THERMAL CONDUCTIVITY ENHANCEMENT TECHNIQUES AND THERMAL AGING OF NANOFLUIDS-A REVIEW

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Abstract- Nanofluid, a simple product of nanotechnology is prepared by dispersing small particles of size $10^{-9}$ m in a base liquid. Due to its excellent heat conducting properties, nanofluids can be used in a wide range of applications. Still there is a need to enhance its thermal conductivity to extend its service in many more applications. In order to make the nanofluid a long term sustainable work fluid, there is a necessity to predict its aging effect which is termed as thermal aging. This review mainly focuses on thermal conductivity enhancement techniques of nanofluids and also suggests methods to calculate their effective lifetime.

Keywords- Nanofluids, Thermal Conductivity, Thermal Aging

I. INTRODUCTION

The fluids that were traditionally used for thermal conducting applications had a problem of exhibiting low thermal conductivity. Taking into account the rising demands of reality, there was a need to develop new types of fluids that would be more effective in showing their thermal conducting performance. Nanofluid is simply a colloidal suspension of nanoparticles in a base fluid. It is experimentally found to have enhanced thermal conductivity than its parent base fluid due to which they can be used in cooling, power generation, nuclear, space and biomedical applications. Though it has a high thermal conductivity, there are many techniques using which its thermal conductivity can be even more enhanced. Also, the nanofluids must have reduced thermal aging in order to be highly reliable to endure radical conditions inside the appliances. Despite thermal aging, nanofluids are of more need in upcoming future due to their ultra heat transfer ability, less friction co-efficient, less corroding and clogging properties in micro channels. Thus, the study of nanofluids is a thrust area where many solutions for existing problems can be obtained.

II. PREPARATION METHODS

Nanofluid preparation is the first and foremost step to study nanofluids. There are two main ways in which nanofluids can be prepared: (a) Single step preparation process (b) Two step preparation process. The preparation methods are described below.

(a) SINGLE STEP PREPARATION PROCESS:
Single step preparation method is the method mainly adopted to avoid agglomeration of nanoparticles. The principal behind this is vapour condensation method. As this method involves instantaneous formulating and dispersion of nanoparticles in the form of vapour it avoids agglomeration. This method is advantageous as there is no need for drying and storage of nanoparticles. Due to its complex production process it becomes more costly when compared to other processes.

(b) TWO STEP PREPARATION PROCESS:
Two step preparation method is the most widely used method for synthesizing nanofluids. This method is most suited for large scale production as it involves mixing of nanoparticles which are readily available from industries with the base fluid. The nanoparticles used in this method are prepared by powdering of nanotubes, nanofibers, etc. Due to large surface area, the nanofluid prepared can tend to agglomerate, but this can be choked by stabilizing the nanofluids.

III. THERMAL CONDUCTIVITY ENHANCEMENT TECHNIQUES

Liquids inherently have low thermal conductivity. Scientists tried to solve this by dispersing ultrafine particles into the liquid. But these particles were found to coagulate very easily in the suspension and solving the problem of coagulation became a serious problem. Eventually scientists failed to succeed in their attempt. This was finally choked after the invention of nanofluids. Though the nanoparticles face the same problem of coagulation in the base fluid, there are many ways to overcome it unlike in the case of microparticles.

Thermal conductivity of a nanofluid depends mainly on its stability, particle size and composition, nature of the nanoparticles involved in its synthesis. Viscosity of the base fluid also influences its thermal conductivity to some extent. By varying these factors the thermal conductivity of a nanofluid can be enhanced.

III.a. BY IMPROVING THE STABILITY OF NANOFLUID: By improving the stability of nanofluid during the work process, the coagulation of nanoparticles is prevented and this was proved by
Alexander Kraynov. Thus, the thermal conductivity of the nanofluid is found to increase as its stability is enhanced.

