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Sizing of triple concentric pipe heat exchanger

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***Abstract*— The triple concentric pipes heat exchanger is an improved version of double pipe heat exchanger. Most of the previous study on the heat exchanger is confined to two fluids and few of many possible flow arrangements. The present study involves the sizing of triple concentric pipes heat exchanger where in two cold water streams flow through the central tube and outer annular space at same mass flow rates and same inlet temperatures in co-current direction while hot water flows through inner annular space in counter-current direction. This paper proposes a basic procedure for calculating overall heat transfer coefficients and length of triple concentric pipes heat exchanger. Length of triple pipe heat exchanger is computed for a required temperature drop of hot water with available dimensions of three pipes by LMTD method. Overall heat transfer coefficient and length of the equivalent double pipe heat exchanger are compared with that of the triple pipe heat exchanger. The theoretical analysis shows that introducing an intermediate pipe to the double pipe heat exchanger reduces effective length of heat exchanger, which results in savings in material and space. The triple concentric pipes heat exchanger provides large heat transfer area per unit heat exchanger length and better heat transfer efficiencies compared to double pipe heat exchanger.**

***Index Terms*— Heat exchanger, Triple concentric pipe, Double pipe, Sizing, Overall heat transfer coefficients**

I. INTRODUCTION

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact [2]. Heat exchanger have been classified in several ways, according to transfer process (direct contact, indirect contact), according to geometry of constructions (plate, tube, extended surfaces), according to heat transfer mechanisms (single phase, two phases), according to flow arrangements (parallel, counter, cross flow) [3]. The type of heat exchanger to be used is determined by the process and product specifications. Nevertheless, concentric tube heat exchanger play a major role in accomplishing the heat exchanger needs of food industry. The most common heat exchanger is double pipe heat exchanger [4]. A typical double pipes heat exchanger consists of one pipe places concentrically inside another of a large diameter pipe with appropriate fitting to direct the flow from one section to the next [3]. Introducing an intermediate pipe to a double concentric pipe heat exchanger provides triple pipe heat exchanger and the latter performs better compared to the prior one. Triple concentric pipes heat exchanger consists of three pipes of different diameters and three fluids exchange heats between them. Thus in this case, there are three sections: central pipe, inner annular space and outer annular space. In triple pipe heat exchangers, a thermal fluid is passed through an inner annular space and heat transfer mediums are passed through the central pipe and outer annular space. Triple concentric-pipes heat exchangers are used for food processing, pasteurization of viscous food products (milk, cream, pulpy orange juice, apple mash), sterilization, cooling, energy conversion, Refrigeration.

