Effect of Air Bubble Injection on the Performance of a Double Pipe Heat Exchanger Using CFD

Prof. Pushparaj Singh[1], Jeewan Prakash Chauhan[2]
[1]*Rewa Institute of Technology, Professor, REWA, MP, INDIA*
[2]*Rewa Institute of Technology, M.Tech Scholar, REWA, MP, INDIA*

***Abstract*- Upgrade the thermal performance of heat exchangers, increasing the heat transfer coefficient is largely based on, and it is referred to as the technologies of the enhanced heat transfer. Because of the energy crisis occurred in the 70s last century, the technology of enhanced heat transfer achieved rapid development and the number of published papers in this field grew fast every year. In recent years, researchers have tried to reduce the size and weight of heat exchangers without reduction of heat transfer rate. Numerous methods have been presented to increase the heat transfer rate and performance of heat exchangers in the past decades. Generally, these techniques can be categorized into two principal types: (1) passive techniques which require no direct application of external power, such as using of nanofluids, coarsening heat exchanger surfaces and inserting fluid turbulators (2) active techniques which require external power, for instance surface vibration and electrostatic fields.**

Air bubble injection is one such technique but passive one to enhance the heat transfer rate. Air bubbles are induced to any flowing fluid channels to maximize the heat transfer characteristics of the fluid. As per the different studies, the bubble dynamics creates much impact on the wall skin friction drag. Injecting bubbles in the flowing fluid reduces the density of the liquid that leads to the generation of baroclinic vorticity on larger scale.

In present work attempts are made to enhance the heat transfer rate in double pipe heat exchangers by injecting air bubbles. For this a double pipe heat exchanger were used in which a tube is inserted with 12 no. of holes by which air bubbles are injected. Modelling is done using ANSYS. The CFD simulated results achieved from double pipe heat exchanger are compared with with and without air bubble injection. Based on the results, From the CFD analysis it has been observed that using air bubble the Nusselt number and overall heat transfer coefficient increased. As compared the overall heat transfer coefficient using air bubble increase by 1.27 times as compared to without air bubble injection. Nusselt number using air bubble increase by 1.23 times as compared to without air bubble injection.

Index terms- Heat exchanger, double pipe, Air bubble injection, Heat transfer, ANSYS 14.5, Overall heat transfer coefficient, Nusselt number.

I. INTRODUCTION

Heat exchangers are widely used in industries, and the improvement of their performances will raise the efficiency of energy utilization, and minimize the equipment. With the rapid growth of energy consumption in recent decades, improvement of heat exchanger becomes more important for energy conservation. Generally, to upgrade the thermal performance of heat exchangers, increasing the heat transfer coefficient is largely based on, and it is referred to as the technologies of the enhanced heat transfer. Because of the energy crisis occurred in the 70s last century, the technology of enhanced heat transfer achieved rapid development and the number of published papers in this field grew fast every year. In recent years, researchers have tried to reduce the size and weight of heat exchangers without reduction of heat transfer rate.

Researchers proposed different methods for improving the thermal performance of heat exchangers. Some of said methods such as using corrugated tubes, turbulators and finned tubes are termed passive methods which do not need external power. Others methods such as vibration and electrostatic fields which require external powers are termed active methods .All methods are based on increasing the turbulence level of the fluid flow and mixing the thermal boundary layer of heat exchanger. As we know double pipe heat exchanger is one of the non-contact type heat exchanger widely being used in many process industries. About 45% of the total heat exchanger used is double pipe heat exchanger and is widely being used in power plants, food processing industries, chemical industries, petro-chemical industries etc. Different methods have been introduced to enhance the performance of the double pipe heat exchangers. Studies are being done with different models of double tube, with different cooling medium, introduction of turbulence in flow fields etc.

Air bubble injection is one such technique but passive one to enhance the heat transfer rate. Air bubbles are induced to any flowing fluid channels to maximize the heat transfer characteristics of the fluid. As per the different studies, the bubble dynamics creates much impact on the wall skin friction drag. Injecting bubbles in the flowing fluid reduces the density of the liquid that leads to the generation of baroclinic vorticity on larger scale.

