ISSN 2395-1621

Effective Parameters Analysis of Heat Transfer Coefficient in Nano fluids by Taguchi Method

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ABSTRACT

In this new era, a nanofluid serves as energy efficient fluids over traditional heat transfer fluids. In this paper the water based metal oxides Al_2O_3, TiO_2, and SiO_2 are analyzed as a three different nanofluids using Taguchi methodology. Numerical investigations for heat transfer coefficient were done at three levels of four different parameters like Reynolds Number, Tube Diameter, Nanoparticle Concentration, and Nanoparticle Diameter Size. For experimental analysis L9 orthogonal array was selected. It is found that these parameters have a significant influence on heat transfer coefficient. Geometrical configuration consist circular cross sectional pipe of one meter length and forced turbulent internal flow with constant temperature (350K) wall condition. The predicted experiment shows up to 42% increment in heat transfer coefficient by using nanofluid flow than conventional fluid water. Furthermore randomly selected combinations of parameters were compared with actual results of experiments and it shows that less error and successfully tuning of Taguchi method for prediction of heat transfer coefficient.

Keywords— Heat transfer coefficient, Nanofluids, orthogonal array, Taguchi method, turbulent flow.

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. Introduction

The thermal conductivity of heat transfer fluids plays vital role for the development of energy efficient devices. The low heat transfer performance of conventional fluids such as water, engine oil and ethylene glycol puts a fundamental limit in improving performance and the compactness of many engineering equipments. The conventional way to enhance the heat transfer rate is to increase the area of heat transfer but it’s contradicted to compactness. To overcome this disadvantage, there is the need to develop advanced heat transfer fluids with substantially having higher thermal conductivities. [1-4]

Nanofluids are engineered by suspending a small quantity of nanosized (average size below than 100 nm) particles in conventional fluids. A very small amount of guest nanoparticle, when uniformly and suspended stably in host fluid can shows remarkable improvement in thermal properties of host fluid. Choi, conceived the novel concept of nanofluid (nano particle fluid suspension), a new class of engineered fluids with higher thermal conductivity and stably suspended in conventional fluids. More than a century, Scientist and researchers have made great effort for preparation of nanoparticle and adding it in liquids for understandable and drastic enhancement of thermal conductivity. [5-7]

The suspended nanoparticles are divided into three groups: ceramic particle, pure metallic particle, and carbon nanotubes. This research paper has focus on only ceramic particles Al_2O_3, TiO_2 and SiO_2 for thermal performance. From the past researches and literatures, conclude that properties of nanofluids are strongly depends on nanoparticle material, volume concentration of particle, particle dimension, Reynolds number and flow area. This paper attempts combinations of these nanofluid parameters for numerical investigation and set best property combination for integrated heat transfer coefficient. [8-10]

For experimentation where many variables are taken into consideration, Taguchi methodology provides a structured approach for determination of the right combination of variables for best results. Taguchi techniques are experimental design optimization techniques [11, 12] which use standard 'Orthogonal Arrays' for forming a matrix of experiments in such a way to extract the maximum important information with minimum number of experiments. Using Taguchi techniques, the number of parameters can be tested at a time with probably least number of experiments as compared to any of the other experimental optimization techniques. Moreover, the technique provides all the necessary information required for optimizing the problem. The main advantage of Taguchi Techniques is not only the smallest number of experiments required but also the best level of each parameter can be found and each parameter can be shared towards the problem separately. The main steps of Taguchi Method are determining the quality characteristics and design parameters necessary for the product/process, designing and conducting the experiments, analysing the results to determine the optimum conditions and carrying out a confirmatory test using the optimum conditions. [13]

II. METHODOLOGY

A. Governing Equations: It is important to set the governing equations to complete numerical analysis for circular tube. The phenomenon under consideration is steady state, two dimensional form of continuity; time averaged incompressible Navier-Stokes equation, and energy equation.[14]

