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Film Coefficient Optimization for Al_2O_3 (50%) – CuO (50%)/ Water Hybrid Nanofluid using Taguchi Technique

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Abstract: ***To have the maximum benefits of nanofluid for high film 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 (50%) – CuO (50 %)/water hybrid nanofluid was used as a coolant for making pen barrel in injection moulding 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 film coefficient. To optimize it, total nine different experiments were conducted by controlling these factors. All these three parameters were considered in three levels. Regression equation was established to predict film coefficient by incorporating independently controllable process parameters. Based on the optimization result, it was found that the high film 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, film coefficient, optimization***

I. INTRODUCTION

It is well known that the life span of any electronic or electrical system purely depends on, how the system was designed with cooling circuit. To remove the heat, initially the conventional fluid such as water, ethylene glycol & oil was started using. On the demand of high film rate, using suspended nanoparticles in the fluid was invented. By using nanofluids in thermal management systems will not only bring an enhanced heat transfer rate but also moderates the dimensional size and weight of the equipment. There is a need to improve the heat transfer and other thermophysical properties, to do this some modifications are needed to the conventional fluids. Many researchers have conducted experiments on different nanofluids and concluded that they give more enhanced heat transfer rates than traditional fluids. The further innovation in the zone of nanofluids shown the way to the hybrid nanofluids and it offered enhanced results in film compared to single nanofluids. A single material may not have the all required properties. So, a combination of two or more different nanoparticle materials was used for making nanofluids are called Hybrid nanofluids. Hybrid nanofluids are an extension of mono nanofluids.

Jahar Sarkar et al [1] stated that the hybrid nanofluids are somewhat new nanofluid group, an intensive research is required before they are intended for industrial applications. Because of its synergistic effect, it finds many applications on film. Many typical liquids, such as water, have poor thermal conductivity so it could be improved by adding some nano-particles like Al_2O_3, Cu and TiO_2. Ghasemi et.al [2] performed an Al_2O_3-water nanofluid-filled triangular cavity mixed convection test. It was identified that the film rate increases as the fraction of nanoparticles in the nanofluid increases. Sundar et al [3] analyzed the nanodiamont ND –Co_3O_4 thermal conductivity with different base fluids like water and ethylene glycol (EG) distinctly. The researcher also researched the combination of EG – liquid base fluid in the mixture ratio of 20:80, 40:60 and 60:40. Suresh et al [4] reported a 12.11% improvement in thermal conductivity at 2% volume portion with Al2O3/Cu hybrid fluid base liquid. Megatif et al [5] done extensive investigation to explore TiO2-CNT hybrid nanofluid convective film coefficient via shell and tube heat exchanger; during the experimentation the laminar flow condition was maintained. Finally, it was reported hybrid nanofluid was suitable for more film. Madhesh et al [6] worked on copper-titania / water hybrid nanofluid run complete a tubular heat exchanger to assess film behaviour and discovered that the overall film coefficient amplified to 30.4% at 0.7% hybrid nanofluid fraction. Esfe et al [7] optimized nanodiamond (ND) – cobalt oxide (Co3O4)/water using the Design Expert software and NSGA-II technique, and authors finally acknowledged that hybrid nanofluids with larger thermal conductivity can be achieved at raised up temperatures. Javad et.al [8] optimized film coefficient using Taguchi L25 orthogonal array under various volume fractions of nanofluid and wall angles. Many researchers carried out numerical analysis to find out the film coefficient for several nanofluids including alumina water, Titania water, silica-water etc. in different geometries like rectangular enclosure, cylindrical enclosure and etc.

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From an industrial perspective, the hybrid nanofluids are still in the growth and development stage. These are capable to perform the role in film with excellent performance [9]. Guo et al [10] also said work on hybrid nanofluids is quite minimal and there's still a huge amount of experimental study going on. Application concerned researches on hybrid nanofluids are very limited. 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 filling, pressing, cooling and ejection.

From the literature it was comprehended the film properties of nanofluids relies upon several aspects like the size, quantity (volume fraction), shape, use or non-use of surfactant, pH value and temperature of nanofluids [11]. Hence in this investigation the film 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.

