Enhancement of Thermal Properties of Dielectric by Adding Nanoparticle

Anurag Pandey[1], Dr. S. M. Hussain[2]

[1]M.Tech. Scholar, Department of Mechanical Engineering, Institute of technology & Management, Aligarh, U. P., India
[2]Associate Prof., Department of Mechanical Engineering, Institute of technology & Management, Aligarh, U. P., India

---***---

Abstract - In this thesis, an enhancement of thermal properties of dielectric has been performed by adding copper nanoparticle into it. For this purpose the nano-particles were manufactured and whole process is demonstrated experimentally. It was found that up-to some extend conductivity of the base fluid increasing with the concentration of nanoparticle addition. Moreover, the practical application of the present concept has been experimentally analyzed by conducting the experiments on Electrical discharge machining (EDM). This work primarily focuses on enhancement of thermal conductivity of dielectric fluid used in Electric Discharge Machining. Experiments were conducted on electric discharge machine to investigate the influence of copper nano particles on the material removal rate, surface roughness and enhancement of thermal conductivity of the dielectric fluid used in Electric Discharge Machining. Here, PMEDM, a new EDM technique is used where a powder is added in the dielectric fluid. PMEDM has shown good results as compared with conventional EDM. It has been observed that material removal rate increases with the increases in discharge current. The results were obtained 18 to 36 % increment in the metal removal rate due to enhancement of thermal conductivity.

Key Words: PMEDM, Electric Discharge Machining, conductivity,

1. INTRODUCTION

The thermal conductivities of the fluids like ethylene glycol, water, etc. are quite less than solid phases. One can say that mostly solids have better heat transfer properties than traditional heat transfer fluids. This leads to the development of heat transfer fluids with high thermal conductivity. Another method is the use of additives, which enhance the heat transfer performance of base fluids. The deferred metallic or non-metallic particles increase the transport properties and heat transfer properties of the base fluid. The most operative way to improve the thermal conductivity of base fluids is to add some small solid particles into the fluids.

It was studied that solid particles of micron size were added in the base liquid to improve heat transfer co-efficient. But these small sized particles tend to settle down rapidly, clog flow through channels, corrode pipelines and that reduces process efficiency and pressure drops takes place in the pipe. It was found that, fluid with micron-sized particles were not efficient enough to outweigh the disadvantages connected with their uses and the result which comes out by the use of nanoparticles in heat transfer liquids (Nano fluids)are very much in demand from the last decade. Nano fluids are heat transfer liquids with dispersed nanoparticles. Nano fluids are effectual of increasing the heat transport properties, thermal conductivities of the base fluid and increase the efficiency and may require applications in the field of enhanced heat transfer.

It is projected that these could be used in airplanes, micro reactors, micro machines in MEMS etc. Nano-fluids can be used in future for efficient heat transfer for the new possibilities to enhance heat transfer performance compared with pure liquids.

1.1 Production of nano-particle

It was found that several studies used a double-step method, in the first step nanoparticles or nanotubes are formed as a dry powder and in the second step they are spread into the base fluid. On the other hand, in the single-step method mixture of nanoparticles is directly fed into the heat transfer fluid. Both the double-step and single-step methods

1.2 Crushing in Ball Mills:

Crushing in ball mills is an important technical method to decrease the size of particles which may have unlike nature and a wide variety of chemical, mechanical and physical properties. Few examples are the various ores, limestone's, minerals, etc. The various applications of this ball mills are universal in mineral processing and mining industry, chemical industry, pharmaceutics and cosmetics, ceramics, metallurgy, cement production, etc. Instead of particle size reduction, ball mills are also able to use for mixing, blending, mechanical alloying, dispersing and amorphisation of materials .In construction, a ball milling device is used which consists of a cylindrical vessel and at both the ends it allows rotation of the vessel with respect to center axis. Girth gear is used to drive this mill and a prime mover moves the pinion shaft. This prime movers is mostly synchronous motors fitted with an air clutch or gear transmission. After filling the starting material (ore, rock, etc.) and the grinding media (balls), the milling process starts during rotation result causes transfer of kinetic energy into grinding products due to moving grinding media.