Continuity equation:

$$\mathrm{div}(\ \rho\vec{V}) = \qquad (1)$$

Momentum equation:

$$\mathrm{div}(\rho\vec{V}\,\vec{V}\ ) = -\mathrm{grad}P + \nabla\ (\mu\ \nabla \qquad (2)$$

Energy equation:

$$\mathrm{div}(\rho\vec{V}C_p\ T\ ) = \mathrm{div}(k\mathrm{grad} \qquad (3)$$

The standard k-ε model is used for numerical analysis according to Launder and Spadling.[15]

B. Physical properties of the nanofluid:

By assuming that the nanoparticles are well dispersed within the base fluid i.e. the particle concentration can be considered uniform throughout the domain and, knowing the properties of the constituents as well as their respective concentrations, the effective physical properties of the mixtures studied can be evaluated using some classical formulas. In the following equations, the subscripts 'p', 'bf' and 'nf' refer respectively, to the particles, the base-fluid and the nanofluid.

TABLE I

PHYSICAL PROPERTIES OF THE BASE FLUID AND NANOPARTICLES USED IN THIS STUDY [16]

Property	**Pure water**	**Al_2O_3**	**TiO_2**	**SiO_2**
Density ρ (kg/m^3)	996.5	3850	4175	2220
Specific heat Cp(J/kg K)	4187	765	710	745
Thermal conductivity k (W/mK)	0.6103	40	8.4	1.4
Dynamic Viscosity μ (Ns/m^2)	0.000853	-	-	-

1) Density of nanofluid: In the absence of experimental data for nanofluid densities, constant value temperature independent values, based on nanoparticle volume fraction, are used. [17]

$$\rho_{nf} = \varphi\rho_p + (1-\varphi)\ \rho \qquad (4)$$

2) *Heat capacity*: It should be noted that for calculating specific heat of nanofluid some of prior researcher have used the following correlation.[17]

$$C_{nf} = \varphi C_{p_{np}} + (1-\varphi)\ C \qquad (5)$$

3) Thermal Conductivity: The model used here includes various material parameters that can change the effective k of Al_2O_3 nanofluids. The material parameters that involve the liquid are kinematic viscosity, Prandtl number, liquid thermal conductivity, and Re. One study that is of interest is the impact of the density of the particles. Two extreme cases have been considered Thermal conductivity of the nanoparticle is much larger than the thermal conductivity of the liquid.[18]

$$k_{nf} = k_{bf}(1 + A\ R_{eb}{}^{m}Pr^{0.333}\varphi)\left[\frac{1+2}{1-}\right. \qquad (6)$$

Where A and m are constants having values 4×1 and 2 respectively.

R=Brownian-Reynolds number

$$R_{eb} = \frac{1}{\upsilon}\sqrt{\frac{18\,k}{\pi\,\rho_p}} \qquad (7)$$

The thermal conductivity of TiO_2 and SiO_2 nanofluid is accurately calculated by W. H. Azmi, [19] in his research paper, he compared different thermal conductivity models with his experimental work and proposed modification in equation,

$$\frac{k_{nf}}{k_{bf}} = 1.219\left(\frac{\varphi}{100}\right)^{0.021}\left(\frac{T_{nf}}{70}\right)^{0.0989}\left(\frac{d_p}{150}\right)^{-0.005485}\left(\frac{\alpha_p}{\alpha_{bf}}\right)^{0.01137} \qquad (8)$$

4) Dynamic Viscosity: In this study dynamic viscosity dependence only on concentration ( ), in order to evaluate a least square fitting, based on some experimental data available was performed by Miaga et.al.[6] leading to following equation,

