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EXPERIMENTAL INVESTIGATION ON HEAT TRANSFER AND FRICTION FACTOR CHARACTERISTICS OF A WATER AND ETHYLENE GLYCOL MIXTURE FLOW OF INTERNALLY GROOVED TUBES

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Abstract- This paper reports experimental investigations on friction factor, Nusselt number and thermal hydraulic performance of a tube equipped with the classic three modified internally grooved tubes. The working fluid is water and ethylene glycol mixture 90:10 (by weight). Local heat transfer by forced convection from plain and grooved tubes is investigated for Reynolds number ranges 4900 to 13300. The increase in forced convective heat transfer coefficient in water and ethylene glycol mixtures results in a heat exchanger under turbulent flow is also reported. Among the grooved tubes, heat transfer enhancement obtained for the flow of water and ethylene glycol mixture is up to 36% for circular grooved tube 55% for square grooved tube and 10% for trapezoidal grooved tube in comparison with the plain tube.
Key words - Heat transfer enhancement, Heat exchanger, Grooved tubes, Ethylene glycol, Friction factor, Thermal hydraulic performance, Heat flux, Convective heat transfer coefficient

1 INTRODUCTION

Heat exchangers using viscous liquid working fluids are encountered in highly specialized areas microelectronics cooling, aerospace, biomedical processes, robotics and automotive applications. To achieve high heat transfer, the smaller units become an increasing demand from commercial applications. Internally grooved tubes to be used in a heat exchanger produced the results are high heat transfer, reduced weight and space compare with plain tube. Heat transfer enhancement (HTE) techniques can the divided into two categories passive and active. In passive heat transfer enhancement an object which does not use external energy, such as groove inside the tube, has the duty of increasing the heat transfer rate. Heat exchangers are used the forced convection mode of heat transfer very often.

Masoud Dehghandokht et al [1], investigated that fluid flow and heat transfer characteristics in a multi port serpentine meso-channel heat exchanger are numerically analyzed. Two liquid working fluids, namely water and an ethylene glycol water mixture, are used as coolants. The results are compared with experimental data for the same geometrical operating conditions. Sanitjai et al [2], carried out an experimental investigations are local heat transfer by forced convection from a circular cylinder in cross flow is investigated for Reynolds number from 2×10^3 to 9×10^4 and Prandtl number from 7 to 176. The working fluids are water and mixtures of ethylene glycol and water.

Garcia etal [3], investigated experimentally the heat transfer characteristics on helical wire-coil-inserts fitted inside a round tube, in order to characterize their thermal hydraulic behavior in laminar, transition and turbulent flow. By using water and water-propylene glycol mixtures at different temperatures, a wide range of flow conditions have been covered. At low Reynolds numbers, wire coil behaves a smooth tube within the transition region, if wire coils are fitted inside a smooth tube heat exchanger; heat transfer rate can be increased up to 200 % keeping pumping power constant. Wire coil inserts offer their best performance within the transition region where they show a considerable advantage over other enhancement techniques. Liao et al [4], carried out an experimental studies on heat transfer and friction characteristics for water, ethylene glycol and ISOVG46 turbine oil having inside four tubes with three dimensional internal extended surfaces and copper continuous or segmented twisted tape inserts. During the experiments, Prandtl numbers range from 5.5 to 5.9 and Reynolds numbers from 80 to 50000. The experimental results show that this compound entrance heat transfer technique, a tube with three-dimensional internal extended surfaces and twisted-tape inserts, is of particular advantage to enhance the convective heat transfer for the laminar tube side flow of highly viscous fluid.

Vincente et al [5], carried out an experimental investigation on heat transfer and frictional characteristics of spirally corrugated tubes in turbulent flow at different Prandtl numbers. Masoud Rahima et al [6], an experimental and CFD studies on heat transfer and friction factor characteristics of tube equipped with modified twisted tape inserts. Kadir bilen et al [7], carried out an experimental investigation on heat transfer and friction factor characteristics with internally grooved tubes.

