EXPERIMENTAL ANALYSIS OF HEAT TRANSFER ENHANCEMENT OF WAVY TWISTED TAPE INSERT

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ABSTRACT

The need to increase the thermal performance of heat exchangers, thereby affecting energy, material & cost savings have led to development & use of many techniques termed as Heat transfer Augmentation. Augmentation techniques increase convective heat transfer by reducing the thermal resistance in a heat exchanger. Twisted tapes-a type of passive heat transfer augmentation techniques have shown significantly good results in past studies. Different designs of twisted tapes used are-Reduced width twisted tapes (RWTT), Baffled reduced width twisted tapes (BRWTT1) & Baffled reduced width twisted tape with holes (BRWTT2). The proposed work is aimed at finding the heat transfer performance in a circular pipe by employing wavy twisted tapes& also results are to be compared with plain twisted tape. These tapes will be tested for different configurations of twist ratios & wave angles. It is to be verified whether wavy nature of twisted tape assists the heat transfer by turbulence enhancement or if it increases the pressure drop. Also the use of 'CFD' software is proposed for analysis work & developing correlations.

Heat transfer augmentation techniques (passive, active or a combination of passive and active methods) are commonly used in areas such as process industries, heating and cooling in evaporators, thermal power plants, air-conditioning equipment, refrigerators, radiators for space vehicles, automobiles, etc. Passive techniques, where inserts are used in the flow passage to augment the heat transfer rate, are advantageous compared with active techniques, because the insert manufacturing process is simple and these techniques can be easily employed in an existing heat exchanger. In design of compact heat exchangers, passive techniques of heat transfer augmentation can play an important role if a proper passive insert configuration can be selected according to the heat exchanger working condition (both flow and heat transfer conditions). In the past decade, several studies on the passive techniques of heat transfer augmentation have been reported. The present paper is a review on progress with the passive augmentation techniques in the recent past and will be useful to designers implementing passive augmentation techniques in heat exchange. Twisted tapes, wire coils, ribs, fins, dimples, etc., are the most commonly used passive heat transfer augmentation tools.

Keywords: Heat Exchanger, Twisted Wavy Tape, Twist Ratio, Turbulence..

I. INTRODUCTION

Heat exchangers are widely used in various industrial processes for heating and cooling applications such as air conditioning and refrigeration systems, heat recovery processes food and dairy processes, chemical process plants etc.The major challenge in designing a heat exchanger is to make the equipment compact and achieve a

high heat transfer rate using minimum pumping power. Techniques for heat transfer augmentation are relevant to several engineering applications. In recent years, the high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchange equipment. Furthermore, sometimes there is a need for miniaturization of a heat exchanger in specific applications, such as space application, through an augmentation of heat transfer. For example, a heat exchanger for an ocean thermal energy conversion (OTEC) plant requires a heat transfer surface area of the order of 10000 m^2/MW. Therefore, an increase in the efficiency of the heat exchanger through an augmentation technique may result in a considerable saving in the material cost. Furthermore, as a heat exchanger becomes older, the resistance to heat transfer increases owing to fouling or scaling. These problems are more common for heat exchangers used in marine applications and in chemical industries. In some specific applications, such as heat exchangers dealing with fluids of low thermal conductivity (gases and oils) and desalination plants, there is a need to increase the heat transfer rate. The heat transfer rate can be improved by introducing a disturbance in the fluid flow thereby breaking the viscous and thermal boundary layer. However, in the process pumping power may increase significant lyand ultimately the pumping cost become high. Therefore, to achieve a desired heat transfer rate in an existing heat exchanger at an economic pumping power, several techniques have been proposed in recent years and are discussed under the classification section.

1.1 Types of Artificial Roughness, Corrugated or Wavy Channels

The roughness elements are classified as follows:

a) According to arrangement of ribs: Depending on whether one complete rib or ribs in pieces are placed on absorber plate, the ribs can be full (continuous) or broken (discrete).

b) According to orientation of ribs: transverse, inclined and V- shaped.

c) According to shape of cross section of ribs: square, rectangular, circular, semi-Circular, trapezoidal, triangular.

d) According to material of ribs: Aluminum, copper, brass etc.

e) According to geometry: Sand grains, ribs, dimples, expanded metal wire mesh, Compound rib groove arrangement Corrugated or wavy channels.

f) According to method of attachment of ribs: Gluing, casting, machining of roughness elements on heat transfer surface.

