International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 02, February-2022

Heat Transfer Characteristics with Effect of Viscosity of Newtonian Fluids & Corrugation Angle of Corrugated Heat Exchanger

N.Venkateswara Rao[1], M. V. S. Murali Krishna[2]* and P. Usha Sri[3]
[1,2] Department of Mechanical Engineering, Chaitanya Bharathi Institute of Technology,
Gandipet, Hyderabad- 500 075,
[3]Department of Mechanical Engineering, Osmania University, Hyderabad

***Abstract*: Heat exchangers are used for industrial applications. Plate heat exchangers are highly efficient heat exchangers, out of which corrugated heat exchangers are one of them. In the present investigations heat transfer studies were made on three different types of corrugated plate heat exchangers having a length of 300 mm and width of 100 mm. The corrugated channel has a spacing of 5 mm. Three different corrugation angles are used in this study were 30^0, 40^0 and 50^o.** Hot fluid, thin motor oil was taken as **test fluid as well as the heating medium. The cold fluid was Glycerol mixed with water by 10%, 20% and 30% by volume. Cold fluid was flowing inside the heat exchanger, while hot fluid was flowing outside the heat exchanger in counter-flow direction. The duty of heat transfer of heat exchanger was 5 kW. The wall temperatures were determined by temperature sensors. The inlet and outlet temperatures of test fluid and hot fluid were measured by means of four more thermocouples. The experiments were carried out at a flow rate ranging from 0.5 lpm to 6 lpm with the test fluid. From the experimental observations film heat transfer coefficient as well as Nusselt number were calculated. These values are compared with different Reynolds numbers as well as corrugation angles. The effect of corrugation angle and** viscosity **on heat transfer rates was discussed. Heat transfer rate increased with higher corrugation angle and higher viscosity of blend ratio of Glycerol with water.**

INTRODUCTION

Giampietro Fabbri (2000) studied the heat transfer in a channel composed of a smooth and a corrugated wall under laminar flow conditions. The velocity and temperature distributions were determined with the help of a finite element model. The heat transfer performance of the corrugated wall channel was compared with that of a smooth wall duct. The numerical model was utilized in a genetic algorithm to maximize the heat transfer by optimizing the corrugation profile, for given volume of the corrugated wall and pressure drop in the channel. Some optimum corrugation profiles were presented at the end.

Yilmaza M. et al. (2001) presented second-law based on performance evaluation criteria to evaluate the performance of heat exchangers. They discussed the need for the systematic design of heat exchangers using a second law-based procedure and also they presented a classification of second-law based performance criteria: criteria that use entropy as evaluation parameter, and criteria that use exergy as evaluation parameter. Both classes were collectively presented and reviewed, and their respective characteristics and constraints were given. It was shown how some of these criteria are related to each other.

Ho C.D. et al. (2001) studied the influence of recycle on a parallel-plate heat exchanger of inserting in parallel an insulation sheet to divide an open duct into two channels for double-pass operations with uniform wall temperature. The results were represented graphically and compared with those in an open duct (without an inserted insulation sheet) and a double-pass without recycle. Substantial improvement in heat transfer was obtainable by employing such a double-pass device with external refluxes, instead of using an open conduit with single-pass operations and using double-pass operations without recycle. They also discussed the effect of insulation-sheet location on the enhancement of heat transfer efficiency as well as on the increment of power consumption.

Vlasogiannis P. et al. (2002) tested a PHE under two-phase flow conditions by using an air/Water mixture as the cold stream. They recorded visual observations by a high-speed video camera that lead to the construction of a flow regime map. The heat transfer coefficient of the air/Water stream was measured as a function of air and Water superficial velocities. The flow regime with a gas-continuous phase covering the core of the channel and liquid flowing in the form of rivulets inside the furrows shows particularly favorable heat transfer characteristics.

