ISSN 2286-4822
www.euacademic.org

EUROPEAN ACADEMIC RESEARCH
Vol. III, Issue 10/ January 2016

Impact Factor: 3.4546 (UIF)
DRJI Value: 5.9 (B+)

Mechanism of Heat Transfer in Nanofluids

MANZOOR ATHAR
B.Tech (Mechanical)
M.Tech (Nanotechnology)
Department of Applied Physics
Aligarh Muslim University, India

Abstract:

In this paper the mechanism of heat transfer in nanofluids is studied. Some experiments were conducted to measure specific heat of fluids with and without nanoparticles. A significant reduction in specific heat of fluids with nanoparticles was observed. The explanation of this observation can be given through lumped capacity analysis.

Key words: heat transfer, nanofluids

Introduction:

In this era, we are always surrounded by technologies, most of them are meant to make our life easy for example computers, mobiles, automobiles etc., these devices that make our life easy often get heated while performing, which leads to a lack in performance of these devices.

To overcome the above mentioned problem and for our personal comfort we need cooling systems.

And to produce the power to be used for these purposes we need heat.

In other words we can say that heat is one of the most important forms of energy we use. The statement would also be true if we say that there is no existence of cold, it is just the absence of heat.

Thermal energy is the type of energy that a thing has because of its temperature. In thermodynamics, thermal energy is the internal energy present in a system in a state of thermodynamic equilibrium because of its temperature [1]. That is, heat is defined as a spontaneous flow of energy (energy in transit) from one object to another, caused by a difference in temperature between two objects; so objects do not possess heat [2].

To understand heat it is very important for us to understand temperature, temperature is basically the measure of average kinetic energy of particle the elements is made of and the energy of the particles is called as the internal energy of the system. The heat transferred to the system is the increment in the internal energy and the total work done by the system according to first law of thermodynamics. The unit of heat is Joule.

Measurement of Heat:

Heat is measured using a calorimeter (an insulated vessel through which heat cannot escape) and water is placed into it which has a known specific heat (amount of heat required to raise the temperature of one gram of substance by one degree), the initial and final temperature of water is recorded and heat supplied is calculated using the following formula-

$$Q = mC_p(T_2 - T_1) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \{1\}$$

Where, m = mass of the water

C_p = Specific heat of water at constant pressure

T_1 and T_2 = these are initial and final temperature of water

It is clear that the ability to absorb heat by any material depends largely on the specific heat of the material.

Nanofluids:

Fluids with nanoparticles dispersed in them are called nanofluids. Nanofluids, first suggested by S.U.S. Choi of Argonne National Lab in 1995(Choi), is a new, innovative working fluid for heat transfer created by dispersing highly thermal conducting solid particles smaller than 50 nm in diameter in traditional low thermal conducting heat transfer fluids such as water, engine oil, and ethylene glycol. Micro-refrigerator (Zhang et al., 2005), spray cooling (Vanam et al., 2005), and heat pipes (Peterson, 1994) are some of the recently developed highly efficient heat transfer technologies but the application of these technologies are limited to small scale cooling.

One of the biggest questions regarding nanofluids is that, why nanofluids are so much stable? Answer to this question can be given by following equation.

$$U_s = \frac{2\, d_p^2(\rho_p - \rho_{BF})g}{9\mu_{BF}} \quad [4] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \{2\}$$

Where, U_s = Sedimentation speed
d_p = Diameter of particle
ρ_p = Density of particle
ρ_{BF} = Density of base fluid
g = Acceleration due to gravity
μ_{BF} = Viscosity of base fluid

From the above equation it can be noticed that the sedimentation speed is related directly to particle size and inversely related to base fluid viscosity. In case of nanoparticles the problem of sedimentation is eliminated since the particle size is very less. Not only that nanoparticles have extremely large surface area and heat transfer occurs on surface of fluid resulting into enhancement of fluid's thermal conductivity. The smaller the size of particle is the larger the thermal conductivity. And that is why nanofluids can be used in microchannels as well as large scale cooling such as heavy duty vehicles engines.

Related Work:

Nanofluids attracted many researchers due to surprisingly higher thermal conductivities than those of the theoretical prediction by Maxwell (1904) and Hamilton- Crosser (1962), whose theories have good agreement to estimate the effective thermal conductivity of solid particles in continuum phase. To understand the mechanism of these abnormalities, many researches have conducted experiments and published papers by numerical/ theoretical and experimental approaches.

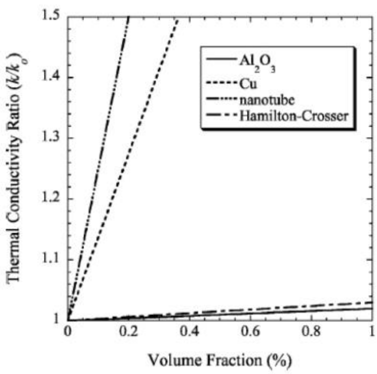

Figure 1.2 Thermal conductivity enhancements of example nanofluids depending on particle's volume fraction [5].

