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EXPERIMENTAL INVESTIGATION ON THERMAL CONDUCTIVITY OF SnO_2 NANOFLUID USING STATISTICAL ANALYSIS

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Abstract- Metallic fluids like CuO, Al_2O_3, ZnO, SiO_2 and TiO_2 nanofluids are used for the development of coolant fluids in nuclear reactors, heat exchangers and flat plate heat pipes. So we initiate our idea to synthesize novel SnO_2 nanofluid (Tin oxide nanofluid). SnO_2 nanopowders will be synthesized by simple chemical reduction method using tin tetra chloride as a precursor and diethylene glycol as a solvent. Solid state characterizations of synthesized nanopowders will be carried out by Ultraviolet spectroscopy (UV), Fourier transform infrared spectroscopy (FTIR), Scanning electron microscopy and X-Ray diffraction (XRD) techniques. Synthesized SnO_2 will be mixed together by adding water and as well as water/ethylene glycol to form a nanofluid. Thermal conductivity measurements of prepared nanofluids will be measured using transient hot wire apparatus. Response surface methodology based on the Box-Behnken design will be implemented to investigate the influence of temperature (30-60 °C), particle fraction (1.5-4.5 vol %), and solution pH (4-12) of nanofluids as the independent variables. A total of 17 experiments will be accomplished for target output. All the influential factors, their mutual effects and their quadratic terms will be statistically validated by analysis of variance (ANOVA). The optimum thermal conductivity of SnO_2 nanofluids with various temperature, volume fraction and particle fraction will be investigated and compared with experimental results.

Keywords – Tin oxide. Nanofluid, Box Behnken, Thermal conductivity, Analysis of Variance

I. Introduction

It has been acknowledged that the fluid suspensions of solid particles provide plenty of advantages in heat transfer fluids, magnetic fluids, and lubricant fluids (Hrishikesh et al 2003). Nanofluids, i.e. fluid suspensions of nanometer-sized solid particles and fibers, have been proposed as a route for surpassing the performance of common heat transfer liquids (Keblinski et al 2005). Nanofluids can be considered to be the upcoming medium of heat transfer fluids as they offer new exciting possibilities for enhancement of heat transfer performance compared to non-organic liquids. Superior thermal transport properties are expected for nanofluids compared to conventional heat transfer fluids, as well as fluids containing micro-sized metallic particles. The much larger relative surface area of nanoparticles, compared to those of micro-scale particles, not only significantly improves heat transfer capabilities, but also increases the stability of the nanofluid suspensions. Also, nanofluids can improve abrasion-related properties as compared to the conventional solid/fluid mixtures [Hwang et al., 2007, Hwang et al., 2008, Lee et al., 1999]. In general, there are three principles for dispersing fine particles in water: (i) the repulsions between the particles arisen by their zeta potentials, (ii) the steric hindrance of the adsorption layer, and (iii) the reduction of hydrophobic linkages among dispersed particles [Jiang et al 2003]. Agglomeration is a major problem in the synthesis of nanofluids. Generally, there are two common synthesis techniques for the preparation of nanofluids: the single-step (Zhu et al., 2004) and the two-step method (Wang et al., 1999). The two-step technique shows better results for oxide nanoparticles than the single step method, while it is lesser successful for metallic particles. Since the two step method strongly depends upon the method of synthesis of nanoparticles, we utilize the SnO2 nanoparticles synthesized by a novel technique named chloride solution combustion synthesis. The combustion method of synthesis, i.e. CSCS, is a simple and single-step method for preparation of tin oxide nanoparticles. Solution combustion synthesis method relies upon a self-sustained combustion reaction of a fuel and an oxidizer (Mukasyan et al., 2007). Microwave assisted method has been used for fast and homogeneous heating of the combustion synthesis solutions (Srider 1998). Nanofluids are considered as promising alternatives for the conventional heat transfer fluids. Long-term stability is a crucial characteristic of nanofluids; colloidal stability of the nanofluids plays a crucial role in it. In this work, SnO_2 nanofluids are prepared by dispersion of tin dioxide nanoparticles in water/Ethylene glycol as the basefluid. The ultrasonication technique is employed to disperse the nanoparticles properly and form nanofluids with high stabilities.

