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An experimental analysis for performance improvement of circular pipe

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Abstract
Thermo physical properties like Re, Nu, heat transfer coefficient are experimentally simulated in this work for circular pipe. The work is preformed on water and Nano-fluid for same circular pipe, which is made of Cu material. The length of pipe is 600 mm having 21 mm diameter. Thickness is 1 mm of pipe. Inserts are applied to circular tube to increase its heat transfer coefficient during flow conditions. Total 16 experiments are designed for present study using Taguchi method. Different type of Model equation is generated for the present work and experimental validation is also preformed for present work. The thermal properties of Nano-fluid are solved using correlation equations for present study. Three design cases are generated for experimental studies which are following, first are simple tube, second are simple insert and last are twisted insert. The experimental analysis is performed for transient modeling environment. Mass flow rate and Pressure outlet boundary conditions are applied to inflow and outflow.

Keywords: twisted insert, experimental setup, taguchi method, ANOVA

1. Introduction
A Heat exchanger is a device designed to efficiently transfer or "exchange" heat from one matter to another. When a fluid is used to transfer heat, the fluid could be a liquid, such as water or oil, or could be moving air. It has various applications for different type of industries like conversion, utilization and recovery of thermal energy. Heat exchanger are energy saving device, it can save precious energy losses from heat applications devices. It can improve overall thermal performance of full thermal system. Heat exchanger is made of tubes, which are its main component. There are lots of researches carried out to improve heat exchanger tubes by applying various heat enhancement techniques on it.

The enhancement techniques of heat transfer are widely applied to improving the performance of heat exchangers in chemical industries and air conditioning systems to reduce the size and costs of the heat exchangers, these techniques are classified as active, passive and compound techniques. The active techniques requires some external source of power for its running performance. It doesn’t have so much potential because it is more complicated to provide power supply as input in many other cases. Some active techniques are given as surface vibration, fluid vibration, mechanical aids or suction. The passive techniques are not directly helpful to exchange heat from one fluid to another fluid like active method, but can boost heat transfer rate by applying its technique in heat exchanger. One important technique of this method is applying inserts in circular tubes. These inserts provide more disturbances in flow so it is effective to use them in device. The inserts converts flow pattern in to shape of the insert used. Due to which pressure drop takes place. The main advantage of passive techniques is that it doesn’t require external input power source. The methods and surfaces used in passive method are given as: rough surface at inner section of circular pipe, plain fins, twisting the coil, nano fluid. Compound method is combination of both direct and passive method. In this method material modification also plays important role in heat enhancement of fluid. Viper tube increases transfer of heat by combination of all these input factors which includes increased fluid flow turbulence, generate secondary fluid flow pattern, boundary layer disturbance and increased heat transfer surface area, which results in a recent transition to increase heat transfer. Use of heat transfer tubes is very effective design for cost and it can be used in development of great efficient thermal system.

i) Fabrication of Setup
The experimental test facility is designed according international standard. The main reference for setup making is taken from literature review. Length of circular heat pipe is 600 mm with 21 mm diameter. The thickness of tube is 0.5 mm. this tube is made of copper material. Test rig have temperature measuring devices, air velocity measuring devices, U tube manometer, insulation material, multi-meter. Thermal electrical insulation material is used for cu pipe to prevent electrical energy from heat pipe but allow thermal energy in tube. Gypsum is one good example of this category. Cu tube is connected to fluid pipe which carry water from pump to tube initial point without any leak. Local available heating Coil is used for heating the tube. It is made of high electrical conductor material. Internal section of tube is highly polished and it reduces turbulence of water flow, so roughness is increased by giving it rubbing with metal wires. Water leveling is used to maintain setup at true horizontal. Total five

holes are drilled in cu tube. These holes are used for temperature measurement. Figure 1 and figure 2 shows schematic and real photograph of setup.

