Preparation of MCM-41 nanofluid and an investigation of Brownian movement of the nanoparticles on the nanofluid conductivity

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Abstract
In this investigation the silicate nano structure of MCM-41 has been used for the production of nanofluid. The particles have negligible heat conductivity and therefore by their dispersion in a base fluid like water, it is possible to study the increase of heat conductivity due to the Brownian motion effects. In this work a suitable apparatus for the measurement of heat conductivity has been built and calibrated and then using the apparatus and preparing suitable nanofluids, the conductivity and the volumetric heat capacities have been measured. Experimental results show that the preparation time of the nanofluid using the ultrasonic method has pronounced effect on the increase of the conductivity. A twenty four hours preparation time for the nanofluid containing 2.5% (vol) of the particles results in a 7% increase in the conductivity of the base fluid while showing no significant increase in the volumetric heat capacity. Investigating the effect of increasing the temperature and volumetric percentage of the particles it can be deduced that Brownian nano particles movement is one of the main factors in increasing the thermal nanofluids conductivity.
Keywords: *Nanofluid, Nano particles, Effective thermal conductivity, Specific heat capacity.*

1. INTRODUCTION

Nanofluids are engineered by suspending nano-sized particles into base fluids. The main and fundamental difference between a nanofluid and the conventional suspensions is due to the very small sizes of the particles dispersed in the fluid. Quantum effects in nanofluids allow the experimenter to change many physical features of materials without changing their bulk chemistry.

As metals and their oxides have always higher thermal conductivity than fluids, the idea of dispersion of such solid particles in a fluid to increase the fluid conductivity has been proposed. Choi [1] in 1995 was the first person to use the phrase "nanofluid" for suspensions of nano particles in base liquids and claimed that such fluids are different from the usual suspensions with regard to their preparation, stability and property behavior. Nanofluids not only increase the heat transfer properties of the fluid but also increase the suspensions stability and provide the lack of sedimentation and blockage of flow channels. Also due to the low kinetic energy imparted by nanoparticles when impacting on a surface cause much less friction and erosion and hence results in practically no damage to pumps and flow channels. Many nanoparticles have been proposed to produce nanofluids, some of which are aluminum oxide, copper, iron, gold, silver, silica and carbon nano tubes which apart from silica they all have high thermal conductivities. Base fluid was used to produce nanofluids are distilled and de ionized water, engine oil, acetone and ethylene glycol.

2. THERMAL AND RHEOLOGICAL PROPERTIES OF NANOFLUIDS

Thermal conductivity is the main parameter to indicate the increasing of thermal potentials in a fluid. Therefore determination of nanofluid conductivity has great importance and many investigations are carried out on this. Choi and Lei [2] used four nanofluids in their investigation. They used the hot wire technique to determine the thermal conductivity of alumina and copper oxide nanoparticles in water and ethylene glycol. The nanofluids were stable for a few days despite the fact that no surfactants had been used. This investigation showed that addition of small amount of nanoparticle has big effect on the conductivity of the base fluid and this increase is at its most for the copper oxide / ethylene glycol combination [2].

The results of the work by Wang and Lei [3] using 1% of carbon nanotubes resulted in 12.4% increase in the thermal conductivity of the base fluid. The variation of the effective thermal conductivity was linear with the volumetric percentage of the particles. By using copper oxide particles thermal conductivity increases were less and this was attributed to the higher thermal properties and the shape of carbon nanotubes.

Young [4] used nanofluids containing titanium and suitable stabilizing surfactants and noted 33% increase in the thermal conductivity of the base fluid when containing 5 volume percent of particles in the fluid. Amount of surfactant that was used was only 0.01% of the amount of particles which have no effect on the thermo- physical properties of the suspension:

Limited theoretical and experimental study has also been carried out in the fields of convection heat transfer [5,6] and boiling heat transfer [7-9] of nanofluids.

3. EXPERIMENTAL METHODS FOR MEASUREMENT OF NANOFLUIDS THERMAL CONDUCTIVITY

The measurement of fluids thermal conductivity is carried out in two steady and transient techniques for both of which the measurement fundamentals are the same and only the governing equations are different. The main advantage of unsteady methods is the fast measurement and hence prevention of free convection in the system. In the hot wire method [10] , a constant electrical current is passed in a thin wire which acts both as the heater and also a resistance thermometer sensor for determination of the temperature. The hot wire is one arm of a Wheatsone bridge.