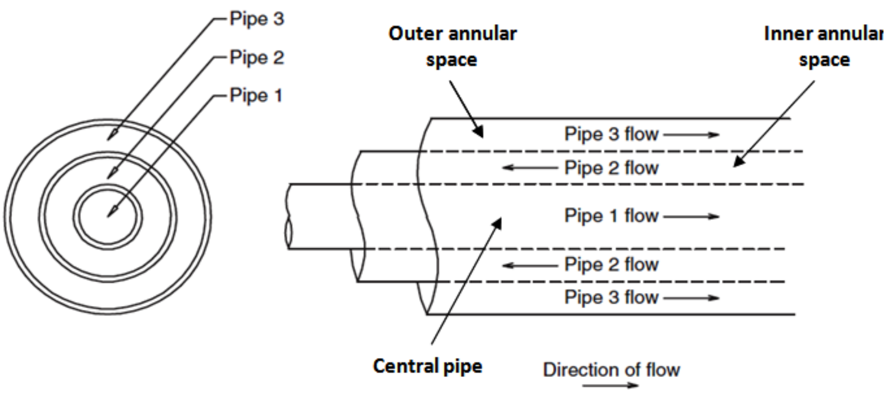

Fig. 1 Triple concentric pipes

The most common problems in heat exchanger design are rating and sizing. The rating problem is concerned with the determination of the heat transfer rate and the fluid outlet temperatures for prescribed fluid flow rates, inlet temperature, and allowable pressure drop of an existing heat exchanger. On the other hand, the sizing problem is concerned with determination of dimension of heat exchanger, that is, selecting an appropriate heat exchanger type and determining the size to meet the specified hot and cold fluid inlet and outlet temperatures, flow rates, and pressure drop requirements [3]. In this study, the sizing procedure of triple concentric pipe heat exchanger is presented, in which, length of the heat exchanger is calculated for the available dimensions of three pipes to meet the required temperature drop of hot water.

II. Literature review

An impressive list of information is available in relevant references for double pipe heat exchanger. Many researchers have performed the design and analysis of double pipe heat exchanger. Researchers have done theoretical as well as experimental analysis of triple concentric pipe heat exchanger. The set of equations for design and performance analysis of TTHE have been developed. But the information available for TTHE is still less compared to double pipe heat exchanger. From the available literatures, the major contributions of researchers are as follows:

C. A. Zuritz developed a set of analytical equations for fluid temperatures at any axial location along the heat exchanger for parallel and counter flow configurations and conducted simulation of triple concentric pipe heat exchanger. The equations account for heat losses to the surroundings and are useful for design purposes Simulations show that the creation of an annular region within the inner pipe increases the overall heat transfer efficiency and reduces the heat exchanger length requirement by almost 25% [5].

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 [6].

Ahmet Unal in his first part developed a mathematical model, consisting the derivation and possible solutions of the governing equations for both counter-flow and parallel-flow arrangements. The equations derived in this study can be used for both design calculations and performance calculations, besides they can be used for the determination of bulk temperature variation along the exchanger [7].

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 [8].

Ahmet Unal derived the effectiveness-NTU relations for triple concentric tube heat exchanger including both counter-flow and parallel flow arrangements. Some representative data are represented in graphical form. This graphs can be used for determining effectiveness of triple concentric pipe heat exchanger by using input parameters i.e. heat capacity ratio and number of transfer units [9].

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 [10].

Ediz Batmaz developed a more generic way of calculating overall heat transfer coefficient in a triple tube heat exchanger for both counter-flow and parallel-flow arrangements using the energy balance equations on a control volume. Further, he derived the equations for determining the axial temperature distribution of the fluids. He concluded that 1) overall heat transfer coefficients and the temperature profiles are useful for designing a heat exchanger to meet the process requirements. 2) Overall heat transfer coefficients values may also be useful for determining the convective heat transfer coefficient values (h) [11].

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:

$$Nu_H = 2.718\ Re_H^{0.597}\ Pr_H^{1/3} \left(\frac{d_{h2}}{L_1}\right)^{2/3}$$

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 [12].

G.A. Quadir et al. analyzed performance of heat exchanger for two flow arrangements, called N–H–C and C–H–N, and for insulated as well as non-insulated conditions of the heat exchanger. The three fluids being considered are hot water, cold water and the normal tap water. Under N–H–C arrangement, normal water flows in the innermost pipe, hot water flows in the inner annulus, and the cold water flows in the outer annulus. All fluids flow parallel to each other. Cold and normal water are interchanged in the C–H–N arrangement keeping hot water flow unchanged. He concluded that the heat transfer between the three fluids considered is more effective in N–H–C arrangement of the heat exchanger as compared to that in C–H–N arrangement [13].