If an air flow is injected into the inner or outer tube (annular space between the two tubes) of a horizontal double pipe heat exchanger, many ambulant air bubbles are formed inside the test section. The mobility of said air bubbles (because of buoyancy force) makes considerable commixture inside the heat exchanger. Hence, the movement of air bubbles through the heat exchanger increases the heat transfer rate by increasing the turbulence level of the water flow and mixing the thermal boundary layer. This mechanism was employed to enhance the heat transfer rate through a horizontal double pipe heat exchanger in this paper as described below.

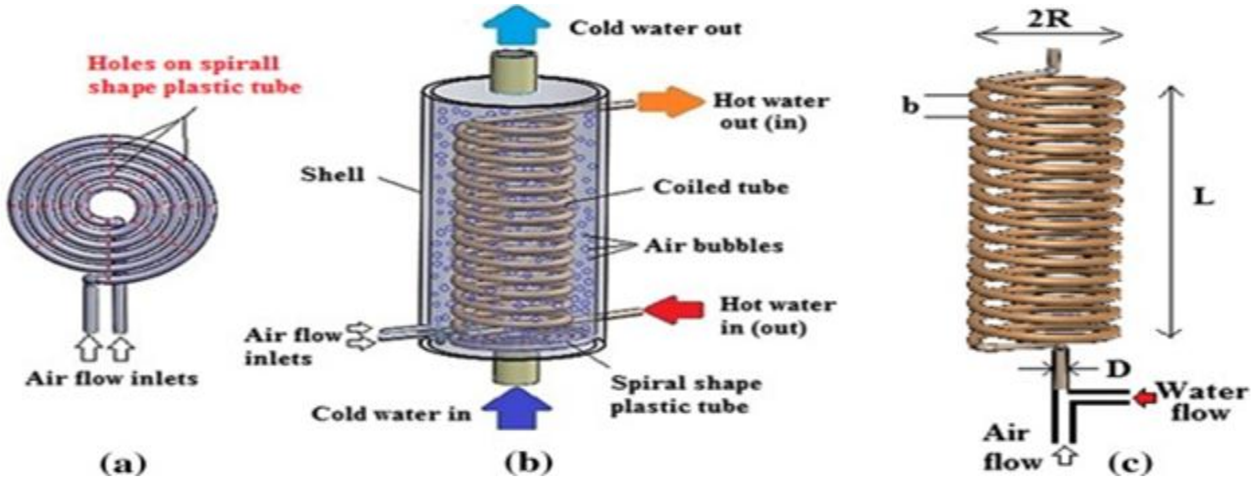

Figure 1. Air bubble injection method in a Heat Exchanger

For a laminar flow, the bubbles create turbulence in the flow and hence cause a higher heat transfer by reducing the skin friction drag around the wall. However in the case of a turbulent flow, smaller bubble doesn't create much effect while larger bubbles create more impact. They can penetrate much to the turbulent flow and reduces the skin friction drag. While bubble flows along with the flowing fluid, it creates a void, which is filled by the fluid surrounding the bubbles. This creates extra turbulence and allows more heat to be carried out from the surfaces by the cooling fluid.

A bubble can be injected at the nucleation site, throughout the flow or in the middle of the flow depending on the requirement. It is one of the simplest method which is cheaper, environmental friendly and easy to maintain. It doesn't include any complicated system to handle. This method can be wisely and widely being used in order to enhance the performance of any system involving heat transfer process.

II. LITERATURE REVIEW

D.Han et al. (2017) studied heat transfer enhancement using nanofluid in double tube heat exchanger. Study aims at experimentally investigating the effect of Al2O3 /water nanofluids on the heat transfer enhancement inside the double tube heat exchanger at variable inlet temperature. Al2O3 nanoparticle with concentration of 0.25% and 0.5% by volume concentration has been used at different inlet temperature. The experimental setup consisted of double tube heat exchanger with nanofluids on the cold side was used in turbulent regime with Reynolds number ranging from 20000 to 60000. Results from the study shows that the heat transfer increases with the increase in temperature and volume concentration of nano-particles. Significant improvement over the water is seen with maximum Nusselt number increase up to 24.5% at 50℃ inlet temperature.

