Augmentation of Heat Transfer in a Duct with Rotating Turbulator using Al_2o_3 Nanofluid

Pavan K. N, Madhusudhan, Sagar M.N, Chethan K. S

***Abstract:** The heat transfer enhancement is one of the essential factors to be considered in the design of heat exchangers. The rate of heat transfer can be enhanced by inserting and modifying the geometric configuration of the turbulators in the tube of heat exchangers. In our present work we conducted the experiment to investigate the rate of heat transfer enhancement in a tubular in a heat exchanger by using rotating twisted tape turbulator of twist ratio 3.27 using water and Al_2O_3 nanofluid as a testing fluid at the flow rate of 1, 2, and 3 LPM. The range of Reynolds number used is 2000<Re<10000, the heat transfer rate calculated for each case of rotating TTT with the speed of 0 to 300 RPM with the step of 100 RPM. The obtained results are compared between water and Al_2O_3 nanofluid, with and without rotating TTT. From the comparisons, it was found that the TTT with U-cut and the use of Al_2O_3 nanofluid gives the better rise in the heat transfer rate of about 39.63%. The augmented rate of heat transfer is due to the more turbulence when the rotating TTT is used and replacing the water with nanofluid as the testing fluid which of high thermal properties.*

***Keywords:** Heat transfer coefficient (h), Nanofluid, Nusselt number (N_u), Rotating Twisted Tape Turbulator (TTT), Reynolds number (R_e).*

I. INTRODUCTION

Heat transfer enhancement is the method of improving the performance of a heat transfer system. The heat exchangers are the tool where in heat transfer between at least two fluids, due to the difference in temperature [1]. Several approaches are accessible for fulfilling the enhanced heat exchange and are indicated as "Heat Transfer Enhancement" is encouraged with improvement methods called "Augmented Heat Exchangers". The goal is to enhance diverse elements like Capital Cost, Power Cost and Maintenance Cost and under the requirements of Space and Weight, and so on. The technique is widely applied in many areas such as power plants, automotive, aerospace, etc [2]. In this present investigation, the twisted tape turbulator (TTT) is broadly used in various fields [3]-[4]. Insertion of TTT in a duct provides a simple passive technique, to increase the heat transfer rate in the system there by increasing the swirl motion inside the duct, due to frequent variation in the surface geometry [5]-[7].

In the process of heat transfer, instead of using the conventional fluid (water, glycol, lubricating oils, and many more), nanofluids are used since they show better-enhancing properties than the conventional fluids [8]. Oxides of aluminum, copper, silver and zinc etc. and metallic particles like iron, copper, silver, gold, and titanium etc are suspended in the base fluid say water to generate nanofluids using ultra sonification process. In the present research, the performance of rotating TTT using 0.4% Al_2O_3 is studied. The experimentation was carried out with revolving TTT with twist ratio (y) of 3.27 in the flow passage under identical test conditions 1, 2 and 3 LPM flow rates, the rotational speed of TTT is varied from 0 to 300 RPM with a step of 100 RPM.

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* Correspondence Author

Pavan K N*, Mechanical Department**,** Assistant professor, P.E.S College of Engineering, Mandya, India. Email: pavankn1988@gmail.com.

Dr. Madhusudhan Mechanical Department, Professor, Nitte Meenakshi institute of technology, Yelahanka, Bangalore, India. Email: acharyamadhusudhan@gmail.com.

Sagar M N, Mechanical department, P.G Student, Nitte Meenakshi institute of technology, Yelahanka, Bangalore, India. Email:manusagar198@gmail.com.

Chethan K S, Mechanical Department, Assistant Professor, Nitte Meenakshi institute of technology, Yelahanka, Bangalore, India. Email: chethan84@gmail.com.

II. EXPERIMENTAL SETUP

A. Fabrication of Experimental setup

The experimental setup Fig. 1 consists of the trial section which is made up of stainless-steel pipe of inner and outer diameters are 30 mm and 34 mm respectively. The system consists of a DC motor, water pump, control valves, K-type thermocouples storage tanks & power supply units, couplings and some pipe linkages. On both ends of stainless steel flanges with bearings are provided for supporting the twisted tape shaft to rotate freely inside the tube. To find out the temperature, there are washer shaped thermocouples are incorporated on the outer surface of the tube, and two stem type of thermocouples are incorporated on tapped holes of the device to measure the inlet and outlet temperature of base fluid flowing through a test section. The collar type of electrical heater of capacity 1.5 kW is used for heating the water flowing into the channel, the temperature of water heating can be controlled. The fluids can be supplied to the test section or into the channel by the application of centrifugal pump.