II. MATERIALS AND METHODS

In this experiment to produce Polypropylene homo polymer grade-based pen barrels weighing about 3.5 grams, the water-based hybrid nanofluid was utilized as a coolant in injection moulding machine. To prepare the 0.1 % VF of hybrid nanofluid, 50% of Al_2O_3(46.5 gms), 50% CuO (46.5 gms) and 18 liters of water was used. Similarly, 0.15% and 0.2% volume fraction of hybrid nanofluid were prepared. The corresponding nanoparticle weights required for 0.1%, 0.15% and 0.2% VF can be seen in Table 1. The injection moulding machine which was used in this investigation is shown in Fig.1. The specifications of the Injection moulding machine (Make: DEMAG) viz; capacity, injection pressure, injection speed, and mould clamping force 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(50%) (gms)	CuO (50%) (gms)	Total Weight of Nanoparticles (gms)
1	0.1	46.58	46.58	93
2	0.15	69.4	69.4	138.8
3	0.2	92.6	92.6	185.2

Fig. 1 Experimental Set-up

Fig. 2 Core inserts and sketch pen barrel

The measured values of thermal conductivity and specific heat capacity for various VF at different temperature can be seen 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 film 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	0.8675	0.8901	0.9094
2	0.15	1.0493	1.0801	1.0918
3	0.2	1.3378	1.3514	1.3801

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

Table. 4 Design matrix and experimental results of film Coefficient

Expt. No	Coded Value			Actual Value			film Coefficient	S/N Ratio
	Vol. Fraction	Vol. Flow Rate	Temperature	Vol. Fraction	Vol. Flow Rate	Temperature		
1	1	1	1	0.1	4	25	18158.3	85.1815
2	1	2	2	0.1	5	30	26247.2	88.3816
3	1	3	3	0.1	6	35	32834.1	90.3265
4	2	1	2	0.15	4	30	24811.2	87.8929
5	2	2	3	0.15	5	35	30744.6	89.7554
6	2	3	1	0.15	6	25	31407.3	89.9406
7	3	1	3	0.2	4	35	32339.4	90.1946
8	3	2	1	0.2	5	25	30495.9	89.6848
9	3	3	2	0.2	6	30	42459.0	92.5594

III. TAGUCHI METHOD AND DESIGN OF EXPERIMENT

The Taguchi design gives solution to most of the optimization problems where the number of experiments is required less. Basically this design is from orthogonal array. This technique uses the concept of signal to noise ratio from loss function. It is nothing but the deviation between experimental & expected values. According to this investigation's objective, the film coefficient 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 film coefficient 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

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

IV. RESULTS AND DISCUSSIONS

A. Analysis of S/N Ratio for film coefficient

As the aim of this investigation was to accomplish the maximum film coefficient "larger is better" approach was selected. In Table 5 and Table 6, respectively, the response table for S / N ratios and film coefficient means are displayed. Moreover, the main effects plot for means of film coefficient and S/N ratios are displayed Fig. 3 and Fig. 4 respectively.

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

Level	VF	VFR	TEMP
1	87.96	87.76	88.27
2	89.20	89.27	89.61
3	**90.81**	**90.94**	**90.09**
Delta	2.85	3.19	1.82
Rank	2	1	3

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

Level	VF	VFR	TEMP
1	25747	25103	26687
2	28988	29163	31172
3	**35098**	**35567**	**31973**
Delta	9352	10464	5286
Rank	2	1	3