$$\mu_{nf} = \mu_{bf}(123\varphi^2 + 7.3\varphi + \quad (9)$$

D. Geometrical Configuration and Numerical Method:

Fig1.shows the geometrical configuration under consideration for analysis. It consists of a tube with length (L) of 1 m with different diameters (D). The single phase approach was used for nanofluid simulation. The nanofluid considered is composed of water and particles. It is taken to be Newtonian, incompressible and turbulent. The nanoparticles are assumed to have uniform shape and size with thermal equilibrium state. The fluid enters with uniform velocity with uniform temperature (300 K). The tube has appropriate axial length in order to obtain fully developed profiles (velocity and thermal) at outlet section (L/D>10). The condition of tube wall is maintained at constant temperature (350 K) for simulation. Also flow and thermal field are assumed to be axis symmetric. Flow and heat transfer are considered by continuity, momentum and energy equation. In this present study of heat transfer to turbulent nanofluids in circular tube, the standard k-ε turbulent model was used. The time independent, incompressible Navier -Stokes equation and turbulent model were solved by using finite volume method. The solution is considered to be converged when normalized residual value reach $\leq 10^{-5}$ for parameters. [20-23]

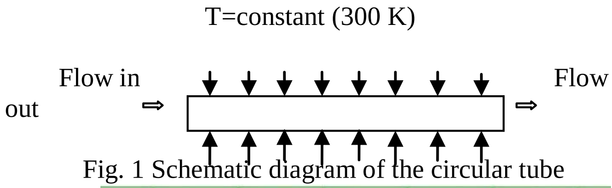

Fig. 1 Schematic diagram of the circular tube

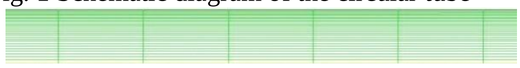

Fig.2 Mesh layout of present geometry, axisymmetric about X-axis.

III. TAGUCHI METHOD

Taguchi's methods of experimental design provide a simple, efficient, and systematic approach for the optimization of experimental designs for performance, quality and cost. The main purpose of Taguchi method is reducing the variation in a process through robust design of experiments. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied; it allows for the collection of the necessary data to determine which factors most affect process quality with a minimum amount of experimentation, thus saving time and resources.[24-25].

A. Selection of Process Variable:

From past literature survey [7] I found that several factors influence the convective heat transfer coefficient. Flow through the heat exchanger is one of the examples of fluid flow through the pipe which is widely used in the industries therefore it is taken for the analysis. The enhancement of convective heat transfer and non dimensional Nusselt number depends upon the many parameters like tube diameter, Reynolds number, nanoparticle concentration, size of nanoparticle, etc. So form the investigation, optimize that parameters which will give effectiveness of the heat exchanger [26].

B. Selection of Process Variable Levels:

From study of literature of past researcher, the varying levels of process parameter (like Reynolds number, tube diameter, its concentration, and size) are selected as three parameters are varying in three levels of Reynolds numbers. The variation levels value for each parameter is given in Table 2.

TABLE –II
PROCESS VARIABLE RANGE

Variation level	**Re**	**Pipe Dia.(mm)**	**Particle concentration (%)**	**Particle Size(nm)**
Lower	20000	6	2	10
Medium	27500	8	3	20
Higher	35000	10	4	30

A. Selection of Orthogonal Array:

The selection of orthogonal array for experiment was done by use Minitab-15 statistical software [27]. By putting parameter variation levels as per Table 1 in Minitab-15 statistical software the Mini tab suggest that mix level L9 (1*2, 3*3) factorial orthogonal array is most compatible for our experiment. The experiment table suggested by Minitab- 15 for L9 orthogonal array is shown in Table 3.

TABLE –III
STANDARD ORTHOGONAL ARRAY ARRANGEMENT

Expt. No.	Col 1	Col 2	Col 3	Col 4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

The final experiment are designed by proving selected parameters values as per Table 2, suggested by in Minitab-15 statistical software is shown in Table 3. The experiment suggested by this table is specifying the parameter level value of that particular experiment for find out the response value.

D. Analysis of Variance (ANOVA) and Data Analysis:

Different factors affect on heat transfer characteristics of nanofluids at different levels. The relative magnitude of factor effect can be decided from table no.3 to better feel for effect of different factor can be obtained by decomposing of variance i.e. analysis of variance(ANOVA).

