Analysis of heat transfer characteristics of nanofluid synthesized using green method

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Abstract. The use of additives in the base fluid is one of the techniques to strengthen the heat transfer with the amelioration in the field of nanotechnology. A new class of heat transfer fluids has been engineered, a base fluid (host) in which nano particles (guests) are dispersed and suspended stably. Researches have showed that these fluids exhibit higher thermal conductivity than the base fluid. As a result, the study of nanofluids has materialized as a new field of scientific interest and innovative application. The present work mainly focuses on the study of heat transfer characteristics and to analyze the thermal stability & other properties of nanofluid prepared by dispersing nanoparticles that are synthesized using green method. This work not only focuses on the heat transfer enhancement but also on the phenomena that are possible for this enhancement.

1. Introduction

As a result of development in the field of nanotechnology, a new kind of material has emerged which typically falls in the nano range. The material which is known as nanoparticles has wide range of application. Metal oxide nanoparticles has been widely used in many applications such as surface coating, medical science and also as a heat transfer fluid. Aluminum Oxide or alumina generally refers to corundum, which is a white oxide. Alumina has several phases such as gamma, delta, theta, and alpha. However, the alpha alumina phase is the most thermodynamically stable phase. In general, alumina possesses different properties like high hardness, high stability, high insulation, and transparency [1]. Synthesis of alumina nanoparticles can be carried out using different methods like chemical method, physical method, biological method and green method. Miscellaneous methods like wet chemical reduction, reverse micelles, electrochemical and non-electrochemical methods are still used, but due to the assortment in the micro wave assisted green methods it is being widely used [2-6]. Synthesis of nanoparticles from plant extract is an approach of green chemistry that connects nanotechnology and plant biotechnology. Reduction of metal ions can be done by using plant extract and this process is known as bio reduction which helps to form nanoparticles. Experiments proved that plant metabolites like sugars, terpenoids, polyphenols, alkaloids, phenol acids and proteins play an important role in metal ions reduction into nanoparticles and in supporting their subsequent stability [7]. The conventional methods that are used for the synthesis of nanoparticles especially the chemical method where the chemicals used creates a toxic nature to the synthesized nanoparticle which will
eventually be a threat to the environment when disposed out. The green synthesis method aims at eradicating this threat to the environment by using plant extract for the synthesis process where nanoparticles can be synthesized more effectively and easily.

Conventional heating method can be used while synthesizing and in this method the container or the reactor is heated either by conduction or convection. But the problem with this method is that it would take time for a uniform temperature distribution. This problem of non-uniform temperature distribution can be tackled with the use of micro wave heating. Micro wave heating is a promising option for both organic and inorganic methods. The method helps in obtaining uniform heating which in turn saves time and energy [8].

Ionic Liquids which are liquids at room temperature does not possess high thermal conductivity but the improvement in thermal conductivity has been studied by Sen et al. [9] that can be used in absorption refrigeration system. Escher et al. [10] has studied the application of liquid cooling with high thermal conductivity fluids in microelectromechanical systems which helps in achieving high heat transfer rate. Prasher et al. [11] made a comparison between Brownian-diffusion and Brownian-convection based models and it was concluded that the effect of convection was instantaneously felt with that of diffusion.

2. Experiment
The experiment which is a forced convective heat transfer is conducted by using an automobile radiator with water and commercially available coolant. The nanoparticles that are synthesized using green method were dispersed in water and further analysis and performance comparison were done with the available coolants. The radiator which is used for the experiment is a commercially available one which is used in Tata Nano. The radiator was fixed to a wooden frame. The experimental setup consists of an automobile radiator mounted on a wooden frame. The coolant to be tested is stored in a container which has a capacity of 8 liters in which only 2 liters of the working fluid was taken. The heat source is a hot plate which can give a maximum heat of 2KW. A small container of 2 liters with water is embedded in the main container where two heat sources were used each of 2KW. The connection lines were made using rubber pipes of 0.5-inch ID. The flow was controlled with help of ball valve. Temperature readings were taken using K-type thermocouple bank.