Khorasani et al. (2017) studied experimentally the effects of air bubble injection on the performance of a horizontal helical shell and coiled tube heat exchanger. The variations of number of thermal units (NTU), exergy loss and effectiveness due to the air bubbles injection with different air flow rates are evaluated. A new procedure for injecting the air bubbles into the shell side flow of the heat exchanger is proposed. The results exhibited a significant increase in the effectiveness and NTU of the heat exchanger as the air bubbles were injected. It is suggested that the disturbance and perhaps the turbulence intensity of the shell side flow are increased due to the motion of air bubbles resulting in an increment in the value of NTU and exergy loss. In addition, the mixing effect of the bubbles and the interaction with the thermal boundary layer can increase the velocity (hence the Reynolds number) of the shell side flow.

Andrew et al. (2016) studied due to their compact design, ease of manufacture and enhanced heat transfer and fluid mixing properties, helically coiled tubes are widely used in a variety of industries and applications.

Dizaji et al. (2015) studied experimentally the effects of flow, thermodynamic and geometrical characteristics on exergy loss in vertical shell and coiled tubes heat exchangers. Pressure drop and heat transfer characteristics in shell and coiled tube heat exchangers have been widely studied in the resent years. However, the effects of flow, thermodynamic and geometrical parameters on energetic characteristics have not been explicitly and experimentally studied. Hence, the main scope of the present work is to clarify the effect of shell and coil side flow rates, inlet temperatures, coil pitch and coil diameter on exergy loss in shell and coiled tube heat exchangers. Both of the total exergy loss and dimensionless exergy loss are studied.

From the literature review introduction of Injecting air bubbles in a fluid flow path is one of the promising techniques to increase the turbulence in the flow. The air can either be injected at the entrance of the fluid in the channel or tube so that it can properly mixed before entering or throughout the channel or tube so that there would be a reduction in the skin friction. This also increases the turbulence and thus enhances the different parameters such as heat transfer rate, efficiency etc. Studies have been done on different conditions with air bubble injection and results show a considerable enhancement in the different parameters such as heat transfer performance, turbulence etc.

III. RESEARCH OBJECTIVES

It can be observed that the problem describes on the previous chapter can be dissolving by the improvement in the double pipe heat exchanger by applying various techniques which causes the result in the enhancement of heat transfer rate in the heat exchanger. The effort make to enhancement of heat transfer in heat exchanger are as follows:

- To develop model of double pipe heat exchanger, injecting air bubbles in it.
- Develop a proper Heat Exchanger for maximum heat transfer rate.
- Provide the turbulence in the fluid flow of the heat exchanger.
- Increase the overall heat transfer coefficient in the Heat Exchanger.
- Decrease the pressure drop in the heat transfer system.
- Use of air bubble injection will affect the heat transfer rate and overall heat transfer coefficient.

IV. METHODOLOGY

Computational fluid dynamics is the computer based analysis by which we can analyses the various things like fluid flow, pressure distribution, heat transfer, and related to the phenomenon in the chemical reactions.CFD tools which are required for the CFD analysis of the problem. There are the three main elements for the processing of the CFD simulations: the pre-processor, solver, and post-processor.After studying the basic steps in CFD to be followed to analyzed the performance of heat exchanger using air bubble injection. Now we can start the analysis of the heat exchanger using air bubble injection using actual data .Following steps are required to run the simulation-

1- Geometry modelling, 2- Meshing, 3- Name Selection, 4- Type of solver, 5- Physical model, 6- Material property, 7- Boundary condition.