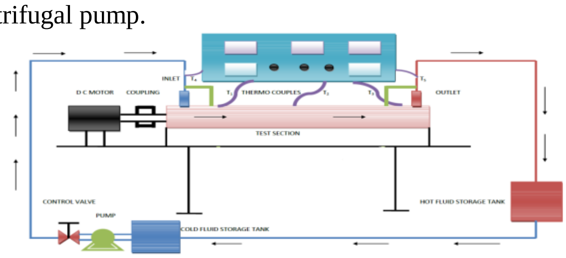

Fig. 1. Test set up

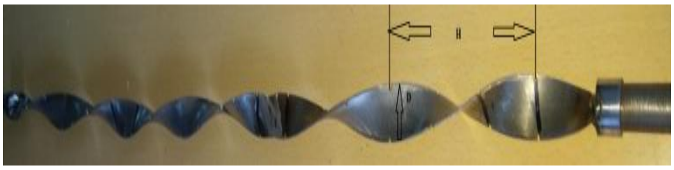

Fig. 2. Twisted turbulator

The T.T.T having a one-direction twist is shown in Fig. 2, the turbulator has a pitch of 110mm, length 800 mm, the thickness of the tape is 1.5 mm and also having a twist ratio (H/Do) is 3.27. Plain TTT and U-cut TTT are the two geometric modifications made with respect to the insert used for the enhancement of the heat transfer rate. In the U-cut turbulator, the cut is equally distributed at both sides of the tape (40mm distance), and 5mm is the depth of cut is as shown in Fig. 2. The twisted tape coupled with DC motor and RPM sensor assembly for computing the speed of the turbulator inside the tube.

III. PREPARATION OF AL2O3 NANOFLUID

Nanofluids are dilute fluid suspensions of nanoparticles of size 100nm [9]-[10]. In the present experimental study, an average size of 30-50 nm Al_2O_3 Nanoparticles having density 3900 Kg/m^3 is used. With the help of the TEM image of Al_2O_3 Nanoparticle on a 50 nm scale is shown in Fig 4. In this present work, 0.4% volume concentrations of Al_2O_3 nanofluid is used which requires 62.56g of aluminium suspended in 40lts of base liquid (water). Sodium dodecyl sulphate is used as a surfactant in the ratio of 1:1. Then proper agitation is made through stirring process and later it is subjected to the ultra-sonication process for 6 hours.

Fig. 3. Nanoparticles are mixed in a base fluid using a Magnetic stirrer

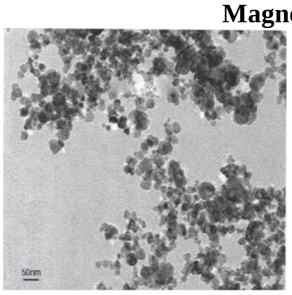

Fig. 4. TEM image of Al_2O_3 nanoparticles

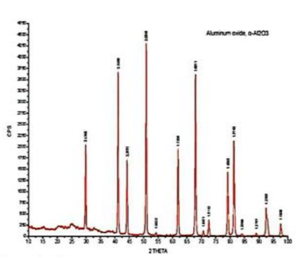

Fig. 5. XRD Image of Al_2O_3 nanoparticles

The thermo-physical properties of 0.4% volume concentration of Al_2O_3 nanofluid are as shown in the following Table. I.

