Experimental and CFD Simulation of Curved Delta Wing Vortex Generator Insert for Heat Transfer Enhancement

R. B. Shilwant, PG Student of Mechanical Engineering Department, Sinhgad College of Engineering, Savitribai Phule Pune University, Pune

Dr. A. P. Pandhare is with the Mechanical Engineering Department, Sinhgad College of Engineering, Savitribai Phule Pune University, Pune

Abstract : The heat transfer occurs in laminar and turbulent flow regime in various engineering application. In this paper experimental work of heat transfer enhancement and friction factor which is carried out in smooth circular tube with Curved Delta Wing Vortex Generator (VG) inserts. The paper present, the difference and pressure drop measured and it has compared with and without vortex generator insert in turbulent flow by using water as fluid. Here central rod is used for attaching VG insert on opposite sides of the rod. The range of Reynolds number is varied from 4000 to 20000 for both with and without perforation of VG inserts. The Nusselt number increases and friction factor decreases for entire range of Reynolds number. The validation is done by using CFD software (ANSYS FLUENT 16.0) and it shows reasonable accuracy in results..

***IndexTerms* - Heat transfer enhancement, Curved delta wing vortex generator, Turbulent flow**

I. INTRODUCTION

In the laminar flow regime heat transfer occurs in various engineering application. Heat exchanger is very common device which is used in heating and cooling system in various industries such as air conditioning, refrigeration system, chemical reactors and power plant stations. Therefore various techniques have been suggested for enhancing heat transfer rate and decrease the size and cost of the heat exchanger.

Heat exchanger has complex design procedure for analyzing pressure drop, heat transfer rate to develop efficient compact heat exchanger required. The flow through the tube is turbulent for heat transfer enhancement by using curved delta wing vortex generator insert. Different types of insert used for generating swirling motion in circular tube. These techniques produces disturbances in the boundary layer which promotes fluid mixing and increases heat transfer rate. There are three methods of heat transfer enhancement which are explained given below.

1.1 Active Method

In this method external power sources are required for heat transfer enhancement. It includes reciprocating plunger magnetic field, fluid vibration, surface vibration, injection and jet impingement which need external power source.

1.2 Passive Method

In this method external energy is not required. Additional devices are used for augmented heat transfer rate. Some inactive methods are swirl flow devices, rough surfaces, extended devices. One of the most general methods of heat transfer by using different types of insert in tubes.

1.3 Compound method

Compound method is nothing but the combination of active and passive method which is implemented at the same time like rough surface, swirl flow devices or fluid vibration.

ROLE OF INSERT

An insert is small fin like device that attached to the surface of the central rod inside the pipe in order to the increase effective surface area and creates secondary flow, which changes the speed and efficiency of fluid flow. The purpose of any insert is to scatters the fluid particles and generates the swirls flow within the system. Insert is nothing but a turbulence generators in fluid flow system.

WORKING OF VORTEX GENERATOR INSERT

Consider a fluid flowing over flat solid surface. A part of flow area which is in close proximity to a surface of the flown block. This type of flow is called boundary layer. Viscosity and friction forces are required for boundary layer formation. The viscosity of flowing fluid and friction of the surfaces generates high transverse velocity gradients.

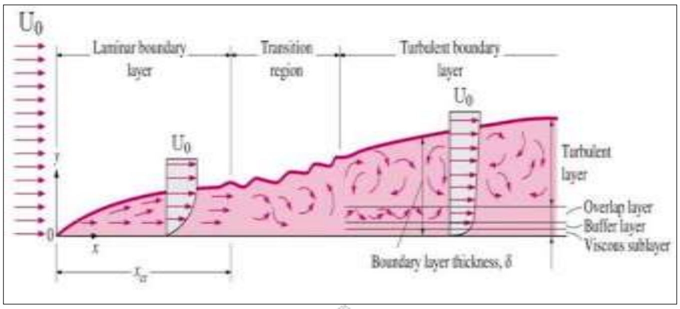

Fig.1 Fluid flow over a surface [18]

In laminar boundary layer the flow is smoothly, regularly. The fluid molecules move along regular path and imposed by flow boundaries. This is cause due the mass and momentum transfer between the layers occurs only at the microscopic level. Laminar flow is also called as the stable flow. In turbulent flow particular of the fluid in addition to the main movement also oscillate so it is also called rough. A formation of boundary layer near the leading edge of flat surface is thin and laminar. Boundary layer thickness gradually increases with movement toward the tailing edge. Despite the turbulent nature of this area there is still laminar sub layer where there is turbulence. This is due to damping effect of viscosity.