1.2 Research Opportunities

The aim of insert is to enhance heat transfer rate by reducing the size and cost of heat exchanger but not with the increase in pumping power. By referring the above literature it was observed that the objective can be achieved if one goes for passive techniques. After referring the results obtained from the twisted tape inserts, they are offering less pressure drop than the other techniques mentioned in above literature. There exists a lot of work on twisted tape by various researchers by varying various pitches by diameter ratios or by varying thickness to pitch ratio. The material used by them is normally Teflon which is a non metal also the material is solid in shape. The inserts can be modified by giving new design as it can be made corrugated or wavy; as if a material becomes corrugated the turbulence may rise in the fluid flow. Also if it is given a twisted shape then due to

nature of inserts an extensive contact surface between solid and fluid surfaces are generated. The extensive contact surface enhances the internal heat exchange between the phases and consequently results in an increased thermal diffusivity. A wavy twisted tape insert is a swirl producing geometry where the secondary fluid motion is generated by the continuous change in direction of the tangential vector to the bounding curve surface of the duct, which results in the local deflection of the bulk flow velocity vector. Therefore a wavy twisted tape insert may prove to be beneficial by improving the heat transfer rate and by reducing the pressure drop.

1.3 Experimental Work Done on Various Inserts

Computational Fluid Dynamics or CFD is the analysis of systems involving fluid flow, heat transfer and associated phenomena such as chemical reactions by means of computer-based simulation. The technique is very powerful and spans a wide range of industrial and non-industrial application areas.

1.4 CFD Code Procedure

CFD codes are structured around the numerical algorithms that can tackle fluid flow problems. In order to provide easy access to their solving power all commercial CFD packages include sophisticated user interfaces to input problem parameters and to examine the results. Hence all codes contain three main elements:

- Pre-processor,
- Solver and
- Post-processor.

We briefly examine the function of each of these elements within the context of a CFD code.

1.5 Pre-Processor

Pre-processing consists of the input of a flow problem to a CFD program by means of an operator-friendly interface and the subsequent transformation of this input into a form suitable for use by the solver. The user activities at the pre-processing stage involve

- Definition of the geometry of the region of interest: the computational domain.
- Grid generation-the sub-division of the domain into a number of smaller, non overlapping sub-domains: a grid (or mesh) of cells (or control volumes or elements).
- Selection of the physical and chemical phenomena that need to be modeled.
- Definition of fluid properties.
- Specification of appropriate boundary conditions at cells which coincide with or touch the domain boundary.

The solution to a flow problem (velocity, pressure, temperature etc.) is defined at nodes inside each cell. The accuracy of a CFD solution is governed by the number of cells in the grid. In general, the larger the number of cells the better the solution accuracy. Both the accuracy of a solution and its cost in terms of necessary computer hardware and calculation time are dependent on the fineness of the grid. Optimal meshes are often non-uniform: finer in areas where large variations occur from point to point and coarser in regions with relatively little change. Efforts are under way to develop CFD codes with a self adaptive meshing capability. Ultimately such programs will automatically refine the grid in areas of rapid variations. A substantial amount of basic

development work still needs to be done before these techniques are robust enough to be incorporated into commercial CFD codes. At present it is still up to the skills of the CFD user to design a grid that is a suitable compromise between desired accuracy and solution cost.

1.6 Numerical Simulation by the Solver

There are three distinct streams of numerical solution techniques: finite difference, finite element and spectral methods. In outline the numerical methods that form the basis of the solver perform the following steps:

- Approximation of the unknown flow variables by means of simple functions.
- Discretisation by substitution of the approximations into the governing flow equations and subsequent mathematical manipulations.
- Solution of the algebraic equations.

The main differences between the three separate streams are associated with the way in which the flow variables are approximated and with the discretisation processes.

1.7 Finite Difference Methods

Finite difference methods describe the unknown λ of the flow problem by means of point samples at the node points of a grid of co-ordinate lines. Truncated Taylor series expansions are often used to generate finite difference approximations of derivatives of λ in terms of point samples of λ at each grid point and its immediate neighbours. Those derivatives appearing in the governing equations are replaced by finite differences yielding an algebraic equation for the values of λ at each grid point.