TABLE –IV
EXPERIMENTAL DESIGN FOR L9 ORTHOGONAL ARRAY

Expt. No.	Re	Pipe Dia.(mm)	Particle concentration (%)	Particle Size(nm)
1	20000	6	2	10
2	20000	8	3	20
3	20000	10	4	30
4	27500	6	3	30
5	27500	8	4	10
6	27500	10	2	20
7	35000	6	4	20
8	35000	8	2	30
9	35000	10	3	10

For experimental data analysis ANOVA larger to better is given by,
Sound to noise ratio(S/N Ratio),

$$\eta = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y}\right. \quad (10)$$

smaller to better is given by,
Sound to noise ratio(S/N Ratio),

$$\eta = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y\right. \quad (11)$$

Where y is output parameter and n is the number of the experiment. In this research, the main objective is to determine main effects of the nanofluid performance parameters to perform ANOVA and to find out optimum condition based on the Taguchi method. Table 4 gives the CFD simulation results for L9 orthogonal array for heat transfer coefficient and S/N ratio ( ). [28]

IV. RESULT AND DISCUSSION

A. Mesh and data validation:

A careful check of independence of numerical solution was done to ensure the accuracy. In order to demonstrate the validity and accuracy of model, heat transfer coefficient of water is calculated from outlet temperature of nanofluid by using ANSYS Fluent 13.The calculated heat transfer coefficient of water is compared with the correlation given by Gnielinski over the traditional Ditus-Bolter equation because errors are usually limited to ±10%. [29]

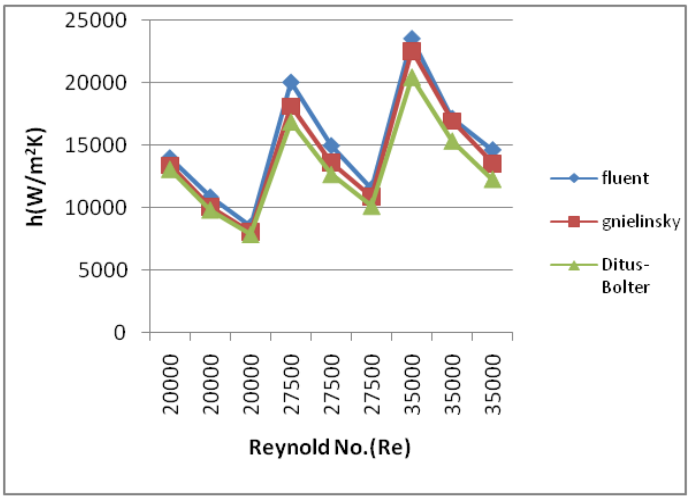

Fig 3. Mesh validation with correlation

Heat transfer coefficient (h_{fluent})

$$h_{fluent} = \frac{C_p\,\rho\,V\,A\,(T_2-T_1)}{\pi\,D\,L\left(\left(Ts-\left(T_2+T_1/_2\right)\right)\right)} \quad (12)$$

Where, T_1 and T_2 are the inlet and outlet temperature of fluid,
Ts is the surface temperature of wall
From Definition of Nusselt number,

$$Nu = h.L/k \quad (13)$$

Ditus and Bolter equation for water and nanofluid:

$$N_u = 0.023R_e^{\,0.8}\,Pr^{0.4} \quad (14)$$

Gnielinski equation for water and nanofluid:

$$N_u = \frac{f/_8(R_e-1000)\,Pr}{1+12.7\left(f/_8\right)^{0.5}\left(Pr^{2/3}-1\right)} \quad (15)$$

Where f=(0.79ln Re-1.64)$^{-2}$
Pak and Cho equation for nanofluid

$$N_u = 0.021R_e^{\,0.8}\,Pr^{0.5} \quad (16)$$

B. Taguchi Analysis and Verification:

Level average analysis as described by Taguchi method, it is one of the technique to explore the average effect of each factor on the outcome. Figure-5-9 displays the effect of each factor on heat transfer coefficient and friction factor. The aim is to find out those factors that have strong effect and whether they exert their effect independently or through interaction with other factor from table number –v,vi,vii, the results are plotted. From figure-5-9 optimum combinations can be found. In this study, graphs are ascending or descending, the optimum combination contains maximum or minimum level of each factor. An estimated predicted response values (ηopt) [31-32]

$$(\eta opt) = m + (m_{Re} - m) + (m_D - m) + (m_\varphi - m) + (m_{np} - m) \quad (17)$$

Where, m is overall mean of S/N ratios.