Geometry setup

The ANSYS Design Modeller provides the following approaches for model generation: Creating a surface model within ANSYS Design Modeller. The heat exchanger setup the geometry of double pipe heat exchanger performing the simulation study is taken form one of the research scholar's D.Han et.al. (2017) paper with exact dimension .The part of model was designed in ANSYS (Fluent) workbench14.5 software. The geometric dimension of the double pipe heat exchanger is shown in the Table 1 and 2.

Table 1 Dimensions of the double pipe heat exchanger

Pipe	All dimension in mm			Material
	d_o	d_i	L	
Inner	38	34	2100	Copper
Outer	100	96	2100	Copper

Table 2 Dimension of tube used for air bubble injection

Tube used for air bubble injection (Material-Copper)	All dimension in mm				No. of holes
	d_o	d_i	L	Air eject hole dia.	
	15	13	2100	5	12

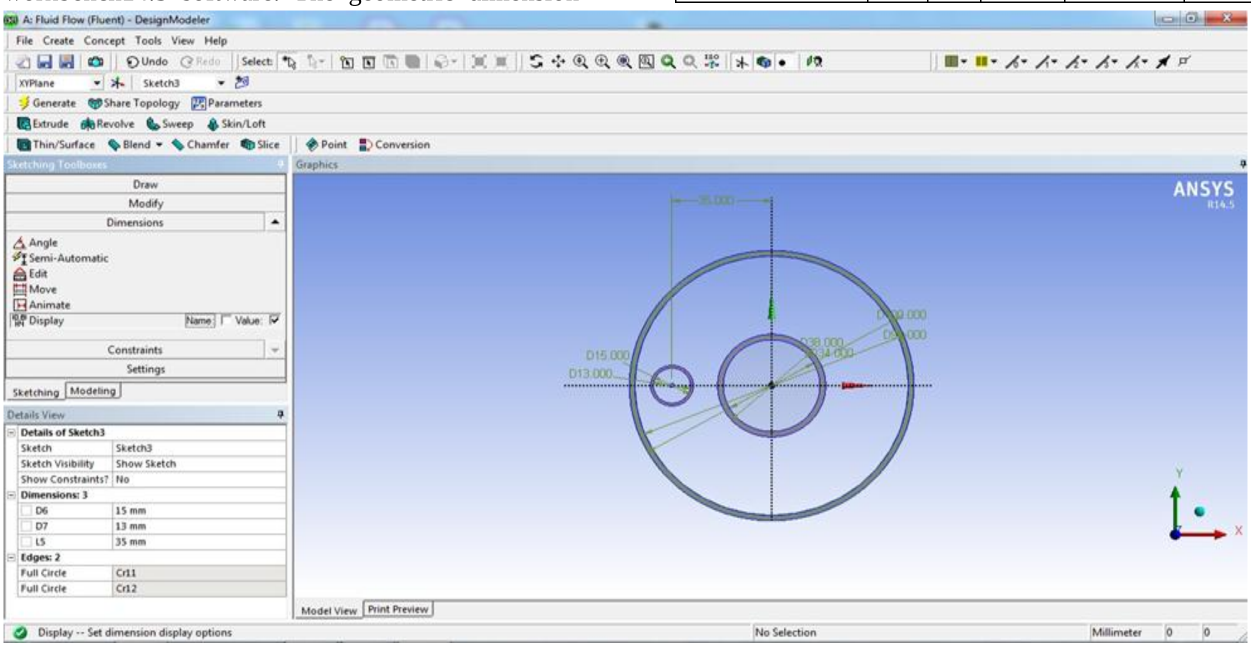

Figure 2 Geometric dimensions used in double pipe heat exchanger for air bubble injection

After mesh generation defined the following setup in the ANSYS fluent.

Problem Type- 3D, Steady State

Type of Solver- Pressure-based solver

Viscous: k- ε (epsilon) two equation turbulence model.

Table 3 Material properties which are used in analysis.

