}^{0.5}P_{rc2}^{1/3}(P_{rc2}/P_{rw2})^{0.25}$

$N_{uc2}=22.28$

Convective heat transfer coefficient:

$\alpha_{c2}=(N_{uc2}*k_{c2})/d_{h2}$

$\alpha_{c2}=1144$ w/m^{2}k

5 .Overall heat transfer coefficient:-

Overall HTC of inner tube and intermediate hot tube

$(1/U_{o1})=[(d_{out1}/d_{in1}\,\alpha c1)+\{d_{out1}\ln(d_{out1}/d_{in1})/2k_{copper}\}+(1/\alpha_H)]$

$U_{o1}=540.4$ w/m^{2}k

Overall HTC of outer and intermediate hot tube

$U_{i2}=[(1/\alpha_H)+\{d_{in2}\ln(d_{out2}/d_{in2})/2k_{copper}\}+(d_{in2}/d_{out}*\alpha_{c2})]$

$U_{i2}=563.4$ w/m^{2}k

6. Logarithmic mean temperature difference:

$\Delta T_{em1}=(T_{Hi}-T_{c1e})-(T_{He}-T_{c1i})/\ln[(T_{Hi}-T_{c1e})/(T_{He}-T_{c1i})]$

$\Delta T_{em1}=18.01$

$$\mathbf{\Delta T_{em2}=(T_{Hi}-T_{c2e})-(T_{He}-T_{ce2i}) / \ln[(T_{Hi}-T_{c2e})/(T_{He}-T_{c2i})]}$$

$\Delta T_{em2}=18.01$ .... (Counter Flow)

7. Heat Transfer Rates:-

$$\mathbf{Q_H=m_H C_{ph}(T_{c1e}-T_{c1i})}$$

$Q_H=1380W$

$$\mathbf{Q_{c1}=m_{c2}*C_{pc2}(T_{c2e}-T_{c2i})}$$

$Q_{c1}=689.8W$

$$\mathbf{Q_{c2}=m_{c2}*C_{pc2}(T_{c2e}-T_{cei})}$$

$Q_{c2}=689.8W$

8. COMPARE RESULTS:

From the above calculation result obtained for DTHE and TCTHE are compared in the parameters heat transfer rate and overall heat transfer coefficient.

Double Tube Heat Exchanger	Triple Concentric Tube Heat Exchanger
Heat Transfer Rate: Q= 980 W	Heat Transfer Rate: Q=1382 W
Overall Heat Transfer Coefficient $U_0=681.5W/m^2K$	Overall Heat Transfer Coefficient: $U_0=1103.8\ W/m^2K$

9.CONCLUSION:

The study is conducted on the specified experimental model to investigate the heat transfer rate and the overall heat transfer coefficient for TCTHE. It is found that the heat transfer rate and overall heat transfer coefficient is much higher in TCTHE than double tube heat exchanger. TCTHE provides considerable amount of space and material saving as compared to double tube heat exchanger. It is also observed that heat transfer rate is higher at higher flow rate in inner tube, inner anular space and outer annular space.

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