II. LITERATURE REVIEW

Deshmukh et al. [1] clarified the utilization of bended vortex generator embeds for warm exchange upgrade for course through a tube in the turbulent stream administration. Bended delta wing formed vortex generators were found near the tube divider utilizing an exceptionally created insert which gave a twirling movement of the liquid near the divider. The increase in heat transfer was appeared to be better than the current additions utilizing both the consistent Reynolds number and steady pumping power criteria. They utilized air as the working liquid and nearby warmth exchange estimations for both smooth and unpleasant surface sides of the tube are accounted for completely created turbulent stream with Reynolds number (Re) changing in the vicinity of 250 and 1500.

Chamoli et al. [3] carried out experiment in circular tube in turbulent flow region with Reynolds number range 3000-21000 using air as working fluid under uniform wall heat flux boundary conditions. A shape which is novel type perforated vortex generator developed with four different perforation indexes PI = 4%, 8%, 12%, 16% and three relative pitch lengths p/pa = 2, 4, 6. The main result found that the heat transfer and pressure drop increase with decreasing PI and p/pa, while thermal enhancement factor (TEF) increases as PI increases. It is also fund that maximum TEF of 1.65 by using the PVG at the maximum PI of 16% and the smallest p/pa of 2 at Reynolds number of 3000.

Numerical study of novel type vortex generator heat transfer characteristic's evaluated by Xu Zhiming et al. [7] at Reynolds number range 8900 to 29900. The results are came out when thermohydraulic performance factor R and and performance evaluation criterion R*, the half cylinder vortex generator insert was best. With increase in generator length the thermohydraulic performance factor R increases first and then decreases and when increase radius and decrease spacer length R decreased.

In Applied Thermal Engineering journal Vashistha et al.[4], explained the heat transfer and fluid flow characteristics of a circular tube fitted with various Twisted tape inserts arranged in co-swirl and counter-swirl orientations. This work gathered different blends like single, twin and four curved tape supplements of fluctuating turn proportions. By utilizing different blends of bent tape inserts, they presume that Nusselt number and friction factor esteems are expanded by diminishing the turn proportion of twisted tapes and the counter-swirl kind of wound tape embeds brought out higher warmth move and contact in contrast with the co-swirl curved tape inserts.

Lei et al. [2] carried out experimental examination of thermal hydraulic characteristics of circular tube with delta winglet vortex generators. Attack angle effects on delta-winglet vortex generators for heat transfer and fluid flow are examined. Swirling motion occurs in circular tube the heat transfer augmentation with extensive pressure drop. It was found that the Nusselt number increase with the increasing attack angle and decreasing pitch of the delta-winglet vortex generators.

Deshmukh and Vedula [5] explained the use of curved vortex generator inserts in circular tube with turbulent flow region for their heat transfer. The insert has specially fabricated and located close to the wall surface which generating swirling motion. It is used for both constant Reynolds number and pumping power using air as working fluid. It is applicable for bot smooth and rough surface of tube with Reynolds number (Re) varying between 10,000 and 45,000.

Skullong et al. [6] he studied the effect of curved winglet insert on thermal and flow behaviors in constant heat flux tube. For that air flow the Reynolds number range is 4150 to 25400. Parametrrs involved in this insert are attack angle of 45˚ with relative winglets heights (b/D=0.1, 0.2, 0.3) and winglets pitches (P/D=0.5, 1.0, 2.0). It contains five different punched diameters (d=1.0,1.5, 2.0, 2.5, 3.0). the experimental result show that TEF of all P-CWTs is higher than the CWT and maximum TEF of 1.76 higher than the CWT around 9% is found for d=1.5mm.

