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Optimization of Al_2O_3Nanofluid Flow Rate In A U-Tube Heat Exchanger Using Taguchi Method

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Abstract:U-tube Heat exchanger is fabricated to investigate the effect nanofluid flow rate on Nusselt number and Friction factor of twisted tape strips. The volume concentrations of Al_2O_3 nanofluid as 0.01%, 0.02% and 0.03% were considered as working medium for experimentation. Three parameters were taken as input parameters namely volume concentration of aluminum oxide nanofluid, Reynolds number and twist designs. Experiments were carried out using the Taguchi's L_9 orthogonal array to find the optimal value. From the test it was observed that the performance of heat exchanger is depends on Reynolds number and high volume concentration of nanofluid.

Keywords: Heat exchanger; inserts;nanofluid;taguchi method.

1. INTRODCTION

A heat exchanger is a device, which is used to transfer the heat from a hot body to a cold body. Heat exchangers are have a wide variety of applications including power plants, nuclear reactors, refrigeration and air-conditioning systems, automotive industries, heat recovery systems, chemical processing, and food industries. On the basis of nature of heat exchange method, are classified as direct contact and indirect contact heat exchangers. In direct contact heat exchangers, the heat exchange takes place by mixture of hot and cold fluids. Generally, passive technique, active technique and compound techniques are used to get better the heat transfer rate. Passive technique method doesn't need any directinput of external power; rather during this technique power is generated from the system itself, which will successively increase fluid pressure drop. It frequently uses surface or geometrical modifications to the flow conduit by using inserts. It promotes high heat transfer rates by troubling or fixing the prevailing flow behavior aside from extended surfaces. S.K.Saha A. Dutta, [1] investigated the flow of servo thermoil in circular pipe with twisted tape insert of insulated stainless steel material. They studied the result of changing length and changing pitch twisted tape with dissimilar twist ratios on heat transfer rate and friction factor. The significant outcomes were - small length twisted tapes shows less heat transfer rate, and standardized pitch twisted tape gives highest heat transfer rate. Zhi-Min Lin.et.al [2] investigated the air flow in Plexiglas circular pipe with twisted tape insert of Stainless steel material. Inserts with varying twist ratios are used. With low twist ratios, higher heat transfer is achieved as compared to high twist ratio. Sundar. L.S .et.al [3] experimentally proved that the Heat transfer enhancements of low volume concentration of Al_2O_3nanofluid with longitudinal strip inserts in a circular tube. P.V. Durga Prasad, A.V.S.S.K.S. Gupta and M. Sreeramulu, et.al, [4] experimented that, thermal Performance of Al_2O_3nanofluid in a double pipe U-bend heat exchanger with longitudinal strip inserts. It was concluded that the longitudinal insert has major effect on enhancing heat transfer rate and correspondingly the pressure drop increases. Correlation of frictio factor and heat transfer and based on the experimental data is presented. He studied effects of relevant parameters on heat transfer and pressure drop. Smith Eiamsa-ard et al., [5] investigate to analyze coefficient heat transfer and flow friction factor characteristics in a copper pipe counter flow heat exchanger, containing the stainless steel helical screw-tape with or without core-rod inside. Hot and chilled water used for experimentation. They concluded that helical screw-tape insert has a significant effect on enhancing heat transfer rate and also considerable increase of friction. Ashis K. Mazumder and Sujoy K. Saha, [6] performs the investigational study in a square and rectangular ducts with acrylic material fixed with full and small length twisted tapes. It was completed that regularly spaced full length twisted tape improved as compared to short length tape. Seth A. Lawson et al.[11] Experiments were conducted to determine the effects on independent distance wise and stream wise spacing on heat transfer and pressure loss through multiple row arrays of pin fins. If the stream wise spacing was larger than the span wise spacing, the heat transfer was maximized farther upstream in the array. Dong H.Leeet al.[12] investigated the air-side heat transfer performance of a heat exchanger with perforated circular finned tubes. The air-side convective heat transfer coefficients for 2-hole and 4hole PCFT cases increased by 3.55% and 3.31% respectively pressure drop by 0.68% and 2.08%, respectively. The fin factor for the 2-hole PCFT case was 5.19, whereas that for the 4-hole PCFT case was 1.59,

2. EXPERIMENTAL DETAILS

A. Preparation of Nanofluid

The nanofluids to the current study were ready by dispersing Al_2O_3 nanoparticles in pure water. The nanoparticles are procured from Aldrich Chemicals, USA. The thermal properties of pure water and the physical properties of Al_2O_3 nanoparticles are shown in Table 1.

