EFFECT OF RED MUD AS A NANOFLUID ON COOLING PERFORMANCE

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Abstract

Fluids such as water, oil, glycerin and ethylene glycol are conventional heat transfer fluids that are used in heat exchangers. Improving heat transfer and effectiveness of heat exchangers by means of fluids is one of the principle topics. A type of improvement works is adding solid materials that have high thermal capacity and conductivity into the fluid. Al_2O_3, CuO, TiO_2, SiC, TiC, Ag, Au_2, Cu_2 and Fe are the most common materials as solid particles that are used for enhancing heat transfer of fluids. Early on, macro scaled additives were tried; however desired outcomes couldn't be obtained due to fouling, blockage and sedimentation. Recently, studies on ability to be enhanced and improved in terms of heat transfer and hence heat exchangers with high effectiveness by the addition of nano-particles to fluid have become intensive. It is known that precious elements such as Al_2O_3, SiO_2, Fe_2O_3, TiO_2, Na_2O, CaO, P_2O_5 are contained in the body of red mud that is a disposal material coming from the process of producing aluminum from bauxite. Thermal capacity and thermal conductivity of these matters are very high. Effects of nano scale red mud added into heat transfer fluid on the cooling performance are investigated in this work.

Keywords: Enhancement, Heat exchanger, Heat transfer, Nano fluid, Red mud.

1. Introduction

Energy need constantly increases depending on the increasing population and advancing technology in our day. In return, limited energy sources, restrictions that are brought by environmental problems in energy supply and usage makes more efficient utilization of energy sources alongside with searching new sources indispensable. The most important

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topic in transferring heat energy from a medium to another one is realizing heat transfer by consuming the least possible power and in the least possible time; in other words, by the most efficient way. One of the most important elements about energy and heat transfer in most of the industrial practices is heat exchangers. Among the important parameters of heat exchangers that affect heat transfer performance and energy efficiency of heat exchangers, on the other hand, the thermal conductivity of the heat transfer fluid is very essential. Thermal performances of fluids such as water, mineral oils and ethylene glycol that are commonly used in heat exchangers currently are limited. Changes are observed in properties of fluids such as thermal conductivity, viscosity by adding solid metal particles and various matters which have higher thermal capacity than the fluid in order to increase the thermal conductivity capacity of the fluid. Struggles for improving heat transfer properties of the fluids by adding solid particles into the fluids are a method that was previously tried. However, desired results cannot be acquired due to reasons such as sedimentation of the particles, wearing of the system components and pressure drop while big scale solid particles improves thermal properties only by slightly with only by high volumetric rates. By the advancement of the technology, studies for enhancing and improving thermal properties of the heat transfer fluids are reconsidered and are continuing with an increasing trend by the realization of the production at nano scale. Constituting a suspension mixture by adding particles at nano scales to the conventional fluids is called nanofluids. Solid metal particles that have high thermal conductivity and that are most commonly used are defined as; copper, aluminum, silver, gold and iron while alloys are; aluminum oxide (AI_2O_3), copper oxide (CuO), TiO_2, ZnO, SiO_2. Enhancing thermal conductivity of nanofluids is depending on sizes of nano particles and rates of nano-particles. Some of the studies on nanofluids are given in [1,2] and below.

