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Heat Transfer Enhancement Using Alumina Nanofluids Effect of Sonication Time on Unsteady Cooling

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Abstract Liquid–solid suspensions have got a good promise in convective cooling applications. Suspension of common fluids with particles of the order of nanometers (typically 10–100 nm) in size are called nano-fluids, which have been found to enhance the heat transfer capability of the base fluid to a considerable extent. Heat transfer enhancement using nanofluids have been reported in literature pertinent to thermal conductivity under the static conditions, convective heat transfer and phase change heat transfer. Except for the studies from the first category where the nanofluids exhibited much higher thermal conductivities than those of base liquids, the investigations on nanofluids behaviour under convective heat transfer studies and phase change heat transfer studies have reported results of paradoxical nature. This apparently paradoxical behaviour of heat transfer has motivated the authors to carry out a critical analysis of all the possible factors that affect the heat transfer process using nanofluids with a special focus on the particle–fluid interactions which is greatly influenced by the sonication time. To this end Alumina nanofluids of different concentrations at various sonication times are prepared and an unsteady state heat transfer analysis of a heated vertical cylinder cooled in the aforesaid alumina nanofluids is carried out, with a special focus on the heat transfer rate. A comparative study of the heat transfer rates of different concentration nanofluids at various sonication time indicates that the best performance characteristics is spreading over the spectrum of the nanofluids of all mass concentration under consideration and requires to be investigated more closely in the future.

Keywords Alumina, Rate of Heat Transfer, Nanofluids, Heat Transfer Enhancement, Sonication Time

1. Introduction

Over the past few decades, the fields of science and engineering have been seeking to develop new and improved types of energy technologies that have the capability of improving life all over the world. In order to make the next leap forward from the current generation of technology, scientists and engineers have been developing Energy Applications of Nanotechnology. Nanotechnology, a new field in science, is any technology that contains components smaller than 50 nanometers. Energy enhancement by augmenting heat transfer is one of the most important technical challenges facing many diverse industries, including transportation, power generation, micro-manufacturing, chemical and metallurgical industries, as well as heating, cooling, ventilation and air conditioning industry. There is, therefore, an urgent need for new and innovative coolants with improved performance. Nanofluids, which are a colloidal mixture of nanoparticles (1–100 nm) and a base liquid (nanoparticles fluid suspensions), is the term first coined by Choi in 1995[1] at the Argonne National Laboratory to describe the new class of nanotechnology-based heat transfer fluids that exhibit thermal properties superior to those of their base fluids or conventional particle fluid suspensions.

Extensive research activities in heat transfer intensification using nanofluids have been done in the past decades. An exhaustive review of this is found in Wang and Mujumdar[2,3], where the published studies can be classified into three categories namely, effective thermal conductivity studies under the static conditions[4-16], convective heat transfer studies[17-29]) and phase change heat transfer studies[30-37]. A summarized report on nanofluids behavior under these conditions can be found in the study reported by Ramis et al.[38]. (The readers may refer the same and the details are omitted here for the sake of brevity). The apparently paradoxical behaviour of heat transfer intensification reported in the literature has motivated them to carry out a critical analysis of all the possible factors that affect the heat transfer process using nanofluids. A special focus on the particle–fluid interactions which is greatly influenced by the sonication time was given in the study.

While Ramis et al.[38], investigated the effect of sonication time on the heat transfer enhancement with CuO nanofluids, the present investigation is to study the effect of sonication time on the heat transfer enhancement with

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Alumina nanofluids. The findings in this regard are very important due to the fact that nano-fluids are being advocated as alternative heat transfer fluids, where alumina nanofluid is one of the most popular. Hence their characteristics during storage or low velocity applications where unsteady natural convection can be significant have to be known with sufficient accuracy. Thus the prime objective of this investigation is to study the effect of sonication time on the unsteady cooling of a heated cylinder.

2. Methodology

2.1. Preparation of Nanofluids

Nano-fluids are prepared by dispersing Al_2O_3 nano-particles into water as a base fluid. The reasons for using Alumina nano-fluids are that they are widely used in this research area owing to requirements such as stable, uniform, and continuous suspension without any outstanding chemical change of the base fluid and also that the physical properties of alumina nanofluids have been well documented. Alumina nano-particles used in this work are manufactured by Sigma Aldrich Limited, USA. The following are the properties of alumina nanoparticles: bulk density = 260 kg/m^3, true density = 3600 kg/m^3, specific heat = 765 J/kg K, melting point =2046°C. The size has a normal distribution in a range from 10 nm to 100 nm (47 nm avg. diameter is given from the manufacturer).