They also reports of groove geometry effect on heat transfer for internally grooved tubes. Tests were performed for Reynolds number range 10,000 – 38,000 for all the grooved tubes. Sivashanmugam and Suresh [8], investigated the heat transfer and friction factor characteristics of a circular tube fitted with a full length helical screw element with different twist ratios. They reported higher performance of helical twisted insert in comparison with the twisted tape insert. Goto et al [9,10], investigated the condensation and evaporation augmentations in internally grooved tube.

The measured data yield a set of Nusselt number correlations. There are numerous investigations using the periodic and fully developed flow concepts on fluid flow and heat transfer for the parallel plate channels with periodically grooved parts. Pongjet Promvonge [11] investigated that the snail entry with the coiled square-wire provides higher heat transfer rate than that with the circular tube of under the same conditions. Heat transfer enhancement can create one or more combinations of the following conditions that are favorable for the increase in heat transfer rate with an undesirable in increase in friction (i) Interruption of boundary layer development and rising degree of turbulence (ii) increase in heat transfer area (iii) generating of swirling and / or secondary flows. To date, several studies have been focused on passive heat transfer enhancement methods reverse / swirl flow devices (rib, groove, wire coil, conical ring snail entry, twisted tape, winglet, etc.,) form an important group of passive augmentation technique by Promvonge [12].

Dong Jung et al [13], conducted test for air side Reynolds number in the range of 800 – 1500 with different fin pitches, fin lengths and fin heights, at a constant tube side water flow rate of 2.5 m^3 / h. Xiaoyan Zhang et al [14], investigated experimental study on evaporation heat transfer of R417A flowing inside horizontal smooth and two internally grooved tubes with different geometrical parameters was conducted with the mass flow rate range from 176 to 344 kgs^{-1}. Based on the experimental results, the mechanism and mass flow rate, heat flux, vapor quality and enhanced surface influencing the evaporation heat transfer co-efficient were analyzed and discussed.

The thermo physical properties of the liquids with temperature especially the glycol-water mixture, the properties such as the specific heat, thermal conductivity, and dynamic viscosity of ethylene glycol-water mixture are evaluated from ASHRAE Handbook [15].

In the present study, the water and ethylene glycol mixture 90:10 (by weight) flow with three types of grooved tubes (circular, square, trapezoidal) at constant wall flux condition is studied experimentally for Reynolds number ranges from 4900 to 13300 and groove depth is fixed to investigate the effect of the groove shapes on heat transfer. The experimental results are compared to that of the plain tube to obtain the heat transfer and pressure drop are reported to reveal experimentally to find efficient tube groove configurations. The thermal hydraulic performances (thp) for all the cases are also performed.

2. EXPERIMENTAL SETUP AND PROCEDURE

The schematic diagram of the experimental setup is shown in Fig. (1).The circular tube consists of fully developed hydrodynamic section of length 2140 mm, test section of length 1700 mm and the exit section. The test section which is made of carbon steel and have an inner diameter 38.14 mm, outer diameter 48.26 mm and have a thickness 5.060mm. The mass flow rate of water and ethylene glycol mixture is measured by means of calibrated Rotameter (flow meter) having flow ranges from 0.133 to 1.4 kg/sec. An electric resistance heater is wrapped around the test section to provide constant heat flux condition along the tube wall. The experiments are conducted at a constant nominal power 1000 W i.e. constant heat flux is maintained. The outside of the test section is insulated with glass wool to minimize the heat losses. The working fluid is mixture of water and ethylene glycol is reused for throughout the study. The outlet of the test tube is connected with radiator inlet; radiator outlet is connected with the storage tank. Hence the mixture is cooled because it passes through the radiator.

