ENHANCEMENT OF HEAT TRANSFER RATE IN DOUBLE PIPE HEAT EXCHANGER BY SHOT BLASTING THE INNER TUBE

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Abstract*— Heat transfer rate in heat exchangers are being researched till date with various methods. In this paper, a double pipe heat exchanger has been designed and fabricated with a 1 m long copper pipe as inner pipe and 1 m long stainless steel pipe as outer pipe. The experimental analysis is conducted by passing hot water in the inner tube and the cold water in the annulus. The experiment is performed with counter flow configuration under different mass flow rates. The process of shot blasting is used to increase the roughness of the outer surface of the inner pipe, thereby the increasing the rate of heat transfer. Experiments were performed with the designed heat exchanger with and without the shot blasted inner tube. So, this paper has studied the performance of double pipe without taking into account the pressure drop [4] with and without the shot blasted inner tube.

***Keywords*—Heat transfer rate, double pipe heat exchanger, counter flow, shot blasting**

I. INTRODUCTION

Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other. A medium will act as a carrier of heat, from which the other fluid is heated. Heat transfer takes place only when there is a temperature difference between the two mediums. Heat exchangers are used to maintain a cyclic process to bring the working fluid to the required state in a cyclic process. They are also used to recover the waste heat that could be used efficiently other processes. Typical heat exchangers used in our daily lives include condensers and evaporators in air conditioners and refrigerators. Some of the industrial applications include food processing, chemical, pharmaceutical, power plants, etc.

Various researches are being performed till date to increase the efficiency of heat exchangers to tap the maximum amount of heat energy from the hot fluid. This ensures that only a little amount of heat is being lost and thereby a maximum amount of heat energy is being used properly.

Classification of heat exchangers:

Heat exchangers are generally classified based on the transfer process, construction and flow configuration.

Based on the transfer process:

- Direct contact
- Indirect contact

Based on construction:

- Tubular heat exchangers
- Plate heat exchangers
- Plate fin heat exchangers
- Tube fin heat exchangers
- Regenerative heat exchangers

Based on the flow configuration:

- Parallel flow(co-current flow)
- Counter flow(counter current flow)
- Cross flow
- Multi pass flow

Based on the transfer process:

In direct contact heat exchangers, heat transfer takes place between two immiscible fluids like a gas and a liquid coming into direct contact. A typical example is a cooling tower. In indirect contact type of heat exchangers, the hot and cold fluids are separated by a wall. There is no mixing of the two fluids.

Based on construction:

Tubular heat exchangers use tubular arrangement in many sizes, flow arrangements and types. They can withstand a wide range of operating pressures and temperatures. A commonly used design is shell-and-tube heat exchanger. The combination of fluids may be liquid-to-liquid, liquid-to -gas or gas-to-gas. Plate heat exchangers use thin plates which affect the heat transfer. These heat exchangers are suitable only for moderate temperature or pressure as the plate geometry restricts the use of high pressure and temperature differentials. Plate fin heat exchangers use corrugated fins separated by flat plates. Fins can be arranged on each side of the plate to get cross-flow, counter-flow or parallel-flow arrangements. These heat exchangers are used for gas-to-gas applications at low pressures (10 atm.) and temperatures not exceeding 800°C. Tube fin heat exchangers are used when a high operating pressure or an extended surface is needed on one side. Tube-fin heat exchangers are used in fuel cells, automobiles, heat pump and refrigeration. Regenerative heat exchangers may be either static type or dynamic type. The static type has no moving parts and consists of a porous mass like balls, pebbles, powders etc. through which hot and cold fluids pass alternatively. For example, air preheaters used in coke manufacturing and glass melting plants. In dynamic type regenerators, the matrix is arranged in the form of a drum which rotates about an axis in such a manner that a given portion of the matrix passes periodically through the hot stream and then through the cold stream. The heat absorbed by the matrix from the hot stream is transferred to the cold stream during its run.

Based on flow configuration:

In parallel flow heat exchangers, the hot and the cold fluids enter at the same end of the heat exchanger and flow through in the same direction and leave together at the other end. In counter flow heat exchangers, the hot and cold fluids enter in the opposite ends of the heat exchanger and flow in opposite directions. In cross flow heat exchanger, the two fluids flow at right angles to each other. Multi pass heat exchangers increase the overall effectiveness over individual effectiveness.