Parameter	Air	Water	Copper
Density (Kg/m^3)	1.225	998.2	8978
Thermal Conductivity (W/m-k)	0.0242	0.6	387.6
Specific heat (J/kg-k)	1006.43	4182	381
Viscosity (kg/m-s)	$1.789*10^{-5}$	0.001003	--

Table 4: Boundary condition of different parameters

Name	Temperature(K)
Cold water inlet	323
Hot water inlet	342
Air inlet	300

Solution Method

Pressure- velocity coupling – Scheme -SIMPLE

Pressure – Standard

Momentum – Second order

Energy - second order

Turbulent Kinetic Energy (k) – First order

Turbulent Dissipation Rate (e) - First order

Solution Initialization- Initialized the solution to get the initial solution for the problem.

Run Solution- Run the solution by giving 500 no of iteration for solution to converge.

V. RESULTS AND DICUSIONS

After validating the CFD model of heat exchanger, we then used the heat exchanger having air bubble injection. Air bubble injection is mainly used to increase the turbulence inside the heat exchanger.

For Re=20,000

Here in this section water as cold fluid is flowing at a Re 20,000. Whereas the hot fluid is flowing at a speed of 0.5911 m/s and air bubble injected at a speed of 0.4368 m/s. The Temperature, Pressure contour and Nusselt number of heat exchanger for this Re number is shown in the below fig.

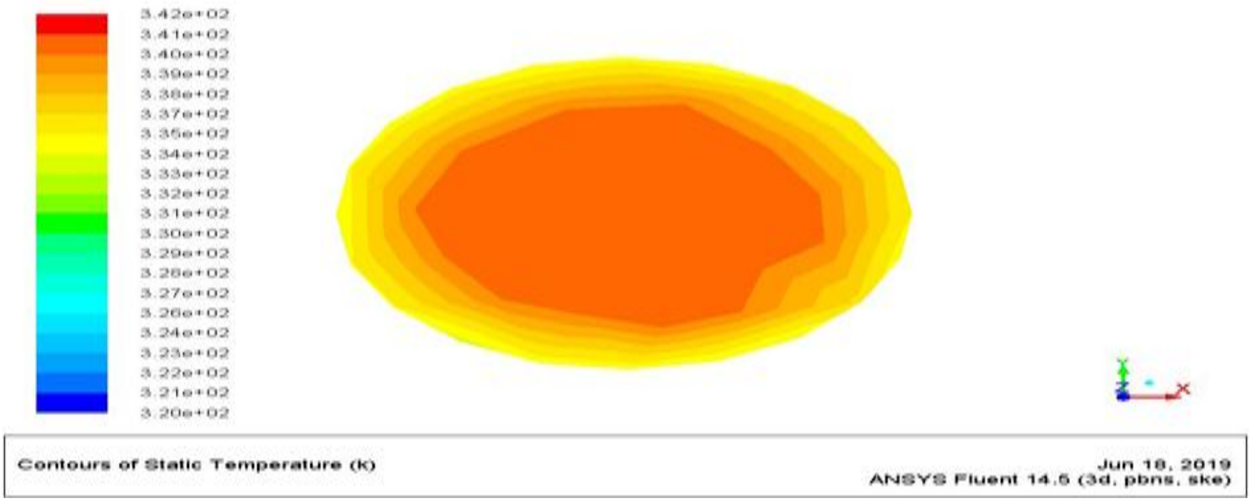

Figure 3 Static temperature contour of the heat exchanger for air bubbles at Re=20,000

For Re=30,000

Here in this section water as cold fluid is flowing at a Re 30,000. Whereas the hot fluid is flowing at a speed of 0.8866 m/s and air bubble injected at a speed of 0.6553 m/s. The Temperature, Pressure contour and Nusselt number of heat exchanger for this Re number is shown in the below fig.