III. CONSIDERATIONS AND ASSUMPTIONS MADE FOR SIZING

The major considerations and assumptions made for sizing of triple concentric pipe heat exchanger are as follows:

1. Two cold water streams (cooling medium) flow through central pipe and outer annular space in same direction. Hot water flows through the inner annular space in opposite direction to that of the cold water streams.
2. Heat exchange from hot water to cold water streams take place without phase transformation.
3. Heat exchanger is well insulated against atmosphere.
4. Two cold water streams enter the heat exchanger at same mass flow rates and same inlet temperatures.
5. Heat transfer from hot water to cold water streams are assumed symmetrical. Thus two cold water streams leaving the heat exchanger at almost same outlet temperatures.
6. Heat exchanger is made of three copper pipes of different diameters.
7. Heat exchanger has no deposit of dirt on the pipe because pipes are thin.
8. For the design purpose, hot water temperature drop is considered as 8˚C.
9. The diameters of three pipes are prescribed and we have to determine the length of heat exchanger.

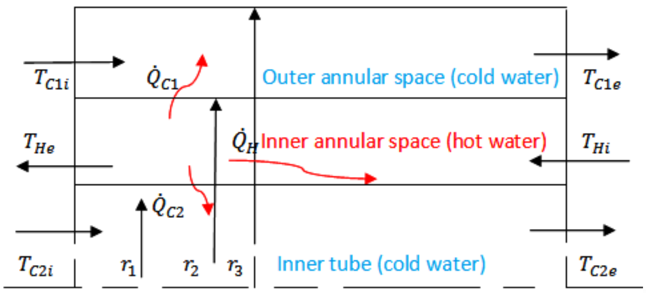

Fig. 2 Physical model of triple concentric pipe heat exchanger

IV. SIZING PROCEDURE

LMTD method can be used to solve the sizing problem with the following steps:

1. Calculate unknown outlet temperatures of cold water streams C1 and C2 from energy balance equation. ($\dot{Q}_H = \dot{Q}_{c1} + \dot{Q}_{c2}$).
2. Determine convective heat transfer coefficients for inner pipe, intermediate pipe and outer pipe from the physical properties of fluid.
3. Calculate two overall heat transfer coefficients, one based on outside area of inner tube and other based on inside area of intermediate tube.
4. Calculate logarithmic mean temperature differences from inlet and outlet temperatures of three fluids.
5. Calculate length of heat exchanger by using equation,

$$m_H\, C_{p,H}\,(T_{Hi} - T_{He}) = U_{O1}\,\pi\, d_{01} L\,\Delta T_{lm1} + U_{i2}\,\pi\, d_{i2} L\,\Delta T_{lm2}$$

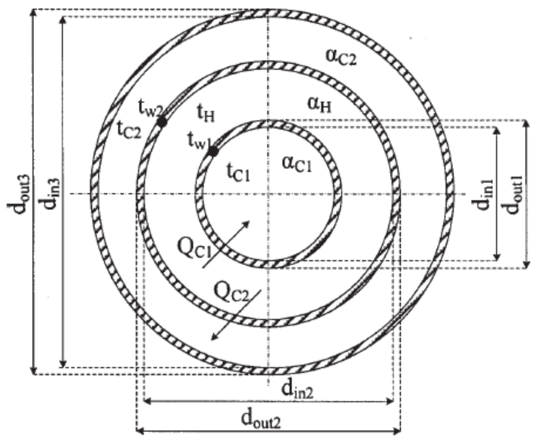

Fig. 3 Cross section of triple tube heat exchanger [12]

Nomenclature

T	Temperature (k)
$\dot{m}$	Mass flow rate (Kg/s)
k	Thermal conductivity (W/m k)
c_p	Specific heat (J/kg k)
Pr	Prandlt number
W	Linear velocity (m/s)
d	Diameter (m)
Re	Reynolds number
U	Overall heat transfer coefficient (W/m^2 k)
A	Heat transfer area, (m^2)
$\dot{Q}$	Heat flow rate, (W)
$\dot{v}$	Volumetric flow rate (m^3/s)
C	Heat capacity rate (W/k)

Subscripts

1	Central pipe
2	Inner annular space
3	Outer annular space
i	Inlet
e	Exit
b	Bulk mean
in	Inside
Out	Outside
h	Hydraulic
lm	Logarithmic mean
C1	Cold fluid in the central tube
C2	Cold fluid in the outer tube
H	Hot fluid in intermediate tube