Table 1

Thermophysical properties of Al_2O_3nanoparticles and base fluid.

Particle/Base fluid	Diameter (nm)	ρ (kg/m^3)	Surface area to mass, (m^2/g)	C (J/kg K)	Purity (%)	k (W/mk)
Al_2O_3	<50 nm	3970	29	525	99	17.65
Distilled water*	$\rho = 1001.67 - 0.10408\,T - 0.0033\,T^2$ $C_p = 4192 - 0.70975\,T + 0.00956\,T^2$					
	$k = 0.55815 + 0.00222\,T - 1.025 \times 10^{-5}\,T^2$ $\mu = 1.445 \times 10^{-6} - 2.525 \times 10^{-8} T + 1.475 \times 10^{-10}\,T^2$					

*All temperatures (T) are in degrees Celsius.

Preparation of stable nanofluids is very important to avoid sedimentation of the particles in the base fluid – a problem that occurs with micro-size particles; to this purpose there available various methods, among others, addition of a surfactant, a stabilizer, or ultrasonic vibration. In the present work the addition of a surfactant was preferred due to its simplicity and effectiveness. Selection of the appropriate surfactant is critical to obtain long-term stable nanofluids; the results were obtained with sodium dodecyl benzene sulphate (SDBS) surfactant. The weight of the surfactant is nearly equal to 1/10th of weight of nanoparticles for a particular concentration; surfactant was prepared by combination with water and then using a high speed stirrer for proper mixing. The nanoparticles required for a known volume concentration is estimated from equation given below.

$$\phi = \frac{1}{(100/\varphi_m)(\rho_p/\rho_w)+1} \times 100\ (\%) \qquad (1)$$

Where $(\rho_p)$and $(\rho_w)$are the particles and water the densities, and $(\phi)$and(ϕ_m) are the dispersed fluid, volume and mass concentrations (%) .

B. Experimental setup and working procedure

The investigational setup is shown in **Fig. 1,** it consists of a test segment, panel board, flow meter, test fluid collecting tank, chiller, hot fluid collecting tank, pump, bypass valve arrangement, and u-tube manometer. The test section consists of a U-bend double pipe heat exchanger; the inner tube is made of copper and it has an inner diameter (ID) of 19 mm, and the annulus tube is made of cast iron with an ID of 50 mm. The total length of the inner tube is 5000 mm and the bend is equidistant from both ends at a distance of 2200 mm and with a radius of 160 mm. The hot fluid is passes through the annular section and the water/nanofluid flows passes through the inner tube by using a pump. The mass flow rates for both the hot fluid and the water/nanofluid are controlled with by-pass valve arrangements. Two flow meters (MAS Technologies Ltd, India) are used to evaluate flow rates of tube side and annulus side fluids. Throughout the experiments the mass flow rate of hot fluid through annulus is 0.095 kg/s and the working fluid mass flow rate of nanofluid is varied from 0.033 kg/s to 0.26 kg/s.The test section consists of (i) inlet pipe (ii) bend (iii) outlet pipe are shown in **Fig. 1.**