II. DOUBLE PIPE HEAT EXCHANGER

Double pipe heat exchanger is the simplest type of heat exchanger consists of two concentric pipes of different diameters. One fluid in a double-pipe heat exchanger flows through the smaller pipe while the other fluid flows through the annular space between the two pipes. Two types of flow arrangement are possible in a double-pipe heat exchanger in parallel flow; both the hot and cold fluids enter the heat exchanger at the same end and move in the same direction. In counter flow, on the other hand, the hot and cold fluids enter the heat exchanger at opposite ends and flow in opposite directions. Only the conductive and convective heat transfer rate is taken into account since the effect of radiation does not play a major role [1]. In our project work, a double pipe heat exchanger is worked on to increase the rate of heat transfer without taking into account the pressure drop. Our double pipe consists of a copper inner tube and a stainless steel outer tube. The flow configuration of counter flow type is chosen since heat transfer rate is found to be more in counter flow [1].

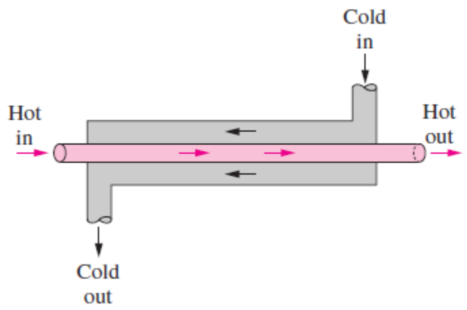

Fig 1. Counter flow configuration of heat exchanger

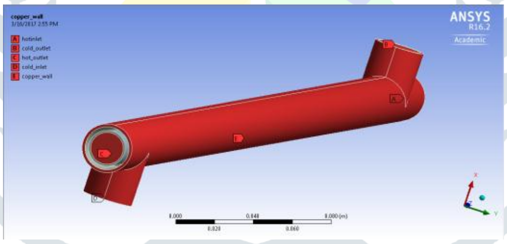

Fig 2. Double pipe heat exchanger model

III. LITERATURE SURVEY:

Design and fabrication of concentric tube heat exchanger [Kadari Deepika]:

In this paper, a double pipe heat exchanger is designed and fabricated with copper pipe and galvanized iron pipe is utilized for tube and shell materials. The experimental analysis is conducted by passing hot water in inner pipe and cold water in the annulus. The experiment was performed with both parallel and counter flow configurations under various mass flow rates. The overall heat transfer coefficient is calculated and compared with both parallel and counter flow for theoretical and actual performance of heat exchanger and found counter flow heat transfer is increased than parallel flow.

Comparison of Effectiveness of Two Different Setups of Double Pipe Heat Exchangers [Swathi Juturu and J. Kishore]:

For given dimensions of the double pipe heat exchanger with selected rectangular fins, copper twisted tape is inserted into the inner pipe of the double pipe heat exchanger as first setup of heat exchanger. In the second setup, the heat exchanger is fabricated with copper twisted tape without fins at the outside of the inner copper pipe. Comparing these two heat exchangers, effectiveness was found to be more for first heat exchanger. So by using fins in addition to twisted tape effectiveness can be enhanced.

Design and experimental analysis of pipe in pipe heat exchanger [Ojha Pramod Kailash, Choudhary Bishwajeet NK, Gajera Umang B, Prajapat Sumit B, Karangiya Gopal A]:

The project carried out design of pipe in pipe heat exchanger having tube with fin and without fin. The fins were taken in the form of semi-circular type arranged in alternating way. The fins were provided on the inner tube for creating turbulence of cold water. Experiment was performed for heat exchanger with fins and without fins for different flow rates of hot and cold fluid. Use of semi-circular baffles increased the heat transfer rate since area of heat transfer in increased.

Performance improvement of double pipe heat exchanger by using turbulator [C. K. Pardhi and Dr. Prasant Baredar]:

In this paper, the objective is to reduce as many of the factors as possible: Capital Cost, Power Cost, Maintenance Cost, Space and Weight, Consistent with safety and reliability. Present work describes the principal techniques of industrial importance for the augmentation of single phase heat transfer on the inside of tubes namely twisted tapes. So twisted tape should be used in heat exchanger when high heat transfer rate is required and pressure drop is of no significance.