II. Synthesis of Nanofluid

Precursor solution was prepared by adding 0.5 M of Tin tetrachloride in the 25 ml of de-ionized water. The precursor solution was vigorously stirred using magnetic

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stirrer. Reducing agent solution was prepared by adding 1 M of sodium hydroxide in the 10 ml of de-ionized water.Add the prepared precursor solution and reducing agent solution for continuous agitation inside the magnetic stirrer at 60ºC for 30 minutes. Then the solution was transferred into a Teflon-lined stainless steel autoclave with a capacity of 200 ml and then sealed. The autoclave was maintained at 100°C for 12 h and cooled naturally to room temperature. The product was centrifuged, filtered out, and rinsed with methanol and distilled water several times, and then dried at 120°C for 1 h in air. Then, hydrolysis will be started by adding certain amount of deionized water in to the mixture. SnO_2 nanocomposites will be obtained by filtering and drying in a vacuum furnace at 120 °C for maximum of 24 hours. Finally, SnO_2 nanocomposites powder will be heated inside the crucible at a heating rate 1 °C/min upto attaining temperature of 450°C inside a furnace.Prepared SnO_2 nanocomposites will be dispersed in a 70:30 (in volume fraction) water and ethylene glycol to make it as a SnO_2 nanofluid after complete stirring. From UV absoption spectra, it is evident that SnO_2 nanoparticles are present in the 296 nm.

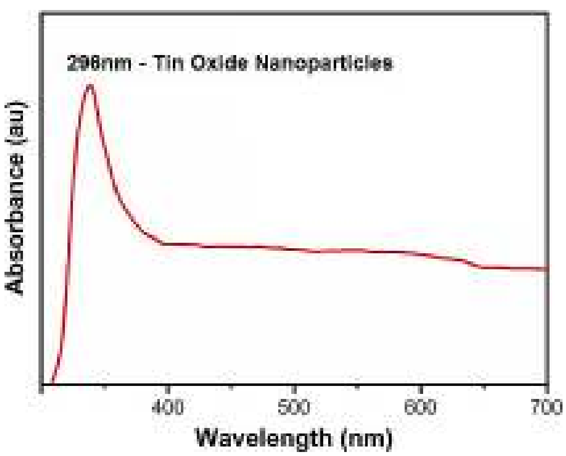

Figure 1. UV spectra

III. Statistical Analysis

RSM modeling combining with three-level BBD design were used in this experiment to validate its statistical analysis. Box Behnken Design is a self-determining quadratic design which needs fewer combinations of the variables to estimate a potentially complex response function than a full factorial design. In this analysis, BBD with three independent variables (x1: Temperature, x2: Particle fraction (% Vol), x3: Solution pH) at three-levels was performed.

$$X_i = (X_i - X_0)/\Delta X$$

Table 1. Coded and Actual Variables using BoxBehnken Design

.

Independent variables	Symbol	Coded and actual variable level		
		Low	Center	High
		-1	0	1
Temperature (ºC)	X_1	30	45	60
Particle Fraction (% Vol)	X_2	1.5	3	4.5
Solution pH	X_3	4	8	12

where Xi is a coded value of the variable, xi is the actual value of the variable, and X0 is the actual value of the ith test variable at the center point. The range and levels of individual variables are presented in Table 1. The whole experiment design consisting of 17 experimental runs is shown in Table 2. In the first step of RSM, a proper approximation is implemented to find the relationship between the dependent variable and the set of independent variables.

Table 2. Experimental data

Std	Run	A	B	C	Thermal Conductivity (SnO_2 with EG/Water)	
					Experimental	Predicted
1	3	45	1.5	12	0.7921	0.7920
2	7	45	3	8	0.7914	0.7914
3	16	30	4.5	8	0.7924	0.7925
4	18	45	4.5	12	0.7931	0.7930
5	9	60	3	12	0.7920	0.7921
6	14	60	3	4	0.7897	0.7897
7	5	30	3	12	0.7899	0.7897
8	15	30	1.5	8	0.7859	0.7859
9	11	45	1.5	4	0.7909	0.7910
10	19	60	1.5	8	0.7928	0.7928
11	20	45	3	8	0.7915	0.7916
12	10	60	4.5	8	0.7949	0.7948
13	17	45	3	8	0.7915	0.7915
14	12	45	3	8	0.7914	0.7914
15	6	45	3	8	0.7915	0.7915
16	8	30	3	4	0.7855	0.7956
17	2	45	4.5	4	0.7918	0.7919

IV. Anova for thermal conductivity

The ANOVA values for the RSM model obtained from Box Behnken was quadratic regression model which is used in the optimization of stability and thermal conductivity. ANOVA for Thermal Conductivity ratio response for SnO_2 with Water/EG was shown in table 3

SOURCE	Sum of Squares	df	Mean of Squares	F Value	P value prob>F	
Model	7.807E-005	9	8.675E-006	6.44	0.0100	significant
A-Temperature	3.076E-005	1	7.807E-005	23.13	0.0014	
B-Particle Fraction	1.347E-005	1	3.076E-005	10.12	0.0148	
C- Solution pH	1.030E-005	1	1.347E-005	7.74	0.0264	
AB	4.835E-006	1	1.030E-005	3.59	0.0975	
AC	1.097E-006	1	4.835E-006	0.78	0.3923	
BC	0.000	1	1.097E-006	0.000	1.0000	
A^2	7.304E-006	1	0.000	5.45	0.0510	
B^2	7.755E-006	1	7.304E-006	5.79	0.0459	
C^2	3.165E-006	1	7.755E-006	2.33	0.1660	
Residual	9.300E-006	7	1.324E-006			
Lack of Fit	9.288E-006	3	3.093E-006	1027.50	< 0.0001	significant
Pure Error	1.195E-008	4	2.995E-009			
Cor Total	8.737E-005	16				

Table 3. ANOVA for thermal conductivity of SnO_2 nanofluid

The Model F-value of 6.44 implies the model is significant. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, B2 are significant model terms. The "Lack of Fit F-value" of 1027.50 implies the Lack of Fit is significant.

