Performance simulation of a double pipe heat exchanger using MATLAB.

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A Graduation Exercise Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Mechanical Engineering.

Department of Mechanical Engineering
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September, 2023

DECLARATION

We hereby Declare that this thesis is our own work and to the best of our knowledge it contains no materials previously published or written by another person, or have been accepted for the award of any other degree or diploma at Sonargaon University or any other Educational Institution. We also Declare that the intellectual content of this thesis is the product of our own work and any contribution made to the research by others, with whom I have worked at Sonargaon University or elsewhere, its explicitly acknowledged.

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CERTIFICATION OF APPROVAL

The Thesis Title "**Performance simulation of a double pipe heat exchanger using MATLAB.**

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NOMENCLATURE

Symbol	Description	Unit
M_h	Mass flow rate of hot fluid	Kg/s
M_c	Mass flow rate of cold fluid	Kg/s
C_{ph}	Specific heat of hot fluid	KJ/Kg.K
C_{pc}	Specific heat of cold fluid	KJ/Kg.K
T_{hi}	Hot fluid temperature at inlet	K
T_{ho}	Hot fluid temperature at exit	K
T_{ci}	Cold fluid temperature at inlet	K
T_{co}	Cold fluid temperature at exit	K
Q	Total heat transfer	W
U	Overall heat transfer coefficient	W/m2 K
A_i	Inner surface area of inner tube	m^2
A_o	Inner surface area of inner tube	m^2
ΔT_{lm}	Log mean temperature difference	K
d_o	Outer diameter of inner tube	M
d_i	Inner diameter of inner tube	M
L	Length of Hairpin	M
N_{hp}	Number of Hairpin	--
h_i	Heat transfer coefficient of inner side	$W/m^2.K$
h_o	Heat transfer coefficient of outer side	$W/m^2.K$
P	Pressure	Pa
R_e	Reynolds number	--
Pr	Prandtl number	--
Nu	Nusselt number	--
k	Thermal conductivity	W/m.K
v	Velocity	m/s

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ABSTRACT

Heat Exchangers are primarily used for transfer the heat. Design of heat exchanger is one of the key factor compact devices. The requirement of heat exchanger rate is low, suitable applications are Refrigeration, air condition, Boiler and space heating etc.

The Design consist of Concentric pipes where the hot oil will pass in the annular Region and the sea water will pass through the inner pipe. Flexibility is achieved in the design about parallel flow and counter flow depending on selection of inlet and outlet of annular fluid. This Heat Exchanger in intended to be installed in a sea vessel to reduce the temperature of the oil used to cooled engine. Different Governing Equations and empirical relations are used for the designation. Simulation was done by MATLAB software.

Copper is Selected for inner tube and outer tube we used iron pipe. 1” copper tube used for inner tube and 2” Iron used for outer tube.

CHAPTER-1. INTRODUCTION

1.1. Background

Heat Exchangers are one of the normally used systems in the industries. Heat Exchangers are used to switch warmth between process streams. One can realize then utilization that any manner which involve cooling, heating, condensation, boiling or evaporation would require a heat exchanger for that motive. Process fluids, commonly are heated or cooled before the method or go through a section exchanger. Different heat exchangers are named according to their application. For instance, warmth exchangers being used to condense are called condensers, in addition heat exchanger for boiling functions are referred to as boilers.

Double Pipe Hair Pipe Heat Exchanger:

Double Pipe Hair Pipe Heat Exchanger is the one of double tubular heat exchanger and is expressed as a single pass shell and tube heat exchanger. It is extended to the required length and bends like hair pin shape oat the edges. This heat exchanger consists of pair of concentric tubes. One of the fluid flows in the inner tube and others fluid flows in the annuls space between them. Double pipe heat exchanger is mostly suitable for extreme temperature crossing, high pressure, high temperature and low to moderate surface area requirements.

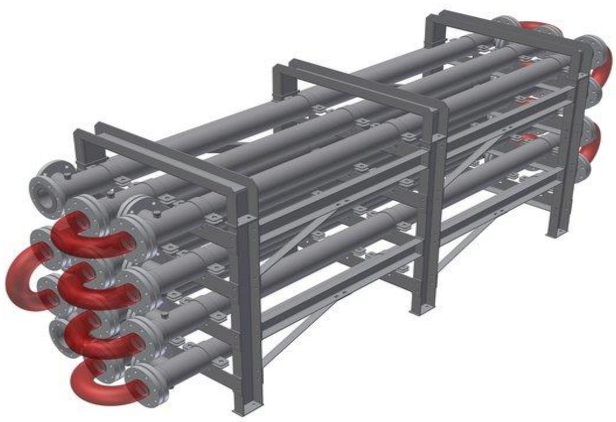


Figure-1: Double Pipe Heat Exchanger.

Present scenario of the miniature heat exchanger is a serious concern to many small devices where required heat transfer area is low. Application of the miniature size double tube hairpin heat exchanger is in radiators of electric transformers, air conditioners, cars radiator and refrigerators etc. Development of faster cooling technologies for increasing thermal loads is the foremost requirement in today area.