Saidur et al. have compiled and reviewed a comprehensive literature on the applications and challenges of nanofluids [3]. Specific applications of nanofluids in engine cooling, solar water heating, cooling of electronics, cooling of transformer oil, improving diesel generator efficiency, cooling of heat exchanging devices, improving heat transfer efficiency of chillers, domestic refrigerator-freezers, cooling in machining, in nuclear reactors, defense and space have been reviewed and presented by them [3]. Akbarinia et al. investigated forced convection Al_2O_3-water nanofluid flowing in two-dimensional rectangular micro-channels for heat transfer enhancement by addition of the nano-particles to the base fluid at low Reynolds number [4]. It is said that constant Reynolds number studies of nanofluids are not an adequate approach to evaluate the heat transfer and the skin friction factor for the nanofluids they used [4]. Liu and Li have reviewed and summarized the research done on heat pipes using nanofluids as working fluids, recently. The effect of characteristics and mass concentrations of nano-particles on the thermal performance in various kinds of heat pipes with different base fluids under various operating conditions were explored. As a result, they show that nanofluids have great application prospects in various heat pipes [5]. Mahian et al. investigated the nanofluids' applications in solar thermal engineering systems. It was found that the effects of nanofluids on the performance of solar collectors and solar water heaters are satisfactory from the efficiency, economic and environmental considerations viewpoints by them [6]. Fang et al. investigated flow boiling heat transfer of nanofluids, with an emphasis on the heat transfer coefficient (HTC), critical heat flux (CHF), pressure drop, nanofluid stability, flow and heat transfer mechanism, and flow pattern and bubble dynamics. The important achievements, inconsistence, and contradictions of the existing research results are identified, and several topics worthy of attention for future investigations are identified [7]. Hemmat Esfe et al. researched an experimental study of Fe–water nanofluids to investigate the effective thermal conductivities and dynamic viscosity of water-based nanofluids containing Fe nano-particles [8]. Li et al. examined the thermal conductivity and viscosity of ethylene glycol based ZnO nanofluids. They find out that thermal conductivity increased slightly by the increasing temperature from 15 to 55 ^{o}C and it is dependent strongly on particle concentration and increased nonlinearly with the concentration within the range studied. Moreover, they found that viscosity increased with concentration as usual for ZnO nano-particles and decreased with temperature [9]. Shafahi et al. investigated the thermal performance of a cylindrical heat pipe utilizing nanofluids with using the most common nano-particles (Al_2O_3, CuO, and TiO). When using a nanofluid, they found a substantial change in the heat pipe thermal resistance, temperature distribution, and maximum capillary heat transfer of the heat pipe [10].

Red mud is a disposal material that comes during the Bayer process for producing alumina from bauxite. Approximately 40 to 45% ratios of the bauxite ore that is used for producing aluminum leave the process as red mud. The red mud obtained during the production of aluminum from bauxite as a by-product contains valuable materials such as Fe, Al, Na, V, Ti etc. Red mud can be utilized in limited fields such as chemical industry, construction business and obtaining some elements inside it. But recycling has a high cost [11].

2. Experimental Setup

A radiator of 4 cylinder vehicle engine was utilized as the heat exchanger in the experimental work. A big portion of the heat generated by the engine in vehicles is transferred to air by means of natural or forced convection through radiator. Normally, the fluid that is circulated between the engine body and the radiator elements by means of a pump transfers the heat to the ambient by natural convection from the outside of the radiator when the engine is in stationary position. However, a fan is used for increasing heat transfer rate for the circumstances where natural convection is insufficient. The heat carrying capacity of the fluid here is an important factor. Generally a mix of distilled water and antifreeze solution is used as engine cooling liquid in vehicles. In this work, red mud is added to the distilled water with the rates of 3, 6 and 9% wt. in order to increase the thermal convection coefficient of the fluid. Before red mud-water mixture was poured into the system, it was put into reaction with Triton X 100 (about 0.3 wt.%) which is a surface activating matter. An ultrasonic vibrator generating ultrasonic pulses of 200 W and 36 kHz was used for dispersing a specified amount of red mud nano-particles in distilled water. The nanofluids were kept under ultrasonic vibrator continuously for 12 h. Tests were repeated first using distilled water only and then using the mixture of distilled water and red mud with previously mentioned ratios. Temperatures that were measured from different locations are recorded by means of a data logger. The schematic cooling system of the engine in the experimental setup is given in Figure 1.