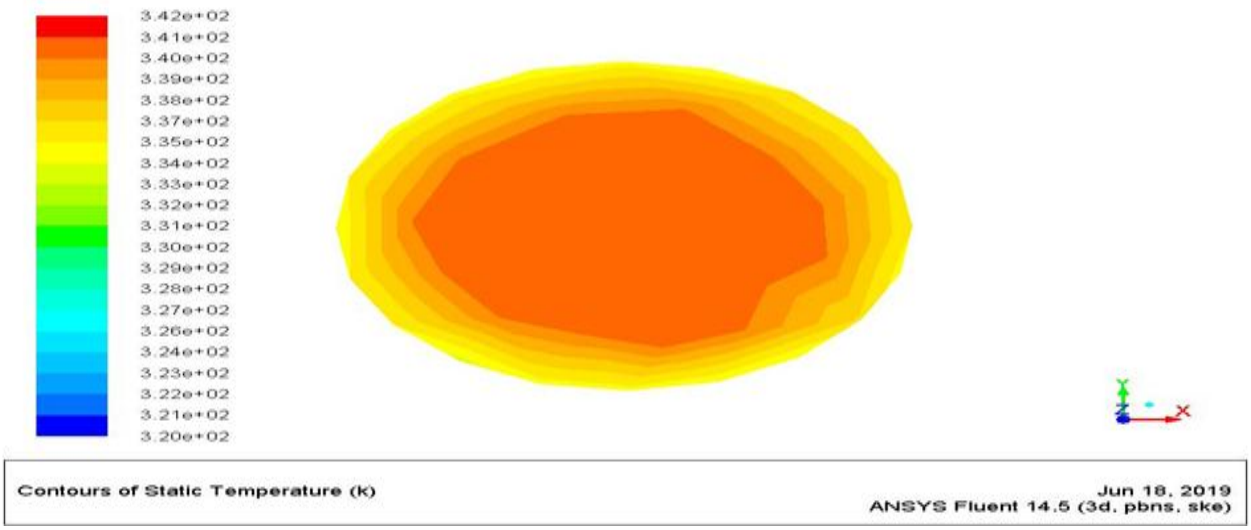

Figure 4 Static temperature contour of the heat exchanger for air bubbles at Re=30,000

For Re=40,000

Here in this section water as cold fluid is flowing at a Re 40,000. Whereas the hot fluid is flowing at a speed of 1.1821 m/s and air bubble injected at a speed of 0.8737 m/s. The Temperature, Pressure contour and Nusselt number of heat exchanger for this Re number is shown in the below fig.

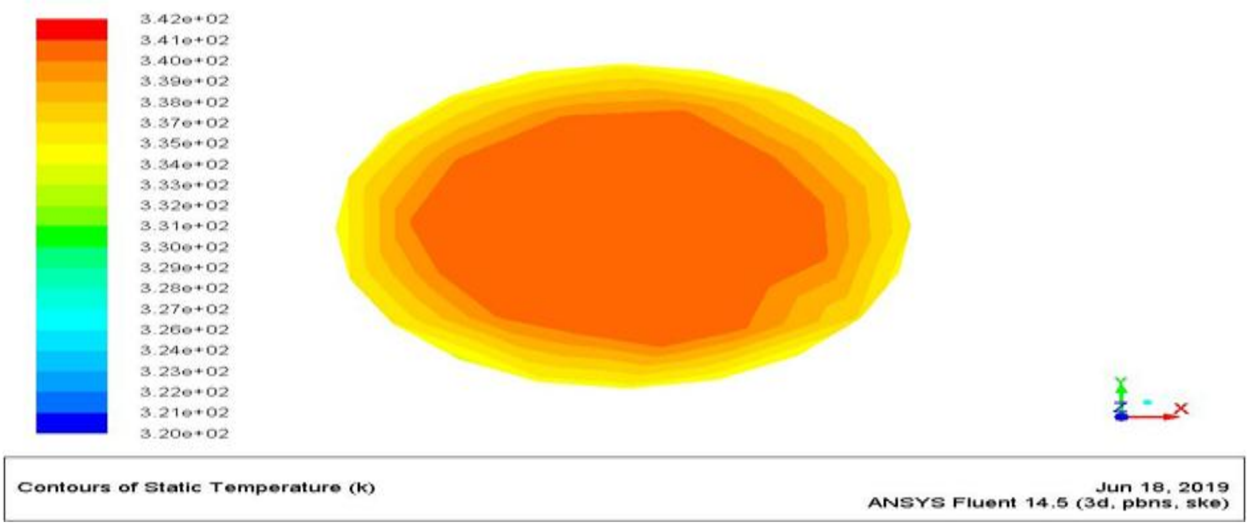

Figure 5 Static temperature contour of the heat exchanger for air bubbles at Re=40,000