1.8 ZFinite Element Method

Finite element methods use simple piecewise functions (e.g. linear or quadratic) valid on elements to describe the local variations of unknown flow variables λ. The governing equation is precisely satisfied by the exact solution λ. If the piecewise approximating functions for λ are substituted into the equation it will not hold exactly and a residual is defined to measure the errors. Next the residuals (and hence the errors) are minimised in some sense by multiplying them by a set of weighting functions and integrating. As a result we obtain a set of algebraic equations for the unknown coefficients of the approximating functions. The theory of finite elements has been developed initially for structural stress analysis.

1.9 Spectral Methods

Spectral methods approximate the unknowns by means of truncated Fourier series or series of Chebyshev polynomials. Unlike the finite difference or finite element approach the approximations are not local but valid throughout the entire computational domain. Again we replace the unknowns in the governing equation by the truncated series. The constraint that leads to the algebraic equations for the coefficients of the Fourier or Chebyshev series is provided by a weighted residuals concept similar to the finite element method or by making the approximate function coincide with the exact solution at a number of grid points.

1.10 The finite volume method

The finite volume method was originally developed as a special finite difference formulation. It is central to four of the five main commercially available CFD codes: PFIOENICS, FLUENT, FLOW3D and STAR-CD. The numerical algorithm consists of the following steps:

- Formal integration of the governing equations of fluid flow over all the (finite) control volumes of the solution domain.
- Discretisation involves the substitution of a variety of finite-difference-type approximations for the terms in the integrated equation representing flow processes such as convection, diffusion and sources. This converts the integral equations into a system of algebraic equations.
- Solution of the algebraic equations by an iterative method.

1.11 Post-Processing

As in pre-processing a huge amount of development work has recently taken place in the post-processing field. Owing to the increased popularity of engineering workstations, many of which have outstanding graphics capabilities, the leading CFD packages are now equipped with versatile data visualization tools. These include:

- Domain geometry and grid display.
- Vector plots.
- Line and shaded contour plots.
- 2D and 3D surface plots.
- Particle tracking.
- View manipulation (translation, rotation, scaling etc.).
- Colour postscript output.

More recently these facilities may also include animation for dynamic result display and in addition to graphics all codes produce trusty alphanumeric output and have data export facilities for further manipulation external to the code. As in many other branches of CAE the graphics output capabilities of CFD codes have revolutionized the communication of ideas to the non-specialist.

II. METHODOLOGY

2.1 Present Experimental Work

The experimental study on passive heat transfer augmentation using wavy twisted tape inserts for varying twist ratio and wave-width with aluminum and copper as a material was carried on in a single phase flow heat exchanger having the specifications as listed below:-

Fig 1: Experimental Set up for Forced Convection

2.2 Specifications of Set up

1   Inner diameter of pipe $=(d_o) = 0.026$ m.

2   Outer diameter of pipe $=(d_i) = 0.03$ m.

3   Length of test section = L =0.7m.

4   Capacity of blower = 0.24h.p.

5   Diameter of orifice (d) =0.016m.

6   Range of Dimmer stat = 0 to 2 amp. 0-270V ac.

7   Temperature indicator =0 to 300 ^{0}C. (12 points)

8   U-tube manometer = Pressure tapings at start and end of the test pipe. 0-300 mm of water column

9   Calibratedchromelalumel thermocouple(K-type- -270^{0}C to 1350 ^{0}C)

10   Voltmeter = 0-200 V; ammeter 0-2 amp.

11   Nichrome wire (resistivity=1.5 x 10^{-6}Ωm) heater wound around test pipe.

2.3 Experimental Set up

The apparatus consist of a blower unit fitted with the test pipe. The test section is surrounded by nichrome heater. Six thermocouples are embedded on test section and two thermocouples are placed in the air stream at the entrance and exit of test section to measure air temperatures. Test pipe is connected to the delivery side of the blower along with the orifice to measure flow of air through the pipe. Input to the heater is given through power unit and is measured by meters. It is also noted that only a part of the total heat supplied is utilized in heating the air. A temperature indicator with clod junction compensation is provided to measure the temperature in the pipe wall in the test section. Air flow is measured with the help of an orifice meter and the water manometer fitted on the board. In addition to this, an inclined manometer is also used to measure pressure drop