TABLE -V
EXPERIMENTAL RESULTS FOR Al_2O_3 NANOFLUID

Ex No	Al_2O_3 nanofluid					
	T_{out} (K)	Heat transfer coeff.(h) W/m^2 K	S/N Ratio (η)	ΔP (kPa)	Fri. factor	S/N Ratio (η)
1	320.02	21996.86	86.85	15.90	0.030	30.32
2	316.66	15349.69	83.72	6.66	0.038	28.35
3	313.73	11327.37	81.08	3.73	0.030	30.40
4	321.44	26522.56	88.47	19.35	0.027	31.25
5	316.44	24797.05	87.89	17.83	0.026	31.74
6	313.03	14847.76	83.43	7.33	0.028	30.95
7	320.86	35731.87	91.06	37.16	0.026	31.78
8	315.00	21400.37	86.61	16.82	0.025	32.00
9	312.64	22928.27	87.21	18.42	0.025	32.03

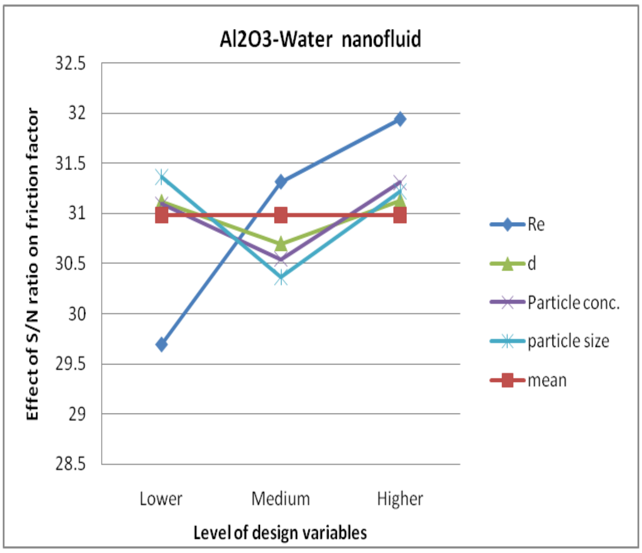

Fig.5 Effect of each factor on friction factor of Al_2O_3 nanofluid

TABLE –VI
EXPERIMENTAL RESULTS FOR TiO_2 NANOFLUID

Ex No	TiO_2 nanofluid					
	T_{out} (K)	Heat transfer coeff.(h) W/m^2 K	S/N Ratio (η)	ΔP (kPa)	Fri. fact. *f*	S/N Ratio (η)
1	326.16	18598.83	85.39	22.72	0.031	30.10
2	320.28	14722.11	83.36	13.75	0.037	28.55
3	315.17	11491.15	81.21	6.90	0.030	30.43
4	323.79	24840.18	87.90	45.50	0.028	31.19
5	315.92	16729.40	84.47	22.58	0.027	31.49
6	316.30	14057.38	82.96	8.27	0.028	31.10
7	323.97	33794.67	90.58	83.51	0.026	31.82
8	318.21	20454.43	86.22	24.19	0.026	31.78
9	316.72	20333.08	86.16	14.68	0.025	31.89

TABLE -VII
EXPERIMENTAL RESULTS FOR SiO_2 NANOFLUID

Ex No	SiO_2 nanofluid					
	T_{out} (K)	Heat transfer coeff.(h) W/m^2 K	S/N Ratio (η)	ΔP (kPa)	Fri. fact. *f*	S/N Ratio (η)
1	323.71	16799.02	84.51	25.13	0.031	30.06
2	318.20	13272.90	82.46	16.50	0.040	27.97
3	313.49	10255.92	80.22	7.77	0.030	30.43
4	322.36	23549.28	87.44	49.45	0.027	31.41
5	316.88	18483.73	85.34	25.75	0.027	31.49
6	315.05	13124.71	82.36	8.99	0.028	31.15
7	320.80	30322.42	89.64	92.16	0.025	32.04
8	317.23	19566.16	85.83	24.95	0.024	32.23
9	314.10	17192.69	84.71	16.60	0.025	31.88