1.2. Problem Statement

Engine Oil is to be cooled from 65°C to 55°C using Sea Water available at 20°C. Hot oil will be flowing through the annulus region at a flow rate of 0.15 kg/s and sea water will be flowing through the tube at a flow rate of 0.15 kg/s.

1.3. Objectives

The main objective of the design was to get maximum heat transfer within a limited space. We used 2 hairpins which are parallel to each other. we used pipes of 1inch diameter for inner tube and 2inch diameter for outer tube. 1 mm (about 0.04 in) thickness is considered for our design consideration and simulation. While working on the design the manufacturability of the product was considered. We used cross flow in our design. The parameters of our design are stated in our calculation chapter.

CHAPTER-2.LITERATURE REVIEW

A typical double pipe heat transfer exchanger consists of one pipe placed concentrically inside another pipe of a larger diameter with appropriate fitting to direct the flow from one section to the next .one fluid flows through the inner pipe and the other flows through the annular space. The inner pipe is connected by U-shaped return bends enclosed in return bend housing. Double-pipe heat exchanger can be arranged in various series and parallel arrangements to meet presser drop and MTD requirements. The major use of the double pipe heat exchanger is sensible heating or cooling of process fluids where small heat transfer areas (up to 50 m^2) are required. This configuration is also very suitable for one or both of the fluids at high pressure because of the smaller diameter of the pipes. The major disadvantage is that they are bulky and expensive per unit of heat transfer surface area. This double-pipe heat exchanger is also called hairpin heat exchanger and they can be used when one steam is a gas, viscous liquid, or small in volume. This heat exchanger can be used under severe fouling conditions because of the ease of cleaning and maintenance. [1]

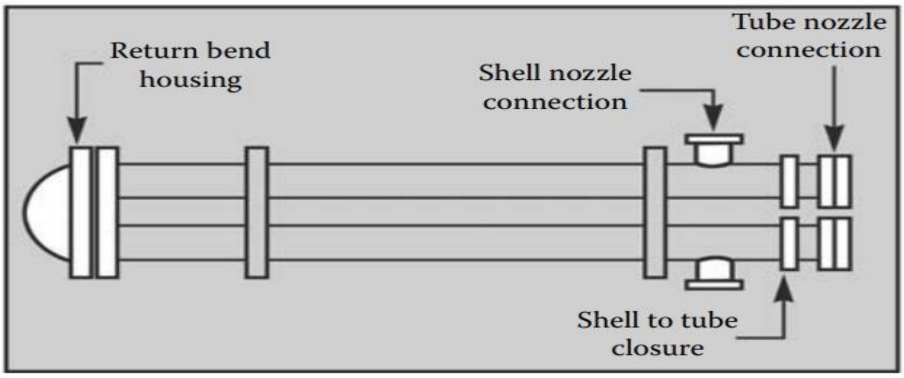


Figure: 2 Schematic Diagram of a Double Pipe Hairpin Type Heat Exchanger

Although shell and tube heat exchanger are the most common heat transfer equipment in chemical process plants, there are many cases for which other heat exchanger types become more suitable. For instance double pipe heat exchanger can be an economically more advantageous option when smaller services are in place (e.g. heat transfer area lower than $50m^2$). If the stream conditions solids in suspension, double pipe heat exchangers may also be a better alternative because they can be built with an inner tube with larger diameter to avoid plugging, smaller diameters of the outer tube in double pipe heat exchangers advantageous for high-pressure services because it implies a smaller wall thickness. In addition, double pipe heat exchangers are easily cleaned and the longitudinal flow avoids the existence of stagnation regions which in shell and tube exchangers are prone to fouling. Double pipe heat exchangers have also the benefit of flexibility due to its modular structure. [2]

Heat is defined as the amount of energy a substance has. A heat exchanger is a heat transfer device whose purpose is the transfer of energy from one moving fluid stream to another moving fluid stream The transfer of heat is done with a separation of a wall to avoid mixing of the two fluids of different properties.

Double pipe heat exchanger design as contained in this technical paper is very straight forward. It is one heat exchanger pipe inside another, for either counter current flow or parallel flow, the heat exchanger surface area is determined from the heat exchange duty, log mean temperature difference and the estimated overall heat transfer coefficient. From this, heat exchanger surface area, the pipe sizes, pipe lengths and the number of bends can be determined. The performance of the heat exchanger can be checked using the fouling factor and the effectiveness of the heat exchanger. The double pipe heat exchanger is recommended for use only where small heat transfer area is required. Several double pipe heat exchangers can be connected in series if a higher capacity is required. [3]

CHAPTER-3: METHODOLOGY

3.1. Design Consideration

When Designing a Double Pipe Heat Exchanger, there are Several Important Considerations that must be taken into account. These include the following.

01-Heat Transfer Coefficient:

Heat Transfer Coefficient One of the most important design considerations for a double pipe heat exchanger is the heat transfer coefficient. This coefficient is a measure of how well heat is transferred from one fluid to another, and it is influenced by a variety of factors, including the fluid flow rate, the type of fluids being used, and the geometry of the heat exchanger.

