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Optimization of Heat Transfer Coefficient for Al_2O_3 (75%) – CuO (25%) / Water Hybrid Nanofluid using Taguchi

K. Prashanth Reddy, Bhramara Panitapu, Ramesh Chilukuri, R. Karthikeyan, A. Kalyan Kumar

***Abstract:** To have the maximum benefits of nanofluid for high heat transfer coefficient, like hybrid composite materials in the material's revolution, the hybrid nanofluid was prepared and its performance was realized by experimentation. In this investigation, the prepared Al_2O_3 (75%)– CuO (25%) / Water hybrid nanofluid was used as a coolant for making pen barrel in injection molding machine. For experimentation, the three process parameters viz., Volume Fraction (VF), Volume Flow Rate (VFR) and Temperature (Temp) were controlled and optimized by using Taguchi's L9 orthogonal array to yield the maximum heat transfer coefficient. To optimize it, total nine different experiments were conducted by controlling these factors. The considered all three parameters were kept three levels. Regression equation was established to predict heat transfer coefficient by incorporating independently controllable process parameters. Based on the optimization result, it was found that the high heat transfer coefficient was achieved at 0.2 %, 6 LPM and 35 °C of VF, VFR and Temp of hybrid nanofluid respectively.*

***Keywords:** Al_2O_3- CuO, hybrid nanofluid, heat transfer coefficient, optimization*

I. INTRODUCTION

It is well known that the life span of any electronic or electrical system depends solely on how cooling circuit crafted in the system. The traditional fluids Like water, oil and ethylene glycol were initially used to extract the heat. Use of suspended nanoparticles in the fluid was invented on the demand for high rate of heat transfer. The further development in the nanofluid field showed the way to hybrid nanofluids, providing improved heat transfer results compared to the single nanofluids. Hybrid nanofluids are the nanofluids formed by a suspension of two or more different nanoparticles in a single base fluid or a mixture of more than one base fluid. Hybrid nanofluids are an extension of mono nanofluids.

Jahar Sarkar et al stated that the hybrid nanofluids are somewhat a new group of nanofluids, an intensive research is required before they are intended for industrial applications. Because of its synergistic effect, it finds many applications on heat transfer [1]. The heat transfer performance of low thermal conductivity of some traditional fluids such as water could be improved by adding some nano-particles like Al_2O_3, Cu and TiO_2. Ghasemi et. al [2] conducted a numerical study on the mixed convection within a triangular cavity filled with Al_2O_3-water nanofluid. It was found that the rate of heat transfer increases as the solid volume fraction increases in the nanofluid.

Sundar et al [3] studied separately the thermal conductivity of nanodiamont ND – Co_3O_4 with various base fluids like water and ethylene glycol (EG), and the researcher also studied the combination of EG – water base fluid in the 20:80, 40:60 and 60:40 mixture ratio. Suresh et al. [4] achieved an improvement of 12.11% in thermal conductivity at 2% volume concentration with base fluid for Al_2CO_3/Cu hybrid fluid. Megatif et al [5] done a research to examine the coefficient of heat transfer of TiO_2-CNT hybrid nanofluid using shell and tube heat exchanger, during the experiment the laminar flow condition was maintained. Hybrid nanofluid was finally confirmed to be suitable for more heat transfer. Madhesh et al [6] investigated the heat transfer behavior of copper-titania/water hybrid nanofluid flow through a tubular heat exchanger and noted that the total heat transfer coefficient increased to 30.4% at a concentration of 0.7%.

Esfe et al [7] optimized the nanodiamont (ND) – cobalt oxide (Co3O4)/water hybrid nanofluids by using the Design Expert application and NSGA-II process, and the researchers concluded that high thermal conductivity of hybrid nanofluids could be achieved at high temperatures. The Taguchi L25 orthogonal array was used by Javad et.al [8] to maximize the coefficient of heat transfer under various volume concentrations of nanofluid and wall angle. Several researchers conducted numerical analysis to evaluate the coefficient of heat transfer in various geometries such as rectangular enclosure, cylindrical enclosure etc. by using so many nanofluids such as alumina-water, titania-water, silica-water etc. The hybrid nanofluids are still in the stage of growth and study from an industrial perspective.

Hybrid nanofluids are capable of playing an excellent performance role in heat transfer. Guo et al [9] have reported very minimal research on hybrid nanofluids, and much experimental study is still underway.