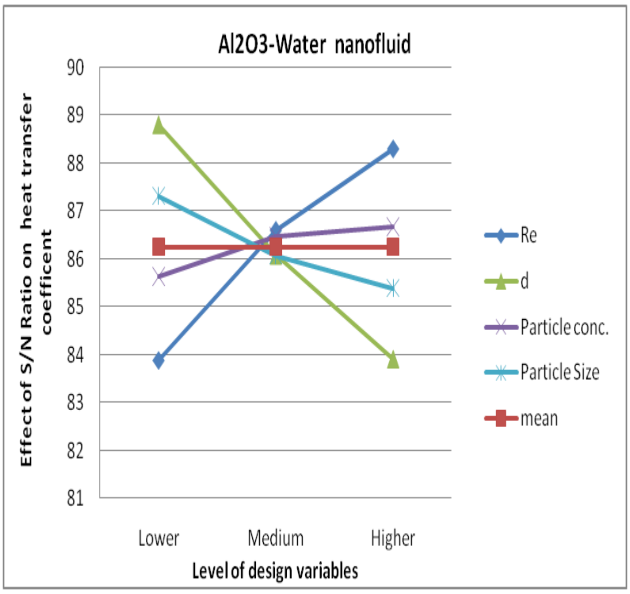

Fig.4 Effect of each factor on heat transfer coefficient of Al_2O_3 nanofluid

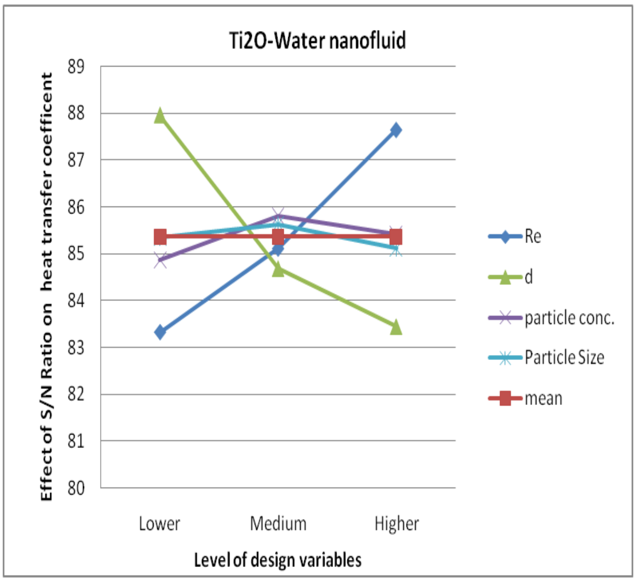

Fig.6 Effect of each factor on heat transfer coefficient of TiO_2 nanofluid

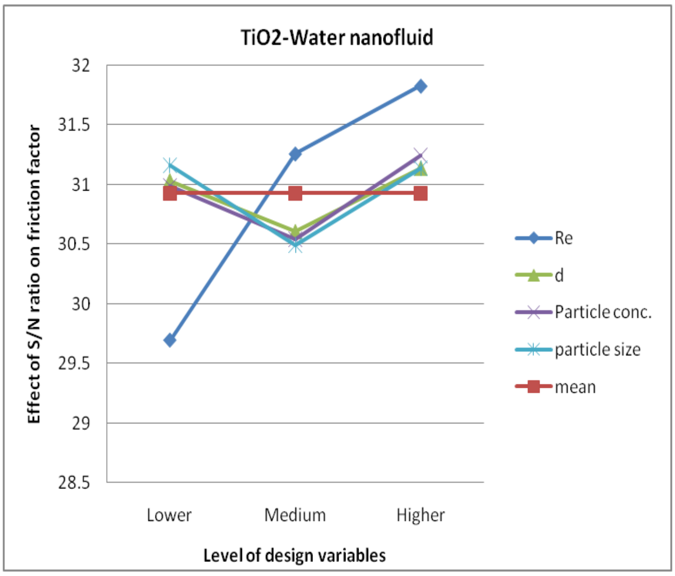

Fig.7 Effect of each factor on friction factor of TiO_2 nanofluid

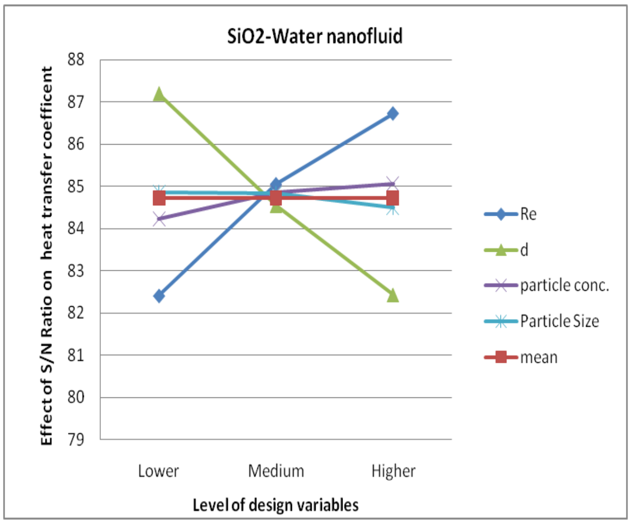

Fig.8 Effect of each factor on heat transfer coefficient of SiO2 nanofluid

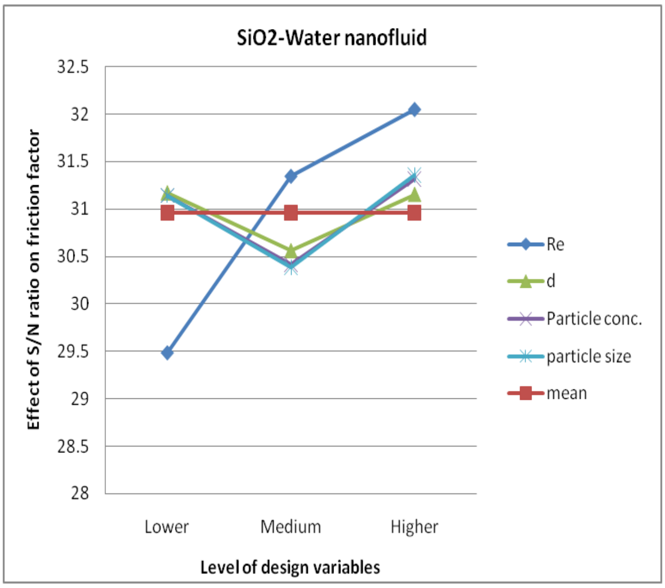

Fig.9 Effect of each factor on friction factor of SiO_2 nanofluid

Figure 4, 6, 8 shows the effects of sound to noise ratio on heat transfer coefficient of nanofluids Al2O3, TiO2, and SiO2 respectively of each factor for various level conditions. Also from the figure 5, 7, 9 indicate the effect of s/n ratio on friction factor of designed parameters. Heat transfer coefficient and friction factor increases with increasing Reynolds number.

A. Optimum combinations:

The heat transfer and pressure drop are generally used to describe the performance of heat exchangers. The results of the studies show that the pressure drop increases with increasing heat transfer. Because of this, it's not easy to simultaneously increase heat transfer and lower the pressure drop. Therefore, the evaluation was based on reaching maximum heat transfer and minimum pressure drop (friction factor) in order to define the optimum value of the parameters in this study. Each experiment was conducted according to plan and observing effect of sound to noise ratio on heat transfer and friction factor.