The Heat Transfer Coefficient is the Proportionally Coefficient Between Heat Flux and The Temperate Difference ΔT.

$$H = \frac{Q}{T_s - K}$$

Where

Q = Amount of Heat Required (Heat Flux) W/m^2

T_s = Solid Surface Temperature.

K= Surrounding Fluid Area Temperature.

This Equation is used in Calculating Heat transfer coefficient, Typically by convection or phase transition between solid and Fluids.

The Heat transfer coefficient Has SI unit in W/m^2k (watt per square meter kelvin)

Overall Heat Transfer Coefficient Table Chart Various Fluids (Liquids and Gasses)

Table-1: Heat Transfer Coefficient of Different Types of Materials in Different Conditions.

SL No	Conditions of Heat Transfer	W /(m√K
1	Gases in Free Convection	5-37
2	Water in Free Convection	100-1200
3	Oil under Free Convection	50-350
4	Gas flow in tubes and between tubes	10-350
5	Water flowing in tubes	500-1200
6	Oil flowing in tubes	300-1700
7	Molten metal’s flowing in tubes	2000-45000
8	Water nucleate boiling	2000-45000
9	Water Film boiling	100-300
10	Film-type condensation of water vapor	4000-17000
11	Drop size condensation of water vapor	30000-140000
12	Condensation of organic liquids	500-2300

2- Fluid Flow Rate:

The flow rate of the fluids through the heat exchanger is another important consideration. The flow rate will determine the velocity of the fluid, which in turn affects the heat transfer coefficient. The flow rate will also influence the pressure drop across the heat exchanger, which can impact the overall efficiency of the system. Fluid Flow in Heat Exchanger Could Happened in Laminar or Turbulent both,

There are several correlations available for calculation of the convective heat transfer coefficient for turbulent flow of a fluid in a pipe, with the fluid and pipe at different temperatures. The temperature of the pipe may be either hotter or colder than the fluid. Or in other words, the fluid may be either heated or cooled by the pipe.in 1936, Sieder and Tate proposed the following equation to accommodate larger temperature differences: [5]

$$Nu = 0.023\ Re0.8\ Pr^{1/3}(\mu b/\mu w)^{0.14}$$

Where: µb is the fluid viscosity at the fluid bulk temperature µw is the fluid viscosity at the pipe wall temperature The fluid bulk temperature at any cross section in the pipe is the average fluid temperature over that cross section. The Sieder-Tate equation is valid for smooth pipes and for:

0.7 <Pr< 16,

700 ReD> 10,000

L/D > 10

Convection heat transfer associated with laminar flow in a circular tube (Re < 2300) is less common than with turbulent flow. Incropera et al gives the following correlation for use in estimating convection heat transfer coefficients for laminar entry region flow.

$$\mathrm{Nu_D} = 1.86\left(\frac{\mathrm{Re\ Pr}}{\mathrm{L/D}}\right)^{1/3}(\mu b/\mu w)^{0.14}$$

3-Material Selection

The choice of materials for the heat exchanger is another important consideration. The materials must be able to withstand the temperature and pressure conditions of the system, as well as any potential corrosive effects of the fluids being used. Additionally, the materials must be compatible with the fluids being used to prevent contamination or other issue. Thermal Conductivity of Materials is important consideration for material selection.

Thermal conductivity of a material can be defined as the heat flux transmitted through a material due to a unit temperature gradient under steady-state conditions. Metals are typically good conductors of heat, and hence have high thermal conductivity. Gases generally have low thermal conductivity and are bad conductors of heat (or, in other words, are good insulators).

The table below shows typical values of thermal conductivity for various materials at 0°C:

Table-2: Thermal Conductivity of Different Materials.

Materials	Thermal Conductivity (W/m.k)
Silver	429
Copper	401
Pure iron	86.5
Steel	51
Aluminum	237
Plastic	.17-.50
Glass	.4-1.0
Wood	.16-.25
Air	0.599
Water	0.0226

4-Size and Geometry

The size and geometry of the heat exchanger will also impact its performance. The length and diameter of the hairpin tubes, for example, will affect the flow rate and pressure drop of the system, as well as the overall heat transfer coefficient. Additionally, the number of hairpin tubes used in the design will impact the overall efficiency of the system.

5-Operational Conditions

Finally, the Operational conditions of the heat exchanger must be taken into account when designing the system. Factors such as the temperature and pressure of the fluids, the desired flow rate, and the required heat transfer rate will all influence the design of the heat exchanger.