In order to ensure a stable, uniform, continuous suspension, the dispersion solutions are vibrated in an ultrasonic Cleaner, Model 405 supplied by Hwashin Technology Co., Korea, shown in Figure 1. Alumina nano-fluids with mass concentrations namely 0.05%, 0.1 % 0.15% and 0.2 % is prepared by controlling the amounts of the nano particles. 800 ml of water was taken in a round bottom flask with appropriate mass fraction of the nanoparticles and placed in the Ultrasonic Cleaner for the required time. The sonication temperature was maintained same in all the cases. In order to study the effect of sonication time on the heat transfer behavior, each concentration sample was sonicated for 2,3 and 4 hours separately.

Figure 1. Ultrasonic Cleaner, Model 405

2.2. Unsteady State Heat Transfer Apparatus

The experimental setup consists of a hot water bath heated by means of a heating coil. A mild steel cylinder serves as the test piece. Thermocouples located at half of the cylinder height measures the centre temperature of the cylinder. The temperatures are measured with digital temperature indicator and a temperature recorder connected in parallel. Another vessel serves as the cold water bath for the cooling purpose. Figure 2 represents the above mentioned experimental set up.

Figure 2. Unsteady State Heat Transfer Apparatus

2.3. Experimental Procedure and Analysis

The test piece was heated to a temperature of 75°C in the hot bath and then at first cooled in the pure water bath. The temperature of the test piece was recorded at a time interval of 5 seconds till it attained almost a steady state temperature. The experiment was repeated for cooling the test piece in Alumina nanofluids of 0.05% mass concentration which was prepared with a sonication time of 2,3 and 4 hours respectively. It is worth mentioning here that the initial temperature of the cooling fluid was maintained uniform in all the cases. The above analysis was repeated for alumina nanofluids of 0.1%, 0.15%, 0.2% mass concentration.

The lumped system heat transfer analysis was used to find the rate of heat transfer q. The variation of q with time is plotted for the various conditions under consideration. Eqn. (1) give the details of the calculation of heat transfer coefficient and Eqns. (2) & (3) give the rate of heat transfer and amount of heat transfer.

$$h = -ln\left[\frac{T(t)-T(\infty)}{T(i)-T(\infty)}\right]\frac{\rho V C_p}{A_s t} \quad (1)$$

$$q = hA_s dT \quad (2)$$

$$Q = mC_p[T(i) - T(t)] \quad (3)$$

Where

h	heat transfer coefficient in W/m^{2}k
q	rate of heat transfer W
Q	total amount of heat transfer
$T(t)$	temp of the test piece at any time instant in ℃
$T(\infty)$	ambient temp in ℃
$T(i)$	initial bath temp in ℃
ϱ	density of the test piece material kg/m^3
V	volume of the test piece m^3
m	mass of test piece material kg
C_p	specific heat capacity of test piece material J/kg K
A_s	surface area m^2
t	time in seconds

2.4. Validation

The validation of the lumped parameter heat transfer analysis was done by calculating the Biot number Bi which is given by the equation:

$$Bi = \frac{hL_c}{k_s}$$

where L_c is the characteristic length and k_s is the thermal conductivity of the test piece. It was found that the value of Bi was far below 0.1, which is the required condition to carry out the lumped parameter analysis.

3. Results and Discussions

3.1. Effect of Sonication Time on Alumina Nanoparticles of Various Concentrations

Figure 3a depicts variation of rate of heat transfer q with time, for alumina nanofluids of 0.05% mass concentration prepared with different sonication time of 2,3 and 4 hrs respectively. Figure 3b depicts the variation of the amount of heat transfer for the same. As expected, it is very apparent from the figure that the rate of heat transfer decreases with respect to time whereas the total amount of heat transfer increases with respect to time. The above mentioned nature is very much in agreement with the physics of the problem. However no conclusive remarks can be drawn regarding the effect of the sonication time, since all nanofluids prepared with different sonication time behaves in almost similar approach.