Table-I: Thermo-physical properties of Al_2O_3 nanofluid

Thermal conductivity(W/m k)	Density (kg/m^3)	Viscosity (Ns/m^2)	Specific heat (J/kg K)
0.791	2158.2	$1.167*10^{-3}$	2857.2

IV. EXPERIMENTATION PROCEDURE:

At first the test rig is arranged to pass the solution (water as working fluid) into the channel by adjusting the constant flow rate at 1, 2, and 3 LPM (liters per minute) then the mains are switched on and the power is to be supplied by using dimmer stat at constant heat rate. The experiment was conducted without inserting the twisted turbulator into the channel the test readings are taken for each flow rate (1, 2, 3 LPM). The procedure followed to find the augmentation of heat transfer by inserting the rotating TTT on the subsequent two phases. In the first phase, the experiment was conducted under identical conditions as mentioned above. Initially the water is allowed to pass into the flow passage and then Al_2O_3 nano fluid corresponding readings were noted for different flow rate (1, 2, and 3 LPM). In the second phase, for the same above test conditions, the geometrically modified U-cut TTT is used to investigate the enchance of better heat transfer rates. The temperature of the test section is proportional dimmer stat current, that is the temperature of the trial section can be increased in addition of heat on the outer surface of test section by the application of dimmer stat of the maximum capacity of 4 amps. After some time the temperature reaches a stable position, the temperatures are displayed on the indicator. To find the surface temperature of test section there are three sensors are incorporated, and at the inlet and outlet duct two separate sensors are incorporated in-order to determine the inlet and outlet fluid temperatures.

V. RESULTS AND DISCUSSION

In this present work, the variation of the coefficient of heat transfer with Reynolds number is discussed separately for Water and aluminum oxide Nanofluid with different rotational speed of the TTT, and at the end of the comparison the performance characteristics for aluminum oxide and Water is discussed for 300 RPM rotational speed of the turbulator. It is evident from figure that insertion of twisted of y=3.27 cause the secondary swirling motion of the fluid inside the tube due to this a new thermal boundary is generated and giving a time of residence for fluids and its heat transfer capacity increases with the reasonable heat transfer rate in the heat exchanger.

A. Comparision of coefficient of heat transfer with Reynolds number for Al_2O_3 as working medium.

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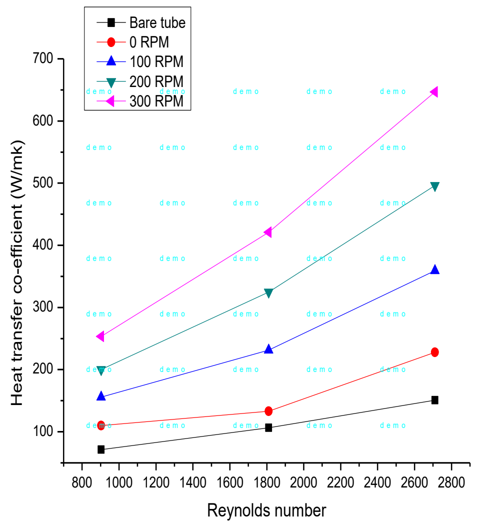

Fig. 6. Variation of coefficient of heat transfer with Reynolds number for Al_2O_3 as working medium for plain TTT.

The variation of the heat transfer coefficient with Reynolds number for plain tube and different RPM of twisted tape inserts for the experimental results for flow rates of 1, 2 and 3 LPM is shown in Fig. 6. The graphs clearly show that the convective heat transfer coefficient increases with increase in flow rate and also with increase in rotational speed of the twisted tape. It is found to be 16.90%, 23.33% and 31.34% increment in heat transfer coefficient for the LPM of 1, 2, and 3 LPM respectively. The heat transfer rate is observed to higher when twisted tapes are used and lower when T.T.T is not used. As the flow rate and RPM of the twisted tape increases heat transfer rate also increases.

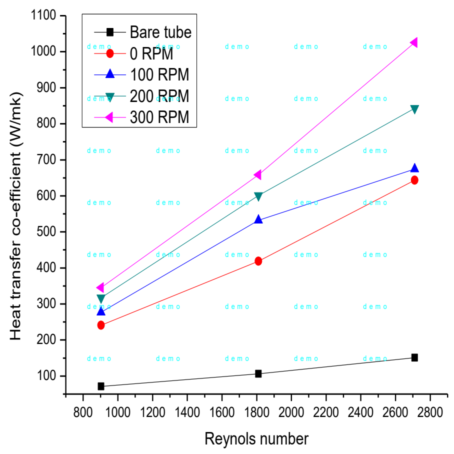

Fig. 7. Variation of coefficient of heat transfer with Reynolds number for Al_2O_3 as working medium for U-cut TTT.