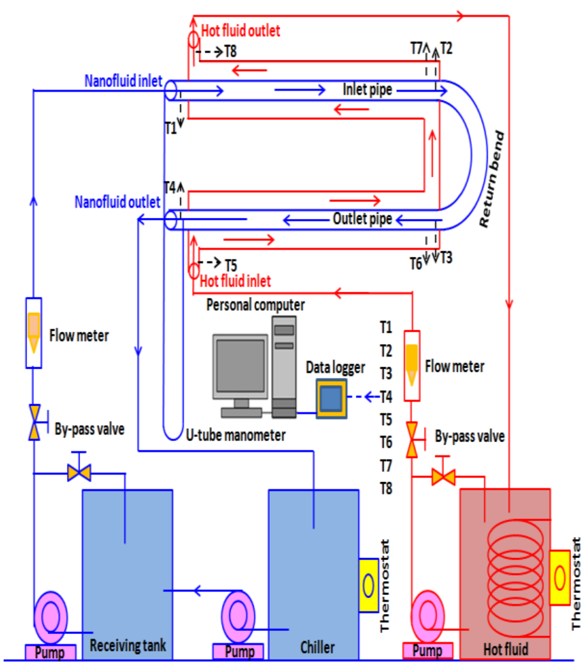

Fig.1 Schematic Diagram of experimental setup

The heat transfer coefficients for the cold fluid to hot fluid are calculated; the heat transfer in the bend region can be neglected with no significant loss of correctness. The outside surface of the outer pipe is wound by asbestos rope for minimize the heat loss from the test region to atmosphere. In order to determine the temperatures of the fluids, a total of 8 numbers K-type thermocouples were used, in which 4 numbers are located at the inner tube of the heat exchanger and 4 numbers are at the outer tube of the heat exchanger. Needles of thermocouple are connected to the data gaining system and the readings of thermocouple are noted in the computer. The thermocouples are calibrated $(\pm 0.1^{\circ}C)$ before placement in the test section. The aspect ratio ($l/d = 354$, *l*: length; *d*: diameter) of the test section is sufficiently high for hydrodynamically developed flow. The receiving and hot fluid tanks both have the capacity of 50 liters and they are made of stainless steel. The nanofluid, which runs in a closed loop, before entering the test section passes through a chiller to maintain the inlet temperature is constant. The Table 2 depicts the twisted tape with various H/D ratios and twisted tape inserts are shown in Fig 2.

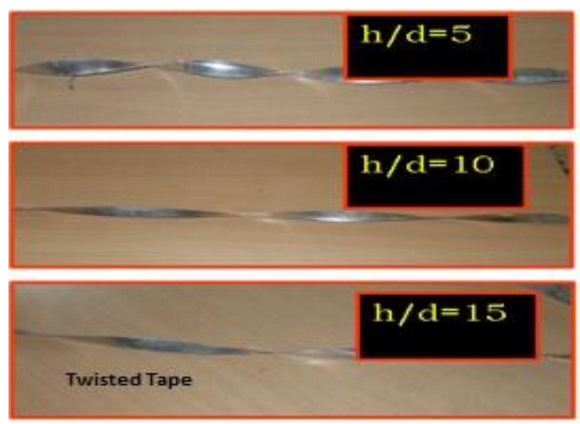

Fig. 2Twistedtape inserts used in experimental work

Table 2: Dimensions of Twisted tape inserts

Twisted tape insert	h(m)	d(m)
h/d = 5	0.085	0.017
h/d = 10	0.170	0.017
h/d = 15	0.255	0.017

3. OPTIMIZATION OF PROCESS PARAMETERS

Conventional experimental design methods are very difficult to use. Additionally, these methods require a large number of experiments when the number of process parameters increases.By using the Taguchi's analysis researchers optimized the wear performance of the material [13], welding procedure [14], and machining processes [15]. From the literature it was identified that the Taguchi's approach is used to attain the best results with minimum experiments and it is found that the no one is attempted to improve the performance of the U-tube heat exchanger using the Taguchi approach. Hence an attempt is made to optimize the volume fraction of nanofluid by varying at 0.01%, 0.02%, and 0.03% volume concentration, test fluid Reynolds number range of 3000 to 30000 and twist ratios of twisted tapes H/D=5,10,15 and also plain tube heat exchanger by using the Taguchi 's orthogonal design. In order to minimize the number of tests required, Taguchi experimental design method, a powerful tool to designing high-quality system developed by Taguchi. This method uses a design of orthogonal arrays to study the entire parameter of Volume concentration, Reynolds number and twisted tape dimensions with experiments. Taguchi recommends analyzing the mean response for each run in the inner array, and also suggests to analyze variation using an suitably chosen signal-to-noise ratio (S/N). There are 3 Signal-to-Noise ratios of common interest for optimization of static problems.

(a) SMALLER-THE-BETTER:

$$S/_N = -10\ log\frac{1}{n}\left(\sum y_i^2\right)$$

(b) LARGER-THE-BETTER:

$$S/_N = -10\ log\frac{1}{n}\left(\sum \frac{1}{y_i{}^2}\right)$$

(c) NOMINAL-THE-BEST:

$$S/_N = -10\log\frac{1}{n}\left(\sum \frac{Y}{S_Y^2}\right)$$

Here yi is the ith observed value of the response, n is the no. of observations in a trial, y is the average of observed values (responses) and S_Y^2 is the variance of Y. Regardless of category of the performance characteristics, and the higher S/N ratio correspondsto a better performance. Therefore, the optimal level of the process parameters is the level with the highest S/N value.

