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Comparative Analysis of Heat Transfer and Pressure Drop in a Double Pipe Heat Exchanger under Parallel and Counter flow by using MATLAB

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ABSTRACT

In this work, the design parameters of a double pipe heat exchanger is analysed in detail using MATLAB software. The experiment is done in a double pipe heat exchanger made of inner tube with copper and annulus tube with stainless steel. The readings were taken at the flow rate of 0.02 Kg/sec in both parallel and counter flow in a double pipe heat exchanger. The MATLAB is one of the high level computational software which is used for the complex calculations involved in the field of engineering. A MATLAB programs were developed using standard algorithms for parallel and counter flow. The initial input values for the program is taken from the observed reading in the double pipe heat exchanger. The computations were done by using the experimental readings in manual method and also analysed using MATLAB program. The results obtained in the manual calculations and MATLAB results are compared and the final conclusion is given.

Keywords: Double pipe heat exchanger, Design calculation, Experimental analysis, MATLAB analysis, Comparison.

1. Introduction

A double pipe heat exchanger is a sort of heat exchanger which includes concentric pipes parted through a mechanical closure. The name of this heat exchanger indicates that it makes use of pipes to exchange heat among fluids. One pipe has hot fluid whilst the opposite pipe has cold fluid. These two fluids do not mix with each other as they are separated by pipes. This heat exchanger is likewise known as a jacketed U-tube, jacketed tube, hairpin, and pipe-in-pipe heat exchanger. There are two types of double pipe heat exchangers based on the type of flow as follows:

1. Parallel flow heat exchanger
2. Counter flow heat exchanger

2. Problem Statement

The problems statement descries the existing difficulties in field of engineering applications. In this project we discuss the problems regards to design and calculations involved in the double pipe heat exchanger are given as follows:

- It is difficult to compute the manual design calculation for the double pipe heat exchanger.
- We have to repeat the same computations for the different flow takes place in the double pipe heat exchanger.
- Manual method of calculations involved in design of double pipe heat exchanger several computational errors.

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- It takes huge time to compute the manual calculation in the determination of heat transfer parameters of double pipe heat exchanger.
- The results obtained in the manual calculations the range of accuracy is low when compared with the software simulation.

To overcome these difficulties we made a computational analysis by using the MATLAB software and the final results are verified with the manual calculations.

3. Literature Review

[1] Mohammed Rabeeh V and Vysakh S designed shell and tube heat exchanger using MATLAB codes. In their work a standard procedure is followed in design of shell and tube heat exchangers and the parameters required for building a heat exchanger are calculated by numerical method until the dimensions satisfy the condition for maximum overall heat transfer coefficient. A code written in MATLAB is used where the calculations are iterated by varying the TEMA specified values for tube length and tube outer diameter. By plotting a temperature v/s tube length graph in MATLAB using the energy balance differential equation and analysing the same, time required for the shell and tube heat exchanger to reach a steady state condition is obtained.

[2] Andre L.H. Costa and Eduardo M. Queiroz worked together for design optimization of shell and tube heat exchangers. The formulated problem consists of the minimization of the thermal surface area for a certain service, involving discrete decision variables. Additional constraints represent geometrical features and velocity conditions which must be complied in order to reach a more realistic solution for the process task. The optimization algorithm is based on a search along the tube count table where the established constraints and the investigated design candidates are employed to eliminate non optimal alternatives, thus reducing the number of rating runs executed. The performance of the algorithm and its individual components are explored through two design examples.

[3] SteinarHauan and Ignacio E. Grossmann developed mathematical programming model for heat exchanger network synthesis including detailed heat exchanger design. This paper addresses the optimal design of shell-and-tube heat exchangers via a mathematical programming approach. It is shown that it is possible to develop a design model for shell-and tube heat exchangers that takes into account some important construction variables: number of tubes, number of passes, internal and external tube diameters and tube arrangement pattern, number of baffles, head type, and fluid allocation (i.e., the allocation of the fluid streams to the shell or tubes).

To overcome these difficulties we made a computational analysis by using the MATLAB software and the final results are verified with the manual calculations.