Kilyoan Chung et al. (2002) performed the heat and flow analyses of a parallel-flow heat exchanger. Two models with and without considering the effects of the geometric characteristic of flat tube were used. Comparing the two models, the modeling using the heat transfer correlations of flat tubes showed the better accuracy and stability of numerical solutions. They proposed the effect of flow distribution on the thermal performance with varying design factors (i.e., the locations of separators and inlet/outlet, and the aspect ratios of micro channels of the heat exchanger). The observations were made for flow uniformities along the paths of the heat exchanger, and to evaluate the thermal performance of the heat exchanger. It was found that the heat transfer rate of the optimized model was increased by 6.0% compared to that of the base type and the pressure drop by 0.4%.

Wright A.D. and Heggs P.J. et al. (2002) showed that the operation of a two stream PHE can be approximated after the plate rearrangement had been made, using the existing PHE performance data. He assumed that the overall mass flow rates do not change with the new configuration and that truly counter-current flow is achieved.

Reay D.A. (2002) observed that the use of heat pumps applications depends mostly on the cost of the unit. Many factors influencing this cost were including the number of units manufactured, the ease of installation, the complexity of the control requirements, and the cost of the working fluid(s). A common feature of all heat pump cycles was the presence of at least one heat exchanger, indeed some heat-driven cycles were composed almost entirely of heat exchangers, each having a different but critical role to play. And also, he observed several important aspects of heat exchangers that can help to reduce first cost of these components and the system (in addition to the possible positive impact on coefficient of performance). Two of these were discussed here — Compact Heat Exchangers (CHEs) and heat transfer enhancement. The latter may be directly associated with CHEs but can be equally beneficial in reducing approach temperature differences in 'conventional' shell and tube heat exchangers. Both factors were essential features of many intensified processes, which his argument need compatible heat pumps if the market for the latter has to be flourish. He described the most recent types of CHE, with emphasis on the benefits they can bring to heat pump; first cost and performance. He also viewed heat transfer enhancement in heat pumps.

Deb Williams (2002) discussed the PHEs that transfer heat effectively by placing thin, corrugated metal sheets side by side and connecting them by gaskets. So, the flow of the substance to be heated and cooled takes place between alternating sheets allowing heat transfer through the metal sheets.

Isabel M. Afonso et al. (2003) conducted an experimental investigation to obtain a correlation for the determination of convective heat transfer coefficients of stirred yoghurt in a PHE. A rheological study was carried out in order to characterize the stirred yoghurt flow behavior, evaluating its dependency both on shear rate and temperature. A shift in the temperature dependency was evidenced at 25 °C. It was also shown that the material shows complex flow behavior, changing from a Bingham fluid to a power-law fluid at shear stresses in excess of approximately 6.7 Pa. As regards the heat transfer behavior of the non-Newtonian stirred yoghurt a correlation for the convective heat transfer coefficient was obtained, that reveals the large effects of the thermal entry length due to the high Prandtl numbers and to the short length of the PHE.

Jorge A.W. Gut et al. (2004) observed that the thermal models of PHEs rely on correlations for the evaluation of the convective heat transfer coefficients inside the channels. They proposed to configure the exchanger with one countercurrent single-pass arrangement for acquiring heat transfer experimental data. This type of configuration approaches the ideal 16 case of pure countercurrent flow conditions, and therefore a simplified mathematical model can be used for parameter estimation. However, it was known that the results of parameter estimation depend on the selected exchanger configuration because the effects of flow maldistribution inside its channels were incorporated into the heat transfer coefficients. This work presents a parameter estimation procedure for PHEs that handles experimental data from multiple configurations. The procedure was tested with an Armfield FT-43 heat exchanger with flat plates and the parameter estimation results were compared to those obtained from the usual method of single-pass arrangements. Finally, they concluded that the heat transfer correlations obtained for PHEs were intimately associated with the configuration(s) experimentally tested and the corresponding flow distribution pattern(s).

Jassim E.W. et al. (2006) conducted the pressure drop experiments for 100C and 200C inlet temperatures and developed two phase pressure drop model based on the kinetic energy of the flow in order to relate the two phase pressure drop data to the single phase data. The model predicts two phase pressure drop within 15% of experimental measurements.