Durga Prasad and Gupta [8] studied the Experimental investigation on enhancement of heat transfer using Al_2O_3/water nano-fluid in a u-tube heat exchanger with twisted tape inserts. Here the test section consists of U-bend double-pipe heat exchanger and twisted tape is inserted in inner tube. The hot fluid is pumped through the annular region and the water base nano-fluid flows through the inner tube with both fluids at different mass flow rate. The heat transfer coefficients and the corresponding friction factors needed for performance analysis are determined at variable operating conditions of the heat exchangers with changing volume concentration of nano-fluid and twist ratios of insert.

Tu et al. [9] studied that, to improve convection heat transfer performance and pressure drop numerically. Pipe insert with different dimensionless spacer length investigated at the Reynolds number range of 100-1750. Here the result showed that the maximum Nusselt number was enhanced by 3.4-10.3 times as that of smooth tube the friction factor increases of 5.6-13.5 times. Here suitable dimensional spacer length (S/D=6.67) is selected. Compared with other insert pipe insert can transfer more heat for same pumping power for their structure because their special structure possible for the fluid flow from central region to wall region.

O. Sadeghi and H. Mohammed [10] studied Heat transfer and nanofluid flow characteristics through a circular tube fitted with helical tape inserts by using finite volume numerical method. To enhance the heat transfer results, Helical tape inserts is used with two different types of nano-fluids Al_2O_3 and SiO_2 with different nanoparticle shapes like spherical, cylindrical and platelets and also varying percentage volume fraction in base fluid (water) and changing nanoparticle diameter were used to identify their effect on the heat transfer and fluid flow characteristics through a circular tube fitted with helical tape insert geometries. The results show that the higher the volume fraction, the better the heat transfer rate; but on the other hand, the increase of volume fraction caused to increase the friction factor.

Fan et al. [11] investigated that, characteristics of heat transfer rate, flow resistance and overall thermo hydraulic performance with conical strip insert in circular tube through their numerical simulation. The result showed maximum friction factor of tube increased by 10 times of smooth tube. Also the numerical result larger slant angle and small pitch can effectively enhance heat transfer rate. The PEC value lies in the range 1.67-2.06 which has good thermo hydraulic performance.

The insert with different spacer length and arc radii were tested at Reynolds number between the ranges 4000-18000 by Yong et al. [13]. They found that, the result of Nusselt number and friction factor increases with decreasing spacer length also decreases in arc radius. Small pipe insert with R=5mm and S=100mm maximum heat transfer rate 2.61-3.33 and friction factors 1.6-1.8 those of empty tube. The tube fitted with small pipe insert can achieve high heat transfer and low friction factor.

Extensive studies have been conducted by S. Pourahmad et al. [12] on the conventional twisted tape and several of its modified versions for enhancing heat transfer coefficients. Hence new insert is need to developed and explain effectiveness-NTU analyses in a double tube heat exchanger equipped with wavy strip considering various angles were experimentally studied. They were installed wavy strip in the inner tube of heat exchanger. The experiments were carried out at turbulent flow regime. Effectiveness-NTU analyses were made for the conditions with and without wavy strips including their different angles and compared.

Ghadi et al. [13], studied CFD Modeling of increase heat transfer in tubes by wire coil inserts. In this experiment, they has been studied the effect of improving heat transfer coils in heat exchanger in a laboratory by the method of computational fluid dynamics. A shell-tube heat exchanger is used in the laboratory. Friction coefficient and Nusselt number in the tubes with wire coils reduce with increase wire coil step.

III. EXPERIMENTAL SETUP

Fig.1 shows experimental setup diagram for present work dimension of setup explained in following table I.