The design and structure of a ball mill depends on the size, the equipment used to load the starting material, and the discharging output product. The size of mill is defined by the ratio of "length to diameter" and this ratio varies from 0.5 to 3.5. The starting material can be loaded either by means of a single or double helical scoop feeder.

In order to require the preferred particle size, the milling under industrial conditions is usually completed in grinding circuits with classifiers which discrete the material according to particle sizes. The possible cases of open- and closed-circuit systems are shown below in Fig. 1.2.

Fig 1.2 Open and Closed circuit system

In the open circuit system output material is simply divided in fractions with different particle sizes and the classifier does not affect the grinding process. In the close circuit system only fine product obtained at the output because the classifier returns rough material back to the mill feed. The main objective of mills and classifier is to increase the grinding efficiency of the overall procedure.

The main purpose of the grinding process is to get preferred particle size supply in the final product without metal or other possible infection, increasing the amount of grinding particles and decrease the production cost of the overall system. To complete these objectives several mathematical and control methods are formulated and applied in practical.

1.3 EDM Process

Electrical discharge machining (EDM) is a nonconventional metal removal process. This process is generally used in modern metal working industry for manufacturing composite cavities in molds and dies, which are not informal to manufactured by conventional machining process and it can also machine on hardened tool steels. Though, it has low machining efficiency (depending on thermal conductivity of dielectric) and reduced surface finish of the restricted applications. To overcome these problems, one new technique was discovered which can improve the efficiency and surface finish in EDM process in the presence of copper nanoparticles added in the dielectric fluid. So this new technique for material removal process is termed as powder mixed EDM (PMEDM). Here very fine abrasive powder of copper is added into the dielectric fluid of EDM. As we mix the nano particles, performance of EDM changes. This powder is electrically conductive which reduces the insulating strength of the dielectric fluid and increases the spark gap between the tool and work piece. Hence we observe that process becomes more stable by enhancing thermal conductivity, so it increases material removal rate (MRR) and surface finish.

1.4 Powder mixed EDM Procedure

An experimental setup established for PMEDM is shown in fig1.3,

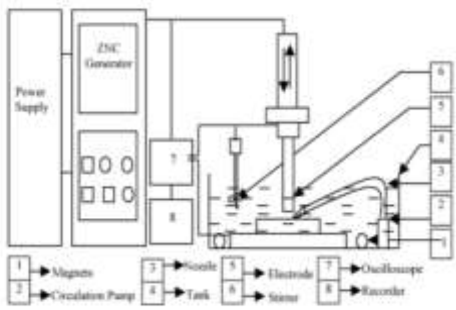

Fig 1.3 Experimental setup for PMEDM

A small dielectric circulating device is added to the designed system. A stirring system is added to avoid the particle settling. These systems are added in such a way that, it can work at commercial level. A pump of micro size is attached for better circulation of the powder mixed dielectric fluid. The stirrer and pump both are attached in the same tank. In this process, copper nanoparticles are added into the dielectric fluid of EDM.

1.6 Thermal Conductivity of dielectric fluid

Heat transfer fluids (HTFs) have many industrial and civil applications, like air-conditioning, transport, energy supply, and electronic cooling, etc. Earlier HTFs, like water, oils, glycols and fluorocarbons have naturally poor heat transfer performance because of low thermal conductivities. Research and progress activities were done to improve the heat transport properties of liquids. Solid metal materials, like as silver, copper and iron, and non-metal materials, like as alumina, CuO, SiC and carbon nanotubes, have much more thermal conductivities than earlier HTFs, solid particles of micron size , in fact millimeter sized were mixed into the base fluids or slurries. However, large solid particles creates some problems, like as abrasion of the surface, obstruction of micro channels, corroding the pipeline and increase the pressure drop, which greatly bounds the practical applications.

So many other ideas were given by researchers around the volume fraction and particles geometry. Hamilton-Crosser (HC) model which depends on the Maxwell's model, about both the factors volume fraction and the particles geometry (Hamilton and Crosser [1]; Hamilton and Crosser [2]).

Mostly, Nano fluids are made by mixing particles of nanometer-sized (1-100 nm) or in the form of drops into HTFs. Nanoparticles have single properties, such as large surface area to volume ratio, physical properties of dimension-dependent and low kinetic energy. A most attractive quality of Nano fluids is that small amount of addition of nanoparticles gives higher enhancement in thermal conductivity about 10 times more than the theoretically predicted. Eastman et al [3] described a 40% increase in thermal conductivity of ethylene glycol with 0.3 vol.% of copper nanoparticles in it.