In the steady state methods a thin layer of the fluid with unknown thermal conductivity is exposed to a constant heat flux. The layer has a very small dimension in comparison to the other dimensions so that one dimensional Fourier equation can be used for the system and thermal conductivity can be calculated and determined by measuring the temperature on both sides of the layer. Many thin layer experimental systems have been developed for determination of thermal conductivity [11 - 13] .

4. EXPERIMENTAL SET UP

Concentric cylinders method is probably the best steady state technique for determination of thermal conductivity. The apparatus have been built for this research based on this technique included two concentric aluminum cylinders with radial 23.5 and 25.5 mm and lengths 200 and 210 mm respectively. The 2 mm gap between the two cylinders is filled by a liquid with unknown thermal conductivity to be measured. Both ends of the system are well insulated insuring no heat loss from these places. An electrical heater is inserted in the middle of the inner cylinder fitting well in the hole drilled for this purpose. The length of the heater is 200 mm and its radius is 8.5 mm. On both sides of the fluid layer temperature sensors with accuracy of 0.1 °C have been positioned. All temperature readings (8 sensors in total) are recorded simultaneously on a computer. All the temperature sensors have been calibrated using the method BSEN60751-1996 which is in fact based on ITS-90 international standards.

Using this system it is possible to write the governing equations for the steady state situation and find

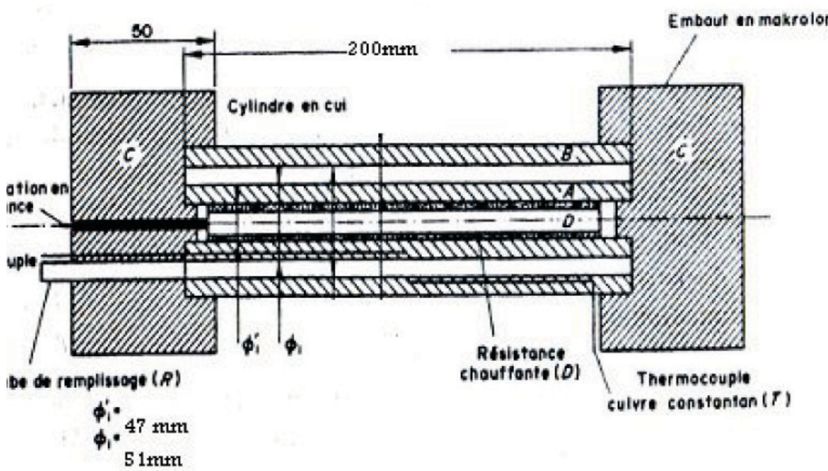

Figure 1: Experimental apparatus for measurement of thermal conductivity and volumetric heat capacity.

the thermal conductivity of the fluid according to equation 1.

$$k_m = \overset{*}{Q}\frac{Ln(R_2 / R_1)}{2l\pi(T_1 - T_2)} \tag{1}$$

In this equation K_m is the fluid thermal conductivity (W /m.º k) , Q• is the heat flux (W/m) , R_1 and R_2 are the radial on either side of the fluid layer , T_1 and T_2 are the temperatures (°K) at these locations. Also in this study the conductivity of the industrial aluminum rods from which the cylinders and cores of the equipment had been constructed were measured accurately to be 75 W/m°K .

With this set up and accurate knowledge of the conductivity of aluminum cylinder there is no need to calculate the real heat flux and by the following simple equation the conductivity of the nanofluid can be determined.