Experimental setup consist of six main parts such as test section pipe with VG inserts, heating coil, centrifugal pump, U-tube manometer, flow control valve and k-type thermocouple. Here water is used as working fluid with Reynolds number varying between the ranges 4000-20000. The test section tube made up of mild steel material which having length 1500mm long and thickness 2mm. The heating coil was wound on the test section and insulation rope over there. Centrifugal pump attached at one end of the test tube with flow control valve. Here 6 k-type thermocouple has taken for measuring temperature at various location of test tube and two thermocouple at inlet and outlet of test tube. The experimental reading was taken.

Table I

Parts of Experimental setup

Name of parts	Materials of part	Geometrical details
1. Outer pipe	Mild steel	ID=38mm, L=1500mm, OD=40mm
2. Central rod	Mild steel	D=6mm, L=1500mm
3.VGs inserts	Mild steel (sheet)	Thickness =1mm

Fig.2 Experimental setup

IV. MATHEMATICAL INVESTIGATION

1. Temperature difference

$$\Delta T = T_8 - T_1$$
$$= 3\ ^\circ C$$

2. Average surface temperature

$$T_{avg} = \frac{T_2 + T_3 + T_4 + T_5 + T_6 + T_7}{6}$$
$$= 35.72\ ^\circ C$$

3. Mean temperature (T_{mean}) in °C

$$T_{mean} = \frac{T_1 + T_8}{2}$$
$$= 28.5\ ^\circ C$$

4. Reynolds number (Re)

$$Re = \frac{\rho * v * D}{\vartheta}$$
$$v = 0.0936\ m/s$$

5. Heat transfer coefficient (h)

$$(Q_w) = (Q_{conv})$$
$$Q_w = \dot{m} * c_p * (T_8 - T_1)$$
$$= 1333.38$$
$$Q_{conv.} = h * A_s * (T_{avg} - T_{mean})$$
$$h = 1032\ W/m^2 k$$

6. Average Nusselt number $N_u$is calculated a

$$N_u = \frac{h * D}{K}$$
$$= 65.34$$

7. Pressure drop (Δp) in $(Pascal)$

$$\Delta p = \rho * g * H_m$$

$$= 65.67\ Pa$$

8. Friction factor

$$F = \frac{\Delta p * 2 * D}{L * \rho * v^2}$$

$$= 0.4107$$

V. GEOMETRICAL DETAILS OF CURVED DELTA WING VORTEX GENERATOR INSERT

The constructional details of curved delta (VG) insert as shown in below figure that part of the insert used in this study.

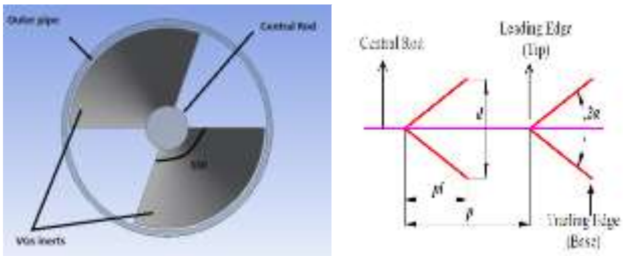

Fig.3 Front view and cross section of VG insert

The left side image show the front view of the vortex generator insert and right side show the section view of VG insert.

The curved delta wing vortex generator insert was made from uniform mild steel sheet having uniform thickness 1mm. Triangular shape given to the sheet by cutting operation with an included angle of attack (α) 30˚, 45˚, 60˚ was bent over the surface to form cone of curved delta wing shaped. The below figure shows VG without perforation.

Fig.4 CAD model of VG insert with tube

The geometry of VG with perforation as shown in below fig. The perforation diameter is 3mm. This geometry also done in ansys design modeler with angle of attack same as that of without perforation. The pitch length is 0.2m maintained at equal interval.