Experimental:

Preparation of nanofluids:

The fluid samples were prepared by taking appropriate amount nanoparticles according to weight percent required. The measured amount of nanoparticles was then mixed with the fluid using magnetic stirring or cyclomixer if the particle is magnetic, then the mixture was subjected to ultrasonic sound waves using ultrasonicator.

Using the above mentioned method following nanofluids were prepared:

1. 0.5 wt % of TiO_2 nanoparticles + lubricant (Zerol 200 TDS)
2. 0.75 wt % of TiO_2 nanoparticles + lubricant (Zerol 200 TDS)
3. 1 wt % of TiO_2 nanoparticles + lubricant (Zerol 200 TDS)
4. 1.25 wt % of TiO_2 nanoparticles + lubricant (Zerol 200 TDS)

Measurement of specific heat:

Water was first kept in the sample container (calorimeter) and the steam was allowed to flow through the pipe which was submerged in water, for some specific time.

The initial and final temperature of water was noted. Since water has a known specific heat i.e. 4186 J kg^{-1} K^{-1} the heat supplied can be calculated using the following formula –

$Q = mC_p(T_2 - T_1)$............................ {3}

Where Q= amount of heat supplied
m = mass of water heated
T_1, T_2 = initial and final temperature
C_p= Specific heat of water

In the third step, fluid in test was replaced by nanofluids with some known mass.

Again steam is allowed to flow through the pipe (B) for same interval of time and initial and final temperature was noted. Specific heat of nanofluid was calculated using the following formula –

$C_p = \frac{Q}{m_{nf}(T_2 - T_1)}$ .... {4}

Observations and Explanation:

The average specific heat of nanofluids with 0.5 wt % of TiO_2 nanoparticles was found to be 3761.6 J kg^{-1} k^{-1} whereas the base fluid has a specific heat 5118.7 J kg^{-1} k^{-1}. That was a 26.5 % reduction in specific heat of fluid.

When the same fluid was tested with 0.75 wt % of TiO_2 nanoparticles a reduction of 28.6 % in specific heat was observed.

At the concentration level of 1 wt % of TiO_2 in same fluid the reduction in specific heat increased to 34.3 %.

When the concentration was increased to 1.25 wt % of TiO_2 nanoparticles the reduction remains to 32.1 %.

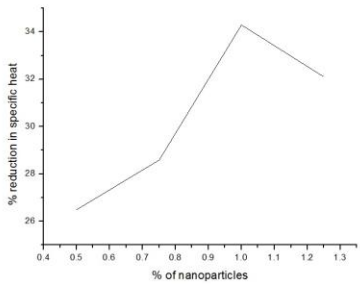

Fig 5.1

Figure 5.1 shows there is an increment in specific heat after the weight % of nanoparticles in fluid exceeds a certain value. This may be because of the reduction in thermophoretic effect, the movement of particles in the direction of thermal gradient is hindered by the high density of nanoparticles encountered in the way of nanoparticles energized by hot fluid molecules.

Mechanism of Heat Transfer in Nanofluids:

In nanofluids the exchange of thermal energy happens between fluid and nanoparticles through convective mode.

To explain heat transfer in between fluid and nanoparticles we have to consider lumped capacity analysis. For lumped capacity analysis Biot number should be smaller than one.

The Biot number is defined as [11]:

$Bi = \frac{hL_C}{k_b}$ ………………………………{5}

where:

- h = film coefficient or heat transfer coefficient or convective heat transfer coefficient
- L_C = characteristic length, which is commonly defined as the volume of the body divided by the surface area of the body, such that

$L_C = \frac{V_{body}}{A_{surface}}$………………………….. {6}

- k_b = thermal conductivity of the body

The characteristic length of a nanoparticle with a spherical shape can be given as:

$$L_C = \frac{V_{body}}{A_{surface}} = \frac{\frac{4}{3}\pi\left[\frac{D}{2}\right]^3}{4\pi\left[\frac{D}{2}\right]^2} = \frac{D}{6} \text{ ……………. } \{7\}$$

Since the diameter of a nanoparticle is very less i.e. in a unit of billionth of a meter. The particles used in the experiment was of 30 to 45 nanometers in diameter.

Since L_C is very small, the value of biot number will also be very small i.e. lesser than one, which can be concluded that lumped capacity analysis is applicable.

Using lumped capacity analysis all the physical parameters can be lumped in one time-constant T [11].

$T = \frac{\rho CV}{\bar{h}A} = \frac{\rho CD}{6\bar{h}}$ ………………………… {8}

$T \; \alpha \; D$ ………………….. ……………. {9}

Where T is the time required for the nanoparticle to attain the temperature of oil.

ρ = density of particle

C = specific heat of particle

Result:

As shown in equation {9} the value of time constant is directly proportional to the diameter of particle. So for particles of size range of nanometers value of time constant will be very less.

The time constant has a very small value and because of thermophoretic effect there will be relatively faster movement of particle in the direction of thermal gradient than fluid molecules resulting into faster heat transfer within the fluid itself and also with the bodies in contact with fluid.

The thermophoretic effect is reduced when the number of particles moving in the direction of thermal gradient is increased resulting into higher values of specific heat of fluid and less efficient heat transfer.

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