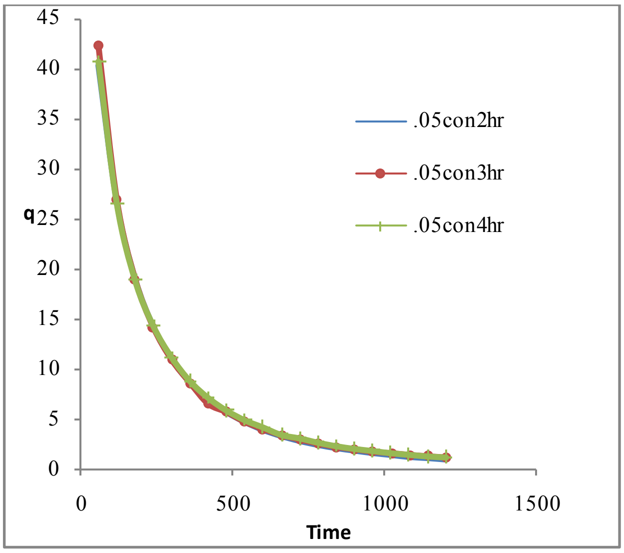

Figure 3a. Variation of rate of heat transfer with time for 0.05 % Alumina nanofluids prepared at various sonication time

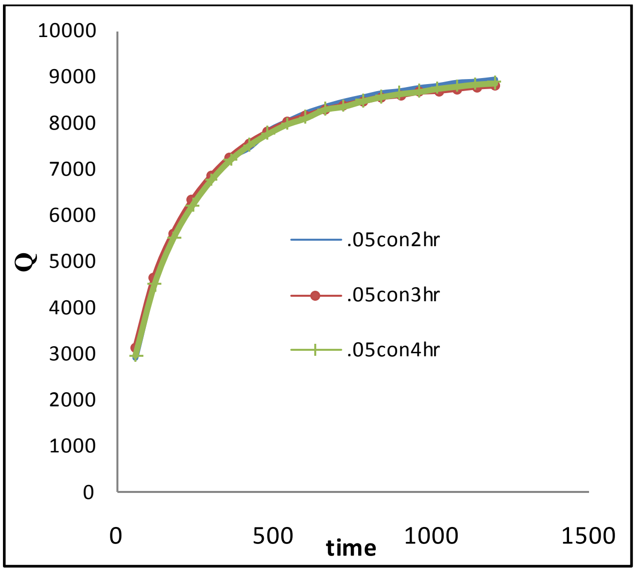

Figure 3b. Variation of amount of heat transfer with time for 0.05 % Alumina nanofluids prepared at various sonication time

Figure 4a & Figure 4b depicts variation of heat transfer rate (q) and amount of heat transfer (Q) with time, for alumina nanofluids of 0.1% mass concentration prepared with different sonication time of 2,3 and 4hrs respectively. Though the general nature of decreasing trend in the case of heat transfer rate and an increasing trend for the total amount of heat transfer remains as in the previous case, the nanofluid prepared with 3 hr sonication time has enabled a slight increase in the heat transfer rate during the later stage of cooling, compared to that of 2 and 4 hours sonicated nanofluids. The same can be noted in Figure 4b, in the form of a slight decrease in the total amount of heat transfer for the nanofluid prepared with 3 hr sonication time.

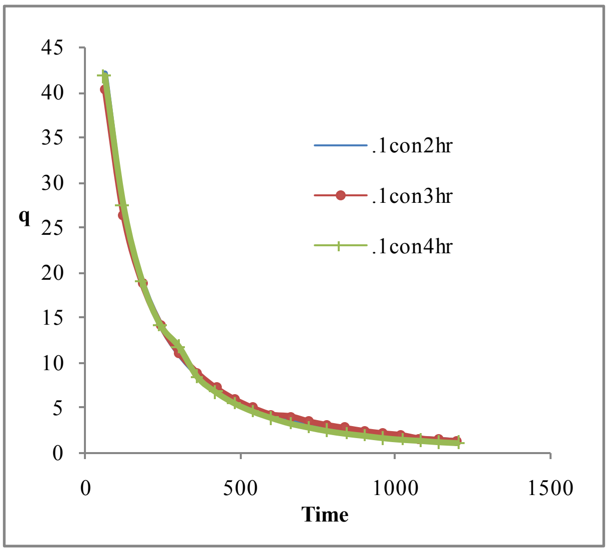

Figure 4a. Variation of rate of heat transfer with time for 0.1 % Alumina nanofluids prepared at various sonication time