across test section. The valve at the outlet of pipe is used to vary the flow rate of air. At inlet of test section a tapping with valve is provided to measure pressure drop.
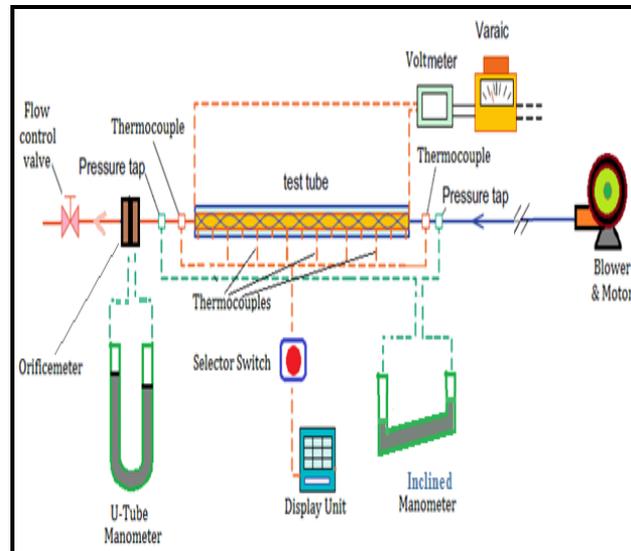
Fig 2 : Schematic Diagram of Forced Convection Set Up

T_1 measures inlet air temp & is indicated by Digital Voltmeter (DV) on the front panel. The thermocouple no 8 is used for measuring outlet air temperature. The thermocouples T_2 to T_7 are used to measure surface temperature of test section. The power control unit uses an isolating transformer for stepping down mains voltage to 130 volts AC & get controlled DC output in the range 0-150 volts using unijunction transistor(UJT), pulse transformer &Silicon Controlled Rectifier (SCR) circuit & capacitive filter. The heater power is necessarily DC. The voltage signals (V) for measurement is obtained by means of a potential divider & current signal (I) is obtained by measuring the voltage drop across a small resistance. This current is measured by means of an ammeter on the front panel & for voltage measurement test points are provided below the ammeter. The output can be controlled by means of potentiometer. The ground is internally connected.

2.3.1 Experimental Work Carried Out on Inserts

The literature that has been discussed above deals with active as well as passive techniques used for heat transfer augmentation, but maximum researchers have used passive technique as it doesn't require any external agency for heat enhancement, hence it is advantageous over the active techniques thus giving ample of room for experimental studies.

The researchers have used twisted tape with varying pitches where they are getting higher friction factor of about 30% to 50 % hence an attempt have to be made to reduce this friction factor. This attempt can be done by changing the shape of insert and also by using various materials. The inserts used for the experiment are wavy twisted tape with different wave-widths and pitches as there is no work done on such type of insert.

The work includes the following:

1. Determination of friction factor and Nusselt number for smooth tube and for various wavy twisted tape inserts with varying pitches and wave-widths.
2. The results of Nusselt number, friction factor, Performance evaluation criteria for all the aluminum wavy twisted tape inserts are plotted on the graph and compared with the values for the smooth tube.

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3. Similarly all the above parameters for copper wavy twisted tape inserts are plotted on the graph and compared with the values for the smooth tube.

4. To observe the effect of varying twists and wave-widths, another set of graphs are plotted for copper and aluminum inserts.

5. Two materials are chosen for the experiment hence to find an optimum value in terms of the above mentioned parameters, combined graphs are plotted for copper & aluminum to find an optimum out of the two materials that can be used for this experimental set up.