TABLE –VIII
FACTORIAL EFFECT AND CONTRIBUTION RATIO FOR HEAT TRANSFER COEFFICIENT

	Level	Re	D	φ	Dp
S/N ratio	1	85.32	87.99	84.85	85.99
	2	85.76	85.33	85.81	85.66
	3	87.68	83.94	86.09	85.11
R(max-min)		4.36	4.54	1.24	0.88
Rank		2	1	3	4
Contribution (%)		39.58	41.21	11.24	7.97

TABLE -IX
FACTORIAL EFFECT AND CONTRIBUTION RATIO FOR FRICTION FACTOR

	Level	Re	D	φ	dp
S/N ratio	1	29.69	31.03	30.99	31.16
	2	31.26	30.61	30.54	30.49
	3	31.83	31.14	31.25	31.13
R(max-min)		2.13	0.53	0.71	0.67
Rank		1	4	2	3
Contribution (%)		52.78	13.14	17.52	16.56

TABLE X
PREDICTED AND PERFORMACE VALUES FOR TiO_2 NANOFLUID

	Parameters					*Heat transfer coefficient*		*Friction factor*	
		Re	D	φ	dp	Predicted	Real	Predicted	Real
Heat transfer coefficient	Optimum level	3^B	1^A	3^C	1^D	35440.41	34929.24	0.032	0.028
	Optimum value	35000	6	4	10				
Friction factor	Optimum level	3^A	3^D	3^B	1^C	2418.43	21427.88	0.02542	0.0250
	Optimum value	35000	10	4	10				
Best combination	Optimum level	3^A	1^A	3^B	1^C	35440.41	34929.24	0.032	0.028
	Optimum value	35000	6	4	10				

TABLE XI
COMPARASION FOR HEAT TRANSFER COEFFICIENT OF WATER AND NANOFLUIDS

Optimum Combination	Water h (W/m^2K)	Nanofluids h (W/m^2K)	% increment
Re=35000;D=6mm ; φ=4%; dp=10 nm	23533.15	39355 (Al_2O_3)	41.92
Re=35000;D=6mm ; φ=4%; dp=10 nm	23533.15	34929 (TiO_2)	32.62
Re=35000;D=6mm ; φ=4%; dp=10 nm	23533.15	30404 (SiO_2)	22.59

For prediction of the results additive model is being used. The model refers the sum of individual factor effect on interactions. The table viii and ix gives the factorial effect and contribution for TiO_2 nanofluid. For other two nanofluids which is considered in this study, we followed the same procedure and its shows the same combinations of factors for optimum conditions with different heat transfer characteristic and friction factor which is tabulated in table xi.

V. CONCLUSIONS

By using Taguchi methodology, the optimal parameters have been designed to maximize heat transfer and minimize friction factor of Al_2O_3, SiO_2 and TiO_2 water based nanofluids. The selected parameters are the Reynolds number (Re), tube diameter (D), particle concentration (φ) and nanoparticle size (dp).The significant results of the present work can be obtained in the numerical analysis are summarized as follows.

i) For convective heat transfer coefficient, among the effective parameters of system performance, the tube diameter and Reynolds number are most effective ones. This means that heat transfer can be improved by controlling change in these parameters.

ii) The friction factor can be significantly reduced considering higher level of Reynolds number and lower level of particle size.

iii) When the whole system is optimized with considering maximum heat transfer and minimum friction factor, the optimum condition of design parameters are Re3=35000; D1=6 mm; φ3= 4%; and dp1=10 nm same for all three nanofluids. This combination includes the effect of all performance goals.

iv)The optimum combinations show that 41.92 % increment in heat transfer by using Al2o3 –water nanofluid over water as a conventional fluid.

iv) The Tio2 and sio2 also shows significant increase in heat transfer coefficient with 32.62 % and 22.59% respectively.

v) The results shows that negligible interactive effects of parameters and proved that there is no need to perform 81 (3^4 =81) experiments to optimize system. Because it will take too much time and experimental cost. Therefore Taguchi method was successfully applied to present work with very limited experiments and short time.

ACKNOWLEDGEMENT

I would like to express sincere thanks to Mechanical Department of G.H. Raisoni College of Engineering for providing me lab facilities for my experimental work.

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