$$q = k_1\beta_1(T_1 - T_2) = k_2\beta_2(T'_1 - T'_2) \tag{2}$$

In this equation K_1 and K_2 are the nanofluid and the aluminum cylinder conductivities , β_1 and β_2 are the equipment shape factors and the T's are the temperatures of either sides of the film and the cylinder. For determination of heat capacity and density of the products i.e. the volumetric heat capacity, the unsteady state governing equation is solved [11] with the proper initial values to result in the following equation :

$$\theta(r,t) = BV(\alpha.r).\exp(-k\alpha^2 t / \rho c_p) \tag{3}$$

Where

$$B = \frac{\rho' c'_p \int_{R'_1}^{R_1} \overline{\theta}(r,0).\overline{V}(\alpha'.r).r.dr + \rho c_p \int_{R_1}^{R_2} \theta(r,0).V(\alpha.r).r.dr}{\rho' c'_p \int_{R'_1}^{R_1} \overline{V}^2(\alpha,r).r.dr + \rho c_p \int_{R_1}^{R_2} V^2(\alpha.r).r.dr} \tag{4}$$

For determination of ρc_p above equation can be written in the form of :

$$Ln\,\theta(R_1,t) = Ln\{\frac{\dot{Q}}{2k\pi}\sum_{\alpha}\{\psi[[V(\alpha.R_1)]\} - k\alpha^2 t / \rho c_p]\} \tag{5}$$

Finally from plotting Ln θ. versus time, these two parameters Pm and μ are found:

$$P_m = \frac{k\alpha_2}{\rho c_p} \tag{6}$$

$$\mu_1(\alpha) = \frac{R_1 P_m \rho' c'_p}{2k} = \alpha\frac{H_{10}(\alpha R_1, \alpha R_2)}{H_{00}(\alpha R_1, \alpha R_2)} \tag{7}$$

Where:

$$H_{10}(p,q) = J_1(p).Y_0(q) - J_0(q).Y_1(p) \tag{8}$$

$$H_{00}(p,q) = J_0(p).Y_0(q) - J_0(q).Y_0(p) \tag{9}$$

Hence volumetric heat capacity will be:

$$\rho c_p = \frac{k\alpha_2}{P_m} \tag{10}$$

The dependence of μ on α is given from the figure 2. The experimental set up has been tested by using distilled water and ethylene glycol at various temperatures. The experiments showed that the

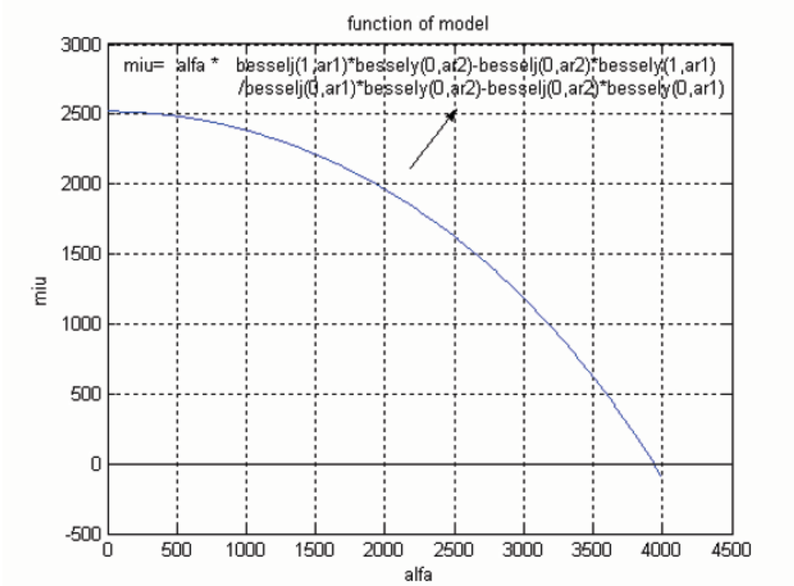

Figure 2: Parameter function for the apparatus

difference between the experimental findings and the values were given in reference book [14] was less than 2% . The set up allows creating three film thicknesses by changing the core and therefore all three were tested and the thickness of 2 mm was chosen as this led to the lowest Rayleigh number resulting in the minimum effect of free convection.

5. NANOFLUID PREPARATION TECHNIQUE

In the preparation of nanofluids, change of pH, use of surfactants and application of ultrasonic vibration are three usual methods of which the third was used in this investigation with various vibration time durations.

In order to measure the volume percent content of particles in each suspension a comparison technique was employed. In this technique the mass density of a non-porous power with known density is determined and then the procedure is repeated for the unknown particles. From the information obtained the density of nano particles is determined using equation (11).

$$\rho_{pX} = k\frac{\rho_{BTX}}{\rho_{BTC}}\rho_{pC} \quad (11)$$

In this equation:

ρ_{BTX} and ρ_{BTC} are the densities of unknown particles, known particles as measured and known particles from reference respectively.