The five T – type thermo couples are placed along the test tube in line with same spacing to measure the wall surface temperature. Besides one thermo couple is used at the inlet, one at the outlet of the mixing chamber. The ambient temperature at the same time is also measured. The Copper constantan thermo couples are calibrated in a thermostat within 0.1°C deviation before the experiments. The data obtained from the thermo couples are recorded and the average of this data is taken as the steady-state temperature of the test surface. The temperature measured along the test tube is used to obtain the average surface temperature of the wall. In the experiments, it took about 60 min to reach the steady state. The pressure difference between inlet and outlet of the test section is measured with an electronic pressure transmitter.

A depth of 4 mm is chosen for grooves because of their pipe thickness (t = 5.060 mm). In order to investigate the effect of grooved shapes in a commercial tube on heat transfer and friction factors, three different grooved tubes and plain tube are used for the present tests. Three different geometrical grooved tubes shape as circular, square and trapezoidal are shown in Fig. (2). The depth and length of circular and trapezoidal grooves are fixed as 4 mm and 8 mm respectively.

The depth and length of square groove are 4 mm each. The same number of grooves (n=93) is designed for all the three geometries, because of the fixed pitch length. The test tube length is divided into six parts of same space and then grooves are machined at the inner surface of the tube as transverse to the flow direction. These test tube are joined the pressure using its conic ends at both sides avoiding leakage.

3. DATA REDUCTION

The net heat transfer rate (Q_{net}) from the inner tube surface to the fluid flow passing through the test tube by convection can be calculate subtracting heat losses (Q_{loss}) from the total electrical power input (Q_{vol}) at the steady state conditions. The net rate heat transfer is also equal to the rate of the heat transfer given to the fluid passing through the test section. The energy balance equation can be written as follows.

$$Q_{net} = Q_{vol} - Q_{loss} = mC_p\left(T_o - T_i\right) \qquad (1)$$

where Q_{net} is the net heat transfer rate given to the fluid inside the test tube, Q_{vol} (V^2 / R) is the measured electrical power input to the heater. Q_{loss} denotes all the heat losses from the test section.

On the other hand, the heat transfer may be approximated by:

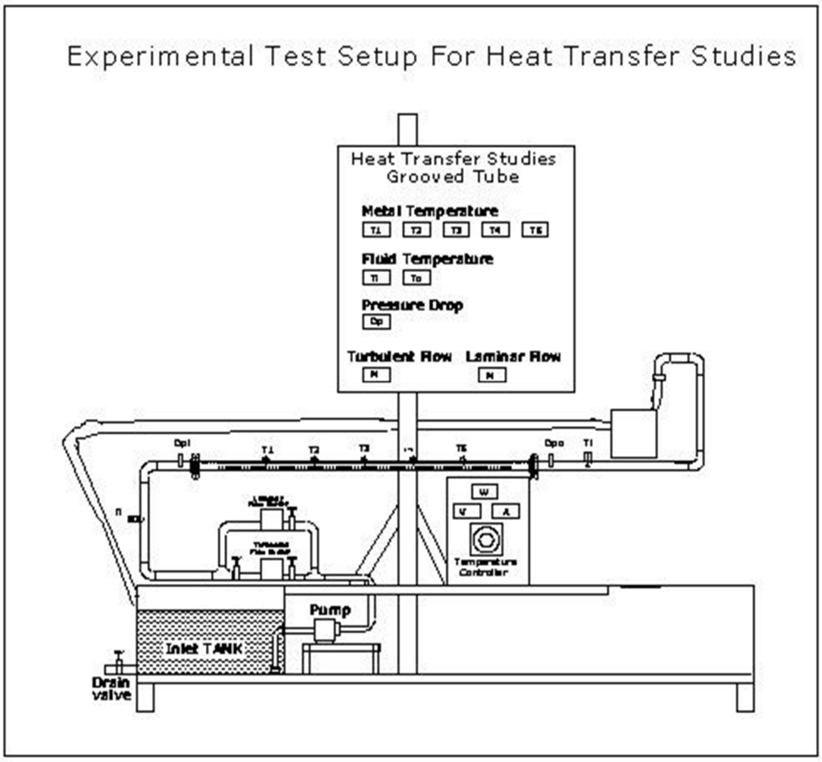

Fig. 1. Schematic diagram of experimental set up

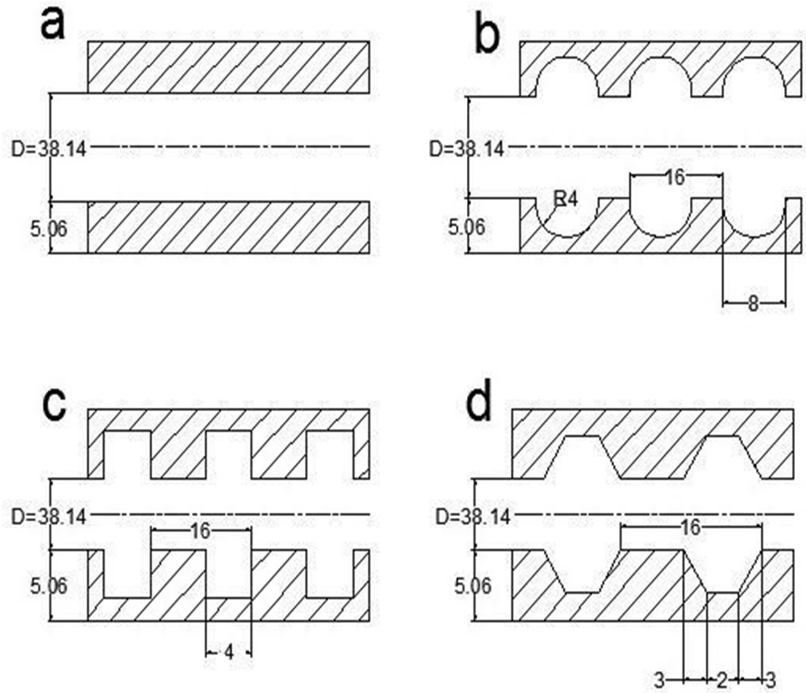

Fig.2. The geometric shapes of the grooved tubes in mm (a) plain tube (b) circular grooved tube (c) Square grooved tube and (d) trapezoidal grooved tube

$$Q = hA(T_W - T_b) \qquad (2)$$

Where,

$$T_b = \frac{(T_o + T_i)}{2} \quad \text{and} \quad T_w = \frac{\Sigma T_w}{5}$$

Using Equation (1) and (2), the convection heat transfer co-efficient on the grooved tube wall at the steady state can be calculated by

$$h = \frac{mC_p(T_o - T_i)}{A(T_w - T_b)} \qquad (3)$$

Where A is the inner surface area of the smooth tube, T_o and T_i are outlet and inlet temperature of water and ethylene glycol mixture flow respectively. T_W is the average temperature of the locations along the tube surface.

In all the calculations the smooth surface area is taken as the heat transfer area. The average Nusselt number is calculated as

$$Nu = \frac{hD}{K} \qquad (4)$$

The Reynolds number is based on the average flow inlet velocity and the tube inlet diameter.

$$\mathrm{Re} = \frac{VD}{\nu} \qquad (5)$$

The friction factor (f) can be determined by measuring the pressure drop across the test tube length as follows.

$$f = \frac{\Delta P}{(L/D)(\rho(V^2/2))} \qquad (6)$$

Where, ΔP is the pressure drop across the test tube measured by an electronic transmitter. L is the test tube length and V is the mean velocity of water and ethylene glycol mixture at the entrance of the test section which is calculated from volumetric flow rate divided by the cross section area of the tube. D is the inner diameter of the test tube at the inlet. The volume of the thermo physical properties of water and ethylene glycol mixture are evaluated at the bulk fluid temperature $T_b = (T_o+T_i)/2$.