Comparison between with and without air bubble injection

Table 5 shows the value of Nusselt number (Nu) of heat exchanger at different Reynolds number for with and without air bubble injection.

S.No	Reynolds number	Nusselt Number(without air bubble)	Nusselt Number(with air bubble)
1	20,000	110.63	136.83
2	30,000	159.21	194.161
3	40,000	203.33	240.46

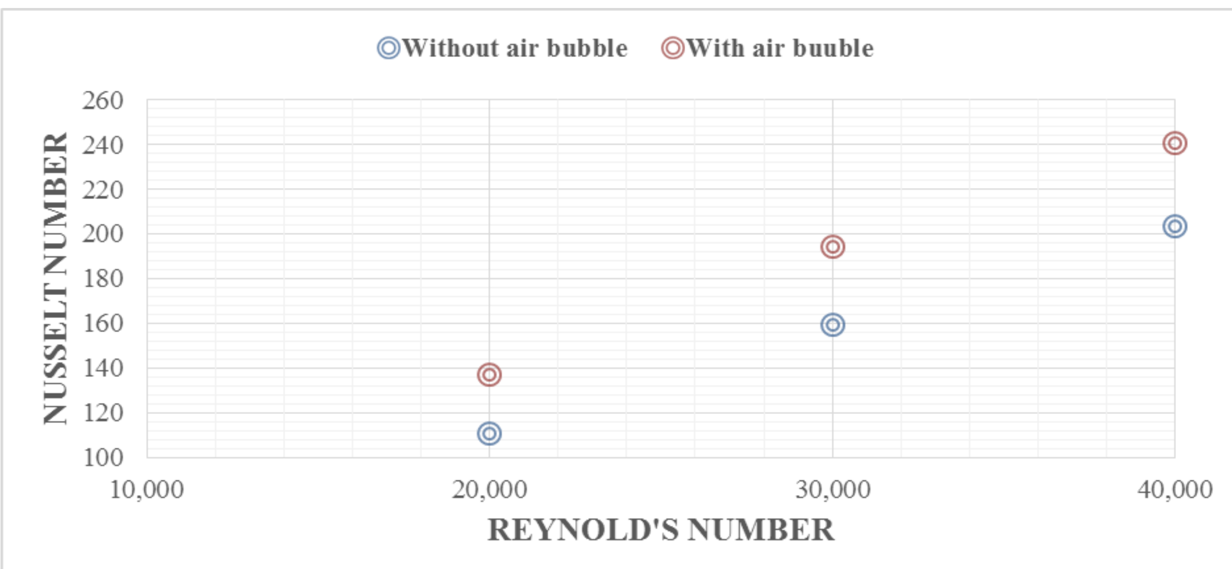

Figure 6. Shows the value of Nusselt number at different Reynolds number for with and without air bubble injection.

Table 6. Shows the value of Heat Transfer coefficient of heat exchanger at different Reynolds number for with and without air bubble injection.

S.N o	Reynold s number	Heat Transfer coefficient(with out air bubble)	Heat Transfer coefficient (with air bubble)
1	20,000	70.49	82.95
2	30,000	102.26	115.24
3	40,000	150.45	167.84