K is a constant which depends on the shape of reference particles and nano particles.

MCM-41 is produced from amorphous silica which has a regular structure with honey comb type pores. The production method for this material is the sol-gel technique and for their production a silica source and a molding agent are used. Mean diameter of produced particles is 28.84 Å, their density is 470 Kg/m^3 and the mean specific area is 908 m^2./gr.

6. EXPERIMENTAL

For the production of the nanofluid, based on the volume percentages and the density of the nano particles the correct amount of MCM – 41 is weighed and poured into an erlenmeyer flask. Distilled water is added without any surfactant and the content is vibrated using ultra sonic waves for different time periods. Nanofluids with 0.5 , 1.0 , 1.5, 2.0 and 2.5 volume percentage were prepared. In the experiments two variables thermal properties

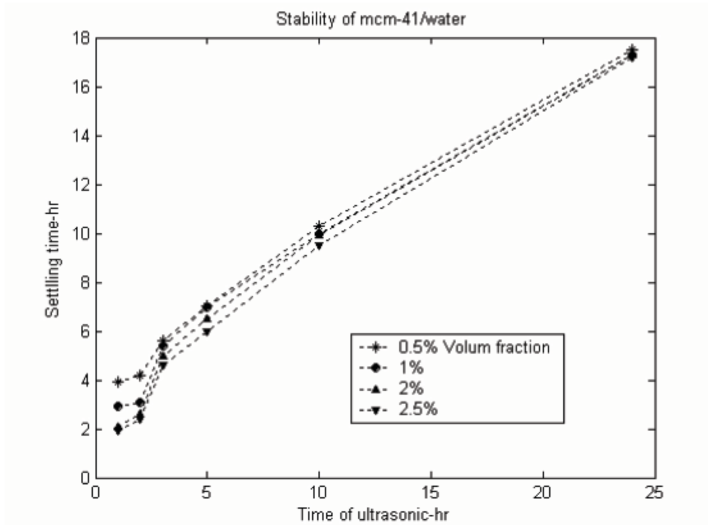

Figure 3: Settling time of MCM – 41 nanofluid vs. concentration and ultrasonic time.

and settling time were measured as a function of temperature, volume percentage of particles and the vibration time of the ultra sonic shaker. The results are shown in figures 3 to 7.

As it can be seen from figure 3 for times longer than two hours, increasing the ultrasonic shaking time results in increasing the settling time due to break up of the particle clusters in the fluid. For higher volume percentage (2.5%) the settling time is lower than that for lower volume percentages. Experiments showed that for times longer than 10 hours the variation of settling time with ultrasonic shaking time becomes less pronounced. The effect of volume percentage and the duration of ultrasonic shaking on thermal conductivity are shown in figure 4 . It can be seen that the increasing of 2 to 7% in thermal conductivity of the fluid is noted and attributed to the Brownian motion of the particles. For longer ultrasonic shaking time higher thermal conductivity is measured which indicated the breakage of nano particles clusters. For times longer than ten hours the little change of thermal conductivity may be due to the fact that for times above this value little change can be detected in the dispersion of the nano particles in the fluid. The data in figure 4 has all been gathered at the temperature of 25 °C. The effect of temperature on the thermal conductivity of the nanofluid is shown in figure 5. It can obviously be seen that increasing the temperature results in increasing of thermal conductivity.

The ultrasonic time for all these experiments was 10 hours. Figure 6 shows the effect of volume percentage of particles in the nanofluids.