Heat transfer enhancement in a double pipe heat exchanger using CFD [Kanade Rahul H, Kailash B A, Gowreesh]:

In this paper, the effect of internal aluminium baffles on heat transfer enhancement and pressure drop in counter flow configured double pipe heat exchanger using CFD. The baffles were taken in the form of semicircular and quarter-circular geometries and arranged on the inner pipe of DPHE. Heat transfer rate, overall heat transfer coefficient and pressure drop are determined for fully developed condition for several Reynolds numbers based on the pipe diameter and flow mean velocity with water as working fluid. Comparative study were employed for heat exchanger without baffles and inner pipe equipped with semicircular and quarter-circular baffles. At similar condition, the heat exchanger equipped with quarter-circular baffles on outer surface of inner pipe offered more heat transfer rate than heat exchanger equipped with semicircular baffles exchanger without baffles as they stimulate more consistent turbulence inside annulus. This unveils that it is possible to derive compromise between enhanced heat transfer and optimum pressure drop by selecting the baffles with proper geometry.

The Effects of Shot and Grit Blasting Process Parameters on Steel Pipes Coating Adhesion[Saeed Khorasanizadeh]:

This paper has studied the effect of varying abrasive flow rate, changing the abrasive particle size, time of surface blasting on steel surface roughness and over blasting on it by using the centrifugal blasting machine. After preparation of numbers of steel samples and applying epoxy powder coating on them, the adhesion strength of coating has been compared by Pull-Off test. The results have shown that, increasing the abrasive particles size and flow rate, can increase the steel surface roughness and coating dhesion strength but increasing the blasting time can do surface over blasting and increasing surface temperature and hardness too, change, decreasing steel surface roughness and coating adhesion strength.

IV. EXPERIMENTAL PROCEDURE

Fig 3. Experimental setup

The experimental setup consists of two concentric tubes. The inner tube is a copper tube of inner diameter 17 mm and outer diameter of 19 mm. The outer tube is a stainless steel tube of inner diameter 23 mm and outer diameter of 25 mm. The length of the heat exchanger is 1 m. Hot water is employed as hot fluid, which is heated in a heater and it flows through the inner tube. Cold water is employed as cold fluid and it flows through the annulus, that is, in the gap between the two concentric pipes. The flow configuration is counter flow, that is, the hot fluid and cold fluid flows in opposite directions. A submersible pump is immersed in the water tank which serves as a source for water supply for both the hot water inlet and cold water inlet. The submersible pump is connected with a T-joint. One end of the tee is connected to the water heater inlet and the outlet from the water heater is connected to the one end of the copper tube through a gate valve to vary the mass flow rate. This end serves as hot water inlet. The other end of the copper tube is set free to measure the mass flow rate with the help of a measuring flask and stopwatch. The other end of the T-joint is directly connected to the cold water inlet area through a gate valve for varying the cold water flow rate in the heat exchanger. The outlet of the cold water is set free. Temperature indicator’s probes are placed at the place of hot water inlet and outlet and the cold water inlet and outlet. Thus the hot water and the cold water flows in the transverse direction in the heat exchanger and heat exchange takes place between the two fluids. The temperature at the two inlets and two outlets are measured with the help of temperature probes and the flow rate is measured using a measuring flask and a stop watch. The readings are taken after the steady state is achieved. The outer pipe is insulated with asbestos rope to minimize the heat loss.

Fig 4. Copper tube before shot blasting

Fig 5. Copper tube after shot blasting

The experimentation is started by providing sufficient water to the submersible pump. The submersible pump is immersed in a reservoir containing sufficient amount of water. The pump and the heater are then switched on. The flow rate in the inner tube and the annulus are adjusted with the gate valve. The mass flow rates of the hot water and cold water is measured at the hot water outlet and cold water outlet with the help of stopwatch and weighing machine. The mass flow rates are adjusted such that the flow is fully developed in the tubes. The experimental setup is kept running until steady state is reached. After steady state has been reached, the temperature at the inlet and outlet of hot water and the temperature at the inlet and outlet of the cold water are noted from the temperature indicators. The same procedure is carried out for varied mass flow rate. After completing the experimentation, the inner tube is removed. The inner tube is replaced with the shot blasted inner tube of copper of same diameter and length. The necessary connections as done before are carried out. The same procedure for experimentation is again performed and the readings are noted for different mass flow rates.