V. Effect of Selected Factors on the Thermal Conductivity Ratio in Binary mixture

Well-dispersed metallic Nanofluids at low volume fractions in liquids always enhance the thermal conductivity over the base-fluid values. The thermal conductivity enhancement of nanofluids depends on several mechanisms such as aggregation, Brownian motion, clustering of the nanoparticles and liquid layering around the nanoparticles. Avoiding clustering effect by increasing temperature enhance the thermal conductivity. Several significant factors such as temperature, particle volume fraction, pH of the nanofluid affects the thermal conductivity phenomena. 3D Response graph and contour line map of the models for the thermal conductivity ratio of SnO_2 nanofluid with binary mixture (EG/Water) are presented in Figures 2-4. Figure 3 demonstrates the variations in the thermal conductivity ratio in terms of the temperature and particle concentration variables while the solution pH was kept constant. By the response graph it is evident that increasing temperature consistently increases the thermal conductivity. This enhancement in thermal conductivity occurred due to Brownian movement increases with the increase of the nanofluid's bulk temperature. Therefore, these nano particles have an ability to transfer more energy from one place to another per time unit. Increase of particle volume fraction also increases the thermal conductivity ratio but it is limited to certain values to become nominal. Increasing particle volume fraction increases agglomeration. Hence to improve dispersion and reduce vanderwalls force, dispersing agents such as SDS were used. It was also evident that change in thermal conductivity with temperature and particle volume fraction was purely dependent on the pH value. The pH value strongly affects the electrostatic charge of the particle surface. Increasing pH increases thermal conductivity upto isoelectric point.

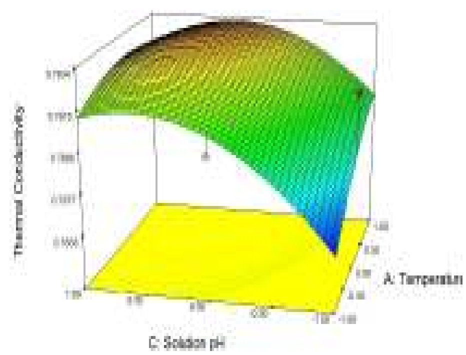

Figure 2. Solution pH vs temperature

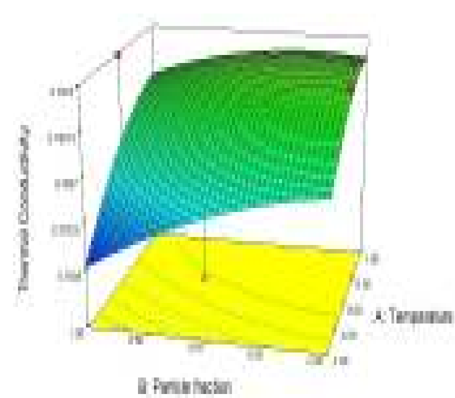

Figure 3. Temperature vs Particle fraction

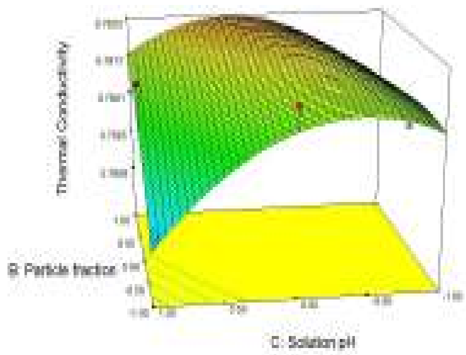

Figure 4. Particle fraction vs solution pH

VI. Conclusion

An experimental investigation was successfully carried out to analyze the thermal conductivity enhancement of SnO_2 nanofluid prepared with water and ethylene glycol/water. The thermal conductivity enhancement value (%) of Ethylene Glycol/water medium was greater than the water medium. In overall, it was also clear that all nanofluids were showing more thermal conductivity enhancement over their literature based on base fluids. These experimental results are compared with the statistical design analysis by Box behnken Method. Using ANOVA technique, Response surface methodology plots are plotted to analyze the optimum values of various parameters like temperature, particle fraction and solution pH. It is conclusive that temperature and particle concentration significantly affects the thermal conductivity than the solution pH.

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