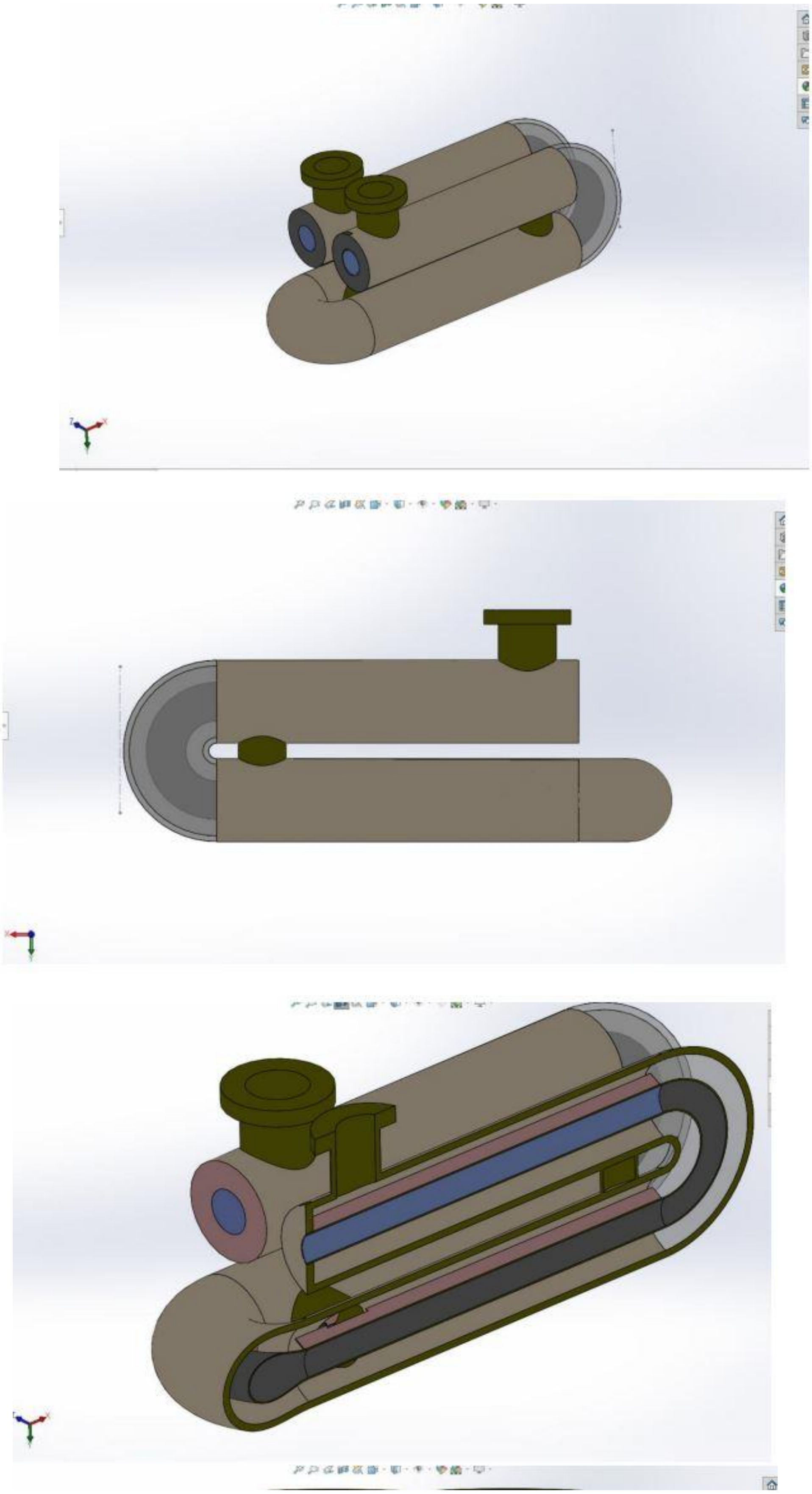


Figure-4: Design of Double Pipe Hair Pin Heat Exchanger

3.2 MATLAB Software.

MATLAB is an abbreviation for "matrix laboratory." While other programming languages usually work with numbers one at a time, MATLAB operates on whole matrices and arrays. Language fundamentals include basic operations, such as creating variables, array indexing, arithmetic, and data types. All MATLAB variables are multidimensional *arrays*, no matter what type of data. A *matrix* is a two-dimensional array often used for linear algebra.

MATLAB is a programming platform designed specifically for engineers and scientists to analyze and design systems and products that transform our world. The heart of MATLAB is the MATLAB language, a matrix-based language allowing the most natural expression of computational mathematics.

MATLAB is a programming and numeric computing platform used by millions of engineers and scientists to analyze data, develop algorithms, and create models.

MATLAB uses C/C++ Language for Operate. MATLAB supports Windows, macOS and Linux Operating System it has released final Update Version MATLAB R2023a in February 2023.

We used MATLAB R2016a for Simulation.

3.3 Microsoft excel

Microsoft Excel is a spreadsheet editor developed by Microsoft for Windows, macOS, Android, iOS, and ipodOS. It features calculation or computation capabilities, graphic tools, pivot tabes, and a macro programming language called Visual Basic for Applications (VBA)
Microsoft Excel has the basic features of all spreadsheets, using a grid of *cells* arranged in numbered *rows* and letter-named *columns* to organize data manipulations like arithmetic operations. It has a battery of supplied functions to answer statistical, engineering, and financial needs. In addition, it can display data as line graphs, histograms and charts, and with a very limited three-dimensional graphical display.
We made Graph for our Thesis report by using Microsoft Excel.