TUBE SPECIFICATION:

Tube	**Inner diameter**	**Outer diameter**	**Length**
Copper tube (inner tube)	d_1 = 17 mm	d_2 = 19 mm	1 m
Stainless steel (outer tube)	D_1 = 23 mm	D_2 = 25 mm	1 m

<u>Setup 1. Double pipe heat exchanger without shot blasted inner tube:</u>

S.NO	**Hot Water**			**Cold Water**		
	Mass flow rate (kg/s)	**T_{hi} (°C)**	**T_{ho} (°C)**	**Mass flow rate (kg/s)**	**T_{hi} (°C)**	**T_{co} (°C)**
1	0.0690	39.5	37.8	0.0693	29.6	32.9
2	0.0683	39.6	37.9	0.0685	29.6	33
3	0.0687	39.6	37.9	0.0690	29.6	33
4	0.0693	39.6	37.9	0.0695	29.6	33
Mean	0.0688	39.58	37.88	0.0691	29.6	32.98

<u>Setup 2. Double pipe heat exchanger with shot blasted inner tube:</u>

S.NO	**Hot Water**			**Cold Water**		
	Mass flow rate (kg/s)	**T_{hi} (°C)**	**T_{ho} (°C)**	**Mass flow rate (kg/s)**	**T_{ci} (°C)**	**T_{co} (°C)**
1	0.0703	38.3	37.3	0.0301	29.6	32.8
2	0.0692	38.5	37.2	0.0302	29.6	32.8
3	0.0683	38.6	37.3	0.0297	29.6	32.6
4	0.0704	38.3	37.3	0.03	29.6	32.8
Mean	0.0696	38.4	37.28	0.03	29.6	32.75

SAMPLE CALCULATION:

<u>For shot blasted inner tube:</u>

Mass flow rate of hot fluid is given by

$$\dot{m} = \rho A V_h$$

$$= \rho \frac{\pi d^2}{4} V_h$$

$$0.0690 = 995.3375 * \frac{\pi(0.017^2)}{4} V_h$$

V_h = 0.305 m/s

Where ρ – density of hot fluid @ mean temperature

A – cross sectional area

Mass flow rate of cold water through annulus is given by

$$\dot{m} = \rho A V_c$$

$$= \rho \frac{\pi d^2}{4} V_c$$

$$0.0693 = 997.1875 * (0.000132) V_c$$

V_c = 0.527 m/s

Where d – diameter of inner copper tube

Annulus characteristic length, $L_c = D_1 - d_2$

$$= \frac{23-19}{1000}$$
$$= 0.004 \text{ m}$$

T_{hi} = 39.5 °C T_{ci} = 29.6 °C T_{ho} = 37.8 °C T_{co} = 32.9 °C

T_{hi}, T_{ho} are inlet and outlet temperatures of hot water and T_{ci}, T_{co} are inlet and outlet temperatures of cold water respectively.
Substitute the above temperature values in the given below equation.

$$\text{LMTD} = \frac{(T_{hi}-T_{ci})-(T_{ho}-T_{co})}{log_e[(T_{hi}-T_{ci})/(T_{ho}-T_{co})]}$$
$$= \frac{(39.5-29.6)-(37.8-32.9)}{log_e[(39.5-29.6)/(37.8-32.9)]}$$
$$= 7.37$$

Mean temperature for inner fluid flow is given by

$$T_m = \frac{(T_{hi}+T_{ho})}{2}$$
$$= \frac{39.5+37.8}{2}$$
$$= 38.65 \text{ °C}$$

Properties of hot fluid at mean temperature are taken below from thermal engineering databook @ T_m= 38.65 °C

$\rho = 995.3375 \frac{kg}{m^3}$ ν = 6.8056x10^{-7} m^2/s k = 0.6259 W/mK C_p = 4178 J/kgK Pr = 4.5209

ν is kinematic viscosity, Pr is prandtl number, k is thermal conductivity of respective fluid at corresponding mean temperatures, C_p is specific heat at constant pressure.