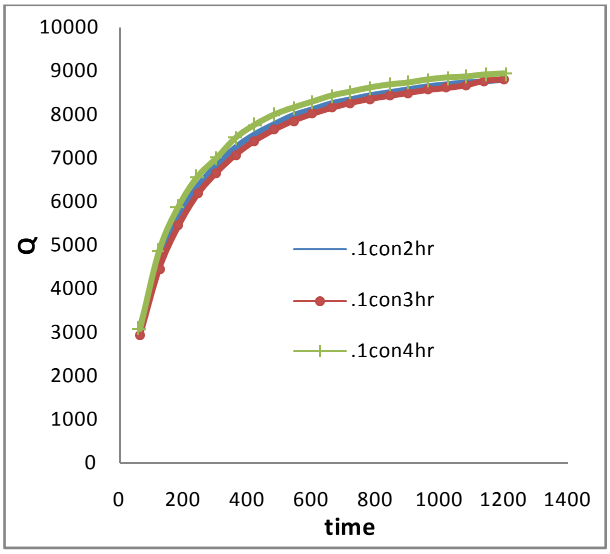

Figure 4b. Variation of amount of heat transfer with time for 0.1 % Alumina nanofluids prepared at various sonication time

Figure 5a & Figure 5b depicts variation of heat transfer rate (q) and amount of heat transfer (Q) with time, for alumina nanofluids of 0.15% mass concentration prepared with different sonication time of 2,3 and 4hrs respectively. Observations from Figure 5a is fairly similar as seen in figure 4a, but in later stage of cooling nanofluids prepared with 2hr sonication time exhibits lesser rate of heat transfer compared to fluids prepared with sonication time of 3hr and 4hrs. But it is clear from Figure 5b that maximum amount of heat is transferred by 2hr sonicated nanofluids.

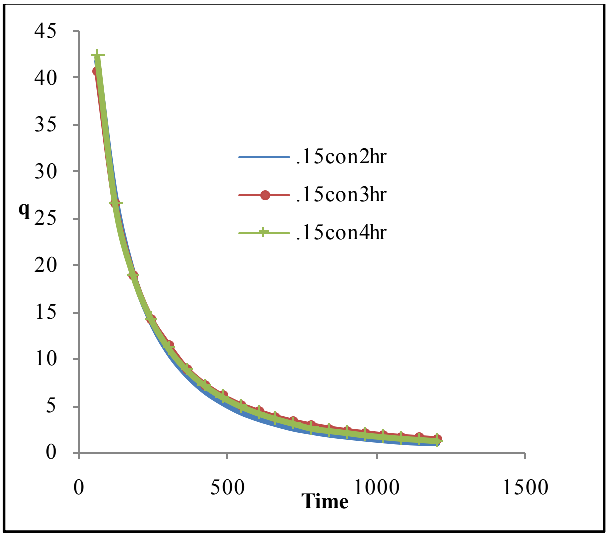

Figure 5a. Variation of rate of heat transfer with time for 0.15 % Alumina nanofluids prepared at various sonication time

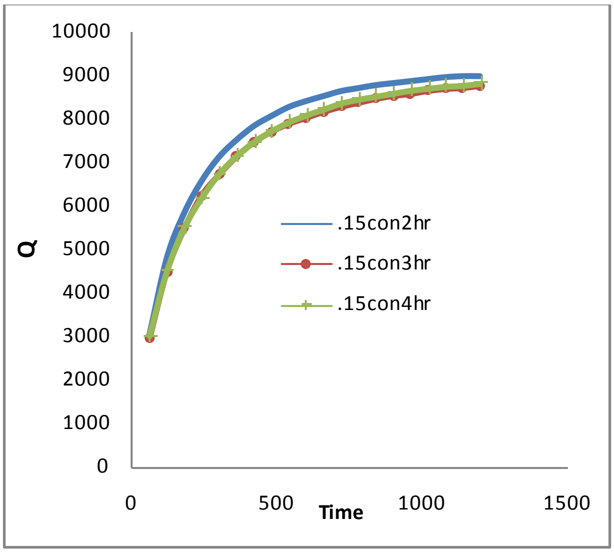

Figure 5b. Variation of amount of heat transfer with time for 0.15 % Alumina nanofluids prepared at various sonication time

Figure 6a & Figure 6b represents the effect of sonication time (2hr, 3hr and 4hrs) on rate of heat transfer (q) and amount of heat transfer (Q) respectively for 0.2% concentration nanofluids. From this also no conclusive remarks can be drawn but in later stage of cooling the rate of heat transfer slightly looks high in 3hrs sonicated nanofluids.