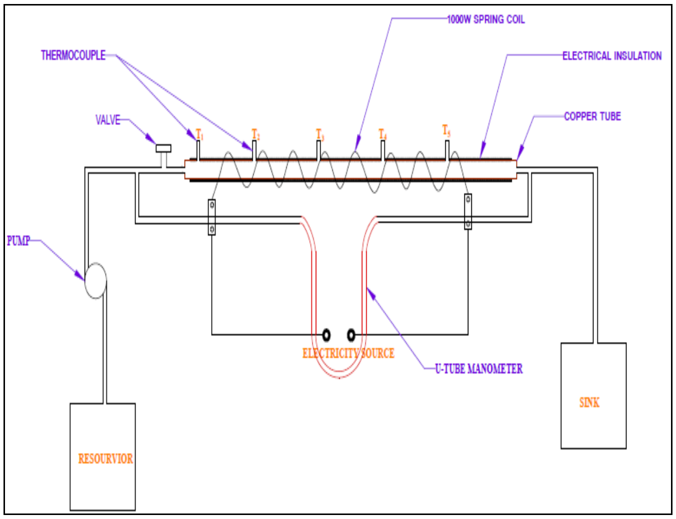

Fig 1: Schematic Diagram

In figure 2 heating coil is highly red, which means it work on circular pipe. Thermocouple are permanent installed at holes so that there is no water loss from them. U tube manometer is also used to find out pressure drop. In simple case there is very less pressure drop. In U tube manometer heavy liquid is used.

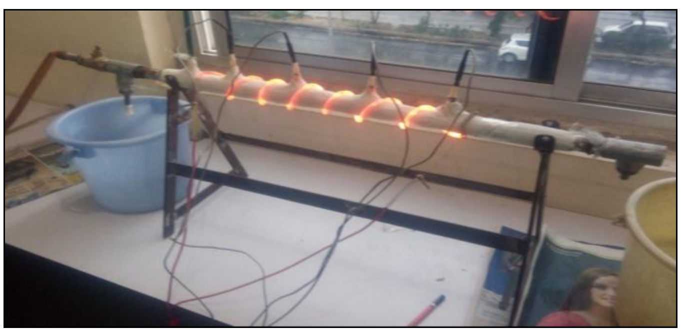

Fig 2: Real photograph of setup

ii) Design of Experiment(DOE)

Heat transfer from circular pipe surface to fluid is dependent on its process factors like heating rate of circular pipe (A), initial temperature of fluid (B), wall roughness (C) and their cross effect like A*A, B*B and others. Circular pipe thermal work is highly dependent on these parameters. The effects of these process parameters were studied by various researchers from last decades. It was very difficult to design, experiments for any type of research and here a scientific approach is helpful for researchers which is known as “Design of Experiment”. This technique is adopted by researcher for this single study. By use of DOE techniques any researcher can determine important factors which are responsible for output result (response) variation of experiments. DOE can found optimum solution for particular experiments.

In this study four designs of heat circular pipe is used for DOE analysis, first is simple circular pipe, second is circular pipe having simple insert, third has 600 angled inserts and fourth is 800 angled inserts in circular pipe. DOE is separately is used for all three cases, but in this study only design variations are not studied, also fluid effect is studied. Three different fluids are used for DOE study also named air, water and nano-fluid (Al_2O_3 nano-particle at different volume fractions)

DOE is very vast subject and it was very difficult to choose proper technique for experiments design. From literature review it was found that DOE based on Taguchi methods was used by various researchers and that’s why this technique was also used in this study.

The preparation required before beginning DOE experimentation depends on research problem. Some important steps were shown below which were followed by researchers during DOE designing.

2. Literature review

S. Eiamsa-ard *et al.* [1] studied heat transfer enhancement experimentally and numerically by overlapped dual twisted-tapes (O-DTs) and TiO_2/water nanofluids. The experimental and numerical results indicated that ODTs with smaller overlapped twisted ratio delivered a stronger swirl intensity and higher turbulent kinetic energy (TKE). The use of O-DTs at the smallest overlapped twist ratio of 1.5 enhanced heat transfer rates up to 89%, friction factor by 5.43 times and thermal performance up to 1.13 times as compared to those of plain tube.

Sajid Hussein Ali Al – Abbasi [2] studied the results of CFD analysis of enhancement of turbulent flow heat transfer in a horizontal circular tube with different shapes of inserts (disc, diamond and trapezoidal), with air as working fluid. It was observed that enhancement of heat transfer as compared to the conventional bare tube at the same mass flow rate was found to be a factor of3 to 5 times, were as the friction factor rise was about a factor of 5 times for different tube inserts.