STABILITY UPHOLDMENT MECHANISM:
A) ELECTROSTATIC STABILISATION:
Stabilisation of nanofluids can be carried out by inducing surface charges on the nanoparticles. This mechanism works on the principle of electrostatic repulsion between two particles which arises from its surface charges. When two Particles approach one another under working conditions, there occurs overlapping of double layer and this develops a repulsive force between two equally sized spherical nanoparticles of radius ‘r’ and separated by a distance ‘S’ is given by the relation:

$$ S^2 = 2 \sigma \varepsilon_0 \varepsilon r E^2 \exp \left(-\frac{S}{r}\right) $$

Electrostatic stabilisation can be controlled by having an upper hand on the pH-level of the nanofluid. By adding acids (HCl) or bases (NaOH), the pH-level of nanofluids can be controlled and this addition helps us in determining the nature of the surface charge on the nanoparticles. This method has very limited usage due to its chemical reactive behaviour with the base fluid & containers in which they are stored.

B) STERIC STABILISATION:
It follows the general mechanism of attaching the polymers (generally referred to as macromolecules) on the surface of the nanoparticles. Functional groups such as carboxyl, hydroxyl and amines are the generally used macromolecular polymers. As these polymers are added into the nanofluids, the gap between the nanoparticles increases and thus coagulation is reduced. As the length of hydrocarbon chain increases, the steric stability is found to increase. Steric stabilisation can be enhanced by the addition of surfactants. However the technique is not applicable for nanofluids which are worked at high temperatures, as high temperature may damage the bond between the surfactant and the nanoparticle or may lead to the formation of foam which becomes undesirable. To overcome this difficulty, scientists tried to stick on to single step preparation process for preparing nanofluids and were making studies to reduce its cost.

If the macromolecules added to the nanofluid are free in solution, then the mechanism is known as depletion stabilisation. It is the enhanced form of steric stabilisation.

III. b. PARTICLE SIZE AND DISPERSION EFFECT:
The extent of dispersion of nanoparticles in the base fluid decides the thermal conductivity of the nanofluid and this was proved by Qiaohuan Cheng and Sourabhi Debnath. A well dispersed nanofluid is found to have better thermal conductivity than a partially dispersed one. The size of the nanoparticles in turn decides to what extent the nanoparticles can undergo dispersion in the base fluid. Experimentally it was found that a nanofluid containing 10-nm-sized Cu possessed greater thermal conductivity than a nanofluid containing 35-nm-sized Al₂O₃ nanoparticles. Thus it is clear that the thermal conductivity of a nanofluid has a direct relationship with dispersion effect which in turn depends on the particle size. The method of sonofragmentation can be used to break large nanoparticles into smaller ones before it is added into the base fluid. After the preparation of nanofluids, the dispersion of nanoparticles can be improved by the method of sonication by high powered pulses. Ultrasonic cell disrupter was used for this purpose.

III. c. COMPONENT SELECTION AND ITS COMPOSITION:
(i) Generally there are two types of nanoparticles that can be dispersed into the base fluid, they are metallic nanoparticles (Al, Cu, Ni etc) and non-metallic nanoparticles (Metal oxides, allotropes of carbon like Graphene, CNS etc). Particles having high thermal conductivity in the root state need not necessarily have an elevated thermal conductivity in their nano state.

For example, experimentally the thermal conductivity of Titanium in its root state is 22 Wm⁻¹K⁻¹ and that of aluminium is 204 Wm⁻¹K⁻¹ both measured at 68°F.

**Fig-1: Electrostatic and steric stabilisation of nanoparticles**

**Fig-2: The graph depicts that as the sonication time increases, dispersion effects of the nanoparticles in the base fluid increases up to a limiting value beyond which the thermal conductivity decreases.**
whereas in the nano state addition of 1% of TiO₂ nanoparticle enhances the thermal conductivity of the base fluid(water) by 14% which is better than the thermal conductivity of nanofluid when 1% of Al₂O₃ is added to the same base fluid.

(ii) The nanoparticles which are used in the preparation of nanofluids must have high purity, as thermal conductivity of nanofluids can be messed up due to the presence of impurities.

