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Investigation of Heat Transfer Efficiency of Alumina Nanofluids in Shell and Tube Heat Exchanger

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Abstract. High energy costs have motivated industries to apply energy saving methods. Heat transfer improvements are one of the most efficient tools to save energy in different processes. Nanoparticle suspension is an innovative fluid, called nanofluid. Nanofluids can enhance heat exchange system by modification of heat transfer performance. In this work, we used commercially available alumina nanoparticles to prepare nanofluids with different concentrations. Sodium polyacrylate (PA) was found to be the best capping agent for alumina nanofluids as compared with sodium dodecyl sulfate (SDS) and hexadecylthimethylammoniumbromide (CTAB) with larger zeta-potentials. The PA stabilized 0.25% alumina nanofluids exhibited the highest overall heat transfer coefficient with about 10% better than the base fluid and it can be continuously used for long run without any change in efficiency.

Keywords: alumina nanoparticles; nanofluids; surfactants; heat exchanger

1. Introduction

Nowadays, high energy costs have forced industry to apply energy saving methods where heat transfer improvement is one of the most efficient tools to save energy in different processes. It is encouraging for thermal engineers to continuously develop and improve the process. Considerations of technological advancement, the higher heat transfer rate and also heat transfer efficiency from smaller areas across a lower temperature differences are continuously raised. Utilization of solid particles has been considered in a few decades as their higher thermal conductivity. However, solid particle suspensions have not been in industries as lot of problems such as fouling, abrasion and high pressure drop reduced the interested in heat transfer applications.

Recently, nanomaterial technological advancement offered us to synthesize nanoparticles in 10-100 nm size that overcome these problems. Nanoparticle dispersion in fluids is an innovative fluid, called nanofluids. Nanofluids have enhanced not only modification of heat transfer performance but also improvement rheological properties of the fluids [1-4]. Nanofluids were first studied by Choi et al [5]. It was reported that nanofluids improve thermal conductivity. Later on, some studies reported that nanofluids have better heat transfer [2, 4, 6, 7] and colloidal stability, reduced energy for fluids pumping and reduced clogging as compared to the use of micron size particles. However, nanofluids are still have the problem of long term stability during the heat transfer processes due to agglomeration and aggregation [8-10] .

In this work, the nanofluids properties without and with various types of capping agents were studied. Overall heat transfer coefficient of alumina/water nanofluids in a counter-current flow shell and tube heat exchanger, heat transfer of hot and cold streams were also discussed.

2. Experimental

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2.1 Materials and Chemicals Used

All the chemicals used for this work were of analytical grade and used as-received without any further purification. Chemicals used in this work are alumina nanoparticles (<50 nm in size), sodium dodecyl sulfate (SDS) and hexadecylthimethylammoniumbromide (CTAB) from Sigma-Aldrich, sodium polyacrylate (PA) from Dow chemical company.

2.2 Heat Exchanging System

The schematic diagram of the heat exchange system is shown in Fig.1(a). The heat exchanger unit, where the heat exchange process takes place, consists of 7 stainless steel tubes for hot water line considered with a water heater and a temperature controller. The cold water is flown from tap water valve counter-currently through the reactor. Temperature sensors were set at hot water in (T_1) and out (T_2) and cold water in (T_3) and out (T_4) and all of them connected to the LED digital display. The real system used in this research is the heat exchanger of P.A.Hilton Ltd. (H102C) as shown in Fig.1(b).

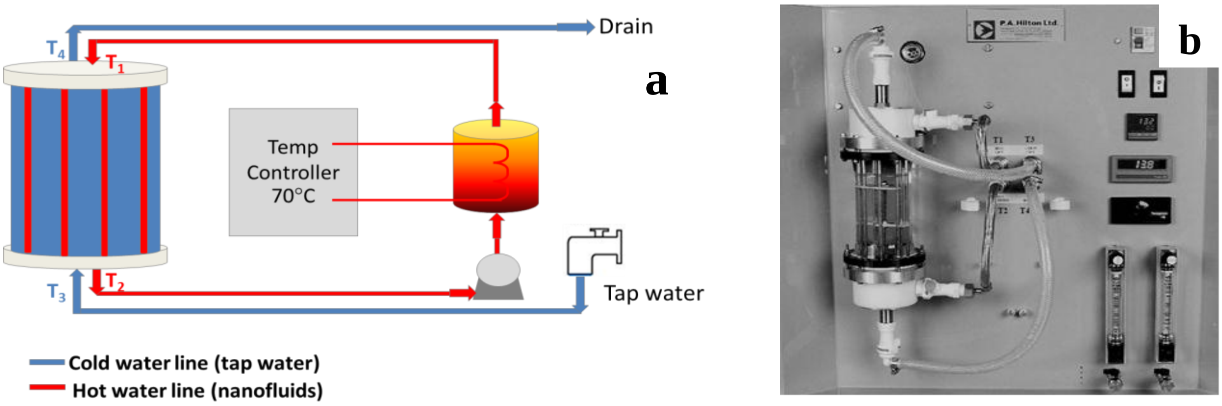


Fig.1 (a) Schematic representation of the heat exchanger and (b) A photograph of the heat exchanging system