Greek symbols

ρ	Density (kg/m^3)
μ	Dynamic viscosity (Pa.s)
α	coefficient of heat transfer (W/m^2 k)
k	Thermal conductivity (W/m k)
Δ	difference

Abbreviations

TPHE	Triple pipe heat exchanger
DPHE	Double pipe heat exchanger
LMTD	Logarithmic mean temperature difference

Table 1: Input parameters for sizing calculations

Input parameters	Symbols	Values
Hot water inlet temperature, ˚C	T_{Hi}	50
Hot water outlet temperature, ˚C	T_{He}	42
Cold water (C1) inlet temperature, ˚C	T_{C1i}	25
Cold water (C2) inlet temperature, lit/hr	T_{C2i}	25
Volumetric flow rate of hot water, lit/hr	$\dot{v}_H$	150
Volumetric flow rate of cold water (C1), lit/hr	$\dot{v}_{C1}$	100
Volumetric flow rate of cold water (C2), lit/hr	$\dot{v}_{C2}$	100
Diameter of central pipe, mm	d_{in1}	12
Diameter of intermediate pipe, mm	d_{in2}	26
Diameter of outer pipe, mm	d_{in3}	40
Thickness of each pipe, mm	t	2
Specific heat of hot water ,$J/Kg\ k$	C_{pH}	4182
Thermal conductivity of copper, ,$W/m\ k$	k_{coper}	401

$\dot{m}_{C1} = \dot{m}_{C2} = 0.02772\ Kg/s$
$\dot{m}_H = 0.04124\ Kg/s$

The outlet temperatures of cold water streams (C1 & C2) are calculated by steady state energy balance equation.

$$\dot{Q}_H = \dot{Q}_{c1} + \dot{Q}_{c2}$$

$$\dot{m}_H\, C_{p,H}\, (T_{Hi} - T_{He}) = \dot{m}_{C1}\, C_{p,C1}\, (T_{C1e} - T_{C1i}) + \dot{m}_{C2}\, C_{p,C2}\, (T_{C2e} - T_{C2i}) \quad (1)$$

$$T_{C1e} = T_{C2e} = 30.9\ {}^{\circ}C$$

Inner tube heat transfer coefficient

Bulk mean temperature of cold water is given as:

$$T_{b1} = \frac{T_{C1i} + T_{C1e}}{2} \quad (2)$$

Thermo physical properties of cold water at $T_b = 301.1\ K$ are:

Properties	Symbols	Values
Density, Kg/m^3	ρ_{C1}	996.3
Thermal conductivity, $W/m\ k$	K_{C1}	0.5997
Specific heat, $J/Kg\ k$	$C_{p,C1}$	4183
viscosity, $pa.s$	μ_{C1}	8.33×10^{-4}
Prandlt number	Pr_{C1}	5.813

Linear velocity of cold water C1 is given as:

$$W_{C1} = \frac{\dot{m}_{C1} \times 4}{\rho_{C1} \times \pi \times d_{in1}^2} \quad (3)$$

$$W_{C1} = 0.246\ m/s$$

Knowing the linear velocity, Reynolds number for cold water is calculated by,

$$Re_{C1} = \frac{\rho_{C1} \times W_{C1} \times d_{in1}}{\mu_{C1}} \quad (4)$$

$$Re_{C1} = 3530$$

Therefore, the flow of cold water C1 is in transition regime.