Prof. Rupesh G *et al.* [3] studied with experimental and CFD technique on the heat transfer characteristics for Natural convection flow through inclined pipe. The parameters varied during the experimentation and software analysis are tube diameter, and heat supplied. The experimental and CFD results were to be validate with each other. Based on this analysis it was found that the temperature was more in large diameter pipe. It reduces with decrease in pipe diameter. The change in temperature was found about 20 % with increase in pipe diameter from 12 mm and 24 mm. As the heat supply increases it will affect on the output temperature and it also increases.

Xiang-hui Tan *et al.* [4] studied fluid flow and heat transfer characteristics in the shell side of twisted oval tube heat exchanger numerically with Realized k–e model. Influence of the geometrical parameters including twisted pitch length P and aspect ratio A/B on the performance of the shell side are analyzed. Results reflect that Nusselt number and friction factor both increase with the increasing of P and A/B. Their influence on the shell side overall heat transfer performance h/DP is also analyzed. It is concluded that the overall heat transfer performance of the shell side increase with the increasing of A/B. But on the aspect of the influence of P, it firstly increases with the increasing of P and then decreases with the increasing of P.

3. Methodology

a. **Define the problem Statement:** Developing a good problem statement helps make sure that researchers are studying the right variables. At this step, identify the questions that will be answered.

b. **Define the objective of study:** A well-defined objective will ensure that the experiment answers the right questions and yields practical, usable information. At this step, you define the goals of the experiment.

c. **Develop an experimental plan:** that will provide meaningful information. Be sure to review relevant background information, such as theoretical principles, and knowledge gained through literature of previous research papers. Researchers may need to identify which factors or process conditions affect process performance and contribute to process variability. Or, if the process is already established and the influential factors have been identified, you may want to determine optimal process conditions.

i) Research analysis flow diagram

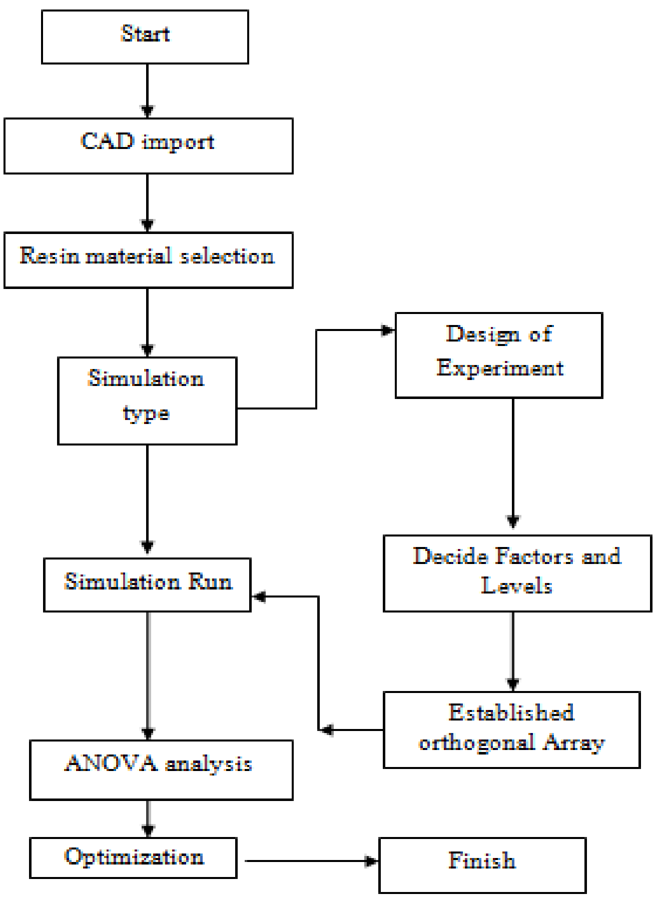

Fig 3: Analysis flow chart

ii) Orthogonal array

In this study two orthogonal arrays are generated according to table 1, these two array tables are shown in table 2. Response data for this study is fluid temperature at exit boundary surface. ANOVA is important analysis, and this task is performed in MINITAB software.