4. Methodology

The methodology provides us the sequence operations carried out in this project by chronological order. The experimental analyses is compared with the MATLAB analyses to check the accuracy of the computational software and the program for double pipe heat exchanger is generated to get output for the different flow conditions. Finally, discuss the result obtained by MATLAB analysis and the give conclusion.

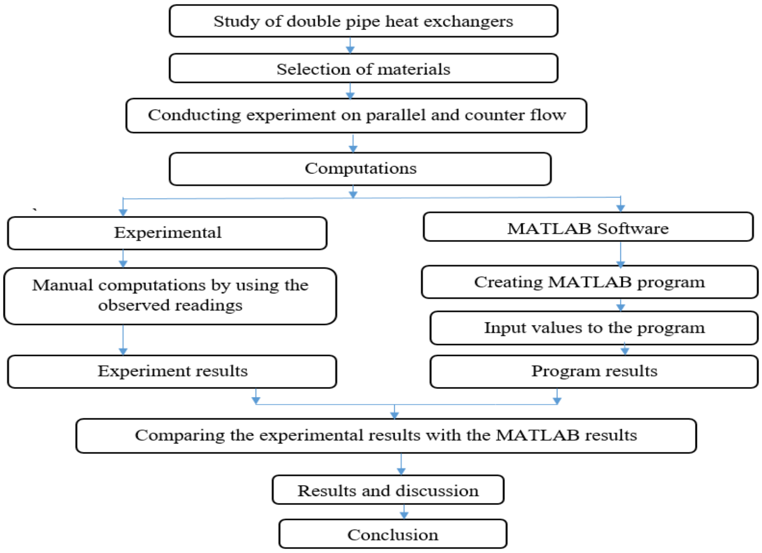


Figure.1 .Methodology

5. Material selection

Material selection is the foundation of all engineering applications and design. This selection process can be defined by application requirements, possible materials, physical principles, and selection. The design or function of the part/application is the application requirements. The application requirements are specific given the application. In present work, the material of stainless steel and copper has been selected for heat pipe. The inner pipe is made of copper and external pipe is stainless steel.

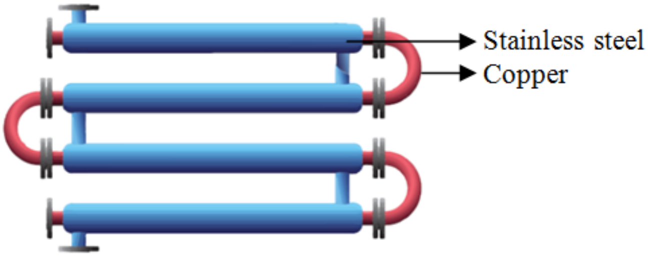


Figure.2. Materials of double pipe heat exchanger

6. Experimental Analysis

A mathematical model for minimizing the annual cost incurred in the operation of a heat exchanger has to be formulated and optimized. The thermal and the physical properties of the two fluids at the inlet conditions are known. It is desired that the heat exchanger be designed for given outlet temperatures of both the inner-side and outer-side fluids. The required heat transfer area and pumping capacity to achieve the desired temperature conditions have been computed as a function of the design variables. The objective function is a function of the effective heat transfer area and the pumping power required to overcome the pressure drop.

6.1 Specifications:

The double pipe heat exchanger has the following specifications and dimensions:

Parameters	**Valves**
Inner tube of copper diameter (d_i)	0.02 m
Outer tube of stainless steel diameter (d_o)	0.038 m
Length of the tube (l)	1 m
Density of the hot fluid (e_h)	980.2 kg/m^3
Density of the cold fluid (e_c)	997.77 kg/m^3
Number of hairpins (N_{hp})	1
Specific heat capacity of hot fluid (C_{ph})	4187 J/kg .K
Specific heat capacity of cold fluid (C_{pc})	4187 J/kg .K

Table.1 Specifications of double pipe heat exchanger

6.2 Calculations for Parallel Flow:

The readings were taken in the double pipe heat exchanger under parallel flow condition are given below:

Flow rate		**Temperature (°C)**			
LPH	**kg/sec**	**T_{hi}**	**T_{ho}**	**T_{ci}**	**T_{co}**
100	0.02	64.3	51.8	26.9	38.2

Table.2 Experimental readings of parallel flow

1) HEAT TRANSFER (Q):