Figure 7a depicts the comparison of the best rate of heat transfer vs. time for the alumina nanofluids of various concentrations, and Figure 7b represents the same for amount of heat transfer Q. Though no conclusive observations can be drawn from Figure 7a, we can notice from Figure 7b that the maximum amount of heat transfer is for 0.15% concentration sonicated with 2 hours and the least can be observed as 0.05% concentration with sonication time of 3hrs. The above results give an assorted nature of deterioration and enhancement of heat transfer rate on addition of nanoparticles. The above results are in concurrence with the inconsistent nature of heat transfer reported in literature— enhancement of heat transfer as found in Khanafer et al.[23], Nnanna *et al*.[28] and Nnanna and Routhu[29] and deterioration of heat transfer as noticed in the study of Putra et al.,[17] and Deng and Wing[21]. Thus, this study indicates that the sonication time of nanofluids has an influence on the particle–fluid interactions at certain concentrations, which in turn affects the heat transfer performance of the nanofluids.

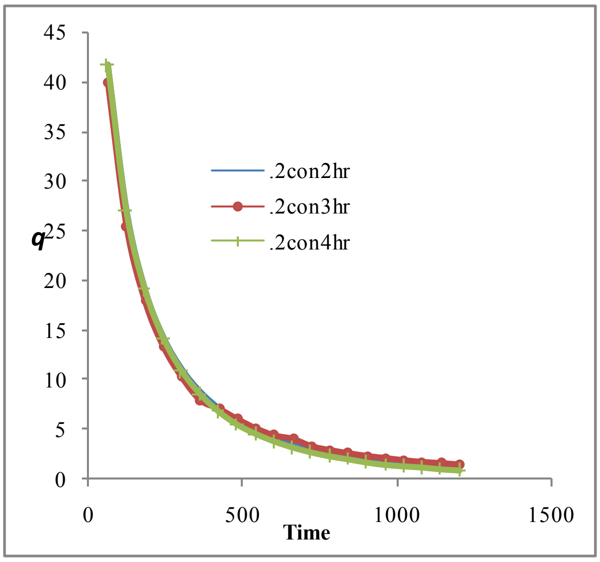

Figure 6a. Variation of rate of heat transfer with time for 0.2 % Alumina nanofluids prepared at various sonication time