6. Comparing results of wavy twisted tape with plane tape.

7. The use of CFD programming to model the experimental results of heat transfer in an circular tube heat exchanger equipped with the wavy twisted tape inserts.
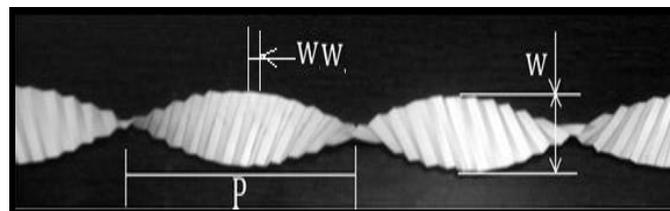
Fig 3: Terminologies of Wavy Twisted Tape

2.4 Specifications of Inserts

  i.   Width of tape = 24mm.
 ii.   Twist ratios, TR=8.33, 8.83,9.375, 9.79 & 10.42.
iii.   Length of insert, L = 700 mm
 iv.   Wave-width, WW = 13,16 & 24 mm
  v.   Thickness of inserts, t = 1mm

Table 1: Detailed Specifications of Wavy Twisted Inserts

SN	Pitch	Width	Wave-width	Material	Description	Twist Ratio
1	225	24	13	Aluminum	Same pitch varying wavelength	
2	225	24	16	Aluminum		9.375
3	225	24	24	Aluminum		
4	200	24	13	Aluminum	Same wavelength varying pitch	8.33
5	235	24	13	Aluminum		9.79
6	250	24	13	Aluminum		10.42
7	212	24	16	Copper	Same wavelength varying pitch	8.83
8	235	24	16	Copper		9.79
9	225	24	NA	Aluminum	-NA-	9.375

2.5 Fabrication Procedure

1. Take aluminum or copper sheet of thickness 1mm.

2. Cut them on hydraulic press in desired width & length (24mm x 750 mm) keeping 50 mm allowance for compensating the length after twisting.

3. The cut tapes are then given corrugations on die for required wave-widths, on both sides.

4. After corrugations drill two holes each on one end on tapes.

5. Hold the tape between headstock & tail stock on lathe machine using drilled holes.

6. Rotate the headstock (chuck) end & at the same time move tailstock by required amount towards the headstock till we get desired shape &pitch.

The actual photographs of twisted tape for varying wave-widths but same twist ratio are shown below from Fig.4 from (a) to (c).

Fig 4 (a) : Aluminium wavy insert TR-9.375, WW-13 mm

Fig 4(b) : Aluminium wavy insertTR-9.375, WW-16 mm

Fig 4 (c): Aluminum wavy insert TR-9.375, WW-24 mm

In figures 5 from (a) to (c) actual images of wavy twisted tapes with same wave-widths but different twist ratios are shown.

Fig 5 (a): Aluminum wavy insert TR-8.33, WW-13 mm

Fig 5 (b): Aluminum wavy insert TR-9.79, WW-13 mm

Fig 5 (c) : Aluminum wavy insert TR-10.42, WW-13 mm

In following figures 6 (a) & (b) the actual view of copper inserts used during experiment are shown.

Fig 6.(a) : Copper wavy insert TR-8.83, WW-16 mm

Fig 6.(b) : Copper wavy insert TR-9.79, WW-16 mm

The following figure shows actual view of the plane twisted tape used in this experimental work.

Fig 7 : Aluminum plane twisted tape insert TR-9.375

2.6 Observation Table

Table 2: Observation table of without insert

SN	Parameters	Value
Temperatures ºC	T_1	32.7
	T_2	42.6
	T_3	48.9
	T_4	52.6
	T_5	56.8
	T_6	57.6
	T_7	54.3
	T_8	40.3
Manometer Difference	h_w	41
Inclined Manometer Reading	h_f	3.25

As per the observation table shown in methodology experimentation was carried out and temperature and manometer difference values obtained are put in the table 4.2.1. This manometer difference indicates change in mass flow rate operated by the valve next to the test section, this increase in manometric head indicates increase in mass flow rate and this causes increase in Reynolds number. As Reynolds number increases the friction factor has to reduce.

Table 3 : Showing Mass Flow Rate, Friction Factor and Nusselt number of without Insert

Re	M (kg/s)	f_{expt}	Nu
10963.77	0.004328	0.0327	36.34

As explained above that as Reynolds number increases then friction has to reduce, so by observing the table 4.2.2 then at lower Reynolds number the friction factor is high however as the Reynolds number increases the friction factor drops as compared to the initial value. The Nusselt number increases with the increase in Reynolds number which indicates that heat transfer enhancement takes place at higher Reynolds number.