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* Correspondence Author
K. Prashanth Reddy*, Research Scholar, Department of Mechanical Engineering, JNTUH, Hyderabad (Telangana) India.
E-mail: kpreddy26@gmail.com
Bhramara Panitapu, Professor, Department of Mechanical Engineering, JNTUCEH, Hyderabad (Telangana) India.
E-mail: bhramara74@jntuh.ac.in
Ramesh Chilukuri, PG, Department of Mechanical Engineering, GRIET, Hyderabad (Telangana) India. E-mail: chramesh0807@gmail.com
R. Karthikeyan, Professor, Department of Mechanical Engineering, GRIET, Hyderabad (Telangana) India. E-mail: drrkyen22@gmail.com
A. Kalyan Kumar, PG, Department of Mechanical Engineering, GRIET, Hyderabad (Telangana) India. E-mail: kalyankumaraddagatla@gmail.com

From the literature it was understood the heat transfer properties of nanofluids depends on many factors such as the size, quantity (volume fraction), shape, use or non-use of surfactant, pH value and temperature of nanofluids [10]. Hence in this investigation the heat transfer coefficient of Al_2O_3 – CuO / Water hybrid nanofluid was optimized, to assist in the reduction of cycle time for pen barrel manufacturing in the injection. Due to high efficiency, high stability, geometric product flexibility, good part execution, and so on injection molding technology has proven to be one of the most widely used processes for assembling plastic parts. Injection molding technology has been used in multiple sectors such as electronics, automotive, medical and items of daily use. Creating goods with various sizes and different structures at minimal cost is a conversant manufacturing process. The involved process is cyclic procedure. In an injection molding machine, the procedure contains four phases. These phases are clamping, injection, cooling and ejection.

II. MATERIALS AND METHODS

In this test, the water-based hybrid nanofluid was used as a coolant in the injection molding machine to manufacture pen barrels produced from 3.5 grams of Polypropylene Random Co-polymer grade. 75% of Al_2CO_3 (61.38 gms), 25% of CuO (20.46 gms) and 18 liters of water were used to prepare the 0.1% volume fraction of hybrid nanofluid. The corresponding nano particles needed for various volume fractions are shown in Table 1. Figure1 and Figure 2 shows the machine used and product produced in this investigation. Injection moulding machine (Make: DEMAG) specifications viz; capacity, injection pressure, velocity of injection and clamping force of mould are 100 tons, 198 bar, 90 mm/sec and 900 kN respectively.

Table 1 Weight of nanoparticles for various volume fractions

S. No	Volume Fraction (%)	Al_2O_3(75 %) (gms)	CuO (25%) (gms)	Total Weight of Nanoparticles (gms)
1	0.1	61.38	20.46	81.84
2	0.15	92.1	30.7	122.8
3	0.2	123	41	164

Fig. 1 Experimental Set-up

Fig. 2 Core inserts and sketch pen barrel

The measured values of thermal conductivity for various volume fractions at different temperature are shown in Table 2. The various factors which were controlled during experimentation and their levels are shown in Table 3. In total 9 numbers of various experiments were conducted by changing the Volume Fraction (VF), Volume Flow Rate (VFR) and Temperature (Temp) to calculate the convective heat transfer coefficient. The experimental parameter of volume flow rate was limited based on the design of cooling circuit provided in the machine. Similarly, the range of volume fraction and temperature of coolant were decided based on the cost of nanoparticles and the availability of coolant temperature.

Table. 2 Thermal conductivity values for various volume fractions at different temperature

S. No	Volume Fraction (%)	Thermal conductivity (W/m-K)		
		25°C	30°C	35°C
1	0.1	0.8451	0.8728	0.9002
2	0.15	0.9894	1.0125	1.1245
3	0.2	1.2736	1.3129	1.4287

Table. 3 Factors and their levels

Factors	Levels		
	1	2	3
VF (%)	0.1	0.15	0.2
VFR (LPM)	4	5	6
Temp (˚C)	25	30	35

III. TAGUCHI METHOD AND DESIGN OF EXPERIMENT

The Taguchi model offers a solution to so many optimization problems that require less experiments. Basically, this model is from the orthogonal set.

This approach uses the idea of the feature of loss, i.e. the ratio of signal to noise [12]. It is nothing but the deviation between experimental & expected values. According to this investigation's objective, HTC should be maximized. To achieve this Larger is better approach has been chosen and L9 orthogonal array was used. Table 4 shows the experiments to be conducted and the results of HTC along with S/N ratio for all experiments. The S/N ratio equation for larger is better is written below.