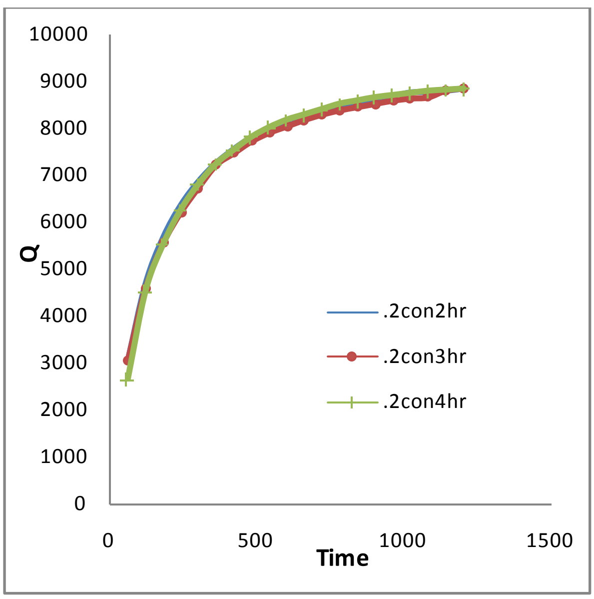

Figure 6b. Variation of amount of heat transfer with time for 0.2 %

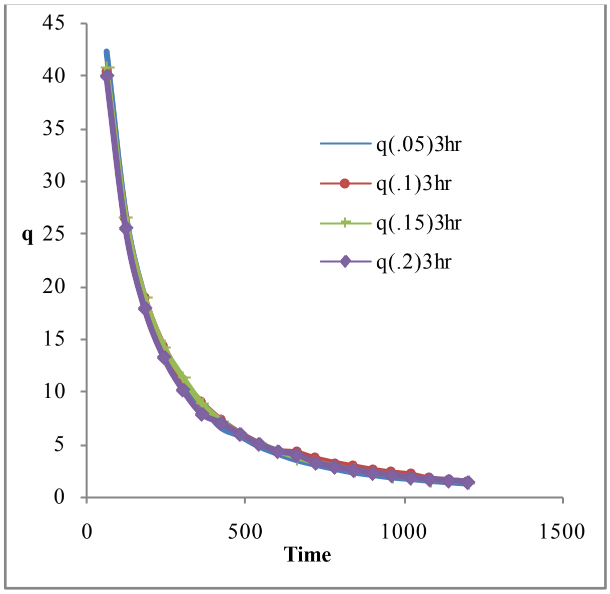

Figure 7a. Comparison of the best rate of heat transfer for Alumina nanofluids of various concentrations

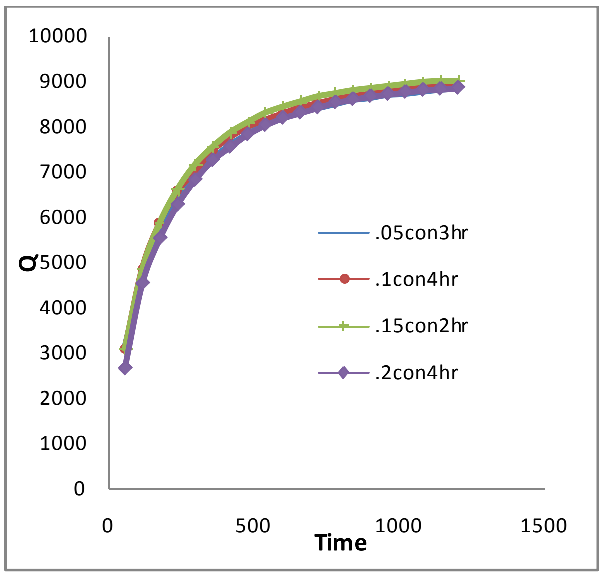

Figure 7b. Comparison of the best amount of heat transfer for Alumina nanofluids of various concentrations

3.2. Comparison of Rate of Heat Transfer of Alumina Nanoparticles of Various Concentrations at Different Sonication Time

Figure 8-10 shows the variation of amount of heat transfer with time for alumina nanofluids of various mass concentrations prepared at 2, 3 and 4 hours sonication time respectively. The general nature of the figures plotted in the previous section is also noted in these figures. However these plots give an insight into the best heat transfer coefficient at various sonication times which is tabulated as follows:

Table 1. Alumina Nanofluids Prepared at Various Sonication Time

Sonication time	Mass concentration with best q
2 hours	0.15% throughout cooling process
3 hours	0.05% throughout cooling process
4 hours	0.1% throughout cooling process

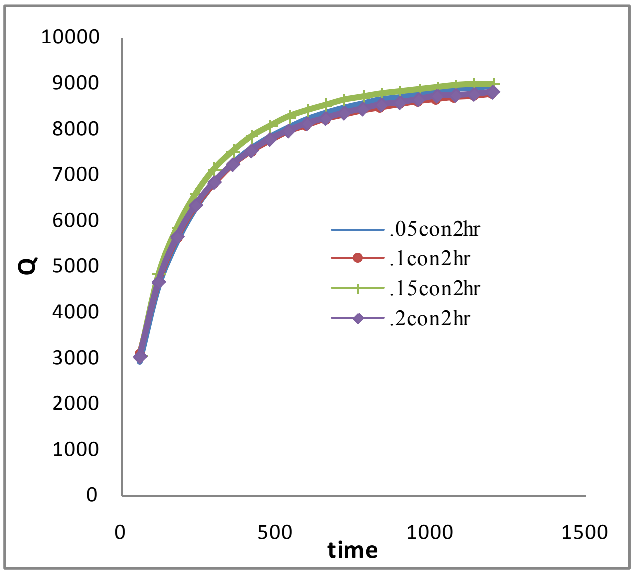

Figure 8. Comparison of amount of heat transfer of Alumina nanoparticles of various concentrations at 2 hours sonication time