Anil Kumar Dwivedi and Sarit Kumar Das (2007) presented a predictive model to suggest the transient response of PHE, subjected to a step flow variation. The work also brings out the effect of the port to channel mal-distribution on the performance of PHEs under the condition of flow variation. The results indicate that flow mal-distribution affects the performance of the PHEs in the transient regime. A wide range of the parametric study has been presented which brings out the effects of NTU and heat capacity rate ratio on the response of the PHE, subjected flow perturbation. They carried out experiments to verify the present theoretical model. Experiments include the responses of the outlet temperatures subjected to inlet temperature transient in the circuit followed by a sudden change in flow rate in one of the fluids. Simulated performance was compared to the performance measured in the experiments. Comparisons indicate that theoretical model developed for flow transient was capable of predicting the transient performance of the PHEs satisfactorily, under the given conditions of changed flow rates.

Lin J.H. et al. (2007) used Buckingham Pi theorem to study dimensionless correlation to characterize the heat transfer performance of the corrugated channel in a PHE. They substituted the experimental data into these correlations to identify the flow characteristics and channel geometry parameters with the most significant influence on the heat transfer performance. They observed that the dimensional analysis reveals local Nusselt number (Nux) is determined primarily by Re, R/Dh (geometry), x/Dh (location) and Θ (corrugation angle), Carla S. Fernandes et al. (2008) studied laminar flows of Newtonian and power-law fluids through cross-corrugated chevron-type PHEs in terms of the geometry of the channels. The plates area enlargement factor was a typi**cal one (1.17),** the corrugation angle, , varied between 30° and 60° and the flow index behavior, n, between 0.25 and 1. Single friction curves fReg = K for both Newtonian and non-Newtonian fluids were proposed for each by developing an adequate definition of the generalized Reynolds number, Reg. The coefficient K compares well with experimental data, for all tortuosity coefficient. It was found that, for each (seven) values of , and depends on the , τ decreases with the decrease of n. Food

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 02, February-2022

fluids were frequently processed in PHEs and usually behave as non-Newtonian fluids. This study can be useful in engineering applications as well as in the characterization of transport phenomena in PHEs.

Aydin Durmus et al. (2009) presented energy analysis and energy saving of very important parameters in heat exchanger design and studied the effects of the surface geometries of three different types of heat exchangers like flat PHE , corrugated PHE and asterisk PHE by considering heat transfer, friction factor and energy loss through experimentation.

Iulian Gherasima et al. (2009) calculated the fluid temperature profiles in a multi-passage PHE and its effectiveness were calculated with a model which includes dissipation, temperature-dependent viscosity and appropriate correlations for the Nusselt number and the friction coefficient. When the viscosity of the two fluids was low (e.g. Water) the results were identical to the classic ε–NTU relations which were obtained by neglecting dissipation and by assuming that fluid properties and heat transfer coefficients were constant. But, when one of the fluids was very viscous (e.g. glycerol) the temperatures of both fluids were significantly higher while the effectiveness can be higher or lower than the value predicted by the classic relations. In particular, for cases with a very viscous hot fluid, the effectiveness may be even higher than unity.

Dovica D. et al. (2009) investigated characteristics of the flow in chevron PHEs were investigated through visualization tests of channels with = β8° and = 61°. Mathematical model has been developed with the aim of deriving correlations for prediction of f and Nu for flow in channels of arbitrary geometry (and b/l). Thermal and hydraulic characteristics were evaluated using analytical solutions for the entrance and fully developed regions of a 18 sinusoidal duct adapted to the basic single cell. The derived correlations were finally adjusted so as to agree with experimental results from tests on channels with = β8° and = 65°. f and Nu calculated by the presented correlations were shown to be consistent with experimental data from the literature at Re = 2**–10,000, = (15–**67)° and b/l = 0.26**–**0.4.
Little reports are available on the effect of corrugation angle and effect of viscosity of cold fluid on heat transfer rate of corrugated heat exchangers. The authors have made effort in this direction.