Reynolds number is given by:

$$Re_1 = \frac{(d_1)V}{\nu}$$
$$= \frac{(0.017)0.305}{6.8056*10^{-7}}$$
$$= 7618.7$$

$(Re_1)^{0.8} = (7618.7)^{0.8} = 1275$

$(Pr_1)^{0.3} = (4.5209)^{0.3} = 1.57$

Nusselt number is given by:

$$Nu_1 = \frac{h_1 d_1}{k} = 0.023*(Re_1)^{0.8}*(Pr_1)^{0.3}$$
$$\frac{h_1*0.017}{0.6259} = 0.023*1275*1.57$$

$$h_1 = 1693.6 \text{ W}/m^2K$$
$$Nu_1 = \frac{1693.6*0.017}{0.6259} = 46$$

Properties of cold fluid at @ T_m= 31.25 °C

$\rho = 997.1875 \frac{kg}{m^3}$ ν = 8.097x10^{-7} m^2/s k = 0.6148 $\frac{W}{mK}$ C_p = 4178 J/kgK Pr = 5.5125

Reynolds number is given by:

$$Re_2 = \frac{(L_c)V}{\nu}$$
$$= \frac{(0.004)0.527}{8.097*10^{-7}}$$
$$= 2603$$

$(Re_2)^{0.8} = (2603)^{0.8} = 540$

$(Pr_2)^{0.4} = (5.5125)^{0.4} = 1.98$

Nusselt number is given by:

$$Nu_2 = \frac{h_2 L_c}{k} = 0.023*(Re_2)^{0.8}*(Pr_2)^{0.4}$$
$$\frac{h_2*0.004}{0.6148} = 0.023*540*1.98$$
$$h_2 = 3781 \text{ W/m}^2\text{K}$$
$$Nu_2 = \frac{3781*0.004}{0.6148} = 24.6$$

Overall heat transfer coefficient 'U' is given by:

$$\frac{1}{U} = \left(\frac{1}{h_1} * \frac{d_2}{d_1}\right) + \frac{1}{h_2} + \left(\frac{d_2-d_1}{d_2+d_1} * \frac{d_2}{k}\right)$$

$$\frac{1}{U} = \left(\frac{1}{1693.6} * \frac{19}{17}\right) + \frac{1}{3781} + \left(\frac{(19-17)*0.019}{(19+17)*385}\right)$$

U = 1078.5 W/m^{2}K

Heat transfer rate is given by

Q = UA(LMTD)

= 1078.5 x π x 0.019 x 1 x 7.37 = 474.45 W

Increase in heat transfer rate:

Increase in heat transfer rate is given by

$$\text{Increase in heat transfer rate} = \frac{474.45-331.63}{331.63}$$

$$= 0.43$$

$$= 43\%$$

V. RESULTS AND DISCUSSIONS

In this paper, a comparison of heat transfer rate in a double pipe heat exchanger before and after shot blasting the inner copper tube are studied. It is observed that the heat transfer rate has increased in the heat exchanger setup with shot blasted inner tube in comparison with the setup without shot blasting the inner tube. The various parameters affecting the heat transfer rate before and after shot blasting the inner tube are presented in the graphs below.