2.7 Sample Observation and Result Table of Copper Insert with TR-8.83, WW-16 mm :

Table 4 : Observation Table of Copper Insert

Sr No.	Parameters	Value
	T_1	31.9
	T_2	40.8
	T_3	45.8
Temperatures $^{\circ}$C	T_4	48.1
	T_5	50.7
	T_6	50.9
	T_7	49.2
	T_8	40.7
Manometer Difference	h_w	41
Inclined Manometer Reading	h_f	5

Table 5 : Showing Mass Flow Rate, Friction Factor and Nusselt Number of Copper Insert with TR-8.83, WW-16mm

Re	M (kg/s)	F	Nu
9466.089	0.003737	0.067640951	51.11746
8231.131	0.003249	0.07156849	46.0319
7242.43	0.002859	0.075109639	42.80081
5913.419	0.002334	0.095331465	38.72239
4181.419	0.001651	0.155996943	30.95081

An sample observation table is shown above for the insert of copper with TR-8.83 & WW-16 mm and it is observed that the Reynolds number increases with the decrease in friction, so at lower Reynolds number the friction factor is high however as the Reynolds number increases the friction factor drops as compared to the initial value. The Nusselt number increases with the increase in Reynolds number which indicates that heat transfer enhancement takes place at higher Reynolds number. There is another parameter PEC which is defined above and it is observed that the performance evaluation criteria decrease with the increase in Reynolds number hence there is increase in heat enhancement.

2.8 Computational Mesh & Numerical Approach for Analysis of Heat Pipe

The geometry is created in a commercial CAD tool and meshing is done in ANSYS ICEM CFD. ANSYS ICEM CFD provides advanced geometry acquisition, mesh generation, mesh optimization, and post-processing tools to meet the requirement for integrated mesh generation and post processing tools for today's sophisticated analyses. Maintaining a close relationship with the geometry during mesh generation and post-processing, ANSYS ICEM CFD is used especially in engineering applications such as computational fluid dynamics and structural analysis. ANSYS ICEM CFD's mesh generation tools offer the capability to parametrically create meshes from geometry in numerous formats:

- Multiblock structured

- Unstructured hexahedral

- Unstructured tetrahedral

- Cartesian with H-grid refinement

- **Hybrid meshes comprising hexahedral, tetrahedral, pyramidal and/or prismatic elements**

- Quadrilateral and triangular surface meshes

ANSYS ICEM CFD provides a direct link between geometry and analysis. In ANSYS ICEM CFD, geometry can be input from just about any format, whether from a commercial CAD design package, 3rd party universal database, scan data or point data. Beginning with a robust geometry module which supports the creation and modification of surfaces, curves and points, ANSYS ICEM CFD's open geometry database offers the flexibility to combine geometric information in various formats for mesh generation. The resulting structured or unstructured meshes, topology, inter-domain connectivity and boundary conditions are then stored in a database where they can easily be translated to input files formatted for a particular solver. In the present study unstructured tetrahedral mesh is used for the whole geometry with prismatic elements along the wall of the pipe so as to capture the boundary layer correctly. The Fig. shows the complete meshed domain of the Heat Pipe. The entire domain consists of majorly two different parts i.e. Heat pipe and twisted tape.
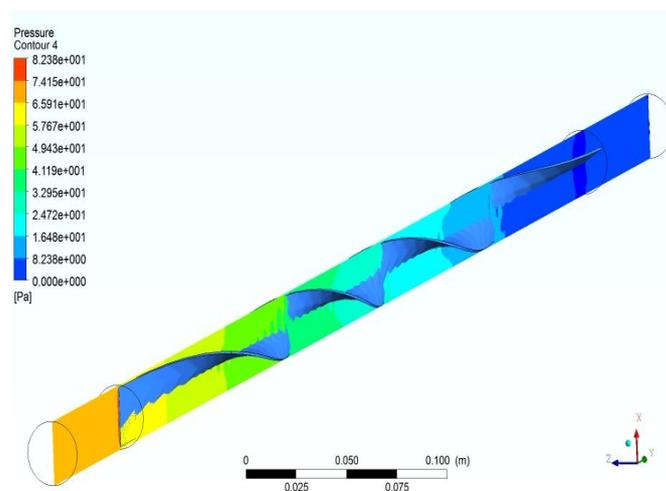