2. MATERIALS AND METHODS

The experimental setup is fabricated using stainless steel material to prevent corrosion during conduction of the experiments. The primary component of the experimental setup is corrugated plate heat exchanger (PHE) with 30^0, 40^0 and 50^0 corrugation angles. It is fabricated using 3 stainless steel plates welded in a well specified manner to form two adjacent channels. The spacing provided for the top channel is 15 mm and that for the bottom test fluid channel is 5 mm. The flow through these channels is supported by other auxiliary components like test fluid storage tank, hot fluid storage tank. The experimental setup used here is shown in Fig. 2. The setup is fitted with a total of 11 thermocouples to measure the wall temperatures at different locations, of this one each is fitted at the inlet and outlet of each channel for measurement of the bulk fluid temperatures and the remaining seven are fitted on the surface of the heat transfer plate. The thermocouples are connected to a digital temperature indicator. The flow pattern adopted here is countercurrent flow. The experimental setup consisted of-Corrugated PHE ,Storage tanks for test fluid and hot fluid, Rotameters, Digital temperature indicato, Pumps and Manometer The experiments were carried out in the plate heat exchanger having 5mm spacing. The experiments were carried out with the biodiesel of viscosity 0.8 cp at 35^0C as test fluid. For each experimental reading, the inlet and outlet temperatures of the fluid as well as the wall temperatures on the heat exchanger plate at seven different locations were noted by means of thermocouples welded at these locations and read through the digital temperature indicator. These temperatures were used for the analysis of heat transfer. For making the heat transfer studies the hot fluid flow rate was maintained constant. The test fluids were pumped into the bottom channel through the calibrated rotameter from 0.5 to 6 lpm. Fig.1 shows schematic diagram of the experimental set-up.

1.Test section 2.cleveron plate, 3. Temperature measuring devices, 4. Temperature measuring devices, 5. Pressure measuring devices, 6. Flow rate devices, 7.Ball valves, 8. Pressurizer 9.Hot water container, 10. Test fluid container, 11. Test fluid collector, 12. Heater. 13. Pipes for fluid, and 14. Pressure measuring devices.