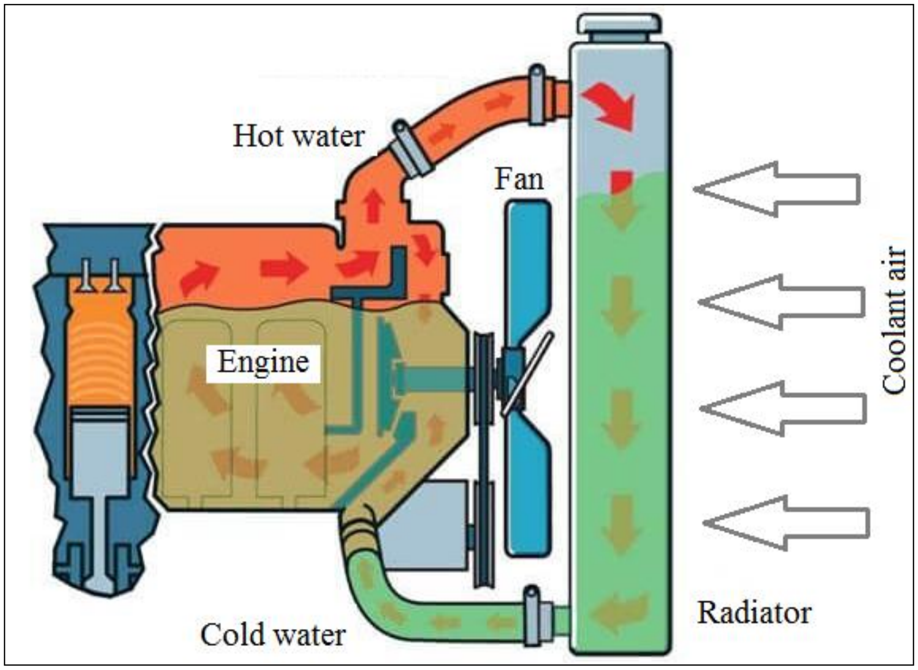

Figure 1. Schematic motor cooling system

Precious elements such as Al_2O_3, SiO_2, Fe_2O_3, TiO_2, Na_2O, CaO, P_2O_5 are contained in the body of red mud as a disposal in the process of producing aluminum from bauxite. The chemical composition of the red mud that was used in the experiments is given in Table 1 while the dispersion of nano-particle sizes is given in Figure 2.

Table 1. Chemical composition of red mud

Component	**%**
Al_2O_3	19.61
Fe_2O_3	39.01
TiO_2	5.90
Na_2O	7.86
CaO	4.47
SiO_2	13.62
Al	8,43
Other	1,10

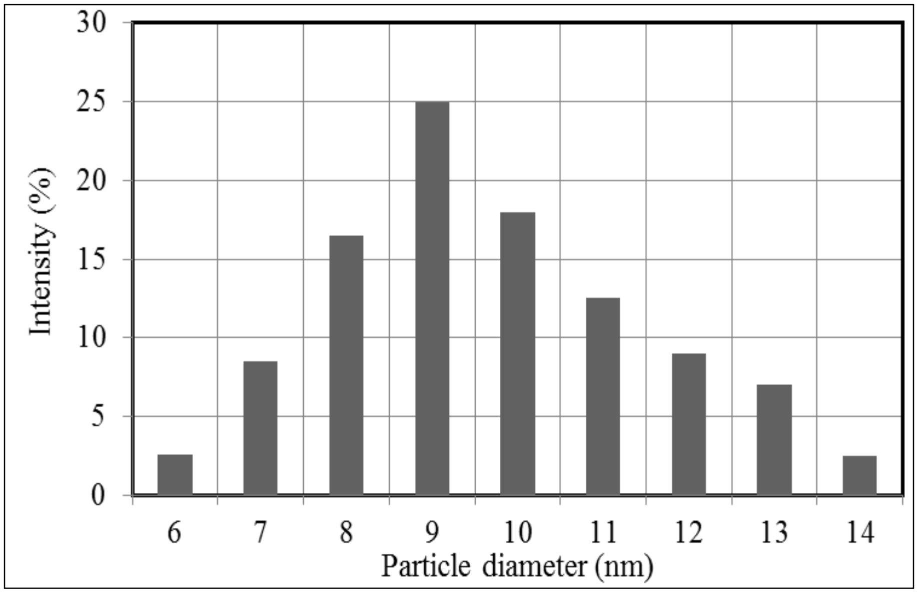

Figure 2. Size distribution of the nano-particles

The grain size of red mud was mostly (>90%) less than 12 nm. The red mud-water mixture is showed in Figure 3.

3 % 6 %

Figure 3. Red mud-water mixture with 3% and 6% concentration

3. Theoretical Analysis

Heat load of hot fluid ($\dot{Q}_h$) is calculated by the following formula.

$$\dot{Q}_h = \dot{m}_h c_{p,h} \left(T_{h,in} - T_{h,out} \right) \tag{1}$$

Where $\dot{m}_h$ is the mass flow of hot fluid, $c_{p,h}$ is the specific heat of hot fluid, $T_{h,in}$ is the inlet temperature of hot fluid and $T_{h,out}$ is the outlet temperature of hot fluid. Transferred heat from the hot fluid to cold fluid in the radiator;

$$\dot{Q}_c = \dot{m}_c c_{p,c} \left(T_{c,out} - T_{c,in} \right) \tag{2}$$

is calculated with the formula. Where $\dot{m}_c$ is the mass flow rate of cold fluid, $c_{p,c}$ is the specific heat of cold fluid, $T_{c,out}$ is the outlet temperature of cold fluid and $T_{c,in}$ is the input temperature of cold fluid.