The variation of the heat transfer coefficient with Reynolds number for plain tube and different RPM of U-cut TTT inserts for the experimental results for flow rates of 1, 2 and 3 LPM is shown in Fig. 7. The graphs clearly show that the convective heat transfer coefficient increases with increase in flow rate and also with increase in rotational speed of the twisted tape. It is found to be 58.24% and 64.77% and 70.77% increment in heat transfer coefficient for the LPM of 1, 2, and 3 LPM respectively. The heat transfer rate is observed to higher when U-cut TTT are used and lower when plain TTT are used as a turbulator.

As observed from those graphs the highest heat transfer rate is observed for 0.4% Al_2O_3 nanofluid in U-cut TTT as compared to the same insert in base fluid, and it was observed that the U-cut TTT insert has significantly more in the heat transfer rate at the higher speed and flow rates in both fluids. The 0.4% volume concentration of Al_2O_3 nanofluid enchances the heat transfer rate about 70.77% compared to water at higher flow rates and speed.

VI. CONCLUSIONS

The flow rate of the fluid greatly influenced the heat transfer rate. At higher Reynolds number, higher heat transfer rate can be obtained. Using turbulator insert cause a secondary swirling motion of the fluid inside the duct there by generating the new thermal boundary layer for fluid flow. The time of residence for the fluid in the duct increases with the insertion of twisted tape. There by increasing heat absorption capability of the working fluid. Turbulence motion of the fluid is created by turbulator insert, and as the RPM of the twisted tape increases more turbulence is created, there by increasing the heat transfer rate. In the nanoparticle, suspended fluid (0.4% concentration Al_2O_3/water nanofluid) there is increase in heat transfer rate, due to the enhanced thermal conductivity. The use of Nanofluids helps in increasing the heat transfer rate, and is better replacement fluids in the place of conventional heat transfer fluid.

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AUTHORS PROFILE

Pavan K N, Assistant Professor, Department of Mechanical Engineering at P E S College of Engineering, Mandya-571401 Pavan K N is presently working as Assistant Professor in the Department of Mechanical Engineering at P E S College of Engineering, Mandya., India. He obtained his B.E. in Mechanical Engineering in 2010 and M.Tech in Thermal Power Engineering in 2012 from Visvesvaraya Technological University, Karnataka. He has 7 years of teaching experience and published several research papers in National and International Conferences and Journals. His research areas are Heat Transfer, Computational Fluid Dynamics, Renewable Energy Technology, etc.

Dr. Madhusudhan, Mechanical department, professor nitte meenakshi institute of technology bengalore, India Dr. Madhusudhan is presently working as Professor in the Department of Mechanical Engineering at Nitte Meenakshi institute of technology Bengaluru., India. He has obtained his B.E. degree in Mechanical Engineering in the year 1996, M.Tech degree in Heat Power Engineering in the year 2005 from National Institute of Technology, Surathkal, and Ph.D in the year 2014 from National Institute of Technology, Surathkal Karnataka. He has 19 years of teaching experience at Nitte Meenakshi Institute of Technology. He has published several research papers in national/international conferences and journals. His research areas are Heat power enginering, Computational Fluid Dynamics, Renewable Energy Technology, etc.

Sagar M N, P.G Student Mechanical department, nitte meenakshi institute of technology bengalore, India Sagar M N has done BE in Mechanical Enginering from Visvesvaraya Technological University Belagavi Karnataka in the year 2017 has done BE project on Rotten coconut bio- diesel blends with diesel oil using single cylinder diesel engine related to non-renewable energy sources, and also pursuing M.Tech in Thermal power engineering from VTU. His research interests are Thermal power generation, Advance and computational fluid dynamics, thermodynamics, Air conditioing and refrigeration system.

Chethan K S, Assistant Professor, Department of Mechanical Engineering at Nitte meenakshi institute of technology bengalore, India. Chethan K S is presently working as Assistant Professor in the Department of Mechanical Engineering at Nitte Meenakshi institute of technology Bengaluru, India. He has obtained his B.E. degree in Mechanical Engineering in the year 2006 and M.Tech degree in Thermal Power Engineering in the year 2012 from Visvesvaraya Technological University, Belgaum, and Karnataka. He has 3 years of industry experience as design engineer at Mahindra Engineering Services and 10 years of teaching experience at Nitte Meenakshi Institute of Technology. He has published several research papers in national/international conferences and journals.