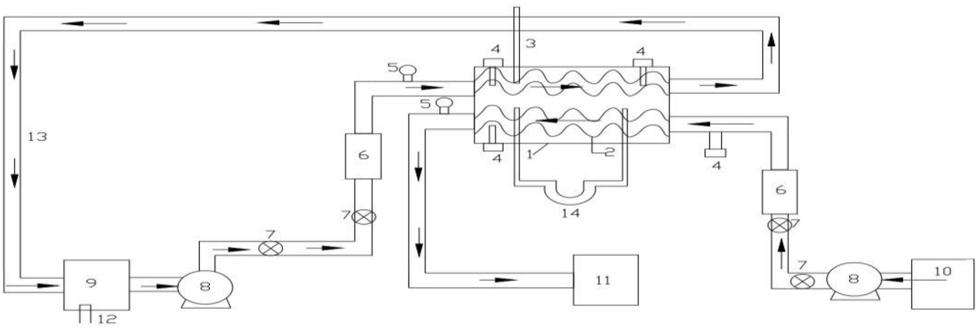

Fig.2. Line diagram of experimental set-up

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 02, February-2022

The middle plate was fitted with 7 thermocouples, along the length and breadth of the plate, to measure the wall temperatures. Four more thermocouples were inserted into the bulk fluid to measure the inlet and outlet temperatures of hot and cold fluids. These thermocouples were connected to a digital temperature indicator having an accuracy of 0.1^0C. For each flow rate the inlet and outlet temperatures as well as the wall temperatures were noted from the temperature indicator, when it shows a constant value. For all the heat transfer studies the inside film heat transfer coefficient (h_i) was calculated by making an energy balance with log mean temperature difference (LMTD). The viscosity and specific gravity of the fluids are determined experimentally by Redwood viscometer and hydrometer respectively. Reynolds number and Nusselt number were determined from the concept of LMTD. Heat lost by hot fluid is equal to heat gained by cold fluid. The detailed calculations of heat transfer coefficient and Nusselt number were given in Reference x.. The average temperature at locations from T4 to T10 was calculated. The temperature drop at inlet and outlet were determined by $T_{average}$-$T_{C\ inlet}$ and $T_{average}$-$T_{C\ outlet}$. LMTD was determined with temperature at inlet and temperature drop at outlet. Mass flow rate of hot fluid and cold fluid were determined with flow rate of respective fluids. Amount of heat gained was determined, which was equal to h A (delta T), from which Nusselt number was estimated. The detailed calculations of heat transfer coefficient and Nusselt number were given in Reference. (Murali Krishna, et al, 2016.

3.RESULTS AND DISCUSSION

3.1. Effect of corrugation angle

Fig.3 shows the variation of heat transfer coefficient and Reynolds number with blend ratio of 30% of Glycerol with water.

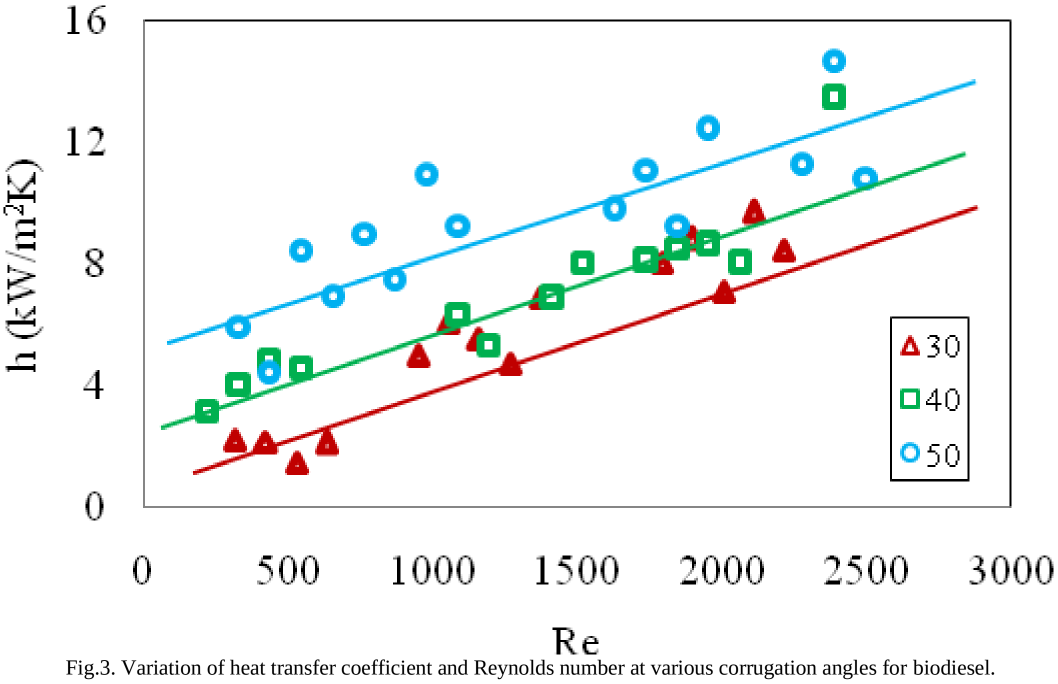

Fig.3. Variation of heat transfer coefficient and Reynolds number at various corrugation angles for biodiesel.

It is observed from this figure that heat transfer coefficient was higher for a given Re for 50^o corrugation angle compared to 30^o and 40^o corrugation angles. This is due to the high turbulence of the fluid generated for higher corrugation angle.

Fig.4 shows variation of Nusselt Number with Reynolds number with at various corrugation angles with blend ratio of 30% of Glycerol with water.