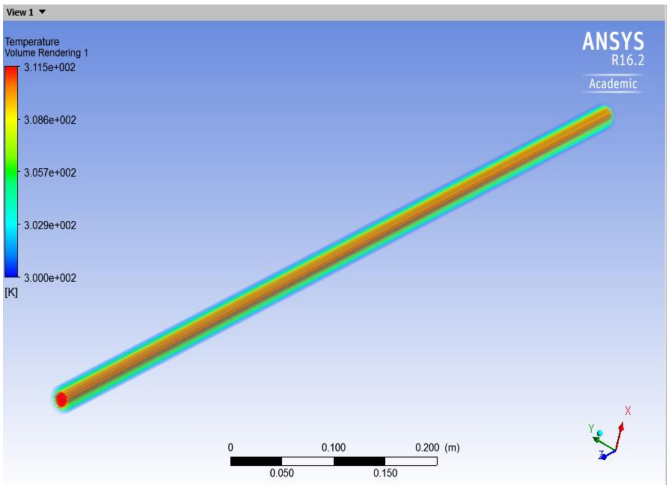

Fig 6. Temperature distribution over the length

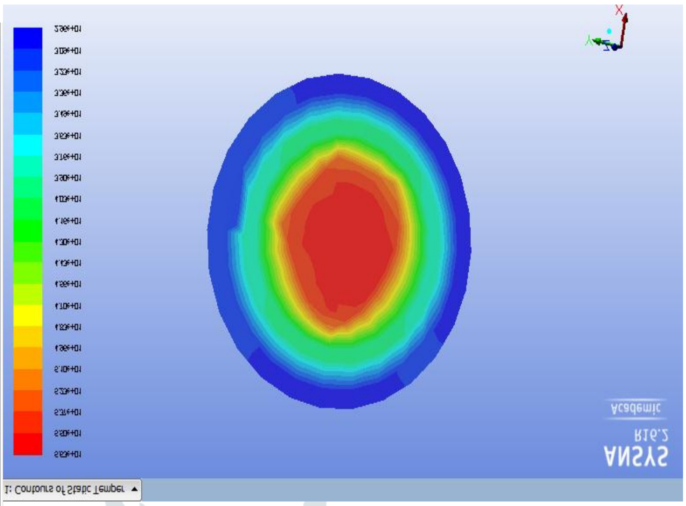

Fig 7. Temperature distribution about the cross section

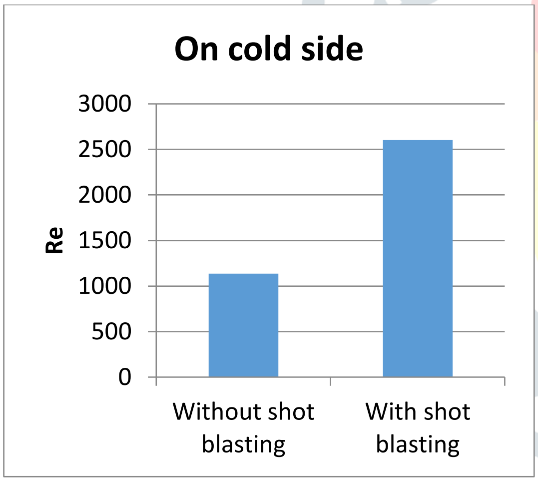

Fig 8. Bar chart representing Reynold's number on hot side

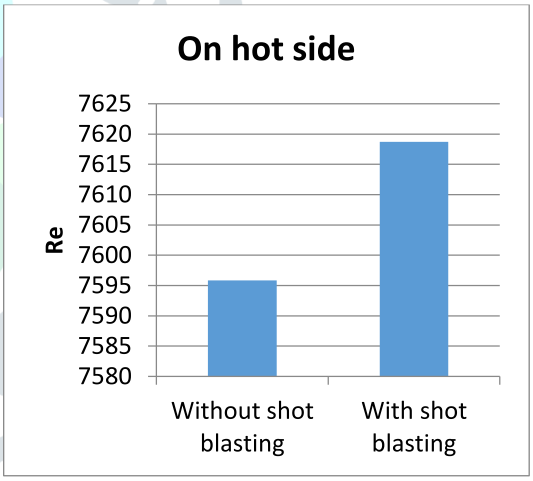

Fig 9. Bar chart representing Reynold's number on hot side

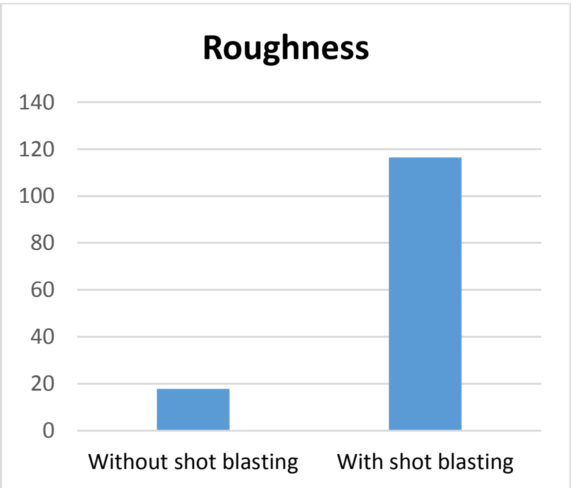

Fig 10. Bar chart representing the roughness of the inner tube

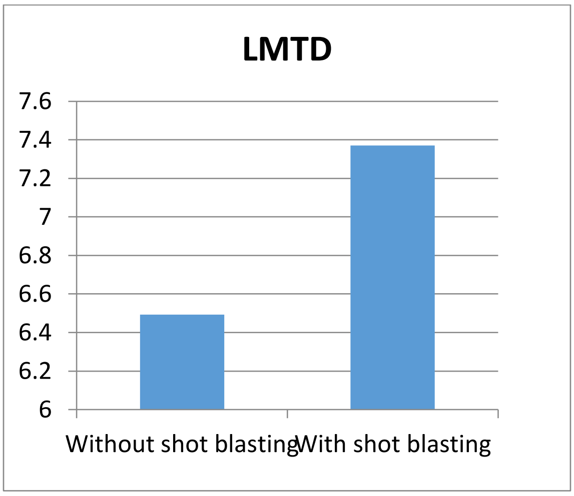

Fig 11. Bar chart representing the Logarithmic Mean Temperature Difference

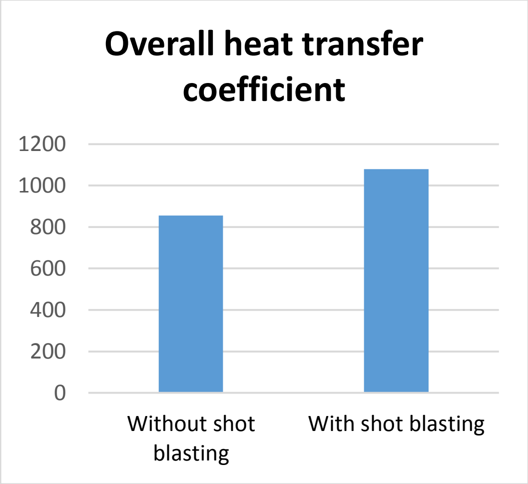

Fig 12. Bar chart representing overall heat transfer coefficient

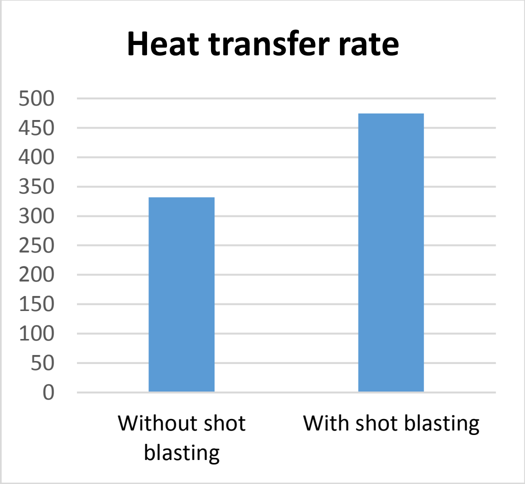

Fig 13. Bar chart representing the heat transfer rate

Heat transfer rate is found to **increase by 43% after shot blasting** the inner tube in comparison with the inner tube which has not been shot blasted.

VI. CONCLUSION

The effect on the rate of heat transfer of both tubes, one without shot blasting and the other after shot blasting are comparatively studied. It is observed that the rate of heat transfer increased by 43% when the roughness of the outer surface of the inner tube is increased using shot blasting.

REFERENCES

[1] Design and fabrication of concentric tube heat exchanger [Kadari Deepika].