For the calculation of convective heat transfer coefficient for cold water C1 which circulates through the central tube for a transition regime we can use Gnielinski correlations which is applicable for Reynolds values ranges between 2300 and 10^4 [3]

$$Nu_{C1} = \frac{(f/2)(Re_{C1} - 1000)Pr_{C1}}{1 + 12.7\,(f/2)^{1/2}\left({Pr_{C1}}^{2/3} - 1\right)} \quad [3] \quad (5)$$

Where, $f = (1.58\ lnRe_{C1} - 3.28)^{-2}$

$$Nu_{C1} = 26.31$$

From the value of Nusselt number, we can determine convective heat transfer coefficient from following equation:

$$\alpha_{C1} = \frac{Nu_{C1}\ K_{C1}}{d_{in1}} \quad (6)$$

$$\boldsymbol{\alpha_{C1} = 1315\ W/m^2k}$$

Inner annulus heat transfer coefficient

Bulk mean temperature of hot water (T_{b2}) is given as:

$$= \frac{T_{Hi} + T_{He}}{2} \quad (7)$$

Thermo physical properties of hot water at $T_b = 319.2\ K$ are:

Properties	Symbols	Values
Density, Kg/m^3	ρ_H	989.8
Thermal conductivity, $W/m\ k$	K_H	0.6257
Specific heat, $J/Kg\ k$	$C_{p,H}$	4182
viscosity, $pa.s$	μ_H	5.859×10^{-4}
Prandlt number	Pr_H	3.916

Linear velocity of hot water is given as:

$$W_H = \frac{\dot{m}_H \times 4}{\rho_H \times \pi \times (d_{in2}^2 - d_{out1}^2)} \quad (8)$$

$W_H = 0.1105\, m/s$

To obtain Reynolds number of hot water, hydraulic diameter is required.
Hydraulic diameter is defined as,

$$d_{h2} = d_{in2} - d_{out1} \quad (9)$$

$d_{h2} = 0.012$ m

Knowing the value of linear velocity and hydraulic diameter, Reynolds number for cold water is calculated by,

$$Re_H = \frac{\rho_H \times W_H \times d_{h2}}{\mu_H} \quad (10)$$

$Re_H = 2241$

Therefore flow of hot water in inner annular space is in transition_regime.

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

$$Nu_H = 2.718\ Re_H^{0.597}\ Pr_H^{1/3} \left(\frac{d_{h2}}{1.193}\right)^{2/3} \quad (11)$$

It is applicable for the Reynolds values that go from 2264 to 7893 [12].

$Nu_H = 19.97$

From the value of Nusselt number, we can determine convective heat transfer coefficient in inner annular space from following equation:

$$\alpha_H = \frac{Nu_H\, K_H}{d_{h1}} \quad (12)$$

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

Outer annulus heat transfer coefficient

Bulk mean temperature(T_{b3}),

$$= \frac{T_{C2i} + T_{C2e}}{2} \quad (13)$$

$T_{b3} = 301.1$ K

Thermo physical properties of cold water at T_b= 300.95K are:

Properties	Symbols	Values
Density, Kg/m^3	ρ_{C2}	996.3
Thermal conductivity, $W/m\ k$	K_{C2}	0.5997
Specific heat, $J/Kg\ k$	$C_{p,C2}$	4183
viscosity, $pa.s$	μ_{C2}	8.33×10^{-4}
Prandlt number	Pr_{C2}	5.813

Linear velocity of cold water C2 which flows through outer annular space is given as,

$$W_{C2} = \frac{\dot{m}_{C2} \times 4}{\rho_{C2} \times \pi \times (d_{in3}^2 - d_{out2}^2)} \quad (14)$$

$W_{C2} = 0.04342\, m/s$

Hydraulic diameter,

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

d_{h3} =0.012 m

Knowing the value of linear velocity and hydraulic diameter, Reynolds number for cold water C2 is calculated by,

$$Re_{C2} = \frac{\rho_{C2} \times W_{C2} \times d_{h2}}{\mu_{C2}} \quad (15)$$

$Re_{C2} = 622.9$

Therefore, flow of cold water C2 in outer annular space is laminar.