- Heat transfer in hot fluid flow: $Q_h = m_h \times C_{ph} \times (T_{hi} - T_{ho}) = 1046.75\ W$
- Heat transfer in cold fluid flow: $Q_c = m_c \times C_{pc} \times (T_{co} - T_{ci}) = 946.26\ W$
- Heat transfer: $Q = \frac{(Q_h + Q_c)}{2} = \mathbf{996.51\ W}$

2) OVERALL HEAT TRANSFER COEFFICIENT (U):

- Area of the double pipe heat exchanger: $a = 3.14 \times d_i \times l = 3.14 \times 0.02 \times 1 = 0.0628\ m^2$
- Difference in temperature at hot fluid flow: $T_1 = T_{hi} - T_{ci} = 64.3 - 26.9 = 37.4°C$
- Difference in temperature at cold fluid flow: $T_2 = T_{ho} - T_{co} = 51.8 - 38.2 = 13.6°C$

- Log mean temperature difference: lmtd = $\frac{(T_1 - T_2)}{\ln(\frac{T1}{T2})}$ = $\frac{37.4 - 13.6}{\ln(\frac{37.4}{13.6})}$ = *23.52°C*
- Overall heat transfer coefficient: U = $\frac{Q}{a\ x\ lmtd}$ = ***674 W/ m $^{2.}$K***

6.3 Calculations for Counter Flow:

The readings were taken in the double pipe heat exchanger under counter flow condition are given below:

Flow rate		**Temperature (ºC)**			
LPH	**kg/sec**	**T_{hi}**	**T_{ho}**	**T_{ci}**	**T_{co}**
100	0.02	54.2	42.4	26.7	36.8

Table.3 Experimental readings of counter flow

1) HEAT TRANSFER (Q):

- Heat transfer in hot fluid flow: $Q_h = m_h$ x C_{ph} x $(T_{hi} - T_{ho})$ = *988.13 W*
- Heat transfer in cold fluid flow: $Q_c = m_c$ x C_{pc} x $(T_{co} - T_{ci})$ = *845.77 W*
- Heat transfer: Q = $\frac{(Q_h + Q_c)}{2}$ = ***916.95 W***

2) OVERALL HEAT TRANSFER COEFFICIENT (U):

- Area of the double pipe heat exchanger: a = 3.14 x d_i x l =3.14 x 0.02 x 1 = *0.0628 m ^{2}*
- Difference in temperature at hot fluid flow: $T_1 = T_{hi} - T_{co}$ = 54.2 – 36.8 = *17.4 °C*
- Difference in temperature at cold fluid flow: $T_2 = T_{ho} - T_{ci}$ = 42.4 – 26.7 = *15.7°C*
- Log mean temperature distribution: lmtd = $\frac{(T_1 - T_2)}{\ln(\frac{T1}{T2})}$ = $\frac{17.4 - 15.7}{\ln(\frac{17.4}{15.7})}$ = *16.53 °C*
- Overall heat transfer coefficient: U = $\frac{Q}{a\ x\ lmtd}$ = ***883.31 W/ m $^{2.}$K***

6.4 Calculation for Pressure Drop in Parallel and Counter Flow:

1) PRESSURE DROP IN TUBE SIDE (D_{pt}):

- Area of the tube: $A_t = \frac{(3.14\ x\ d_i{}^2)}{4}$ = *3.14 x 10^{-4} m ^{2}*
- Mean velocity of the hot fluid flow: $U_t = \frac{m_h}{e_h\ x\ A_t}$ = *0.0649 m/sec*
- Discharge of the hot fluid flow: $q_h = \frac{m_h}{1000} = \frac{0.02}{1000}$ = *0.02 x 10^{-3} m ^{3}/sec*
- Velocity of the hot fluid flow: $u_h = q_h$ x A_t = *6.28 x 10^{-9} m/sec*
- Reynolds number for the hot fluid flow: $R_t = \frac{(e_h\ x\ U_t\ x\ d_i)}{u_h}$ = *2.025 x 10 ^{8}*
- Friction coefficient for the hot fluid flow: $F_t = \frac{1}{((3.64\ x\ (log\ (R_t))-3.28)^2}$ = *1.376 x 10 $^{-3}$*
- Pressure drop per unit length for tube side: $D_{pt} = \frac{(4\ x\ F_t\ x\ e_h\ x\ U_t{}^2\ x\ N_{hp})}{d_i}$ = *1.136 N/m ^{2}*