[2] Comparison of Effectiveness of Two Different Setups of Double Pipe Heat Exchangers [Swathi Juturu, J. Kishore].
[3] Design and experimental analysis of pipe in pipe heat exchanger [Ojha Pramod Kailash, Choudhary Bishwajeet NK, Gajera Umang B, Prajapat Sumit B, Karangiya Gopal A].
[4] Performance improvement of double pipe heat exchanger by using turbulator [C. K. Pardhi, Prasant Baredar]
[5] Heat transfer enhancement in a double pipe heat exchanger using CFD [Kanade Rahul H, Kailash B A, Gowreesh]**.**
[6] The Effects of Shot and Grit Blasting Process Parameters on Steel Pipes Coating Adhesion [Saeed Khorasanizadeh]
[7] Design and analysis of double pipe heat exchanger using computational method [Kuruva Umamahesh, K. Venugopal]
[8] Thermal analysis of double pipe heat exchanger by changing the materials using CFD [M.Z.M. Saqheeb Ali, K. Mohan Krishna, D.V.V.S. Bhimesh Reddy, R.S.M. Ali]
[9] Experimental investigation of double pipe heat exchanger by using semi circular disc baffles [Sarmad A. Abdal Hussein]
[10] Numerical study of heat transfer in a finned double pipe heat exchanger [Shiva Kumar, K. Vasudev Karanth, Krishna Murthy]
[11] Experimental study on effect of heat transfer enhancement for single-phase forced convective flow with twisted tape inserts [Changzhong Man, Xiaogang Lv, Jingwei Hu, Peiyan Sun, Yunbang Tang]