MCM – 41 does not have a significant thermal conductivity and hence the increase of the thermal conductivity can only be explained by the effect that Brownian motion has on thermal conductivity of the nanofluid. The results were obtained from figures 4 – 6 show the effect of concentration of nano particles and the temperature on the thermal conductivity which can be noted as the result of the Brownian motions. In case the nano particles are of conductive nature the collision of particles with each other would also results in further increase in the thermal conductivity of the nanofluid. This issue requires more investigation. Bird et al [15] have reported the following equation for the thermal conductivity of nanofluids.

$$k_{eff} = \frac{1}{2}\rho_p \phi c_p \sqrt{\frac{K_B T}{3\pi r_c \eta}} \tag{12}$$

In this equation c_p, ϕ, ρ_p and r_c are heat capacity, volume fraction, density and the mean rotation radius of the nanoparticles respectively while T, η and K_B are temperature, fluid viscosity and Boltzman constant. The findings of this research

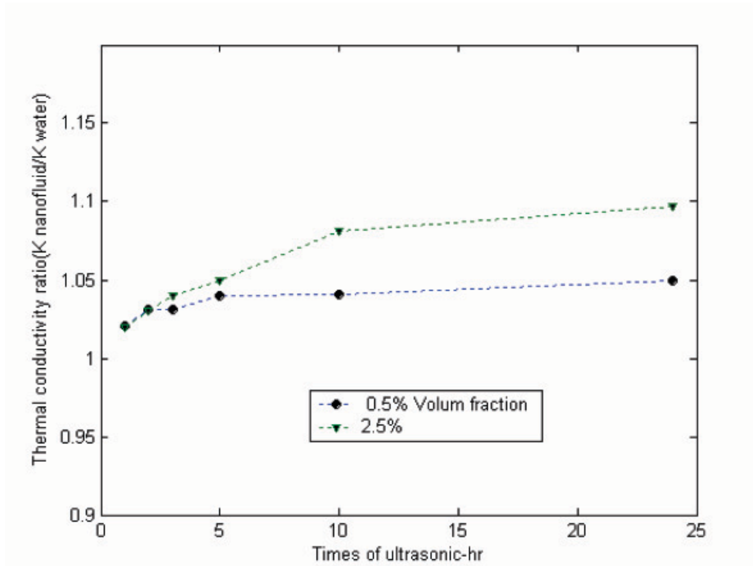

Figure 4: Thermal Conductivity of MCM – 41 nanofluid vs. ultrasonic time.

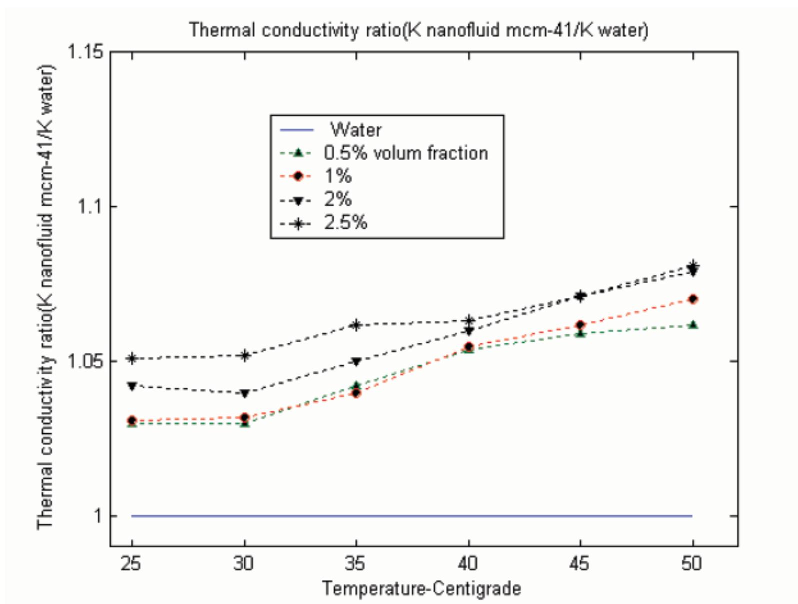

Figure 5: Dependence of thermal conductivity of MCM – 41 nanofluid on temperature and volume percentage.

are in line with the model presented by Bird in the fact that thermal conductivity increases with both temperature and nanoparticles concentration.

It is worth mentioning that various theoretical models have been presented for nanofluids [16 – 18] but the comparison of these models with the experimental finding was not possible due to the lack of required information on the properties of MCM – 41. The variation of the volumetric heat capacity of this nanofluid with temperature and concentration is shown in figure 7.