Table 4: Experimental Result and Corresponding S/N Ratio

S.No	Volume Concentration (%)	Reynolds Number	Twist Ratio(H/D)	Nusselt Number	Friction factor	Nusselt Number		Friction factor	
						S/N ratio	P Mean	S/N ratio	P mean
1	0.01	3936	5	41.23	0.0476	32.30	41.23	26.44	0.047
2	0.01	17440	10	128.90	0.0319	42.20	128.9	29.92	0.031
3	0.01	27340	15	189.45	0.0276	45.54	189.4	31.18	0.027
4	0.02	3936	10	40.98	0.0460	32.25	40.98	26.74	0.046
5	0.02	17440	15	127.48	0.0309	42.10	127.9	30.20	0.030
6	0.02	27340	5	201.45	0.0303	46.08	201.4	30.37	0.030
7	0.03	3936	15	40.45	0.0449	32.13	40.45	26.95	0.044
8	0.03	17440	5	135.43	0.0334	42.63	135.4	29.52	0.033
9	0.03	27340	10	203.23	0.0298	46.15	203.2	30.51	0.029

4. RESULTS AND DISCUSSION

Table 3: Control Parameters and Levels

Control Parameters	Level - 1	Level-2	Level-3
Volume Concentration	0.01	0.02	0.03
Reynolds Number	3936	17440	27340
Twisted Tape(H/D)	5	10	15

A. Validation of the experimental work

In order to validate the experimental setup, compare the experimental average Nusselt number (average between inlet and outlet pipes) for water and with the theoretical correlations of Eq.(2) Gnielinski [7] and Eq.(3) Notter-Rouse [8] is shown in Fig. 3. It is determined from the figure that the distinction between experimental and theoretical Nusselt number for water is obtained the most variation of ± 3%.

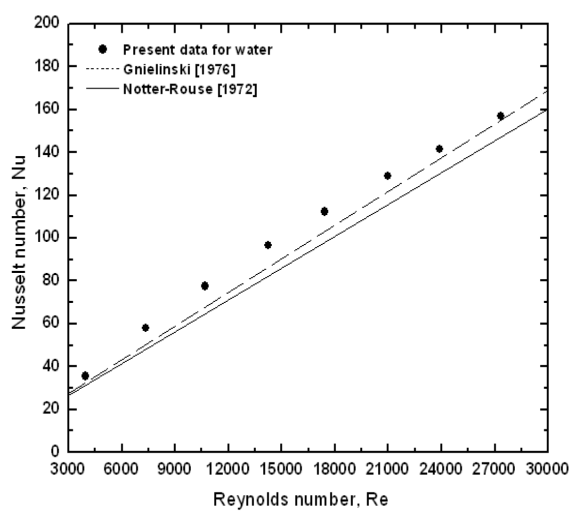

Fig. 3 Experimental Nusselt number of water is in compared with Gnielinski [1976] and Notter-Rouse [1972]

Validation of the experimental data with the following correlations, estimation of Nusselt number for single phase fluid is given below:

(i) Gnielinski [7]correlation for turbulent flow

$$Nu = \frac{\left(\frac{f}{2}\right)(Re-1000)\,Pr}{1.07+12.7\left(\frac{f}{2}\right)^{0.5}\left(Pr^{2/3}-1\right)} \quad (2)$$

(ii) Notter-Rouse [8] equation for turbulent flow

$$Nu = 5 + 0.015\,Re^{0.856} \quad (3)$$

In order to validate the experimental information, the frictional factor experimental data as well as working fluid estimates with the theoretical correlation Eq. (4) of Blasius [9] and Eq. (5) of Petukov [10], it is observed from figure, experimental values with a most of ± 2.5% deviation and the combined data is shown in Fig. 4 below.

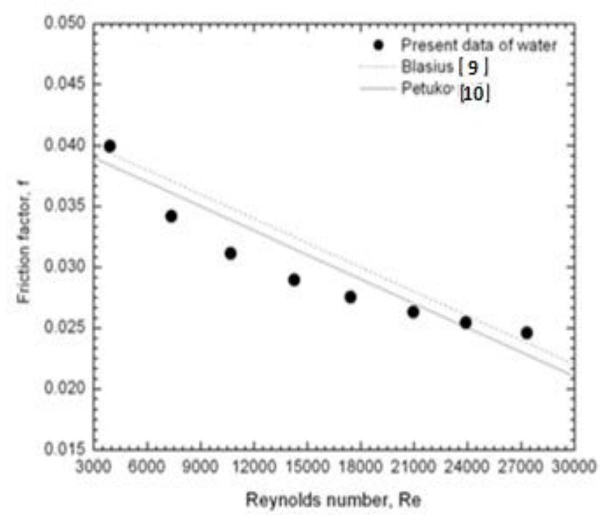

Fig. 4 Experimental friction factor of water comparison with Blasius [1908] and Petukov [1970]

Validation of the experimental data with the following correlations, estimation of friction factor for single phase fluid is given below:

(i) Blasius [9] equation for turbulent region

$$f = 0.3164\,Re^{-0.25} \quad (4)$$

$$3000 < Re < 10^5$$

(ii) Petukov [10] equation for turbulent region

$$f = (0.790 \ln(Re) - 1.64)^{-2} \quad (5)$$

$$2300 < Re < 5 \times 10^6$$

B. Experiment results and Taguchi analysis

From the experimental mean data it was observed that as Reynolds number increases the Nusselt number also increases. At 0.03% of volume concentration the Nusselt number is high but as the H/D ratio increases the relatively Nusselt number decreases which is depicts in fig 5 (a) and 5(b).