3.4 Validation

Table 3-4: Thermal Design

Fluid	Water (Cold)	Engine oil (hot)
Mass flow rate	.15 **m (kg/s)**	.15 **m (kg/s)**
Inlet Temperature	20 T_{ci}/T_{hi} (℃)	65 T_{ci}/T_{hi} (℃)
Outlet Temperature	24.897 T_{co}/T_{ho} (℃)	55 T_{co}/T_{ho} (℃)
Fouling	.000088R_{fi}/R_{fo} $(m^2\,K/W)$	.0000176R_{fi}/R_{fo} $(m^2\,K/W$

Properties	Symbols	Cold Fluids (Tube)	Hot Fluid (Annulus)
Density	**ρ**	997.5(kg/m^3)	864(kg/m^3)
Specific Heat	C_p	4.18(kJ/kg-K)	2.0473(kJ/kg-K)
Viscosity	**μ**	0.9465x10^{-3}(Pa-s)	7.445x10^{-3}(Pa-s)
Thermal Conductivity	k	0.603(W/m-K)	0.140(W/m-K)
Prandt lNumber	Pr	6.575	1081.4

Problem Statement

Engine Oil is to be cooled from 65°C to 55°C using Sea Water available at 20°C. Hot oil will be flowing through the annulus region at a flow rate of 0.15 kg/s and sea water will be flowing through the tube at a flow rate of 0.15 kg/s.

ΔPa, allowable = 3kPa

ΔPt, allowable = 1kPa

Pipe Selection

Inner Tube

We Selected 1” Type M Seamless Copper Tube

Inner Diameter of the tube, $d_i = 0.0268m$

Outer Diameter of the Tube, $\boldsymbol{d_o = 0.0286m}$

Hydraulic Diameter, $\boldsymbol{d_h = d_i = 0.0268m}$

Equivalent Diameter, $\boldsymbol{d_e = d_i = 0.0268m}$

Annulus Side

We Selected 2” Type M Seamless Copper Tube

Annulus Outside Diameter, $D_o = 0.06032m$

Annulus Inside Diameter, $D_o = 0.0525m$

Heat Duty

$$Q=\left(mC_pdT\right)_c = \left(mC_pdT\right)_h = 3.071 \times 10^3$$

Or, $dT_c = \frac{\left(mC_pdT\right)_h}{\left(mC_p\right)_c} = \frac{.15\times2047.3\times(65-55)}{.15\times4181}$

$= 4.897$

$\therefore$ To $= 24.897°C$

Heat Transfer Coefficient, h:

Tube Side (Sea Water)

$V_t = \frac{m}{\rho\pi\frac{d_i^2}{4}} = \frac{.15}{997.5\times\pi\times\frac{0.0268^2}{4}} = 0.0266$ m/s

$Re_t = \frac{\rho v_t d_i}{\mu} = \frac{997.5\times0.266\times0.268}{0.9465\times10^{-3}}$

$= 7.53 \times 10^3$ (Turbulent)

$Nu_t = 0.023Re_t^{0.8}Pr_t^{0.4} = 61.7052$

$h_i = \frac{Nu_i K}{d_i} = 1338.5\ W/m^2K$

Annulus Side (Engine Oil)

$A_c = \frac{\pi}{4}(D_i^2 - d_0^2)$

$= \frac{\pi}{4}(0.0525^2 - 0.0286^2)$

$= 0.001522\ m^2$

$P_w = \pi\ (D_i + d_o)$

$= (0.0525+0.0286)$

$= 0.2547$ m

$P_h = \pi \times d_o$

$= \pi \times 0.0268$

$= 0.08984976$ m

The Hydraulic Diameter is-

$D_h = \frac{4A_c}{P_w}$

$= \frac{4\times0.0015}{0.2547}$

$= 0.0239$ m

The equivalent Diameter for Heat Transfer is-

$D_e = \frac{4A_c}{P_h}$

$= \frac{4\times0.0015}{0.08985}$

$= 0.0667$ m

Fluid Velocity at annular side

$V_a = \frac{m}{P_h A_c}$

$= \frac{0.15}{0.08985\times0.001522}$

$= 0.1157$ m/s

Reynolds Number on the annular side-

$Re_a = \frac{\rho_h v_a D_h}{\mu_h} = \frac{864\times0.1157\times0.0239}{7.445\times10^{-3}}$

$= 320.90$ (laminar flow)

Gz $= Re_a P_{ra} (\frac{D_h}{L})$

$= 320.90 \times 1081.4 \times (\frac{0.0239}{0.6})$

$= 13823.01$

$Nu_a = 1.86\ (Gz)^{1/3}\ \frac{\mu_b}{\mu_w}^{0.14}$

$= 1.86 \times (13823.01)^{1/3} \times (\frac{7.445\times10^{-3}}{0.9465\times 10^{-3}})^{0.14}$