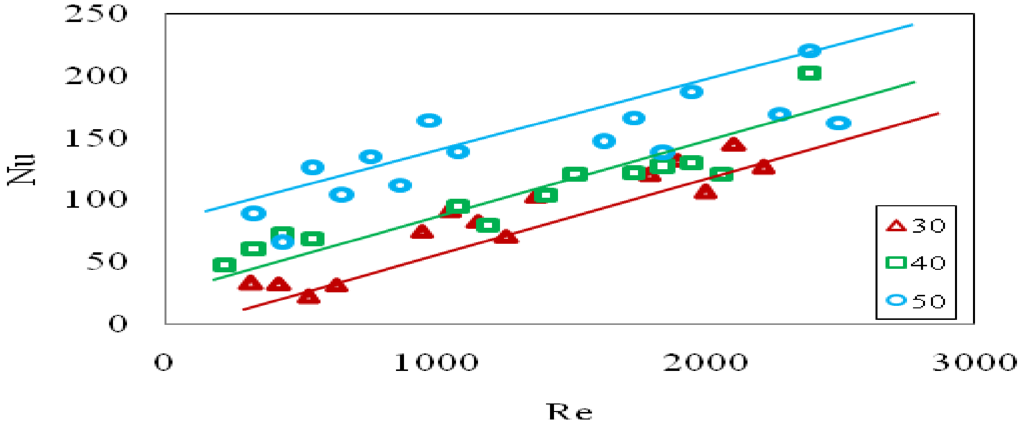

Fig.4 Variation of Nusselt number with Reynolds number with biodiesel operation at various corrugation angles.

The trends are matching well with those of Fig.4 with Fig3 Corrugation angle of 50^o showed higher turbulence causing higher heat transfer rate when compared with other corrugation angles.

3.2. Effect of viscosity

Viscosity of the fluid was changed by changing the blend ratio of Glycerol. Fig. 5. shows variation of Nusselt Number with Reynolds number for 50^o corrugation angle with different blend ratio of Glycerol with water. As blend ratio of Glycerol in water increased, heat transfer rate increased due to increase of dynamic and kinematic viscosity, as the flow was approaching to turbulent flow.