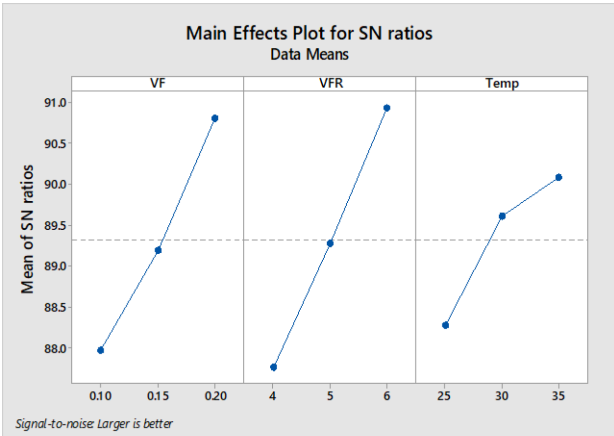

Fig. 3 Main effect plots for S/N ratio of film coefficient

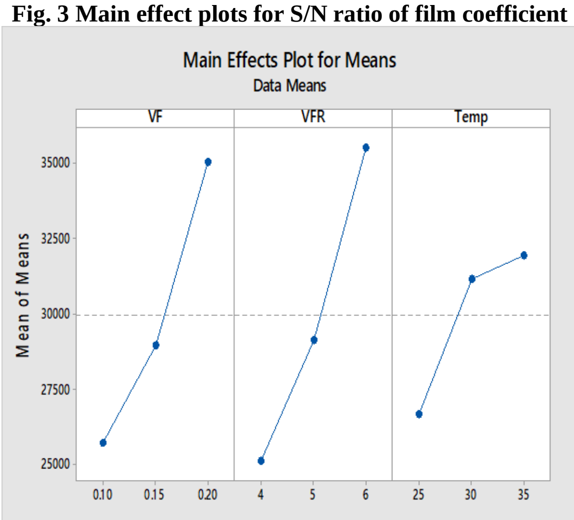

Fig. 4 Main effect plots for means of film coefficient

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 film coefficient would be attained with 0.2 % of VF, 6 LPM of VFR and 35 °C of Temp.

B. Analysis of Variance (ANOVA) for film coefficient

Analysis of variance is an important statistical tool and it was used in this investigation to determine the contribution of specified input process factors viz. VF, VFR and Temp on film coefficient. Table 7 shows the ANOVA results for film coefficient. The confidence level of 95% was maintained to analyze the data. ANOVA provides the required statistics in the condensed form after the detailed analysis. 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 amount 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 of the VF 37.19 %, VFR 46.56 % and Temp 11.88 % on film coefficient was found. The VFR (46.56 %) was seen to be the largest controlling factor among all the process parameters.

Table. 7 ANOVA test results for film coefficient

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution in %
Regression	3	337322302	112440767	36.52	0.001	95.63
VF	1	131177886	131177886	42.6	0.001	37.19
VFR	1	164239386	164239386	53.34	0.001	46.56
Temp	1	41905030	41905030	13.61	0.014	11.88
Error	5	15396408	3079282			4.37
Total	8	352718709				

The order of most influential to least influential is VFR, VF and Temp. The error percentage among the experimental & predicted is 4.37% which is considerably low.

C. Prediction of film coefficient

The relationships between the dependent factor film coefficient and several independent factors viz. VF, VFR and Temp was determined and the equation (regression) is shown below;

$$\textit{Film Coefficient} = -26100 + 93516\ (VF) + 5232\ (VFR) + 529\ (Temp) \quad (2)$$

and the test statistics were adequate. The attained R^2, adjusted R^2 and predicted R^2 of film coefficient are 95.63 %, 93.02 % and 86.75 % respectively. The model could not clarify utmost 4% of the variability in film coefficient, which shows the righteousness of fit for the model.

D. Confirmation Test

After the finding the optimized value for high film coefficient, the experiment was done by setting the optimized values of process parameters and the result is shown in Table.8. The result of optimum condition was compared with last experiment which is shown in Table 4 since it had yielded the highest film coefficient. The optimized values of the factors VF, VFR & Temp are 0.20%, 6 LPM and 35 °C for film coefficient. This condition yielded 43176.3 of film coefficient by investigation and it is confirmed by greater S/N ratio (92.7049) contrasted to S/N ratio (92.5594) of last condition.

Table. 8 Confirmation test results of film coefficient

Conditions		VF = 0.2% ,VFR=6 LPM, Temp = 30 °C (Last)	VF = 0.2% ,VFR= 6 LPM, Temp = 35 °C (Optimal)
Experimental	Value	42459.0	43176.3
	S/N Ratio	92.5594	92.7049
Predicted	Taguchi	41948.56	42749.56
	Regression	39865.2	42510.2
Max % of Error		-6.51	-1.57

V. CONCLUSIONS

In this work, we have taken three process parameters viz., Volume Fraction (VF), Volume Flow Rate (VFR) and Temperature (Temp). These parameters were controlled and optimized by using Taguchi's L9 orthogonal array to yield the maximum film coefficient. Also Regression equation was established to predict film coefficient by incorporating independently controllable process parameters. The final statements have been drawn on the basis of the outcomes of this investigation are given below

i) Under running states of 0.2% of VF, 6 LPM of VFR & 35°C of Temp, a highest possible film coefficient of 43176.3 can be achieved.

ii) Of the three system variables studied, it had been identified that the VFR (46.56 percent) had higher impact on the film coefficient and that VF (37.19 percent) and Temp (11.88 percent) accompanied when optimized.
iii) The Regression equation was generated by integrating system variables to forecast the film coefficient at a confidence level of 95 percent.
iv) After validation tests, the most extreme percentage of regression error among experimental & predicted value is only 6.51%, indicating the reasonably high predictive potential of the connections established.

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