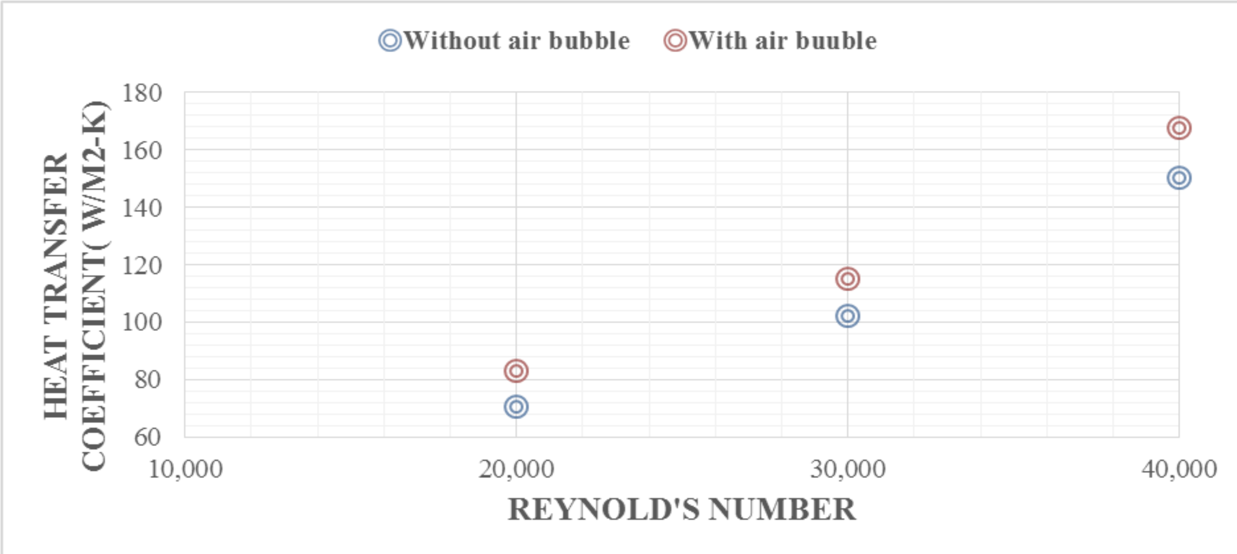

Figure 7 shows the value of Heat Transfer coefficient at different Reynolds number for with and without air bubble injection

VI. CONCLUSIONS

In this analysis, the effect of injection of air bubble in double pipe heat exchanger has been investigated using CFD analysis. Based on the results obtained by the CFD and mathematical calculations it is found that:

- From the CFD analysis it has been observed that using air bubble the Nusselt number and overall heat transfer coefficient increased.
- As compared the overall heat transfer coefficient using air bubble increase by 1.27 times as compared to without air bubble injection.
- As compared the Nusselt number using air bubble increase by 1.23 times as compared to without air bubble injection.
- From the CFD analysis it has been observed that for different Reynold's number; the Nusselt number increases with increase in Reynold's number.
- From this analysis it is concluded that air bubbles best for using, because it give maximum heat transfer.

REFERENCES

[1] D.Han, WF He , FS Asif, Experimental study of heat transfer enhancement using nanofluid in double tube heat exchanger 9th International Conference on Applied Energy, ICAE2017, 21-24 August 2017, Cardiff, UK.

[2] Ahmadzadehtalatapeh M, Yau YH. Energy conservation potential of heat pipe heat exchanger: Exprimental study and predictions. International Journal of Engineering Tran¬section B: Applications. 2012 Aug; 25(3):193–200.

[3] Kahrom M, Haghparast P, Javadi SM. Optimization of heat transferenhancement of flat plate based on pereto genetic algorithm. International Journal of Engineering, Transaction A: Basics. 2010 Apr; 23(2):177–90.

[4] Lee HS. Thermal design. John Wiley and Sons; 2010.

[5] Li H, Kottke V. Analysis of local shell side heat and mass transfer in shell and tube heat exchanger with disc and doughnut baffles. International Journal of Heat and Mass Transfer. 1999 Sep; 42(18):3509–21.

[6] Peng B, Wang QW, Zhang C, Xie GN, Luo LQ Chen QY, Zeng M. An experimental study of shell and tube heat ex¬changers with continuous helical baffles. Journal of Heat Transfer. 2007 Jan; 129(10):1425–31.