2.3 Preparation of Nanofluids

An experimental design was developed to investigate two main parts. First is to compare the most suitable capping agents to stabilize nanoparticles. Three types of capping agents, sodium dodecyl sulfate (SDS), hexadecylthimethylammoniumbromide (CTAB) and sodium polyacrylate (PA) were studied. Different weight ratio of the capping agent to the alumina powder were added to 1% alumina nanofluids and compared with the alumina nanofluid without any capping agent as a control sample. All nanofluids were then sonicated for 30 minutes for complete dispersion of nanoparticles. Zetapotentials, electrical conductivity, turbidity, pH of all nanofluids were then investigated to find out the most active capping agent for alumina nanofluids.

The second purpose of this work is to measure the heat transfer efficiency when using different % by weight of alumina nanoparticles with the most suitable type and weight ratio of capping agent. The heat exchanging system was set up as shown in Fig.1. Five concentration nanofluids were applied in the hot line while tap water was set in cold line. Flow rate of nanofluids were set as 30 $cm^3.s^{-1}$ while tap water flow rates were varied from 10 to 50 $cm^3.s^{-1}$. Specific heat capacity, heat transfer of cold water line, hot water line and overall heat transfer efficiency were investigated and compared with the experiments conducted without the capping agent to ensure that the stabilized polymer does not prohibit heat transfer process.

Table 1 List of nanofluids codes and compositions

Capping agent		PA				SDS				CTAB			
Code of Nanofluids	A	P01	P05	P1	P2	S01	S05	S1	S2	C01	C05	C1	C2
wt.% of Al_2O_3 in nanofluid	1	1	1	1	1	1	1	1	1	1	1	1	1
Capping agent (%v in nanofluids)	-	0.1	0.5	1.0	2.0	0.1	0.5	1.0	2.0	0.1	0.5	1.0	2.0
Capping agent (%wt in nanofluids)	-	0.050	0.250	0.500	1.000	0.010	0.025	0.050	0.100	0.005	0.025	0.050	0.100

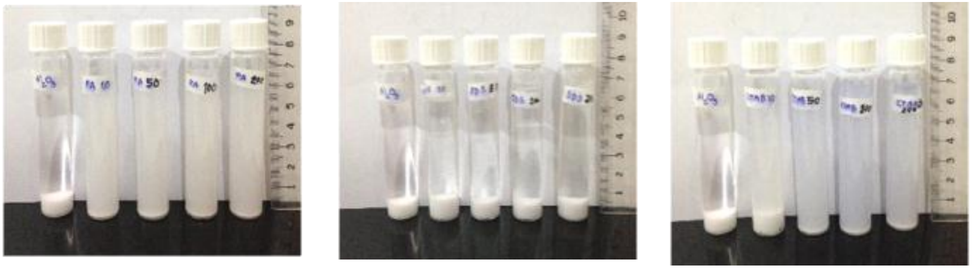
3. Results and Discussion

3.1 Investigation of the most suitable capping agent

The capping agents, PA, SDS and CTAB were added into the alumina nanofluids with different concentration as shown in Table 1. All nanofluids were then measured turbidity, electrical conductivity, pH and zeta-potential as shown in Table 2. It was observed that pH of nanofluids with PA (P-series) exhibited acidic region as the PA is an acidic. Conductivity of the nanofluid P-series were about 200-650 μS and increased with an increase of PA in the nanofluids. Turbidity of the P-series nanofluids showed a very high turbidity (>1000 NTU) even kept after 3 days (Fig.2). The turbidity results are corresponded to the zeta-potential values that all of concentrations were higher than 30 mV presenting well dispersed of nanofluids. For SDS capping agent, it was found to be the worst capping agent of alumina nanofluids as it agglomerated and precipitated quickly and leading to low fluid turbidity with the zeta potentials very closed to zero. These results were corresponded to the photograph of the suspensions taken after 3 days (Fig.2) showing clear solutions with sediment of alumina powders. CTAB is a good capping agent as it could stabilize alumina nanoparticles up to 3 days. At C01 suspension, the amount of CTAB was insufficient to disperse the alumina particles, while C05, C1 and C2 showed a better dispersing ability. pH of C-serie nanofluids were in soft acid region (5-6) with good dispersion ability. As compared P01 with S05 and C05 at the same solid concentration (0.05%), it can be clearly observed that P01 exhibited higher zeta-potential (>-45 mV) while S05 and C05 showed -4 and +34 mV, respectively. As the results of nanofluids stabilization, it can be concluded that using sodium polyacrylate as a capping agent could enhance the stability of alumina suspensions, we, therefore, selected P01 for using as a nanofluids for this research.