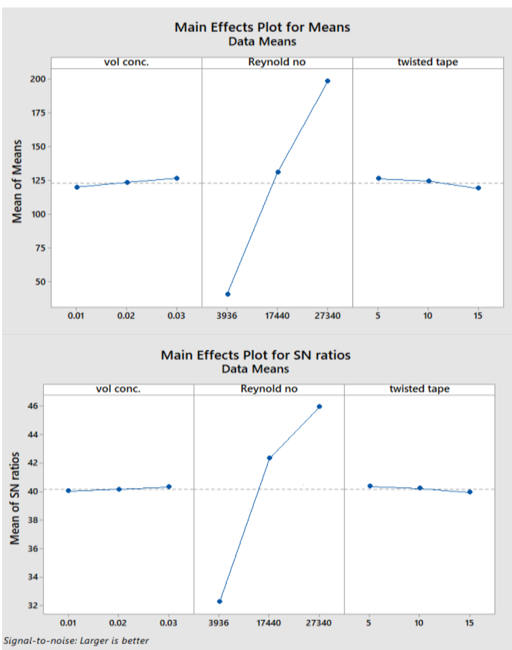

Fig.5(a) Nusselt number Mean plot , Fig. 5 (b) Nusselt number S/N ratio plot

From the experimental mean data it was observed that as Reynolds number increases the Friction factor decreases. At 0.03% of volume concentration the friction factor is high but as the twist ratio increases the corresponding friction factor is decreases which is shown in Fig. 6 (a) and 6 (b).

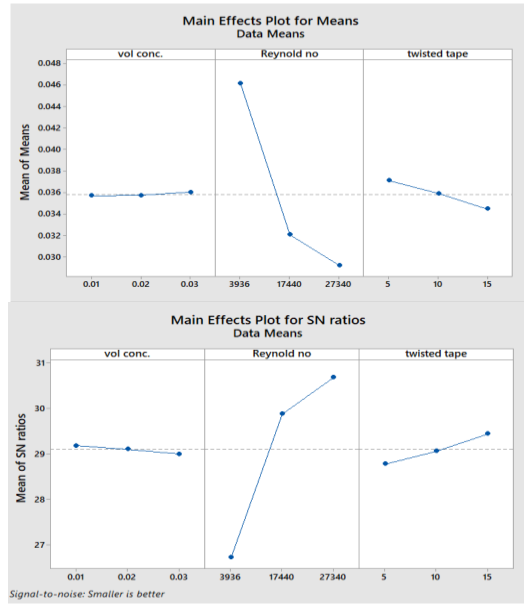

Fig.6 (a):Friction factor Mean plot, Fig.5 (b):Friction factor S/N ratio plot

5. CONCLUSION

The Nusselt number and Friction factor are experimentally tested on the water based Al_2O_3nanofluid with twisted tape inserts. The results shown that as Nusselt number increase with an increase of Reynolds number and volume concentration of nanoparticles. Friction factor decreases with increasing Reynolds number and H/D ratio. At 0.03% of volume concentration both heat transfer and friction factor are increases. The experimental values are optimized with L9 orthogonal array, to study the behavior of responses S/N ratio is larger for Nusselt number and S/N ratio is smaller for Friction factor.

NOMENCLATURE

A	Area, m^2
C_p	Specific heat, $J/kg\ K$
d	Inner diameter of the tube, m
f	Friction factor
h	Heat transfer coefficient, W/m^2K
k	Thermal conductivity, $W/m\ K$

l Length of the tube, m

$\dot{m}$ Mass flow rate, kg/sec

Nu Nusselt number, hD/k

Pr Prandtl number, $(\mu C_p)/k$

Q Heat flow, $Watts$

Re Reynolds number, $4\dot{m}/\pi D\mu$

T Temperature, ^oC

U Overall heat transfer coefficient, W/mk

v Velocity, m/sec

Greek symbols

Δp Pressure drop

ϕ Volume concentration of nanoparticles, %

μ Dynamic viscosity, kg/m^2sec

ρ Density, kg/m^3

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