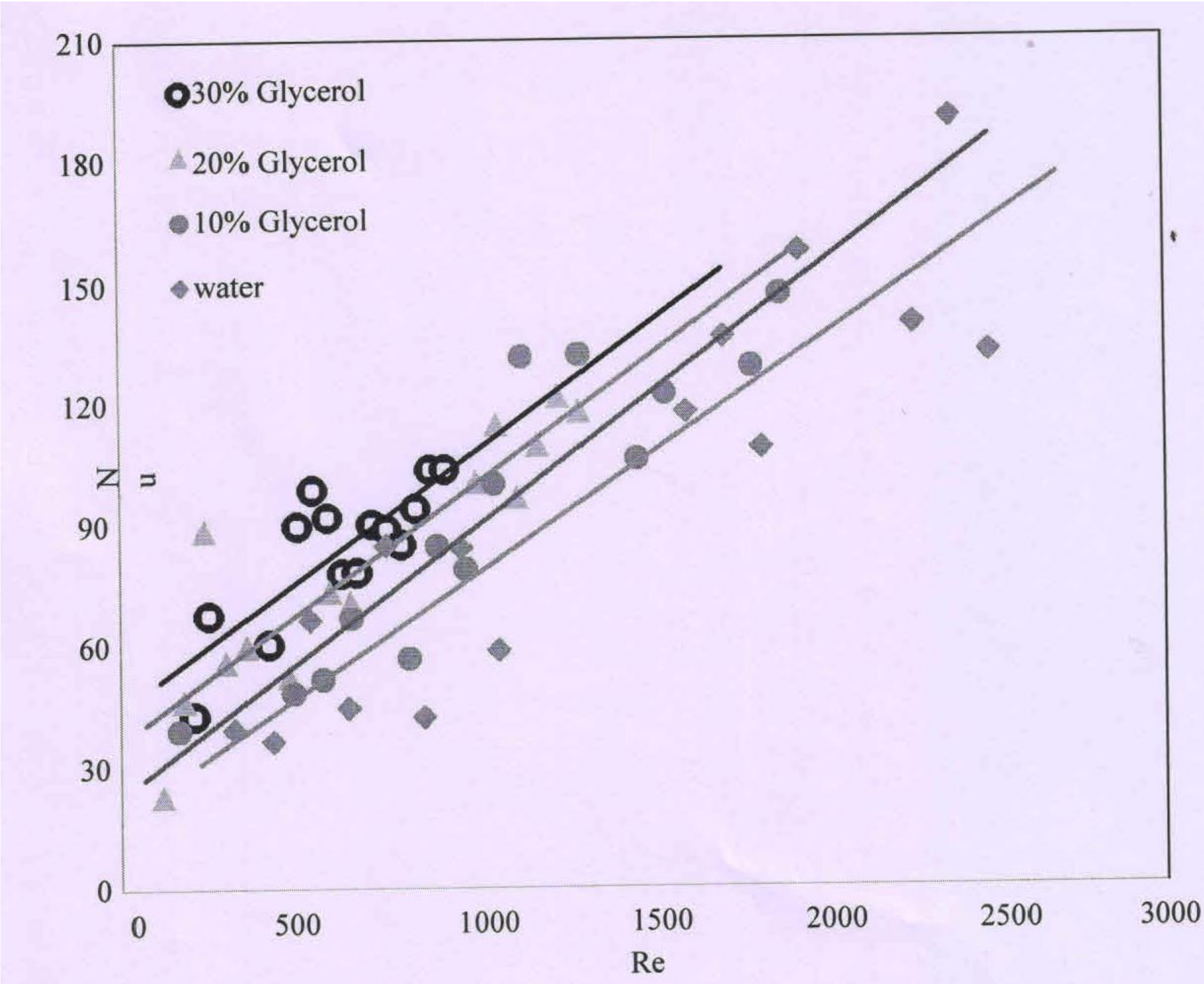

Fig.7. Nusselt Number Vs Reynolds number for 50^o corrugation angle.

CONCLUSIONS

1. It is found that heat transfer coefficient and Nusselt number are higher at a given Reynolds number for 50^o corrugation angle as compared to other corrugation angles.
2. Heat transfer rates were due to high turbulence that is created at high corrugation angles. It is also found that the percentage increase in heat transfer coefficient for water for 30^o to 40^o corrugation angle is 14%, for 40^o to 50^o corrugation angle is 30% and for 30^o to 50^o corrugation angle is 40%. At higher corrugation angles, higher heat transfer rates were achieved.
3. Heat transfer rate increased with increase of viscosity due to increase of blend ratio of Glycerol with water.

ACKNOWLEDGEMENTS

Authors are grateful the authorities of CBIT Hyderabad for providing facility and technical support.

REFERENCES

[1] Giampietro Fabbri, "Heat transfer optimization in corrugated wall channels", International Journal of Heat and Mass Transfer, Volume 43, Issue 23, pp. 4299–4310, Dec. 2000.
[2] Yilmaza M, Saraa O.N, Karslib S, "Performance evaluation criteria for heat exchangers based on second law analysis", Exergy, An International Journal, Volume 1, Issue 4, pp. 278–294, 2001.