(iii) There is a particular limiting volume fraction for each nanoparticle. If the volume fraction increases beyond that limiting value, a fall in thermal conductivity of the nanofluid can be noted. For example, it was observed that in Fe nanofluid as the volume fraction for the sonication time of 70min was increased, the thermal conductivity of the nanofluid started to fall. (Refer Fig-2)

III.d. VISCOSITY:
Korean Space University proclaimed that viscosity also plays a significant role in enhancing the thermal conductivity of nanofluid. Nanofluid having low viscosity is well dispersed in nature. The viscosity of nanofluid can be varied by the following methods.

(i) By varying the pH-level of nanofluid, strong repulsive forces are generated between the nanoparticles and thereby reducing nanoparticles coagulation. Thus a well dispersed suspension is obtained which results in low viscosity of the nanofluid. Same method is used to enhance stability of nanofluid by principle of electrostatic stabilisation.

(ii) By varying the concentration of nanoparticles, the weight fraction of nanoparticles can be altered. By having a controlled rise in the weight fraction, mobility of nanoparticles in the base fluid can be increased. Eventually there is an improvement in the heat transportation properties of the nanofluid.

IV. THERMAL AGING:
Thermal aging is the degradation in the thermal conductivity of the nanofluid due to prolonged exposure to elevated temperature. Thermal aging of nanofluids is a very important factor that needs to be predicted in order to obtain effective reliability and a long life over a prolonged usage. Therefore, it is very important to predict the thermal aging of nanofluids in its

Thus, thermal aging is a hindrance in all long term applications. Thermal aging can be reduced by insulating the nanoparticles but this is said it have a negative impact on thermal conductivity as the heat conductive properties are reduced by insulation.

IV.a. ASPECTS OF THERMAL AGING:
long term service. Also, the working conditions of the nanofluid should be taken into consideration as the thermal aging of nanofluids are found to vary with temperature, pressure and surrounding gases. Scientists derived several formulae to predict the thermal aging of nanofluids in its operating period. One such method is the S770 test method which was developed by the Underwriter’s Laboratories of Canada (ULC). By determining mean initial thermal resistivity (Rₐ), thickness of the unscathed specimen which is usually done within 7-14 days of production and aging factor as the ratio between the thermal resistivity of the specimen at the time of aging (Rₐ,specimen,aged) to its initial thermal resistivity. Though thermal aging occurs in all fluids, it can be overcome by determining the aging period of the fluid under its long term working conditions. Delayed thermal aging is one of the main advantages of nanofluids over other fluids. By calculating the thermal aging, we can judge the effective lifetime of the nanofluid after which a deduction in its thermal conductivity is encountered. Also, all other heat transport properties tend to wane. Thus, we can estimate the decrease in its thermal conductivity during its usage and assess its quality for further usage.

As the effects shown by nanofluids when they are exposed to elevated temperature decides its lifetime and reliability, the study regarding thermal aging of nanofluids is an obligatory area where further research has to take place to understand more about the effects of accelerated aging. Prediction of thermal aging also helps in deciding the service period of nanofluids in its thermal based applications.

Aging period can be calculated by the following relation: Time of aging in days = (No. of days of operation)²(Thickness of the aged specimen/Initial thickness of the specimen)

CONCLUSIONS

In this review, an attempt was made to cover all the major techniques that can be carried out to enhance the thermal conductivity of the nanofluid. Surprisingly, nanofluids exhibited a rise in thermal conductivity which was beyond the expectations and much higher than the theoretical predictions. The following conclusions were made on account of a few available experimental results.

1. Thermal conductivity increases with increase in stability of the nanofluid.
2. A well dispersed nanofluid has a better thermal conductivity compared to a partially dispersed nanofluid.
3. A particle having a high thermal conductivity in its root state need not necessarily have an elevated thermal conductivity in its nanostate, when dispersed in a base fluid.
4. In the preparation of nanofluids, it is found that, as the volume fraction of the nanoparticles in the nanofluid increases the thermal conductivity also increases up to the attainment of a limiting value. The thermal conductivity is found to fall after this.
5. The nanofluid with low viscosity is found to have improved thermal conductivity than the one with a higher viscosity.

In Recent days, thermal aging has become a major problem faced by many fluids in their real time applications. So, there is a necessity to predict the thermal aging of the nanofluids and make studies to overcome it without causing any disturbance to its thermal conductivity.

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