The condition occurring in the engine was replicated by using a heat source, the amount of heat given was 6 KW. Usually in automobile engines the thermostat opens once the engine reaches its operating temperature i.e., generally above 80°C the thermostat opens. Here for the simplicity of analysis the condition was taken below the above-mentioned temperature. Initially the radiator was circulated with water and the steady state temperature was noted down and this process was repeated several times to get a uniform value. The steady state temperature obtained was about 40°C.
| Thickness of fin  | 0.03 mm  |
|------------------|----------|
| Tube Thickness   | 1.56 mm  |
| Total no. of fins| 11374    |
| No. of tubes     | 46       |
| Height of fin    | 8 mm     |
| Fin area         | 272.92 mm² |
| Tube area        | 25,833.6 mm² |
| Radiator total area | 1440 cm² |

Table 1: Radiator Specification.

| T1(°C) | T2(°C) | T3(°C) | T4(°C) |
|--------|--------|--------|--------|
| 34     | 30     | 32     | 40     |

Table 2: Temperature Readings With water.

T1 - Temperature of air at outlet.
T2 - Temperature of air at inlet.
T3 - Temperature of coolant at outlet.
T4 - Temperature of coolant at inlet.

We know that in a heat exchanger heat rejected by the hot fluid is equal to heat absorbed by the cold fluid and the below equation can be used to represent it:
\[ Q = mC_p \Delta T \]
\[ m_{water} = 0.04 kg s^{-1} \]
\[ \dot{m}_{air} = \rho A v \]
\[ A = \text{Area of duct} - \text{Area of radiator} \]
\[ v_{air} = 1.5 m s^{-1} \]

Effectiveness of a heat exchanger is given by:
\[ Effectiveness \varepsilon = \frac{Q}{Q_{max}} \]
After testing the radiator with water the focus has been focused on the commercially available coolant, which is manufactured by Lubz Corporation. About two liters of coolant was transferred to the storage container and same amount of heat was supplied. Composition of the coolant is as given below: According to the composition the specific heat of coolant was calculated.

\[ Q_{\text{max}} = C_{\text{min}}(T_{\text{hi}} - T_{\text{ci}}) \]

\( T_{\text{hi}} \) — Temperature of hot fluid at inlet

\( T_{\text{ci}} \) — Temperature of cold fluid at inlet

After testing the radiator with water the focus has been focused on the commercially available coolant, which is manufactured by Lubz Corporation. About two liters of coolant was transferred to the storage container and same amount of heat was supplied. Composition of the coolant is as given below: According to the composition the specific heat of coolant was calculated.

\[
\begin{array}{cccc}
T1(°C) & T2(°C) & T3(°C) & T4(°C) \\
35 & 30 & 32 & 44 \\
\end{array}
\]

Table 3: Temperature Readings With coolant

| Components                                      | CAS No.  | Range (%) |
|------------------------------------------------|----------|-----------|
| Ethylene Glycol                                 | 107211   | >90       |
| Water                                           | 7732185  | <10       |
| Organic Acids like 2-Ethylhexanoic acid, Potassium salt | 3164850  | 1-3       |
| Corrosion Inhibitor                            | -        | 5         |
| Other Additives                                 | 37344336 | <0.1      |

Table 4: Coolant Composition

The experiment was conducted by circulating coolant through the radiator with same amount of heat. The temperatures were noted down when steady state was achieved. The coolant used in the experiment was light duty vehicle coolant which is distinguished with the help of green color due to the addition of green dye.
3. Thermal stability of colloidal nanoparticles

It is essential to analyze the behavior of nanoparticles at different temperatures. Which is an essential factor that determines the stability of the nanofluid when dispersed in the base fluid. To understand this behavior the colloidal nanoparticles were prepared and were exposed to different temperature for a time interval of 30 minutes. After each exposure, the UV spectrometry was used to analyze the colloidal solution. This study is essential since the nanofluid is used in a forced convective heat transfer system. Since there will be different cycles through the radiator, the study of stability is essential to analyze the thermo-physical properties of the nanofluid. The UV of the colloidal solution was taken after each exposure. It can be observed that after each exposure, for a prolonged period the change in the UV plot is negligible.