"Larger is the better" approach

$$\frac{S}{N} = -10\log[\frac{1}{n}(\sum_{i=0}^{n}\frac{1}{y_i^2})]$$

Table. 4 Design matrix and experimental results of heat Transfer coefficient

Expt. No	Coded Value			Actual Value			Heat transfer Coefficient	S/N Ratio
	Vol. Fraction	Vol. Flow Rate	Temperature	Vol. Fraction	Vol. Flow Rate	Temperature		
1	1	1	1	0.1	4	25	16517.4	84.3588
2	1	2	2	0.1	5	30	23983.9	87.5984
3	1	3	3	0.1	6	35	28805.1	89.1894
4	2	1	2	0.15	4	30	20772.5	86.3498
5	2	2	3	0.15	5	35	27814.9	88.8855
6	2	3	1	0.15	6	25	30368.8	89.6486
7	3	1	3	0.2	4	35	29329.6	89.3461
8	3	2	1	0.2	5	25	29201.6	89.3081
9	3	3	2	0.2	6	30	37863.6	91.5644

IV. RESULTS AND DISCUSSIONS

A. Analysis of S/N Ratio for HTC

Since the ultimate goal of this study was to achieve the highest heat transfer coefficient, the characteristics 'larger is better'
was chosen. In Table 5 and Table 6, the response table for S / N ratios and heat transfer coefficient means are shown respectively. Likewise, the graph of main effects for S / N ratios and heat transfer coefficient means is shown in Fig. 3 and Fig. 4 correspondingly.

Table. 5 Response Table for Signal to Noise Ratios of HTC (Larger is better)

Level	VF	VFR	TEMP
1	87.05	86.68	87.77
2	88.29	88.6	88.5
3	**90.07**	**90.13**	**89.14**
Delta	3.02	3.45	1.37
Rank	2	1	3

Table. 6 Response Table for means of HTC (Larger is better)

Level	VF	VFR	TEMP
1	23102	22207	25363
2	26319	27000	27540
3	32132	32346	28650
Delta	9029	10139	3287
Rank	2	1	3

According to Taguchi, the optimal response is determined by combining the highest S/N ratio [33] of each factor. Table 6 showed the highest S/N ratio of each factor for HTC as bold. The factors giving the optimum coefficient of heat transfer was specified as level 3 of VF (S / N = 90.07), level 3 of VFR (S / N = 90.13) and level 3 of Temp (S / N = 89.14). in other words, the maximum coefficient of heat transfer would be obtained with 0.20 % of VF, 6 LPM of VFR and 35 °C of Temp.

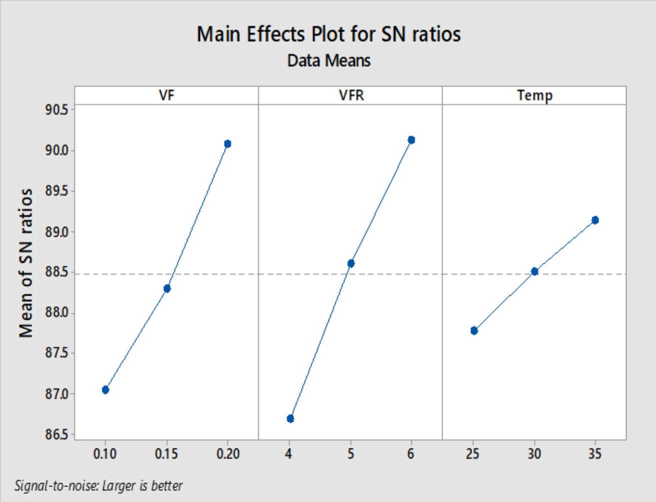

Fig. 3 Main effect plots for S/N ratio of heat transfer coefficient

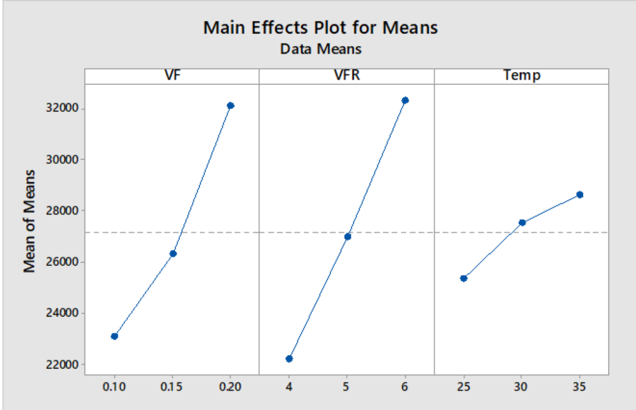

Fig. 4 Main effect plots for means of heat transfer coefficient

In the aspect of Taguchi [12], the blend of maximum S/N ratio of all process parameters decides the optimum response. The maximum S/N ratio of each parameter has been made bold in Table 6. The maximum heat transfer coefficient would be attained with 0.2 % of VF, 6 LPM of VFR and 35 °C of Temp.

B. Analysis of Variance (ANOVA) for HTC

Analysis of variance is significant statistical tool and it was used in this study to figure out the contribution of specified input process factors viz. VF, VFR and Temp on HTC. Table 7 shows the ANOVA results for HTC. The confidence level of 95% was maintained to analyses the data. ANOVA provides the required statistics in the condensed form after the detailed analysis.