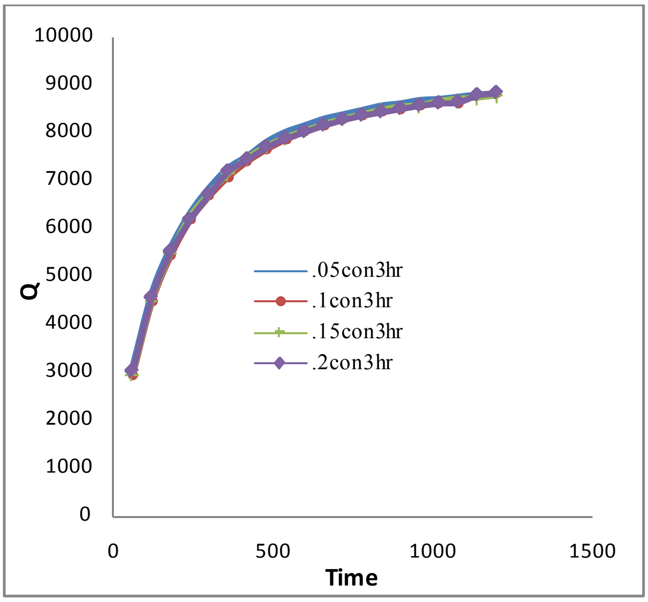

Figure 9. Comparison of amount of heat transfer of Alumina Nanoparticles of various concentrations at 3 hours sonication time

The above table is suggesting that the best performance is spreading over the spectrum of the nanofluids of all mass concentration under consideration. As discussed in the previous section, the sonication time determines the role of particle-fluid slip and sedimentation which seems to be important in the heat transfer process and requires to be investigated more closely in the future.

4. Conclusions

Improvement of the thermal properties of energy transmission fluids may become a trick of augmenting heat transfer. Fluids with nano sized solid particles suspended in them have been given the name nano-fluid which in recent studies has shown tremendous promise as heat transfer fluids. The published studies can be classified into three categories namely, effective thermal conductivity studies under the static conditions, convective heat transfer studies and phase change heat transfer studies. Except for the studies from the first category where the nanofluids exhibited much higher thermal conductivities than those of base liquids, the investigations on nanofluids behaviour under convective heat transfer studies and phase change heat transfer studies have reported conflicting results. A recent study to investigate the effect of sonication time on the inconsistent behavior of heat transfer enhancement with CuO nanofluids was carried by the authors which concluded that the sonication time greatly influences the heat transfer performance of the nanofluids and this influence is affected by the nanoparticle concentration. The same study is carried in this paper to study the effect of sonication time on the heat transfer enhancement with Alumina nanofluids. The findings in this regard are very important due to the fact that nano-fluids are being advocated as alternative heat transfer fluids, where alumina nanofluid is one of the most popular.

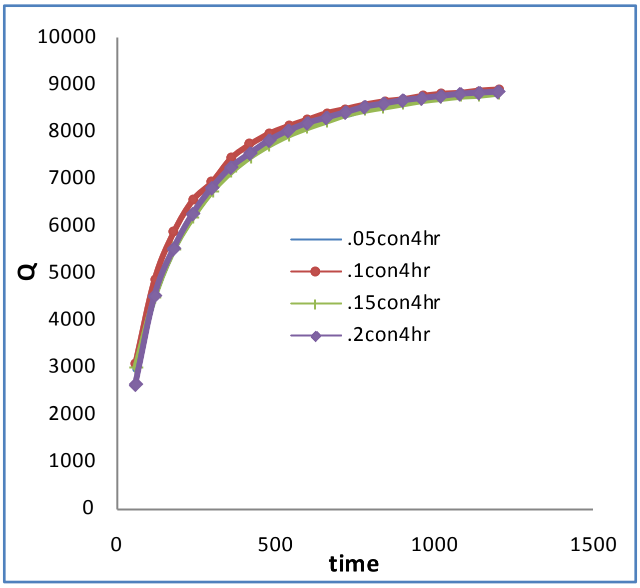

Figure 10. Comparison of amount of heat transfer of Alumina Nanoparticles of various concentrations at 4 hours sonication time

A comparative study of the rate of heat transfer and amount of heat transferred of different concentration nanofluids at various sonication times indicates that the best performance is spreading over the spectrum of the nanofluids of all mass concentration under consideration. Thus it can be concluded that the sonication time determines the role of particle-fluid slip and sedimentation which seems to be important in the heat transfer process and requires to be investigated more closely in the future.

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