For calculating partial coefficient of heat transfer for cold water which circulates through the outer annular section, in laminar regime following correlation is used.

$$Nu_{C2} = 0.51 \times Re_{C2}^{0.5} \times Pr_{C2}^{1/3} \times (Pr_{C2}/Pr_{w2})^{0.25} \qquad [\mathbf{1}] \qquad (16)$$

Where, $(Pr_{C2}/Pr_{w2})^{0.25}$ is considered as 1

Nu_{C2} = 22.88

From the value of Nusselt number, we can determine convective heat transfer coefficient in outer annular space from following equation:

$$\alpha_{C2} = \frac{Nu_{C2}\, K_{C2}}{d_{h2}} \qquad (17)$$

$\boldsymbol{\alpha_{C2} = 1144\ W/m^2k}$

Overall heat transfer coefficients

There are two Overall heat transfer coefficients in triple concentric pipe heat exchanger and they are defined as

Overall heat transfer coefficient based on outside area of central pipe

$$\frac{1}{U_{01}} = \frac{d_{out1}}{d_{in1}\alpha_{c1}} + \frac{d_{out1}\ln(d_{out1}/d_{in1})}{2k_{coper}} + \frac{1}{\alpha_H} \qquad (18)$$

$\boldsymbol{U_{01} = 540.4\ W/m^2k}$

Overall heat transfer coefficient based on inside area of intermediate pipe

$$\frac{1}{U_{i2}} = \frac{1}{\alpha_H} + \frac{d_{in2}\ln(d_{out2}/d_{in2})}{2k_{coper}} + \frac{d_{in2}}{d_{out2}\alpha_{c2}} \qquad (19)$$

$\boldsymbol{U_{i2} = 563.4\, W/m^2k}$

Logarithmic mean temperature difference

$$\Delta T_{lm1} = \frac{(T_{Hi} - T_{C1e}) - (T_{He} - T_{C1i})}{ln(T_{Hi} - T_{C1e}/T_{He} - T_{C1i})} \qquad (20)$$

$\boldsymbol{\Delta T_{lm1} = 18.01}$

$$\Delta T_{lm2} = \frac{(T_{Hi} - T_{C2e}) - (T_{He} - T_{C2i})}{ln(T_{Hi} - T_{C2e}/T_{He} - T_{C2i})} \qquad (21)$$

$\boldsymbol{\Delta T_{lm2} = 18.01}$

Heat transfer rates

The heat flow for the three fluids is calculated using the following calorimeter equations:

Heat transfer rate of hot water is given as,

$$\dot{Q}_H = m_H\, C_{p,H}\, (T_{Hi} - T_{He}) \qquad (22)$$

$\boldsymbol{\dot{Q}_H = 1380\ W}$

Heat transfer rate of cold water C1 is given as,

$$\dot{Q}_{C1} = m_{C1}\, C_{p,C1}\, (T_{C1e} - T_{C1i}) \qquad (23)$$

$\boldsymbol{\dot{Q}_{C1} = 689.8\, W}$

Heat transfer rate of cold water C2 is given as,

$$\dot{Q}_{C2} = m_{C2}\, C_{p,C2}\, (T_{C2e} - T_{C2i}) \qquad (24)$$

$\boldsymbol{\dot{Q}_{C2} = 689.8\, W}$

Length of triple concentric pipe heat exchanger

The heat exchanger length can be calculated from the heat balance equation, which is given below,

$$\dot{m}_H\, C_{p,H}\, (T_{Hi} - T_{He}) = U_{01}\, A_{01}\, \Delta T_{lm1} + U_{i2}\, A_{i2}\, \Delta T_{lm2} \qquad (25)$$

$$\dot{m}_H\, C_{p,H}\, (T_{Hi} - T_{He}) = U_{01}\, \pi\, d_{01} L\, \Delta T_{lm1} + U_{i2}\, \pi\, d_{i2} L\, \Delta T_{lm2}$$

For a given diameters $d_{01} = 0.014\, m$ and $d_{i2} = 0.026m$, heat exchanger length L calculated by heat balance equation is **1.098 m**.