$= 59.5$ W/m^2K

$h_o = \frac{Nu_a k_h}{D_e} = 122.6085$ W/m^2K

Annulus Area, A_u

$A_u = 2(\pi d_o L)$

= 2 x 3.1416 x 0.0286 x 0.6

= 0.1078 m^2

Tube Area, A_i

$A_i = 2(\pi d_i L)$

= 2 x 3.1416 x 0.0268 x 0.6

= 0.1010m^2

Overall Heat Transfer Coefficient

$$U_{of} = \frac{1}{\frac{A_u}{A_i h_i} + \frac{A_u R_{fi}}{A_i} + \frac{A_u Ln\frac{d_o}{d_i}}{2\pi K 2L} + R_{fo} + \frac{1}{h_o}}$$

$$= \frac{1}{7.97\times10^{-4} + 9.39\times10^{-5} + 2.335\times10^{-6} + 0.176\times10^{-3} + 8.15\times10^{-3}}$$

$$= \frac{1}{9.219\times10^{-3}}$$

= 108.46 W/m^2K

Log Min Temperature Difference

$$\Delta T_m = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{Ln\frac{(T_{hi} - T_{co})}{(T_{ho} - T_{ci})}}$$

$$= \frac{(65-24.8966)-(55-20)}{Ln\frac{(65-24.8966)}{(55-20)}} = 37.4938℃$$

The total heat transfer surface area-

$$A_s = \frac{Q}{U_o \Delta T_{lm}} = \frac{3.071\times10^3}{108.46\times37.5}$$

= 0.755 m^2

Number of Hairpins-

$$A_s = \frac{A_s}{A_u} = \frac{0.755}{0.1078} = 7.0037 \cong 7$$

Mechanical Design

Pressure Drop (Tube Side)
Friction Coefficient

$f_t = (1.82\log(Re_t) - 1.64)^{-2}$

=0.0341

$$\Delta P_t = N_{hp} f_t \frac{2L}{d_i} \rho \frac{V_t^2}{2}$$

$$= 7 \times 0.341 \times \frac{2\times0.6}{0.0268} \times 997.5 \times \frac{.266^2}{2}$$

=377.16 Pa

Pressure Drop (Annulus Side)
Friction Coefficient

$$f_a = \frac{64}{Re_a} = \frac{64}{320.90}$$

S$\Delta P_a = N_{hp} f_a \frac{2L}{d_e} \rho \frac{V_a^2}{2}$

$$= 7 \times 0.199 \times \frac{2\times0.6}{0.0268} \times 864 \times \frac{.1157^2}{2}$$

= 360.7 Pa

Table-5: Theoretical Calculation and MATLAB data Comparison

Properties	**MATLAB data**	**Theoretical Data**
$\dot{m}_t$	.15	.15
T_{co}	24.78	24.897
N_{hp}	6.99	7.003
ΔP_t	378.75	377.16

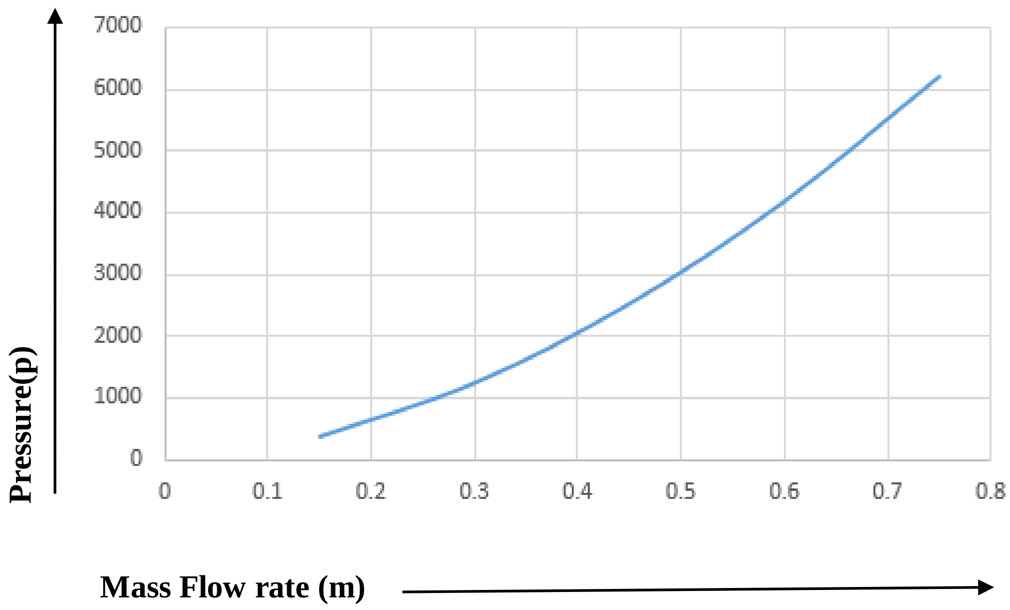
The Value from MATLAB simulation is in Close agreement with calculated value. So, the MATLAB Simulation is validated.