4. RESULTS AND DISCUSSIONS

4.1 Validation of the experimental data for the plain tube

The values of Nusselt number and friction factor determined from experimental data for plain tube have been compared with values obtained from Dittus-Boelter equation for the Nusselt number and modified Blasius equation for the friction factor for turbulent flow is as follows:

The Nusselt number for plain tube is given by the Dittus-Boelter equation as

$$\mathrm{Nu} = 0.023\,\mathrm{Re}^{0.8}\mathrm{Pr}^{0.4} \qquad (7)$$

The friction factor for a plain tube is by the modified Blasius equation

$$\mathrm{f} = 0.316\,\mathrm{Re}^{-0.25} \qquad (8)$$

The average deviation of the experimental values of the Nusselt number is ±15% from the values predicted by equation (7) and average deviation of the experimental values of the measured friction factor is ±20% from the values predicted by equation (8).Thus reasonable good agreement between the two sets of values ensures the accuracy of the data being collected with the experimental setup.

4.2 Grooved tube results for the flow of water and ethylene glycol mixture

4.2.1 Effect of Reynolds number

The experimental investigations on heat transfer for the plain tube and grooved tubes (circular, square, and trapezoidal) for the flow of water and ethylene glycol mixture are calculated and presented. Using the previous relations in data reduction section, the variation of Nusselt number with Reynolds Number for the tubes are shown in Fig.(3) and it illustrates that as Reynolds number increases Nusselt number is also increases. Generally, the test in each plot has nearly the same Prandtl number. The experiments with low Prandtl number mixtures have high Reynolds numbers due to low viscosity of the working fluid [2]. The increase in Nusselt number indicates an enhancement in heat transfer co-efficient due to increase of convection heat transfer. The overall results show that when the tube with internal grooves, the Nusselt numbers is higher than those obtained for the plain tube. Furthermore, the results show that the calculated Nusselt number for square grooved tube was higher than that obtained for others at all examined Reynolds numbers for the flow of water and ethylene glycol mixture. Also results shows that the Nusselt numbers are 37.16 to 66.18, 56.78 to 86.77, 60.49 to 92.22 and 41.85 to 65.95 respectively for plain, circular grooved, square grooved and trapezoidal grooved tubes.

4.2.2 Effects of friction factor

The variation of the friction factor with Reynolds number for the grooved tubes for the flow of water and ethylene glycol mixture is shown in Fig. (4), for all the arrangements, it is found that the friction factor values are higher at lower Reynolds numbers. However, the falling trend is sharper as any of the grooved tube in comparison with the plain tube. As can be seen in the Fig.(4) the lowest of friction factor value belongs to the trapezoidal grooved tube. Due to the viscosity difference occur water and ethylene glycol mixture leads to friction loss and pressure drop in an experiment results.

4.2.3. Effectiveness of grooved tubes for flow of water and ethylene glycol mixture

The effectiveness of heat transfer augmentation for flow of water and ethylene glycol mixture in the grooved tubes relative to the plain tube for various cases are compared in Fig.(5). The effectiveness is indexed by the ratio of the Nusselt Number of grooved tubes to that of plain tube in terms of Nu / Nu0. In the range of Reynolds number from 4900 to 13300, the ratio of Nu / Nu0 for circular, square, and trapezoidal grooves are more than one for all the cases.