Table 2: Output parameters obtained from Sizing calculations

Output parameters	Symbols	Values
Inner annulus heat transfer coefficient, W/m^2k	α_H	1075
Inner tube heat transfer coefficient, W/m^2k	α_{C1}	925.8
Outer annulus heat transfer coefficient, W/m^2k	α_{C2}	1144
Overall heat transfer coefficient based on outside area of central pipe, W/m^2k	U_{01}	461.3
Overall heat transfer coefficient based on inside area of intermediate pipe, W/m^2k	U_{i2}	573.1
Outside surface area of central pipe, m^2	A_{O1}	0.08304
Inside surface area of intermediate pipe, m^2	A_{i2}	0.06685
Length of triple concentric pipe heat exchanger ,m	L	1.095

V. EQUIVALENT DOUBLE PIPE HAET EXCHANGER

The area enclosed by solid rectangle represents triple tube heat exchanger. In case of triple tube heat exchanger, three fluid streams enter and leave the exchanger. On the other hand, there are only two fluid streams entering and leaving the dashed box, one being the hot fluid and the other being the cold fluid. This is similar to double tube heat exchanger with the flow beings in a counter-current mode and hence is an equivalent double tube heat exchanger that can be used to replace the triple tube heat exchanger [11].

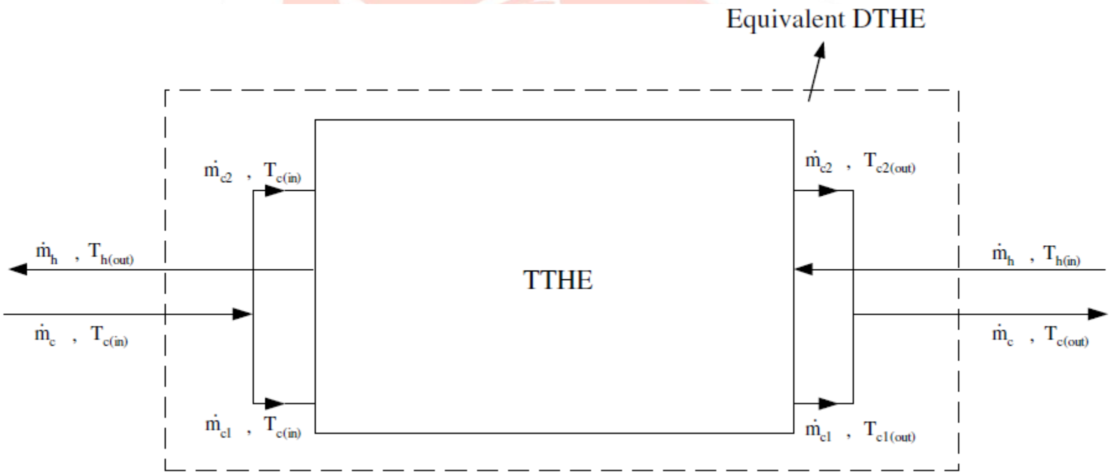

Fig. 4 Converting a TPHE into equivalent DPHE [11]

Logarithmic mean area of Double pipe heat exchanger is equal to sum of the two logarithmic mean area of triple pipe heat exchanger [11].

$$A_{lm1} = \pi \times \frac{d_{out1} - d_{in1}}{ln\left(\frac{d_{out1}}{d_{in1}}\right)} \times L \qquad (26)$$

$A_{lm1} = 0.04475\ m^2$

$$A_{lm2} = \pi \times \frac{d_{out2} - d_{in2}}{ln\left(\frac{d_{out2}}{d_{in2}}\right)} \times L \qquad (27)$$