2) PRESSURE DROP IN ANNULUS SIDE (D_{pa}):

- Area of the annulus: $A_a = \frac{(3.14\ x\ ((d_o)^2 - (d_i)^2))}{4}$ = *8.1954 x 10 $^{-4}$ m ^{2}*
- Mean velocity of the cold fluid flow: $U_a = \frac{m_c}{e_c\ x\ A_a}$ = *0.0244 m/sec*
- Annulus diameter: $D_h = d_o - d_i$ = 0.038 – 0.02 = *0.018 m*
- Discharge of the cold fluid flow: $q_c = \frac{m_c}{1000} = \frac{0.02}{1000}$ = *0.02 x 10 $^{-3}$ m ^{3}/sec*
- Velocity of the cold fluid flow: $u_c = q_c$ x A_a = *1.639 x 10 $^{-8}$ m/sec*
- Reynolds number for the cold fluid flow: $R_a = \frac{(e_c\ x\ U_a\ x\ D_h)}{u_c}$ = *2.679 x 10^7*
- Friction coefficient for the cold fluid flow: $F_a = \frac{1}{((3.64\ x\ (log\ (R_a))-3.28)^2}$ =*1.771 x 10 $^{-3}$*
- Pressure drop per unit length in annulus side: $D_{pa} = \frac{(4\ x\ F_a\ x\ e_c\ x\ U_a{}^2\ x\ N_{hp})}{D_h}$ = *0.2347 N/m ^{2}*

7. MATLAB Analysis

MATLAB is especially used in engineering applications. It is frequently used in systems analysis and mathematical calculations and their visualization. MATLAB has been a significant shift in engineering from in-lab experiments and testing to numerical simulations. We can use MATLAB to check for equation solutions, integrations, derivations and to optimize results in design problems that involve multiple varying parameters. We can apply and design different algorithms and makes algorithm design faster and better using MATLAB. We can upload data from different sources, such as files, databases, or the internet, into MATLAB. At the same time, you can analyse them. We can also use it to process the experimental data and to make plots to visualize experiments and extract conclusions. MATLAB is one of the best programs used for solving mathematical operations such as matrix and linear algebras.