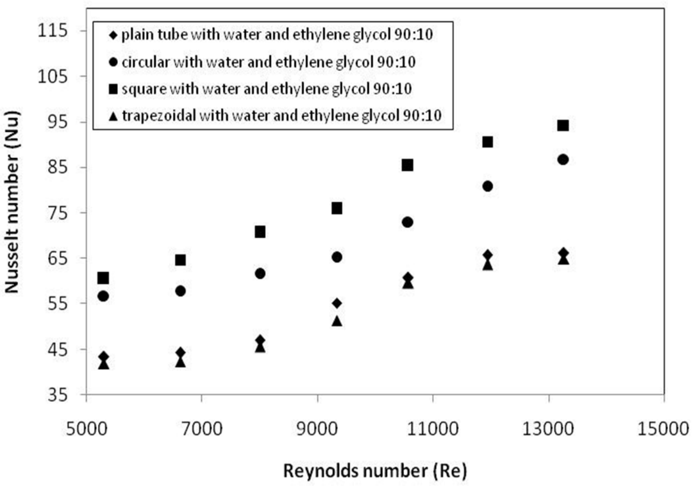

Fig.3- Nusselt number versus Reynolds number for different grooved tubes with water and ethylene glycol mixture

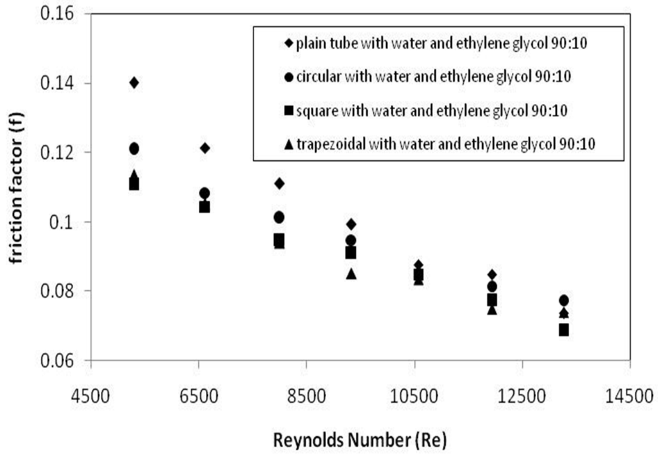

Fig. 4- friction factor versus Reynolds Number for different grooved tubes with water and ethylene glycol mixture

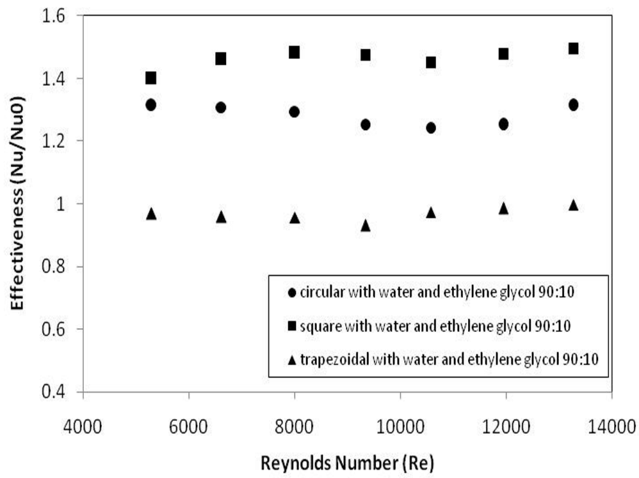

Fig. 5- Nu/Nu0 versus Reynolds number for different grooved tubes with water and ethylene glycol mixture

In the calculated effectiveness, the highest values obtained for square grooved tubes and lowest Values obtained for trapezoidal grooved tubes. This indicates that the role of grooved tubes, water and ethylene glycol mixture increasing turbulence intensity is more significant in lower velocities in comparison with conditions where the fluid regime is turbulent even in plain tube.

Using the data obtained from these tests, the average Nusselt number for both the plain surface and various grooved surfaces are correlated as a function of Reynolds number for the working fluid water and ethylene glycol mixture. The predicted values of Nusselt number and friction factor are compared with the experimental values and are shown in Figs.(6) and (7) respectively. It can be observed that the above correlations lead to a deviation of ±8 % for Nusselt numbers, and ± 8 % for friction factors. Heat transfer measurements indicated that grooved tubes caused much more heat transfer enhancement compared with that of the plain tube.