The data shows that the volumetric heat capacity of the pure fluid increases as the result of addition of the nanoparticles and also with the increase in temperature. Again theoretical models for such suspensions are available [19] but could not be used in this study due to above mentioned reason.

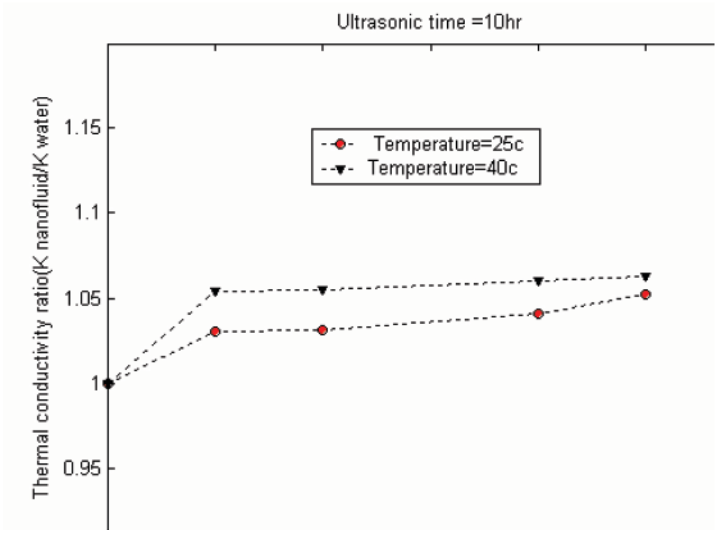

Figure 6: Dependence of thermal conductivity of MCM – 41 nanofluid on concentration.

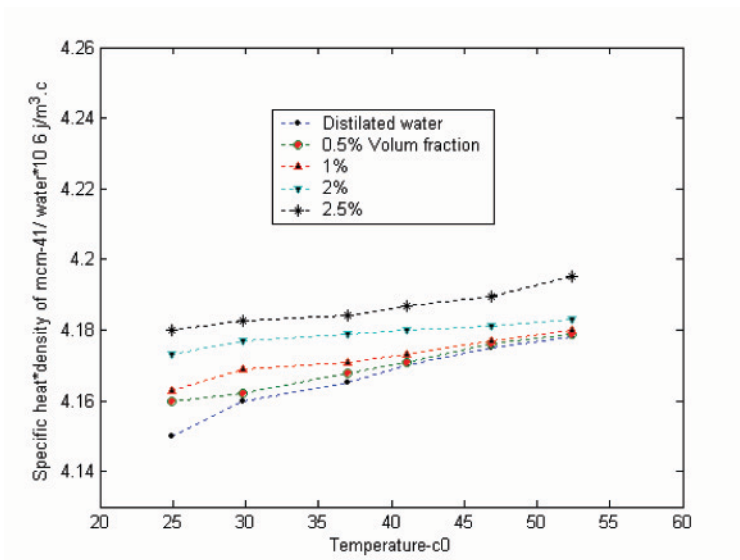

Figure 7: Volumetric heat capacity of MCM – 41 nanofluid at various temperatures and concentrations.

7. CONCLUSION

Thermal conductivity of nanofluid of MCM – 41 particles in distilled water was investigated as a function of temperature, concentration of particles and ultrasonic shaking time. For ultrasonic duration less than 10 hours the stability of the nanofluid was low and decreasing with the increase of concentration of particles (from 0.5 to 2.5%). However for ultrasonic times more than 24 hours the stability of the nanofluid is very good being at its most for the higher concentrations of the particles (2.5%). This may be due to the increased collusions because of the higher number of particles.

For given concentration and ultrasonic time duration the thermal conductivity increases with temperature. For example for 2.5% volumetric concentration of particles the thermal conductivity of nanofluid is 1.05 time that of pure water at 25 °C and 1.07 times that of pure water at 50 °C. Increasing the particles concentration also results in increasing the thermal conductivity and also the volumetric heat capacity.

It is concluded that Brownian motion of the particles in the fluid effects on the thermal conductivity for this type of nano particles.

Study of nanofluid and their properties and also parameters and phenomena such as size, shape or absence of surfactants and the various methods of particle dispersion can be very useful in understanding the behavior of these fluids. This investigation has only been a small part of this very extensive subject.

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