CHAPTER-4: RESULT AND DISCUSSION

After Theoretical Calculation and MATLAB Simulation we have got a result for theoretical Design. The Result is Given Below.

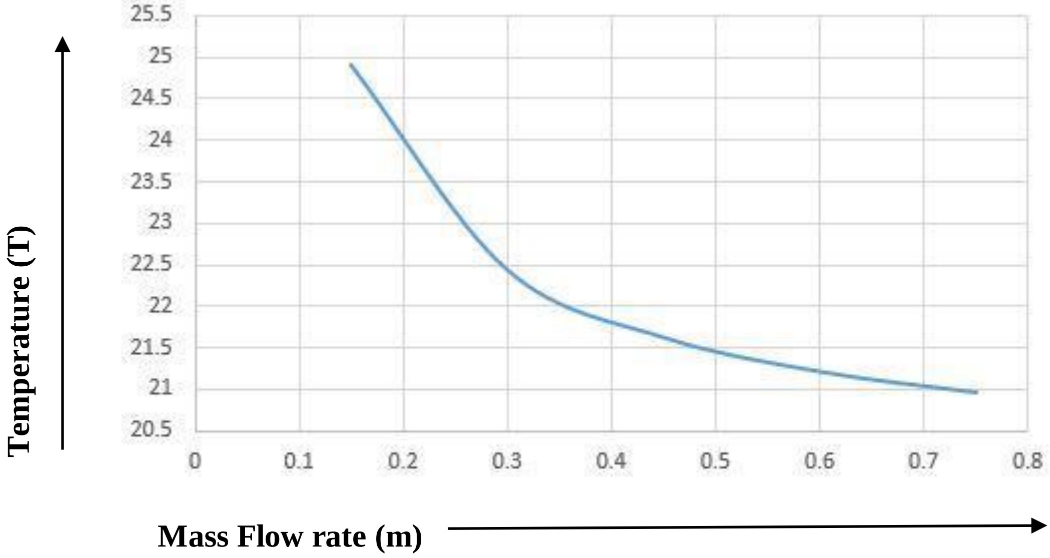
Number of Hair Pin	**07**
Total Heat Transfer Are	**.755$m2$**
Overall Heat Transfer Coefficient	**108.46 $W/m2k$**

We have done MATLAB Analysis with Different mass flow rate, the result of Analysis will discuss below.



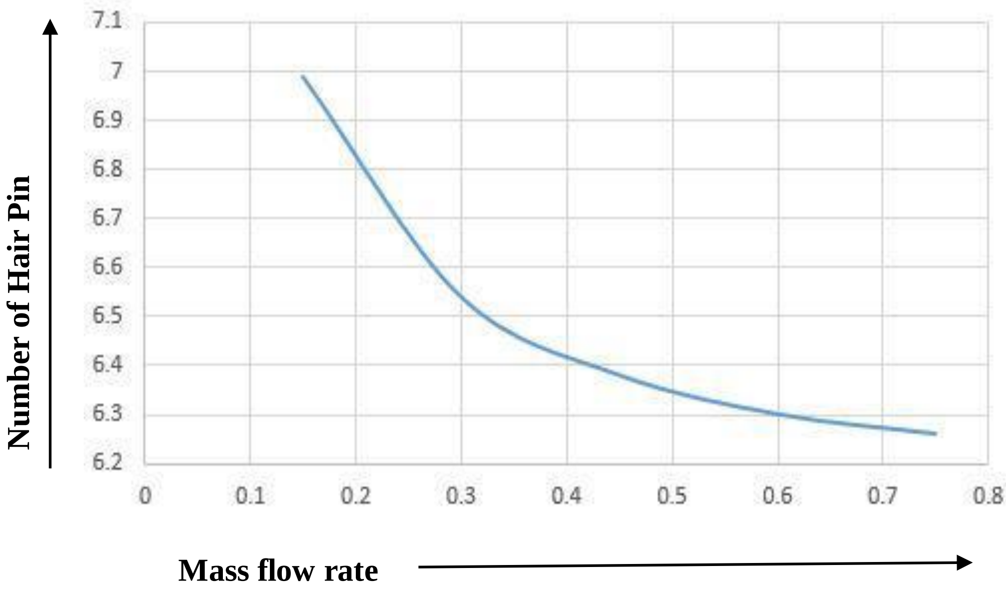
Mass flow rate Vs Pressure Drop.

In this Graph Changing in Pressure drop of a double pipe heat exchanger shown when we change Mass flow rate. We can see that if we change mass flow rate slightly, Pressure drop of the Heat Exchanger will increase so fast.



Mass flow rate Vs Temperature

We can see that Change in Temperature Outlet of Cold fluid is not much with the change of mass flow rate. It is not Satisfactory Result. Change in mass flow rate cannot make a good change in Temperature Difference.