Fig.5 CAD model of VG with perforation

VI. MESHING DETAILS

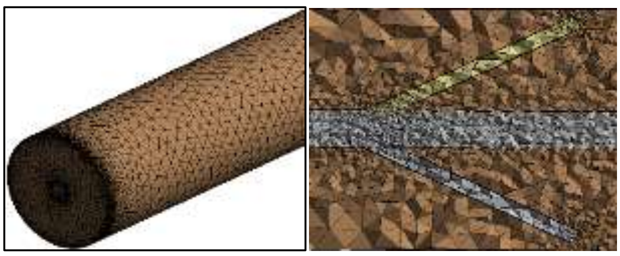

Fig.6 Meshing Model

For construct finite volume meshing is used. This meshing geometry contains tetrahedral type mesh. In this mesh count is 36,65,683 and having number of layers 4. The mesh topology was designed in such way that the sufficient mesh refinements were provided at the boundary layer region. The number iterations took 800 for this simulation. This is done on ansys modeler using CAD function. The simulation is done by Ansys 16.0. For incompressible flow pressure base solver used.

VII. RESULT AND DISCUSSION

The various parameters like angle of attack (α), number of inserts (N) and pitch ratio examined by new formed curved delta wing VG insert. The results came out and were compared with vortex generator insert (VG) with and without perforation.
Following fig.5 and fig.6 shows VG inserts without peroration nusselt number increases with increase in Reynolds number for angle of attack 30˚,45˚ and 60˚.The range of nusselt number is 51 to 194 for all Reynolds number. Because of the increases of turbulent intensity and decreases of thermal boundary layer thickness nusselt number increses consistently with increases Reynolds number. Also there is friction factor versus Reynolds number graph which shows Reynolds number increases as friction factor decreases for all cases. The friction increases with increase of attack angle. The vortex generator causes significantly pressure drop in comparison with smooth tube. It is higher than the smooth tube. The range of friction factor 0.032 to 0.52 for all geometrical parameters.

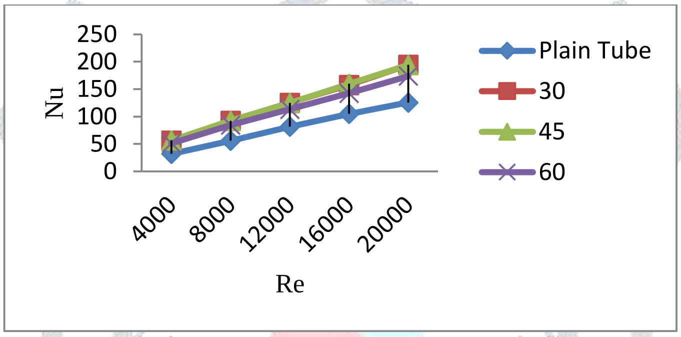

Fig.7. Variation of Nu vs Re

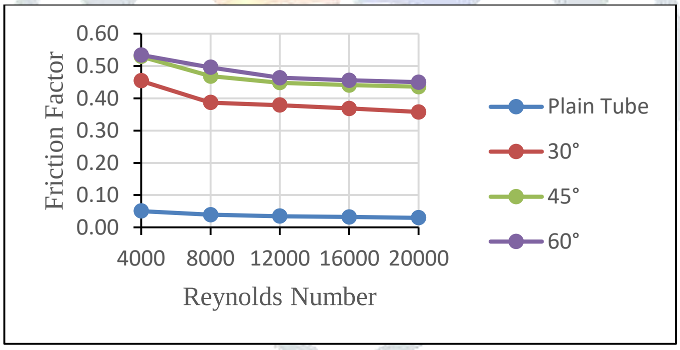

Fig.8. Variation of friction factor vs Re

The following fig.7 and fig.8 shows curved delta wing vortex generator insert with perforation as Reynolds number increases nusselt number also increases for all sets of geometrical parameters. The high Re number provides better fluid mixing and enhances turbulent intensity which diminishes thermal boundary layer. The range of Re is 32-195 for various angle of attack. In fig.8 friction factor decreases as Reynolds number incresses. The utilization of perforated vortex generator in circular tube causes considerable increament in f over smooth tube. The range of friction factor is 0.03 to 0.5 for all geometrical parameters.