Table 2 The physical properties of all nanofluids with different capping agents and compositions

Nanofluids	**A**	P01	P05	P1	P2	S01	S05	S1	S2	C01	C05	C1	C2
Capping agent (%wt in nanofluids)	-	0.050	0.250	0.500	1.000	0.010	0.025	0.050	0.100	0.005	0.025	0.050	0.100
pH	5.4	6.0	4.7	4.3	4.1	6.1	6.8	7.3	7.8	5.3	5.1	5.5	5.9
Conductivity (μS)	175	212	358	510	634	70.9	91.4	130.6	168.5	47.5	60	65	115.8
Turbidity (NTU)													
After Sonication	738	734	708	660	718	698	709	673	732	664	754	748	627
5 hours	17.4	844	834	767	806	16.2	35.4	29.6	29.5	795	902	885	766
1 day	18.4	>1000	>1000	983	>1000	14.7	24.2	31.9	27.3	356	>1000	>1000	944
2 days	10.6	>1000	>1000	>1000	>1000	9.9	11.09	11.5	24.5	172	>1000	>1000	>1000
3 days	9.8	>1000	>1000	>1000	>1000	7.3	10.6	8.9	12.9	64.6	>1000	>1000	>1000
Zeta-potential (mV)	16	-45.73	-40.13	-37.97	-33.77	-8.9	-3.92	0.40	1.28	13.47	33.97	37.80	39.33



PA SDS CTAB

Fig.2 Photographs of 1%alumina nanofluids with different capping agents after sonication for 3 days

3.2 Investigation of heat transfer coefficient

The schematic of heat exchanging system and the actual equipment are shown in **Fig.1(a-b).** Temperatures of hot nanofluids (in, T_1 and out T_2) and cold water (in, T_3 and out T_4) were recorded after the system was stable. Heat transfer and overall heat transfer coefficient of hot and cold streams were calculated using the Eq.1-3.

$$Q_h = V_h \rho_h C_{p,h} (T_1 - T_2) \tag{1}$$

Where Q_h is heat emitted from hot stream (Watt), V_h is flow rate of hot stream ($cm^3.s^{-1}$), ρ_h is the nanofluids density ($g.cm^{-3}$), $C_{p,h}$ is heat capacity of nanofluids ($J.g^{-1}.°C^{-1}$), obtained from the experiments, T_1 is the inlet temperature of nanofluids and T_2 is the outlet temperature of nanofluids (°C).

$$Q_c = V_c \rho_c C_{p,c} (T_4 - T_3) \tag{2}$$

Where Q_c is the heat absorbed by cold stream (Watt), V_c is flow rate of cold stream ($cm^3.s^{-1}$), ρ_c is the density of water ($g.cm^{-3}$), $C_{p,c}$ is heat capacity of water ($J.g^{-1}.°C^{-1}$), obtained from the experiments, T_4 is the inlet temperature of water and T_3 is the outlet temperature of water(°C).

$$U = \frac{Q}{A \times LMTD} \quad (3) \qquad \text{where } LMTD = \frac{(T_1 - T_4) - (T_2 - T_3)}{\ln(\frac{(T_1 - T_4)}{(T_2 - T_3)}} \quad (4)$$

Where U is overall heat transfer coefficient ($W.m^{-2}.C^{-1}$), Q is the heat transfer rate calculated from (1) or (2), A is area of heat transfer and LMTD is logarithmic mean temperature difference.