Taken heat from radiator is equal to given heat to the environment.

$$\dot{Q}_h = \dot{Q}_c \tag{3}$$

Heat transferred from radiator to environment can be given as follows;

$$\dot{Q} = hA\Delta T_{lm} \tag{4}$$

Where h is the convective heat transfer coefficient between the fluid and the radiator, A is the area of the heat transfer of radiator.

As seen in Eq.4, ΔT_{lm} is the logarithmic mean temperature difference between the environment and the surface radiator.

$$\Delta T_{lm} = \frac{\Delta T_{in} - \Delta T_{out}}{ln\left(\frac{\Delta T_{in}}{\Delta T_{out}} \right)} \tag{5}$$

4. Results and Discussion

The difference between inlet and outlet temperatures of the radiator that was used as heat exchanger in the experimental setup gives idea about the cooling performance of the fluid. The temperatures of the radiators should be in control and regulated. This is done by thermostats. The thermostat in the experimental setup turns on the fan at 93ºC and turns off the fan at 84ºC. Natural convection is at stake between 84ºC and 93ºC when temperature is rising. Forced convection is applied between 93ºC and 84ºC when temperature is decreasing. Figure 4 is given in order to show in how much time a test fluid lowers the radiator temperature from 93ºC to 84ºC. This means that, a coolant trend with the shortest time in the figure has a better cooling performance.

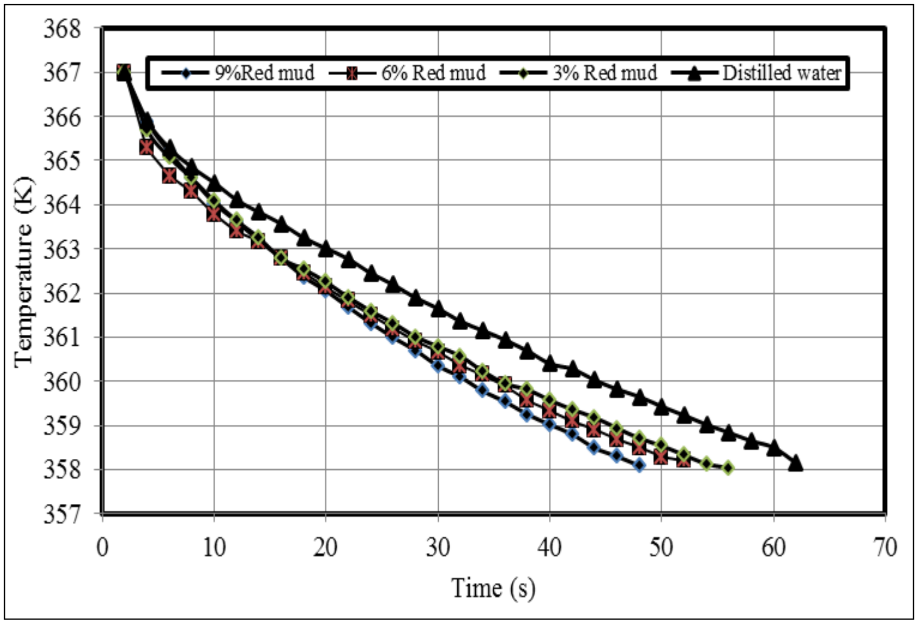

Figure 4. Temperature-Time change

The heat transfer capacity of the coolant fluid is higher for shorter times passing for reaching minimum temperature. The cooling period can be shortened about 14 seconds by using 9% wt. red mud in the distilled water. The percentage of the red mud in the distilled water seems directly proportional with the shortened time.

5. Conclusion

Four different coolants are used in this work. They are distilled water and distilled water-red mud mixtures with 3, 6 and 9% wt. ratios. Following conclusions are drawn:

- Heat transfer is enhanced by means of red mud-distilled water mixtures in every tested condition comparing to the distilled water only test.

- The reduction in time for the closure of the fan by thermostat is 10% for 3% wt. red mud; 16% for 6% wt. red mud; and 24% for 9% wt. red mud.
- The abundance of (Fe2O3) that has a high intensity in the red mud makes sedimentation faster. It is observed that nano particles in the red mud settled down after about 5 days.
- On the other hand, it was observed that red mud forms resident residues on the surfaces.

As a general conclusion, it is detected that red mud increases thermal conductivity and found as a positive factor in respect of heat transfer. However, the sedimentation in relatively short periods and the residues on the surfaces due to the red mud are the disadvantages. Additionally, the load on the circulation pump, imposed by the existence of the red mud, should be investigated theoretically and experimentally in the future.

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