Mass flow rate Vs Number of Hair Pin

This Graph shows Comparison between Mass flow rate and Number of Hair pin, in this graph we can see by increasing mass flow rate, Number of Hairpin do not change or change of number of hairpin is not satisfactory.
After all this discussion we can say that for double pipe heat exchange by increasing mass flow rate we will not get satisfactory result.

CHAPTER-5: CONCLUSION & RECOMMENDATION

After the Simulation and Analysis of Double Pipe Heat Exchanger by MATLAB software, we were able to understand that if we increase the mass flow rate slightly then Pressure Drop increases too much, for this reason need High Pumping Requirement but there's not too much Change in Temperature Difference and Number of Hairpin still stay same. That's why it is not recommended to change mass flow rate to get effect.

To conclude, in order to improve the overall heat transfer coefficient heat transfer rates of the heat exchanger, there is various methods to enhance it such as using enhanced surface, finning the tubes or even add tube inserts such as tabulators to the heat exchanger. It can be concluded for this project that adding fins to the outer wall of the inner tube will have some positive impact towards the heat exchanger performance and heat transfer of fluids, also there was lots of scope of study like changing the fluids, Changing Inlet Temperature of fluids, and Changing materials for tube and annulus side.

CHAPTER-6: APPENDIX

Code-01

```
L=0.6;
k=398;


mdotc=0.15;
Tci=20;
rhoc=997.5;
cpc=4180;
muc=0.9465e-3;
kc=0.603;
Prc=6.575;
di=0.0268;
do=.0286;
Ao=2*pi*do*L;
Ai=2*pi*di*L;
Rfi=0.000088;


mdoth=0.15;
Thi=65;
Tho=55;
rhoh=864;
cph=2047.3;
muh=7.445e-3;
kh=0.14;
Prh=1081.4;
Di=0.0525;
Ac=pi/4*(Di^2-do^2);
Pw=pi*(Di+do);
Ph=pi*do;
Dh=4*Ac/Pw;
De=4*Ac/Ph;
Rfo=0.000176;


vc=mdotc/rhoc/pi/di^2*4;
Rec=rhoc*vc*di/muc;
Nuc=0.023*Rec^0.8*Prc^0.4;
hc=Nuc*kc/di;


vh=mdoth/rhoh/Ac;
Reh=rhoh*vh*Dh/muh;
Gzh=Reh*Prh*Dh/L;
Nuh=1.86*Gzh^(1/3)*(muh/muc)^0.14;
hh=Nuh*kh/De;
```

```
Uo=1/((Ao/Ai/hc)+(Ao/Ai*Rfi)+(Ao*log(do/di)/4/pi/k/L)+Rfo+1/hh);
Qdot=mdoth*cph*(Thi-Tho);
Tco=Tci+Qdot/mdotc/cpc;
LMTD=((Thi-Tco)-(Tho-Tci))/log((Thi-Tco)/(Tho-Tci));
As=Qdot/Uo/LMTD;
Nhp=As/Ao;



mdotc
Tco
Nhp
```

Code-02

```
L = 0.6;
k = 398;

mdotc = 0.15;
Tci = 20;
rhoc = 997.5;
cpc = 4180;
muc = 0.9465e-3;
kc = 0.603;
Prc = 6.575;
di = 0.0268;
do = .0286;
Ao = 2 * pi * do * L;
Ai = 2 * pi * di * L;
Rfi = 0.000088;

mdoth = 0.15;
Thi = 65;
Tho = 55;
rhoh = 864;
cph = 2047.3;
muh = 7.445e-3;
kh = 0.14;
Prh = 1081.4;
Di = 0.0525;
Ac = pi / 4 * (Di^2 - do^2);
Pw = pi * (Di + do);
Ph = pi * do;
Dh = 4 * Ac / Pw;
De = 4 * Ac / Ph;
Rfo = 0.000176;

vc = mdotc / rhoc / pi / di^2 * 4;
Rec = rhoc * vc * di / muc;
Nuc = 0.023 * Rec^0.8 * Prc^0.4;
hc = Nuc * kc / di;
```

```
vh = mdoth / rhoh / Ac;
Reh = rhoh * vh * Dh / muh;
Gzh = Reh * Prh * Dh / L;
Nuh = 1.86 * Gzh^(1/3) * (muh/muc)^0.14;
hh = Nuh * kh / De;


Uo = 1 / ((Ao/Ai/hc) + (Ao/Ai*Rfi) + (Ao*log(do/di)/4/pi/k/L) + Rfo + 1/hh);
Qdot = mdoth * cph * (Thi - Tho);
Tco = Tci + Qdot / mdotc / cpc;
LMTD = ((Thi-Tco) - (Tho-Tci)) / log((Thi-Tco) / (Tho-Tci));
As = Qdot / Uo / LMTD;
Nhp = 7;

fc = (1.82 * log10(Rec) - 1.64)^-2;
delPc = Nhp * fc * 2 * L / di * rhoc * vc^2 / 2;

fh = 64 / Reh;
delPh = Nhp * fh * 2 * L / De * rhoh * vh^2 / 2;

mdotc
delPc
```

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