Table 1: ANOVA analysis for circular pipe

Sr. No.	Mass_FR (kg/s)	DesignInsert	Wall Roughness	VF
1	0.08	1	0.4	0.0
2	0.08	2	0.5	0.5
3	0.08	3	0.6	1.0
4	0.08	4	0.7	1.5
5	0.10	1	0.5	1.0
6	0.10	2	0.4	1.5
7	0.10	3	0.7	0.0
8	0.10	4	0.6	0.5
9	0.12	1	0.6	1.5
10	0.12	2	0.7	1.0
11	0.12	3	0.4	0.5
12	0.12	4	0.5	0.0
13	0.14	1	0.7	0.5
14	0.14	2	0.6	0.0
15	0.14	3	0.5	1.5
16	0.14	4	0.4	1.0

iii) Equations used for validation

Equation used for energy supplied to circular pipe.

$$Q = V * I$$

Here V is voltage and I is current given to be heating coil.
Equation used for energy absorbed by circular pipe.

$$Q = m * C * (T_o - T_i)$$

Equation used for heat transfer coefficient

$$h_{exp} = \frac{Q}{A_s (T_{plate} - T_{avg})}$$

T plate is avg. temperature of heater plate wall and Tavg is avg. temperature at outer part of pipe.
Equation used for Reynolds number

$$R_e = \frac{4\dot{m}}{\pi D \mu}$$

Equation used for Nusselt number

$$Nu = \frac{hD}{K}$$

Correlation equation for Nu number given by Dittus-Boeltler

$$Nu = 0.02 Re^{0.8} Pr^{0.3}$$

Correlation equation for Nu number given by Gnielinski

$$Nu = \frac{\left(f/8\right)(Re - 1000)Pr}{1 + 12.7\left(f/8\right)^{0.5}(Pr^{0.67} - 1)}$$

Where f is friction factor and formula for f is given by Petukhov

$$f = (0.79 \ln(Re) - 1.64)^{-2}$$

4. Result and Discussion

According to figure 5, it is clear that simple insert increase nu number which means it has more heat transfer coefficient than simple circular tube. Maximum improvement in simple insert is achieved to equal to 23%, which is huge quantity but as Re number is increased the performance increment is decreased.

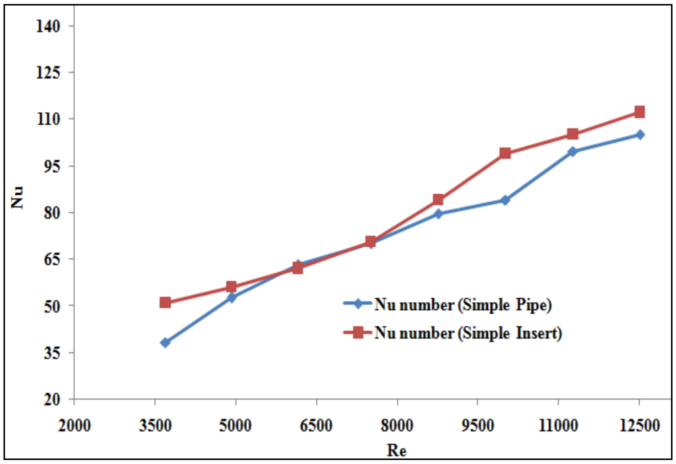

Fig 4: Comparison between simple pipe and insert-I

Experimental results for twisted pipe insert is shown in figure 6. Mass flow rate is equal to 0.06 kg/s to 0.20 kg/s.