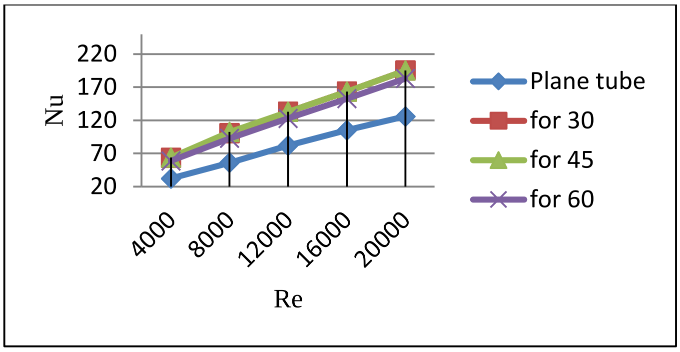

Fig.9. Variation of Nu vs Re

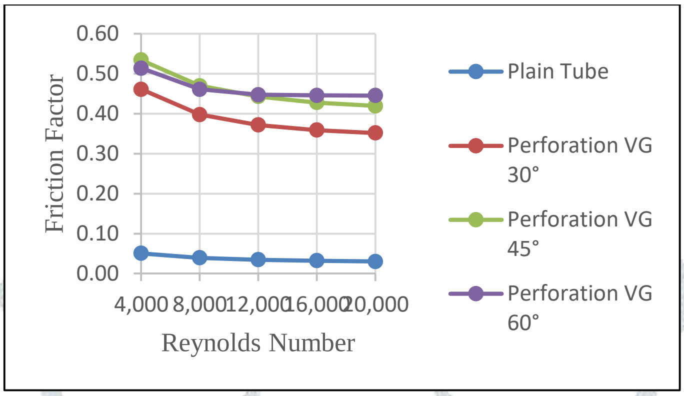

Fig.10. Variation of friction factor vs Re

VIII. CONCLUSION

From this CFD work it shows that, new shape of curved delta wing vortex generator designed for heat transfer enhancement. The concluding works given below.

1. The nusselt number increases with increase in Reynolds number in curved delta wing vortex generator insert without perforation 194.04 which is maximum for angle of attack 45˚.

2. The friction factor for VG without perforation which is in the range 0.03 to 0.53 for various angle of attack.

3. The nusselt number for curved delta wing vortex generator insert with perforation which is in the range 32.01 to 195.11 and for 45˚ it is maximum which is 195.11. The friction factor decreases with increase in Reynolds number and range is 0.05 to 0.55.

4. Out of various angle of attack 45˚ shows better heat transfer performance.

REFERENCES

[1] Deshmukh, P., Prabhu, S. and Vedula, R. (2016, June.). Heat transfer enhancement for laminar flow in tubes using curved delta wing vortex generator inserts, *Applied Thermal Engineering*, Available:http://dx.doi.org/10.1016/j.applthermaleng.2016.06.120

[2] Lei, Y., Zheng, F., Song, C. and Lyu, Y.(2017, Mar.). Improving the thermal hydraulic performance of a circular tube by using punched delta winglet vortex generators, *International Journal of Heat and Mass Transfer*, 111, pp.299-311.

[3] Chamoli, S., Lu, R. and Yu, P.(2017, Mar.). Thermal characteristics of a turbulent flow through a circular tube fitted with perforated vortex generator inserts, *Applied Thermal Engineering*, 121, pp.1117-1134.

[4] Vashistha, C., Pati, A K. and Kumar, M. (2015, Nov.).Experimental investigation of heat transfer and pressure drop in a circular tube with multiple inserts, *Applied Thermal Engineering*, 96, pp.117-129.

[5] Deshmukh, P. and Vedula, R. (2014, Aug.). Heat transfer and friction factor characteristics of turbulent flow through a circular tube fitted with vortex generator insert, *International Journal of Heat and Mass Transfer*, 79, pp.551-560.

[6] Skullong, S., Promvonge, P., Thianpong, C., Jayranaiwachira, N. and Pimsarn, M. (2017, Oct.). Thermal perforamance of heat exchanger tube inserted with curved winglet tapes, *Applied Thermal Engineering.* Available:http://doi.org/10.1016/j.applthermaleng.2017.10.110

[7] Xu, Z., Han, Z., Wang, J. and Liu, Z. (2017, Aug.). The characteristics of heat transfer and flow resistance in rectangular channel with vortex generators, *International Journal of Heat and Mass Transfer*, 116, pp.61-72.