**Fig 8 : Effect of Pressure Drop on Twisted Tape**
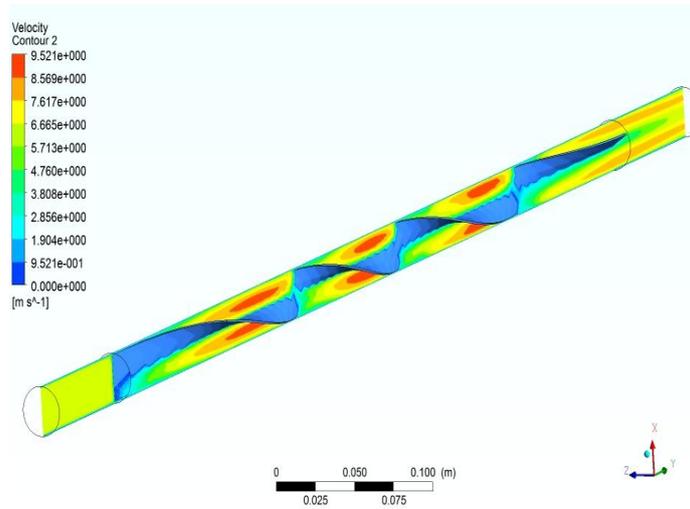
Fig. 9: Effect of Velocity Contour on Twisted Tape
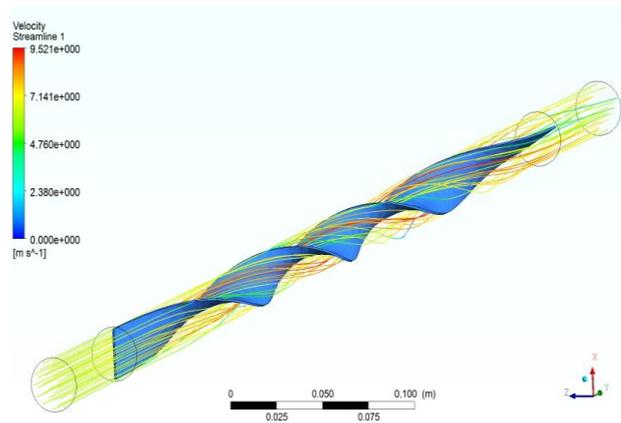
Fig.10 : Velocity Streamline

Fig.11 : Residuals Plot

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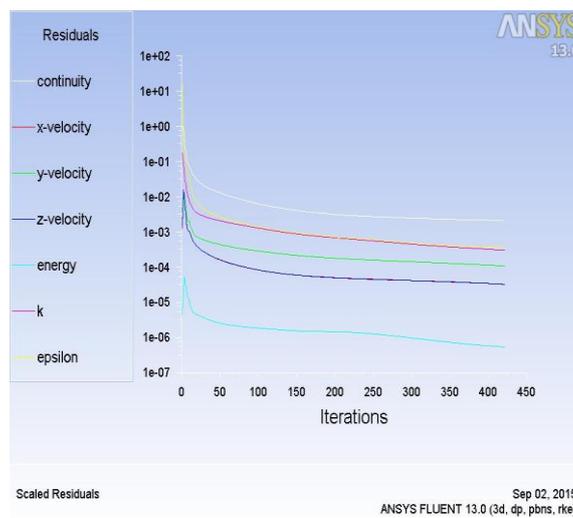
III. CONCLUSION

The heat transfer enhancement, thermal performance and friction factor characteristics of wavy twisted tape inserted tube will be investigated experimentally. The experiments will be performed for the tube fitted with wavy twisted tapes with different pitches (4 & 5), and also for different wave numbers (12 & 8). Based on the experimental results, following will be parameters which could be summarized as follows:

1) The increase or decrease of Nusselt number obtained for the tube with wavy twisted tape inserts in comparison to those of the plain tube values.

2) The highest heat flux among the inserts tested and amount by which it is higher than the value of the plain tube.

3) The friction factor for the tube equipped with twisted tape inserts will be compared with those of the plain tube values.

4) The maximum thermal enhancement efficiency (η) possible with the twisted tape inserted tube with a particular configuration among the tested ones.

5) The empirical correlations will be developed in the proposed study which will predict the Nusselt number and friction factor. The maximum deviations between the predicted results and experimental results for Nusselt number and friction factor will be checked.

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