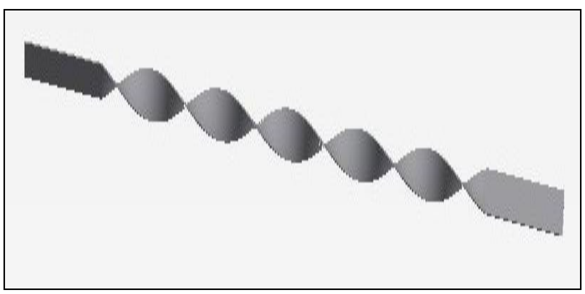

Fig 5: Line Diagram of twisted insert

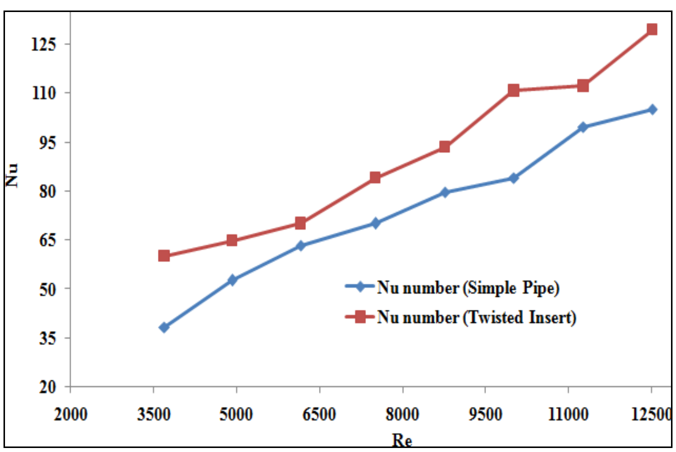

Fig 6: Comparison between simple pipe and insert-II

According to figure 5.3 it is clear that twisted insert is more efficient than simple circular pipe. There is huge improvement in heat transfer rate and maximum improvement is achieved is equal to 35% at low mass flow rate. This work is done for water only. In this study effect of nanofluid is also want to analysis, but it is not possible to purchase nano particle at this level. So CFD is used for nano-fluid analysis. Next research is carried out by helping of design of experiment (DOE). In present study experimental and CFD simulation work is performed. Experimental work is discussed in previous section.

i) Analysis of variance (ANOVA)

ANOVA is solved by using surface response methodology. Steps involved in Minitab software is discussed in Appendix data. In ANOVA analysis F-Test was conduct to compare a model variance with a residual variance. F value was calculated from a model mean square divided by residual mean square value. If f value was approaching to one means both variances were same, according F value highest was best to find critical input parameter. ANOVA table is presented in table 2

Table 2: ANOVA analysis for circular pipe

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value
Model	4	39.1697	9.7924	12.86	0.000
Linear	4	39.1697	9.7924	12.86	0.000
MFR	1	27.8008	27.8008	36.51	0.000
Insert	1	2.9032	2.9032	3.81	0.077
Wall Roughness	1	0.4898	0.4898	0.64	0.439
VR	1	7.9758	7.9758	10.47	0.008
Error	11	8.3757	0.7614		
Total	15	47.5454			

As per shown in table 6 it is clear that all factors which have p value less than 0.05 are treated as significant variables and remaining factors are treated as insignificant factors. Only one factor is insignificant in present study, which is wall roughness. It means wall roughness does not play any important role in heat transfer analysis. F values are much higher for all factors which good indication that model equations works better in future. Figure 9 represents graph which are generated during ANOVA analysis.

ii) Model equations

Model equations are presented here:

$$Temp = 310.80 - 58.95 * MFR + 0.381 * Insert + 1.56 * Wall_{Rough} + 1.263 * VF$$

This equation is valid for only for some specific design inserts used in this study like twisted inserts and simple inserts. This equation is statically representation of experimentation data, not represent any physics for heat transfer. In this equation Insert represents only four numbers which is fixed for this equation (from 1, 2, 3 and 4).

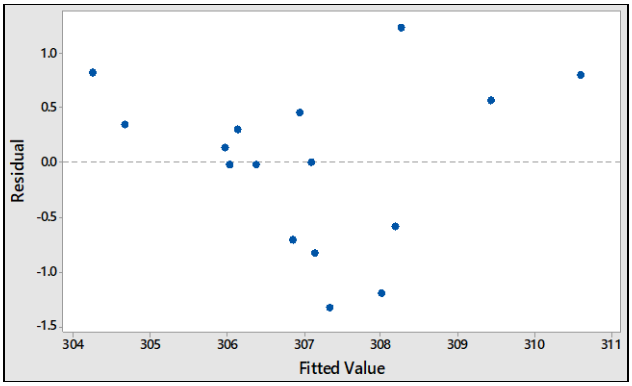

Fig 7: Temperature Residuals against fitted value of temperature

5. Conclusion

In present study experimental work is performed on simple circular tube having twisted inserts. In experimental case, DOE is also used to generate model equation. Main conclusions are following:

1. The regression equation of D-B, Gnielinski, valid for single phase fluids in the turbulent range for both experimental and simulated data. This variation is less than 10%, which is good agreement with results.
2. Heat transfer coefficients for water are more when twisted insert is applied in circular tube
3. Model equation for outlet temperature is presented; this model equation is at 90% R2 value which is acceptable for presented case.
4. Visual results are also presented in this study, according to visual results, it is clear that when inserts are applied heat transfer is increase because more contact is made with heater surface, due to circular motion of fluid.

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