$A_{lm2} = 0.09309\ m^2$

$A_{lm} = 0.04475 + 0.09309$

$\boldsymbol{A_{lm} = 0.13784\ m^2}$

Mass flow rate of cold water in equivalent double pipe heat exchanger is equal to sum of mass flow rates of two cold water streams C1 and C2

$$\dot{m}_c = \dot{m}_{C1} + \dot{m}_{C2} \quad (28)$$

$$\dot{m}_c = 0.05544\ Kg/s$$

For the same temperature drop of hot water (8˚C), the outlet temperature of cold water is obtained by the energy balance equation,

$$\dot{m}_H\ C_{p,H}\ (T_{Hi} - T_{He}) = \dot{m}_c\ C_{p,c}\ (T_{Ce} - T_{Ci}) \quad (29)$$

$$T_{ce} = 30.99\ ˚C$$

And the logarithmic mean temperature difference is:

$$\Delta T_{lm} = \frac{(T_{Hi} - T_{Ce}) - (T_{He} - T_{Ci})}{ln(T_{Hi} - T_{Ce}/T_{He} - T_{Ci})} \quad (30)$$

$$\Delta T_{lm} = 17.98\ ˚C$$

Heat transfer rate is given by,

$$\dot{Q} = \dot{m}_H\ C_{p,H}\ (T_{Hi} - T_{He})$$

$\dot{Q}$ =1380 W

To calculate overall heat transfer coefficient in equivalent double pipe heat exchanger, we use equation

$$U = \frac{\dot{Q}}{A_{lm}\ \Delta T_{lm}} \quad (31)$$

$$\boldsymbol{U = 556.81\ W/m^2k}$$

The $\boldsymbol{U}$ value calculated for this equivalent DPHE combines the effect of the overall heat transfer coefficients $\boldsymbol{U_{01}}$ and $\boldsymbol{U_{i2}}$. Thus, we refer to this value as the effective overall heat transfer coefficient ($\boldsymbol{U_e}$). We can then use this value to compare a TPHE to a DPHE and make the choice of one over the other, depending on the process parameters [11].

Length of double pipe heat exchanger is given simply as,

$$A_{lm} = \pi\ d_{in}\ L_{DTHE} \quad (32)$$

Where,

d_{in}= inside diameter of inner pipe

L_{DTHE}= length of double pipe heat exchanger

$$\boldsymbol{L_{DTHE} = 3.13\ m}$$

VI. RESULTS AND DISCUSSION

The overall heat transfer coefficients and length of triple concentric pipe heat exchanger were found out using input parameters i.e. geometrical characteristics of three pipes, mass flow rates and thermo physical properties of three fluids. The length of triple pipe heat exchanger was computed for 8˚C temperature drop of hot water. The length of triple concentric pipe heat exchanger was found to be1.098 m. There are two overall heat transfer coefficients in triple pipe heat exchanger: one based on outside area of central pipe (U_{01}) and second based on inside area of intermediate pipe (U_{i2}). The overall heat transfer coefficients based on outside area of central pipe and based on inside area of intermediate pipe were found to be 540.4 W/m^2k and 563.4 W/m^2k respectively. The flow regimes in triple pipe heat exchanger were observed to be: transition in the central pipe and inner annular space and laminar in outer annular space.

The overall heat transfer coefficient (U) in equivalent double pipe heat exchanger was found to be 556.81 W/m^2k. The U value calculated for equivalent DTHE combines the effect of the overall heat transfer coefficients U_{01} and U_{i2}. If we compare the overall heat transfer coefficients of triple pipe heat exchanger with that of double pipe heat exchanger, it can be observed that the performance of triple pipe heat exchanger is better compared to double pipe heat exchanger. The length of equivalent double pipe heat exchanger is 3.13m. Thus it can be seen that, length of equivalent DPHE is more than length of TPHE.

Thus, we concluded that triple concentric pipe heat exchanger provides better heat transfer efficiencies and large heat transfer area per unit exchanger length. Triple concentric pipe heat exchanger requires less space compared to double pipe heat exchanger. This study can be used for deciding the dimensions of triple pipe heat exchanger for required temperature drop of hot water.

VII. ACKNOWLEDGEMENT

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