The resultant equations are:
For plain tube

$$Nu = 0.192 Re^{0.8339} Pr^{-1.0659} \quad (9)$$

$$f = 21.15\ Re^{-0.588} \quad (10)$$

For circular grooved tube

$$Nu = 1.504 Re^{0.5607} Pr^{-0.687} \quad (11)$$

$$f = 5.123 Re^{-0.366507} \quad (12)$$

For square grooved tubes

$$Nu = 0.615 Re^{0.4712} Pr^{0.2912} \quad (13)$$

$$f = 20.27\ Re^{-0.6005} \quad (14)$$

For trapezoidal grooved tubes

$$Nu = 0.1912\ Re^{0.6201} Pr^{0.0042} \quad (15)$$

$$f = 6.347\ Re^{-0.4702} \quad (16)$$

4.2.4. Performance Criteria for flow of water and ethylene glycol mixture

In the present study the thermal hydraulic performance of the grooved tubes water and ethylene glycol mixture are calculated and compared. The performance ratio is defined using the Nusselt number and friction factor for grooved tubes and plain tube is as follows.

Thermal–hydraulic performance

$$\eta = \frac{Nu / Nu_0}{(f / f_0)^{1/3}} \quad (17)$$

The Fig.(8) shows that the higher values are obtained for the square grooved tube and trapezoidal grooved tube has the lowest performance. In addition, the Fig. 8 shows that performance ratios decreased by increasing the Reynolds number. These types of plots may be helpful to choose working range so as to proved ≥1. When considering the heat transfer and the pressure drop simultaneously at constant pumping power, the working conditions should satisfy $\eta \geq 1$. As can be seen from the Fig.(8) thermal hydraulic performance is greater than unit ($\eta \geq 1$) for all the present grooved tubes. The present circular, square, and trapezoidal grooves tubes consistently possess higher thermal performance (η), in comparison with plain tube for water and ethylene glycol mixture.

CONCLUSION

The key issue of this study is mixing of water and ethylene glycol mixture 90:10 (by weight) flow through the different geometry of tubes (circular, square and trapezoidal). The ethylene glycol prevents corrosion and also acts as antefreezing agent.

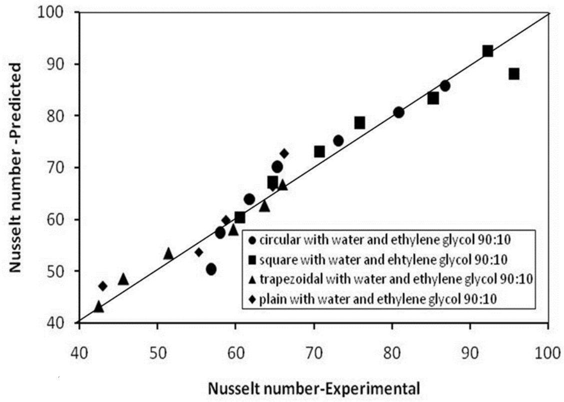

Fig.6- Experimental versus predicted Nusselt number with water and ethylene glycol mixture

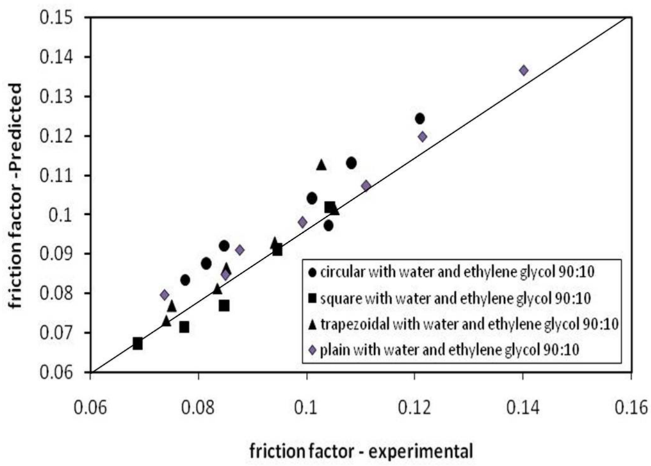

Fig.7- Experimental versus predicted friction factor with water and ethylene glycol