![Figure 2. Thermal Stability test at 40°C](image1)

![Figure 3. Thermal Stability test at 50°C.](image2)
From the above plots, it can be concluded that exposure of the colloidal solution to various thermal condition had negligible effect in the stability of the solution. This in turn can be concluded as the particles when dispersed in the base fluid will retain its property for this range of temperature. This retaining is important when considering same for commercial application. Ordinary coolants will retain its property for long interval of time. The nanofluid that will be used in the automobiles has to be stable for large number of cycles.

4. Study of pH effect on nanoparticles

The stability of nanofluid mainly depends on the electro kinetic phenomenon. Stabilized nanofluid can be obtained by achieving high surface charge, which will help in generating high repulsive force.
The measurement of zeta potential becomes important for understanding the electrophoretic properties of the nanofluid. When considering pH at a value below two, the zeta potential and value of absorbency will be very low. As the pH value increases, the value of zeta potential also increases, which helps in intensifying the electrostatic repulsive force.

From the above plot, it can be understood that temperature and pH are directly proportional. Two conclusions can be drawn from this zeta potential depends on the pH of the nanofluid as the pH is increased the zeta potential also must increase which in turn demonstrate that the nanofluid is more stable. It can be said that when pH reaches an optimum value the repulsive force between the particles will be more due to high surface charge. From the application point of view, since the nanoparticles are prepared with the help of lemon extract, the citric acid content may react with radiator tube surface and erode the surface but as the temperature is increasing the pH value is increasing and it is approaching the neutral value. This ensures long life of the radiator tube.

On analyzing the radiator with water and coolant it was found that the obtained temperature difference for coolant is more when compared to that of water. Further to continue the analysis with nanofluid the nanoparticles were prepared using green method and the same were analyzed using UV spectrometer. The colloidal nanoparticles were then dispersed into the base fluid (water) and it was made to circulate through the radiator and the readings were noted. It was found that there was an enhancement in the temperature difference.

| T1(°C) | T2(°C) | T3(°C) | T4(°C) |
|--------|--------|--------|--------|
| 39     | 30     | 36.5   | 52.6   |

Table 5: Temperature Readings with nanofluid
5. Results and Discussions

From the experimental work the temperatures were noted down when water, coolant and nanofluid were used. Theoretical effectiveness was calculated for both water and coolant. For nanofluid due to certain limitations the conclusion was based on the temperature difference. It was observed that the temperature difference was double that of water for nanofluid at its maximum concentration. when passed through the radiator. It was also observed that nanofluid when subjected to high temperature it still retains its property. The reason behind this maybe that lemon is a rich source of ascorbic acid. The thermal degradation kinetics of ascorbic acid takes place at higher temperature which is above 90°C, which might be one of the several reasons for the high temperature static stability.

| T(°C) (Water) | T(°C) (Coolant) | T(°C) (Nanofluid) |
|---------------|----------------|------------------|
| 8             | 14             | 16.6             |

Table 6: Temperature difference when different coolants were used

6. Conclusion

The increase in temperature difference with nanofluid can be mainly explained with two phenomena. Since nanofluids are created by dispersing nanoparticles in the base fluid, the particles will interact with water molecules which leads to the phenomenon known as Brownian motion. Here the particles will continuously interact with the base fluid molecules which in turn increases the effective thermal conductivity of the entire fluid which in turn leads to more heat transfer. When nanofluids are passed through a cross-section there is a chance for the particles to become micro particles through the process of agglomeration and settle down to form a rapid heat conduction path (percolation paths) and they also play a role to increase the effective thermal conductivity with increase in effective volume fraction. This increase in effective thermal conductivity can be calculated by considering the effective radius of the cluster. But it is unable to predict the level of aggregation since it depends on the synthesis method and purity of the nanoparticles synthesized. The green synthesis of nanoparticles is a promising method for synthesizing the nanoparticles in a cost effective and ecofriendly manner. The nanofluid has a potential application in various fields of engineering. If it has to be brought into reality simplest method has to be adopted to synthesize the particle so that it can be used where ever necessary.

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