Table 7 ANOVA test results for heat transfer coefficient

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution in %
Regression	3	292714575	97571525	58.73	0	97.24
VF	1	122295999	122295999	73.62	0	40.63
VFR	1	154209425	154209425	92.83	0	51.23
Temp	1	16209150	16209150	9.76	0.026	5.38
Error	5	8306148	1661230			2.76
Total	8	301020722				

The value of F ratio determines the factor influence on the response. The utmost F value contributes more on the response. As per 95 % confidence level or 5 % significance level, if the p-value of the term is a smaller than 0.05, the terms are considered significant. In this investigation, VF & VFR are found significant and Temp is fairly close to significant level.

The percentage contributions on HTC of VF 40.63%, VFR 51.23% and Temp 5.38% were found. The most prevalent controlling factor was found to be the VFR (51.23%) followed by VF and Temp. The HTC error percentage (2.76%) is significantly low.

C. PREDICTION OF HTC

The relationships between the dependent variable HTC and many independent variables viz. VF, VFR and Temp was formulated by using multiple linear regression analysis.

The empirical equation is

$$HTC = -21570 + 90294\,(VF) + 5070\,(VFR) + 329\,(Temp)$$

and the test statistics were adequate. The attained R^2, adjusted R^2 and predicted R^2 of HTC are 97.24%, 95.59% and 91.08% respectively. The empirical model gained a high coefficient of determination (R2 = 0.9724) and indicated almost 97% of the variance in the HTC response, noting the accuracy of the model fit.

D. CONFIRMATION TEST

A confirmation test was done to verify the experiment and it is illustrated in Table 8.

The experimentation was done at optimal situation and is correlated with the last condition that recorded the highest HTC. The optimum values of the VF, VFR and Temp parameters for HTC are 0.20%, 6 LPM and 35 °C. This condition yielded the HTC is 38696.6 by experiment and is observed by a higher S / N ratio (91.7535) relative to the last condition's S / N ratio (91.5644).

Table. 8 Confirmation test results of HTC

Conditions		**VF = 0.2%, VFR=6 LPM, Temp = 30 °C (Last)**	**VF = 0.2%, VFR= 6 LPM, Temp = 35 °C (Optimal)**
Experimental	Value	37863.6	38696.6
	S/N Ratio	91.5644	91.7535
Predicted	Taguchi	37649.33	38759.33
	Regression	36778.8	38423.8
Max % of Error		-2.95	-0.71

V. CONCLUSIONS

In this work, we have taken three process parameters viz., Volume Flow Rate (VFR), Volume Fraction (VF) and Temperature (Temp). These parameters were controlled and optimized by using Taguchi's L9 orthogonal array to yield the maximum heat transfer coefficient. Also, Regression equation was established to predict HTC by incorporating independently controllable process parameters. The following statements were made based on the results of this examination.

- Under operating conditions of 0.2% of VF, 6 LPM of VFR and 35 °C of Temp, maximum heat transfer coefficient of 38696.6 could be achieved.
- Of the three system variables studied, the VFR (51.23%) were found to have a bigger effect on HTC, led by VF (40.63%) and Temp (5.38%) when optimized.
- Regression equation was constructed by integrating system variables to predict the coefficient of heat transfer at a confidence level of 95%.
- After the validation examinations, the peak percentage of the experimental and predicted regression error was only 2.95% and it demonstrated high predictive potential of the relationships formed.

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AUTHORS PROFILE

K. Prashanth Reddy, Pursuing Ph.D. (Mechanical Engineering) in JNTUCEH-Hyderabad, He has done his PG M.Tech (Thermal Engineering) in JNTU-Hyderabad. He is a life member of ISHMT. He is currently working as as R&D Manager in Vasantha tool crafts private limited. He has 18 years of experience in teaching UG & PG students of Mechanical Engg.

Bhramara Panitapu, Professor in Mechanical Department of JNTU-Hyderabad has received her Ph.D. (Mechanical Engineering) from JNTU, she is a life member of ISTE and ISHMT. She has published more than 70 research articles in national and international journals of repute. Her research interests include two phase flows and heat transfer enhancement, computational fluid dynamics.

Ramesh Chilukuri, M. Tech (Thermal Engineering) from GRIET-Hyderabad, B.Tech, (Mechanical Engineering) from REC, Nalgonda. Qualified Gate twice, His areas of interest are heat transfer applications, thermodynamics and fluid dynamics.

R. Karthikeyan, Professor of GRIET has received his Ph.D. (Manufacturing Engineering) from Annamalai University. He has published 25 research articles in national and international level on various aspects of friction stir spot welding of age-hardenable aluminum alloys and optimization of machining. He is a life member of The Institution of Engineers (India), the Indian Welding Society and ISTE.

A. Kalyan Kumar, M.Tech (Thermal Engineering) from GRIET-Hyderabad, B.Tech, (Mechanical Engineering) from SREC-Warangal, Qualified Gate-2017, His areas of interest are heat transfer, thermodynamics, strength of materials.