7.1 Program for double pipe heat exchanger:

```
% Program for double pipe heat exchanger
% Program for Parallel Flow and Counter Flow
clc ;
clear all;
% Read input parameters
di=input('Enter tube inner diameter:');
do=input('Enter tube outer diameter:');
l=input('Enter length of the tube:');
Tho=input('Enter hot fluid outlet temperature:');
Thi=input('Enter hot fluid inlet temperature:');
Tco=input('Enter cold fluid outlet temperature:');
Tci=input('Enter cold fluid inlet temperature:');
eh=input('Enter density of hot fluid:');
ec=input('Enter density of cold fluid:');
mh=input('Enter mass flow rate of hot fluid:');
mc=input('Enter mass flow rate of cold fluid:');
Nhp=input('Enter number of hairpins:');
cph=input('Enter the specific heat capacity of hot water');
cpc=input('Enter the specific heat capacity of cold water');
% Calculations for heat transfer
Qh=mh*cph*(Thi-Tho); % Hot fluid side
Qc=mc*cpc*(Tco-Tci); % Cold fluid side
Q=(Qh+Qc)/2; % Heat transfer
% For Parallel Flow
T1=Thi-Tci; % Inlet temperature drop
T2=Tho-Tco; % Outlet temperature drop
if(T1==T2) % If same capacity ratio
lmtd=T1;
else
% For Counter Flow
T1=Thi-Tco % Inlet temperature drop
T2=Tho-Tci % Outlet temperature drop
if(T1==T2) % If same capacity ratio
```

```
lmtd=T1;
else
% Log mean temperature distribution
lmtd=(T1-T2)/(log(T1/T2)/log(2.7));
end;
a=3.14*di*l; % Area
U=Q/(a*lmtd);% Overall heat transfer coefficient
% Calculations for pressure drop in tube side, hot water
At=(3.14*di*di)/4; % Area of tube
Ut=mh/(eh*At); % Mean velocity
qh=mh/1000; % Discharge of tube
uh=qh*At; % Velocity of tube
Rt=(eh*Ut*di)/uh; % Reynolds number
Ft=((3.64*(log10(Rt))-3.28))^(-2);
% Friction coefficient
% Pressure drop in tube side per unit length
Dpt=(4*Ft*eh*Ut*Ut*Nhp)/di;
% Calculations for pressure drop in annulus side, cold water
Aa=(3.14*((do^2)-(di^2)))/4;
% Area of annulus
Ua=mc/(ec*Aa);% Mean velocity
Dh=do-di;% Annulus diameter
qc=mc/1000; % Discharge of annulus
uc=qc*Aa; % Velocity of annulus
Ra=(ec*Ua*Dh)/uc;% Reynolds number
Fa=((3.64*(log10(Ra))-3.28))^(-2);
% Friction coefficient
% Pressure drop in annulus side per unit length
Dpa=(4*Fa*ec*Ua*Ua*Nhp)/Dh;
i=l/5;
k=0;
L=zeros(5,1);
Dpt=zeros(5,1);
Dpa=zeros(5,1);
for j=1:6
L(j)=k;
Dpt(j)=Dpt*k;
% Tube side pressure drop
Dpa(7-j)=Dpa*k;
% Annulus side pressure dropk=k+i;
end
```

```
% Results
disp('Results:');
disp('Heat  transfer in watts =');disp(Q);
disp('Overall heat  transfer coefficient in watts per meter square Kelvin=');disp(U);
disp('Tube side pressure drop Dpt in Pascal =');disp(Dpt(6,1));
disp('Annulus side pressure drop Dpa in Pascal =');disp(Dpa(1,1));
% Graph for tube side pressure drop
figure
plot(L(:,1),
Dpt(:,1)','-r','linewidth',1.75);
xlabel('Length');
ylabel('Tube side pressure drop');
title('Simulation of tube side pressure drop');
% Graph for annulus side pressure drop
figure
plot(L(:,1),
Dpa(:,1)','-r','linewidth',1.75);
xlabel('Length');
ylabel('Annulus side pressure drop');
title('Simulation of annulus side pressure drop');
% Program end
```

1) RESULTS FOR PARALLEL FLOW:

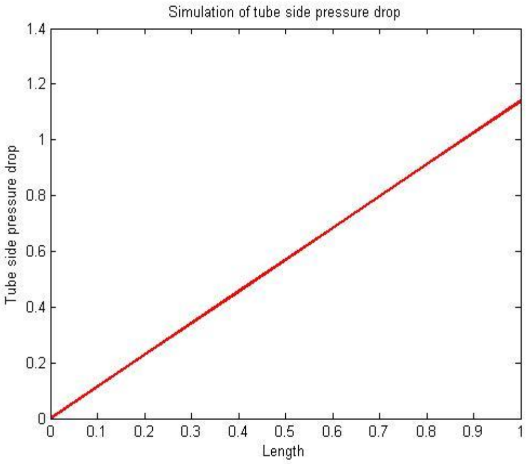
```
Enter tube inner diameter: 0.02
Enter tube outer diameter: 0.038
Enter length of the tube: 1
Enter hot fluid outlet temperature: 51.8
Enter hot fluid inlet temperature: 64.3
Enter cold fluid outlet temperature: 38.2
Enter cold fluid inlet temperature: 26.9
Enter density of hot fluid: 980.2
Enter density of cold fluid: 997.77
Enter mass flow rate of hot fluid: 0.02
Enter mass flow rate of cold fluid: 0.02
Enter number of hairpins: 1
Enter the specific heat capacity of hot Water: 4187
Enter the specific heat capacity of cold Water: 4187
Results:
Heat transfer in watts = 996.5060
Overall heat transfer coefficient in watts per meter square Kelvin = 675.0366
```

2) RESULTS FOR COUNTER FLOW:

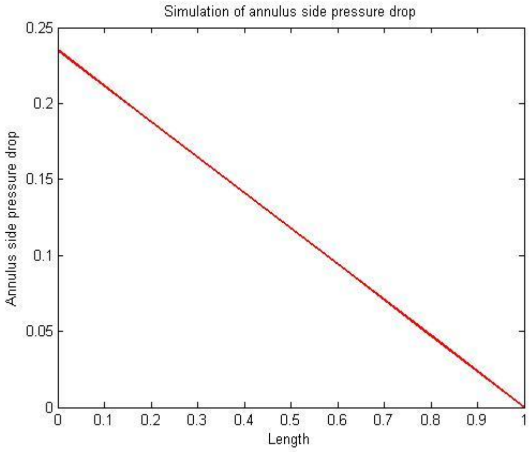
```
Enter hot fluid outlet temperature: 42.4
```

```
Enter hot fluid inlet temperature: 54.2

Enter cold fluid outlet temperature: 36.8

Enter cold fluid inlet temperature: 26.7

Results:

Heat transfer in watts = 916.9530

Overall heat transfer coefficient in watts per meter square Kelvin = 885.0217

Tube side pressure drop Dpt in Pascal = 1.1390

Annulus side pressure drop Dpa in Pascal = 0.2350
```

Graph.1 Length Vs Tube side pressure drop



Graph.2 Length Vs Annulus side pressure drop



8. Result and Discussion

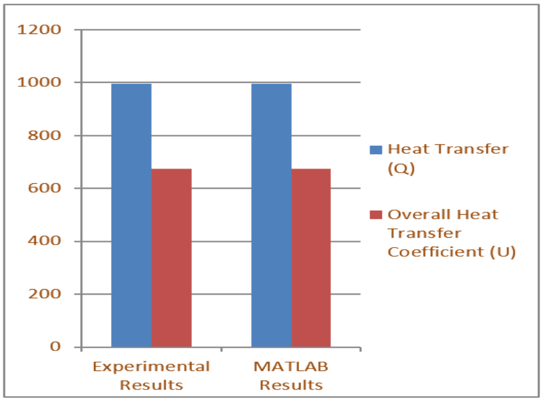
8.1 Comparing the results of Parallel Flow:

In this section, we compare the experimental results with the MATLAB results obtained in the double pipe exchanger under parallel flow condition. The following results were obtained from the above analysis:

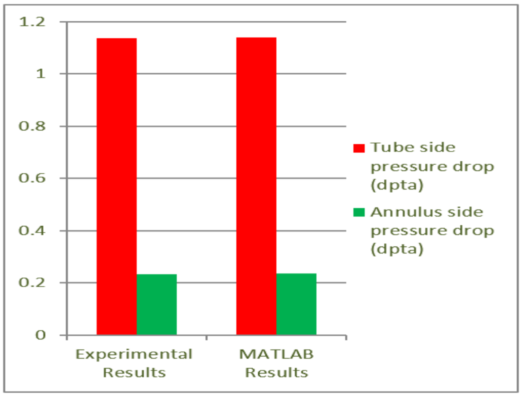
FLOW RATE		EXPERIMENTAL RESULTS			
LPH	**kg/sec**	**`Q**	**U**	**D_{pt}**	**D_{pa}**
		Watts	**W/m^2K**	**Pascal**	**Pascal**
100	0.02	996.51	674	1.136	0.2347
		MATLAB RESULTS			
		996.51	675.03	1.139	0.2350

Table.4 Comparison on the results of parallel flow

The results were plotted in the bar chart to understand the comparison between the experimental results with the MATLAB results for parallel flow.



Graph.3 (a) Experimental results Vs MATLAB results in Parallel flow



Graph.3 (b) Experimental results Vs MATLAB results in Parallel flow

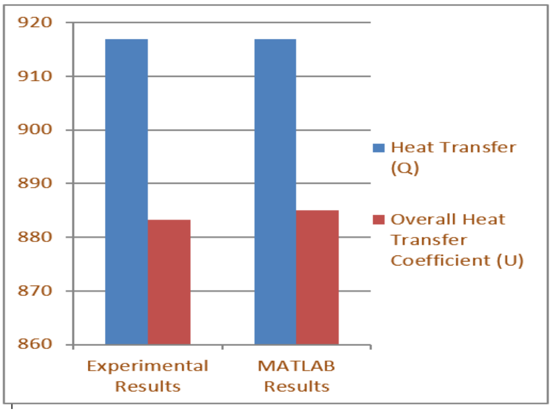
8.2 Comparing the results of Counter Flow:

In this section, we compared the experimental results with the MATLAB results obtained in the double pipe exchanger under counter flow condition. The following results were obtained from the above analysis:

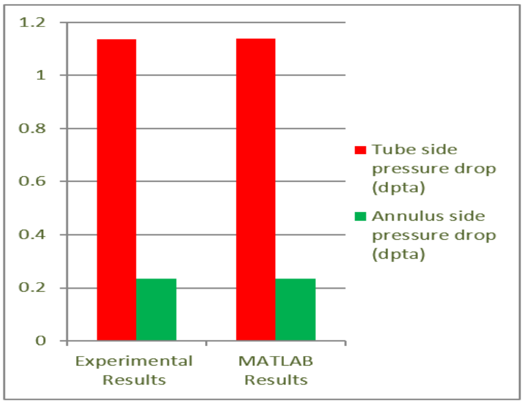
FLOW RATE		**EXPERIMENTAL RESULTS**			
LPH	**kg/sec**	**`Q**	**U**	**D_{pt}**	**D_{pa}**
		Watts	**W/m^2K**	**Pascal**	**Pascal**
100	0.02	916.95	883.31	1.136	0.2347
		MATLAB RESULTS			
		916.95	885.02	1.139	0.2350

Table.5 Comparison on the results of counter flow

The results were plotted in the bar chart to understand the comparison between the experimental results with the MATLAB results for counter flow.



Graph.4 (a) Experimental results Vs MATLAB results in Counter flow



Graph.4 (b) Experimental results Vs MATLAB results in Counter flow

9. Conclusion

In the present work, the design parameters of double pipe heat exchanger is analysed using an experimental method and by using MATLAB software. Here we used MATLAB software is one of the tool for computing the numerical calculation and the final results were plotted in the graph. The experimental readings were taken in the double pipe heat exchanger with flow rate 0.02 Kg/sec in both parallel and counter flow to determine design parameters of the heat exchanger. A program from calculating the design parameters of the heat exchanger is developed using MATLAB software and the input parameters taken from the observed readings. We made an analysis of design parameters of double pipe heat exchangers such as heat transfer rate, overall heat transfer coefficient and pressure drop in tube side and annulus side by which the comparison is taken between the manual calculations results to the MATLAB results. From this comparison the results obtained in the MATLAB program is more accurate with the experimental results. So, we conclude that the MATLAB software is recommended for the calculations involved in heat exchangers to get better results in easier and faster.

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Nomenclature

d_i - Inner tube diameter
d_o - Outer tube diameter
D_i - Annulus nominal diameter
l - Length of the tube
T_{ho} - Hot fluid outlet temperature
T_{hi} - Hot fluid inlet temperature
T_{co} - Cold fluid outlet temperature
T_{ci} - Cold fluid inlet temperature
e_h - Density of hot fluid
e_c - Density of cold fluid
u_h - Velocity of hot fluid
u_c - Velocity of cold fluid
m_h - Mass flow rate of hot fluid
m_c - Mass flow rate of cold fluid
q_h - Discharge of hot fluid
q_c - Discharge of cold fluid
N_{hp} - Number of hairpins
U - Overall heat transfer coefficient
C_{ph} - Specific heat capacity of hot fluid
C_{pc} - Specific heat capacity of cold fluid
Q_h - Heat transfer by hot fluid
Q_c - Heat transfer by cold fluid
Q - Heat transfer
T_1 - Difference in temperature at hot fluid
T_2 - Difference in temperature at cold fluid
Lmtd - Log mean temperature difference
a - Area
A_t - Area on tube side
U_t - Mean velocity at tube side
R_t - Reynolds’s number at tube side
F_t - Friction coefficient at tube side
A_a - Area on annulus side
U_a - Mean velocity at annulus side
D_h - Difference between Di and do
R_a - Reynolds’s number at annulus side
F_a - Friction coefficient at annulus side
D_{pt} - Pressure drop per unit length at tube side
D_{pa} - Pressure drop per unit length at annulus side