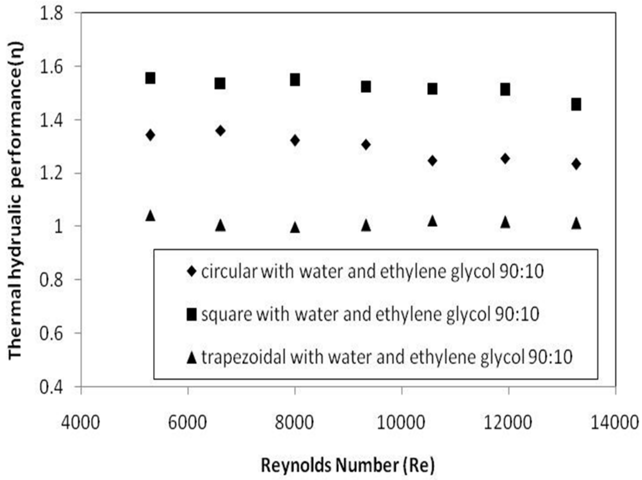

Fig.8- The thermal hydraulic performance versus Reynolds number for various grooved tubes

At uniform heat flux local heat transfer results are obtained. Heat transfer around a cylinder is strongly affected by the Reynolds number and the Prandtl number [2].The performance of the grooved tubes for a flow of water and ethylene glycol mixture are compared with each other. Our experiments revealed that the theoretical and experimental findings are coinciding.

On the experimental part, higher Nusselt number and thermal – hydraulic performance are obtained for the square grooved tube with the other ones in the studied range of Reynolds number from 4900 to 13300. The increase of Nusselt number and Reynolds number indicates that the heat transfer rate also increases [1, 2, 6, 7].The heat transfer co-efficient is also increases due to the mixing of ethylene glycol to the water and the mixture is passes through the grooved tubes.

The study is carried out in different grooved tubes for a flow of water and ethylene glycol mixture; maximum heat transfer enhancement is obtained up to 36% for circular grooved tube, 55% for square grooved tube and 10 % trapezoidal grooved tube in comparison with smooth tube [6]. Since, water and ethylene glycol mixture has a good potential to be used for heat exchangers with a different proportions of water and ethylene glycol and different geometries of tube [1, 2, 6].

NOMENCLATURE

A	heat transfer surface area (m^2)
D	inner diameter of test tube (m)
E	total energy (J)
f	friction factor
g	gravitational acceleration (ms^{-2})
h	convective heat transfer co-efficient (w/m^2k)
k	thermal conductivity of water and ethylene glycol mixture (w/mk)
L	length of test tube (m)
m	mass flow rate of water and ethylene glycol mixture(kg/s)
n	number of grooves in the tube
Nu	Nusselt number (=h D/k)
Q	heat transfer Rate (W)
Re	Reynolds Number (VD/υ)
T	temperature(K)
ΔP	pressure difference(N/m^2)
Q_{net}	Net heat transfer
Q_{loss}	Loss of heat transfer
Q_{vol}	Electrical power input
Pr	Prandtl number ($\mu C_p /K$)
Cp	specific heat capacity water and ethylene glycol mixture (kJ/kgK)

Greek Symbols

η	thermal hydraulic performance
υ	Kinamatic viscosity of water and ethylene glycol mixture (m^2/s)
ρ	density of water and ethylene glycol mixture kg / m^3

Subscripts

w	local wall
b	mean
i	inlet
o	outlet
0	plain tube

Abbreviations

HTE	Heat Transfer Enhancement
thp	thermal hydraulic performance

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