[8] Durga Prasad, P., Gupta, A. V. S. S. K. S., Experimental investigation on enhancement of heat transfer using Al_2O_3/ water nanofluid in a u-tube with twisted tape inserts, *International Communication in Heat and Mass Transfer*, 2016

[9] Tu, W., Tang, Y., Hu J., Wang, Q., Lu, L., Heat transfer and friction characteristics of laminar flow through circular tube with small pipe inserts, *International Journal of Thermal Sciences*, 2015, 96, pp.94-101.

[10] Sadeghi, O., Mohammed, H. A., Marjan, B-N., Wahid, M. A., Heat transfer and nanofluid flow characteristics through circular tube fitted with helical tape insert, *International Communication in Heat and Mass Transfer*, 2015, No. of pages 11

[11] Fan, A., Deng, J., Guo, J., Liu, W., A numerical study on thermo hydraulic characteristics of turbulent flow in a circular tube fitted with conical strip inserts, *Appied Thermal Engineering*, 2011, 31, pp.2819-2828.

[12] Wenbin, T., Yong, T., Bo, Z., Longsheng, L., Experimental studies on heat transfer and friction factor characteristics of turbulent flow through circular tube with small pipe inserts, *International Communication in Heat and Mass Transfer*, 2014, 56, pp.1-7.

[13] Ghadi, A., Moghaddam, R., Mazandarani, M., CFD Modelling of Increase Heat transfer in Tubes by Wire Coil Inserts, World Applied Sciences journal, 2012, pp 1443-1448.

[14] Khoshvaght-Aliabadi, M., Sartipzadeh, O., Alizadeh, A., An experimental study on vortex generator insert with different arrangements of delta winglets, Energy, 2015, pp.1-11

[15] Pourahmad, S., Pesteei, S. M., Effectiveness NTU analyses in double tube heat exchanger equipped with wavy strip considering various angles, Energy and Conversion Management, 2016, 123, pp.462-469.

[16] Datta, A., Sanyal, D., Das, A., Numerical investigation of heat transfer in microchannel using inclined longitudinal vortex generator, *Applied Thermal Engineering*, 2016.

[17] Sharifi, K., Sabeti, M., Rafiei, M., Mohammadi, A., Shirazi, L., Computational Fluid Dynamics Techniques to study the effects of Helical Wire Inserts on heat transfer and pressure drop in double pipe heat exchanger, *Applied Thermal Engineering*, 2017.

[18] Aviation.stackexchange.com

[19] Pourramezan, M., Ajam, H., (2016, Mar.). Modelling for thermal augmentation of turbulent flow in a circular tube fitted with twisted conical strip inserts, *Applied Thermal Engineering*.Available:http://doi.org/10.1016/j.applthermaleng.2016.03.029

[20] Saysroy, A., Eiamsa-erd, S,. (2017, July.). Enhancing convective heat transfer in laminar and turbulent flow regions using multi-channel twisted tape inserts, *International Journal of Thermal Sciences*, 121, pp.55-74.

[21] Nanan, K., Thianpong, C., Promvonge, P., Eiamsa-erd, S., Investigation of heat transfer enhancement by perforated helical twisted-tapes, *International Communication in Heat and Mass Transfer*, 2014, 52, pp.106-112.

[22] Bhuiya, M.M.K., Azad, A. K., Chowdhary, M.S.U., Saha, M., Heat transfer augmentation in a circular tube with perforated double counter twisted tape inserts, *International Communication in Heat and Mass Transfer*, 2016

[23] Song, K., Xi, Z., Su, M., Wang, L., Wu, X., Wang, L., (2016, Nov.). Effect of geometric size of curved delta winglet vortex generators and tube pitch on heat transfer characteristics of fin-tube heat exchanger, *Experimental ThermalandFluidScience* Available:http://doi.org/10.1016/j.expthermaflusci.2016.1.002