[3] Ho C.D., Yeh H.M., Lu C.H., Chiang S.C., "The influence of recycle on a parallel-plate heat exchanger with insulation sheet inserted for double-pass operations",International Communications in Heat and Mass Transfer, Volume 28, Issue 4, pp. 527–536, May 2001.
[4] Wright A.D., Heggs P.J., "Rating calculation for PHE effectiveness and pressure drop using existing performance data", Trans IChemE 80, Part A, β002.
[5] Kilyoan Chung, Kwan-Soo Lee, Woo-Seung Kim, "Optimization of the design factors for thermal performance of a parallel-flow heat exchanger", International Journal of Heat and Mass Transfer, Volume 45, Issue 24, pp. 4773–4780, Nov. 2002.
[6] Reay D.A., "Compact heat exchangers, enhancement and heat pumps", International Journal of Refrigeration, Volume 25, Issue 4, pp. 460–470, June 2002.
[7] Deb Williams, "Plate heat exchangers", State of the Art Engineering Report, MME 499, pp. 1-9, 2002.
[8] Isabel M. Afonso, Paulo Cruz, Joao M. Maia, Luis F. Melo, "Simplified numerical simulation to obtain heat transfer correlations for stirred Yoghurt in a plate heat exchanger", Food and Bioproducts Processing, Volume 86, Issue 4, pp. 296–303, Dec. 2008.
[9] Isabel M. Afonso, Paulo Cruz, Joao M. Maia, Luis F. Melo, "Simplified numerical simulation to obtain heat transfer correlations for stirred Yoghurt in a plate heat exchanger", Food and Bioproducts Processing, Volume 86, Issue 4, pp. 296–303, Dec. 2008.
[10] Jorge A. W. Gut, Jose M. Pinto, "Configuration design for plate heat exchangers and pasteurizers: Mathematical modeling and optimization methods", Em: 6th Int. Conference on Foundations of Computer-Aided Process Design, pp. 357-360, 2004.
[11] Jassim E.W., Newell T.A., Chato J.C., "Refrigerant pressure drop in chevron and bumpy style flat plate heat exchangers", Experimental Thermal and Fluid Science, Volume γ0, pp. 213-222, 2006.
[12] Anil Kumar Dwivedi, Sarit Kumar Das, "Dynamics of plate heat exchangers subject to flow variations", International Journal of Heat and Mass Transfer, Volume 50, Issues 13– 14, pp. 2733–2743, July 2007
[13] Carla S. Fernandes, Ricardo P. Dias, Joao M. Nobregad, Joao M. Maiad, "Friction factors of power-law fluids in chevron-type plate heat exchangers", Journal of Food Engineering, Volume 89, Issue 4, pp. 441–447, Dec. 2008.
[14] Aydin Durmus, Huseyin Benli, Irfan Kurtbas, Hasan Gul, "Investigation of heat transfer and pressure drop in plate heat exchangers having different surface profiles", Heat and Mass transfer, Volume 52, pp. 1451-1457, 2009.
[15] Iulian Gherasima, Nicolas Galanisa, Cong Tam Nguyenb, "Effects of dissipation and temperature-dependent viscosity on the performance of plate heat exchangers", Applied Thermal Engineering, Volume 29, Issues 14–15, pp. 3132–3139, Oct. 2009.
[16] Dovica D., Palmb B., Svaica S., "Generalized correlations for predicting heat transfer and pressure drop in plate heat exchanger channels of arbitrary geometry", International Journal of Heat and Mass Transfer, Volume 52, Issues 19–20, pp. 4553–4563, Sep.2009.
[17] Vlasogiannis P, Karagiannis G, Argyropoulos P, Bontozoglou V, "Air–Water two-phase flow and heat transfer in a PHE ", International Journal of Multiphase Flow, Volume 28, Issue 5, pp. 757–772, May 2002.
[18] Lin J.H., Huang C.Y., Su C.C., "Dimensional Analysis For The Heat Transfer Characteristics In The Corrugated Channels Of Plate Heat Exchangers", Heat And Mass Transfer 34, 304–312, 2007.
[19] Murali Krishna, M.V.S., Basava Omkara Swamy, M., Manjunath, G.H., Venkateswara Rao, N., Sridhara Rao B., Krishna Murthy, P.V., "Heat transfer enhancement in corrugated plate heat exchanger", *British* Journal of Applied Science and Technology, Science Domain, DOI: 10.9734/BJAST/2016/28438, ISSN:2231-0843, December, 18(3), 1–14.2016.