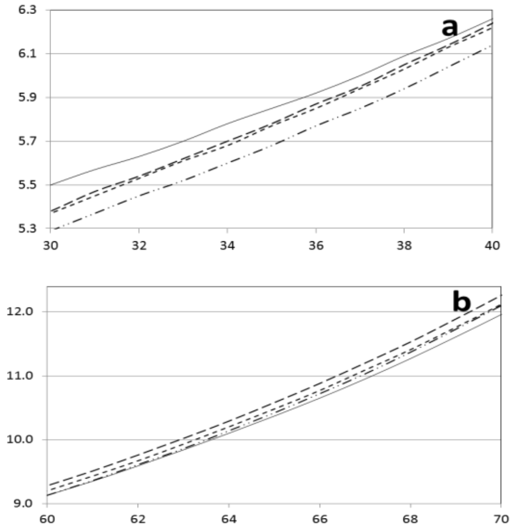


Fig.3 Heat capacity of alumina nanofluids at different concentrations compared to water J/g.°C. At the temperature range of (a) 30-40 °C and (b) 60-70 °C

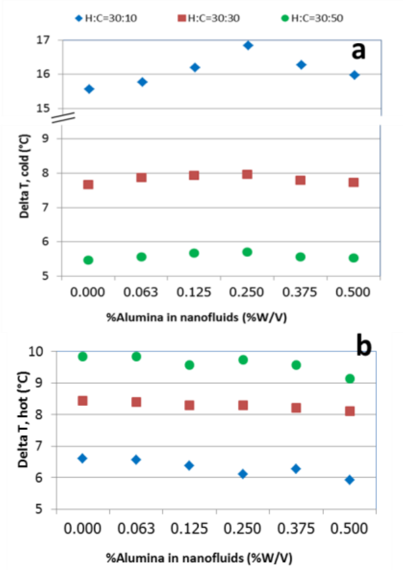


Fig.4 Temperature difference of water in and water out of the heat exchange system as a function of %alumina at different hot and cold stream flow rates, H:C = ratio of hot stream:cold stream flow rate for (a) cold water and (b) hot nanofluids

Prior to the calculation of heat transfer in both hot and cold streams, separated experiments were conducted to measure heat capacities of PA stabilized nanofluids with different alumina contents as compared with nanofluid without PA addition and with deionized water using differential scanning colorimeter (DSC: Mettler Toledo). The plots of C_p values against operating temperatures were shown in Fig.3. It was observed that heat capacity of water was slightly higher than the nanofluids. At temperatures higher than 40 °C, heat capacity of the nanofluids become higher than water.

It can be clearly observed that the temperature difference of inlet and outlet water stream (ΔT_{cold}) (Fig.4(a)) increased at increasing of alumina content in nanofluids until the alumina content reached 0.25%, then, ΔT_{cold} become decreased, especially for H:C at 30:10, while change in the hot stream was barely observed (Fig.4(b)).

It was also observed that the U increased with an increase of alumina concentrations and then tended to decrease after 0.25% alumina content (Fig.5) corresponded to the results of heat transfer rate (Q)(did not show here). It was approximately 10% enhancement of U with H:C = 30:10 of 0.25% alumina as compared with the base fluid (tap water). For other H:C flow rate of cold stream, the changes of U were the same trend as found in H:C 30:10, that 0.25% alumina content exhibited the best overall heat transfer coefficient that 4-5% higher than the base fluid. The 0.25% alumina nanofluid was then used to examine the heat transfer and overall heat transfer coefficient for 60 minutes test run after the system reached the equilibrium. It was observed that both of heat transfer and overall heat transfer coefficient were stable over the experimental period. Therefore, the PA stabilized 0.25% alumina nanofluid was proved to be a good choice as the nanofluids for heat transfer applications.

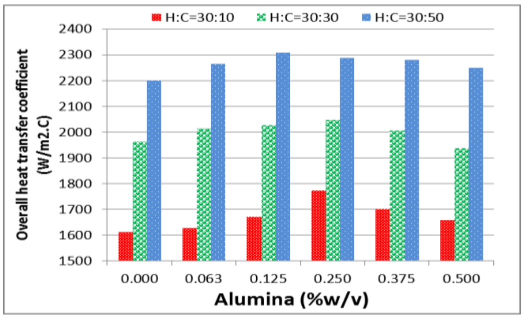


Fig.5 Overall heat transfer coefficient of the system at different alumina concentrations and different in hot and cold stream flow rates (H:C = hot stream flow: cold stream flow rates)

4. Summary

Sodium polyacrylate (PA) is the most suitable capping agent for stabilizing alumina suspension with high zeta-potentials. The addition of PA in nanofluids was not only enhanced the stability of the alumina nanofluids, but also did not interfere the heat transfer efficiency. The highest heat transfer coefficient was achieved at the concentration of 0.25% alumina with about 10% enhancement. The PA stabilized 0.25% alumina nanofluids has the potential to be the innovative nanofluids for industrial applications.

5. Acknowledgements

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