HC model presents a good report of the systems that micron sized or larger-size particles are unable to estimate the measured thermal conductivity of Nano fluids. Keblinski et al [4], presented four possible mechanisms in nanofluids which tells about the thermal conduction:

(1) Brownian motion of nanoparticles;

(2) Liquid layering at liquid/particle border;

(3) Ballistic nature of heat transport in nanoparticles;

(4) Nanoparticle gathering in nanofluids.

It was studied that, Brownian motion of nanoparticles is quite slow to transfer a huge amount of heat through a nanofluid, however, it have an indirect role to create a convection-like micro-environment near the nanoparticles and gather the particles to enhance the heat transfer; an ordered interfacial liquid molecule layer are not only liable for the uneven increase of thermal conductivity, but this mechanism shows good results when the particle size is smaller than 10nm; nanoparticle assembly have both the effects positive and negative to increase the thermal conductivity. Whereas these possible mechanisms can explain only the thermal behavior of Nano fluids partly, therefore we need some more considerable and comprehensive experimental and theoretical searches with new Nano fluids for the better thermal performance.

1.7 Thermal Conductivity of Nano fluids

In this section, the thermal conductivity measurement of the Nano fluids is discussed. Here few mechanisms are discussed for the high thermal conductivity of Nano fluids is shown in different sections. Fig 1.4 shows the relation between relative velocity and volume fraction.

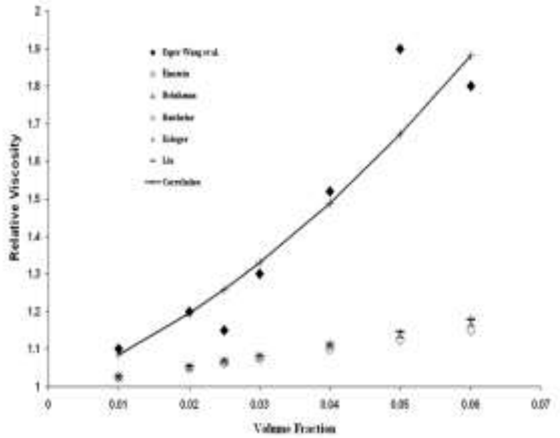

Figure 1.4 Effect of Nanoparticles viscosity with volume fraction

1.8 Thermal Conductivity of Nano fluids models

It was observed that the thermal conductivity enhancement of Nano fluids was more than conventional models for bigger size particle dispersions. Therefore, some researchers (Li and Xuan [9]); Keblinski et.al [8]; Xie etal [13]) discovered the mechanisms of heat transfer in Nano fluids, and concluded four possible reasons for the system of contribution:

2.5.1 Brownian motion of particle

2.5.2 The nature of the heat transfer in nanoparticles

2.5.3 The clustering effects of nanoparticles

2.5.4 Molecular-level layering of the liquid at the solid/liquid interface

Fig 1.5 shows the relation between thermal conductivity and volume fraction for different models.

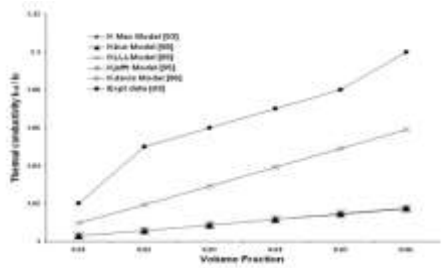

Figure 1.5 Comparisons of the Conventional Models with the Experimental Data

2. Methodology and experimental Setup

2.1 Experimental analysis

In this chapter the enhancement of thermal conductivity has been experimentally analyzed by conducting the experiments on EDM machine. Copper nano particles were added in the base fluid (dielectric) .PMEDM is a new EDM technique in which powder is added to the dielectric fluid. Few powders which are generally added are copper, aluminum, silicon carbide, graphite, chromium, nickel etc. PMEDM shows best results as compared to conventional EDM. It increases machining rate. It is observed that by adding of nanoparticles in the dielectric medium, it improves the break down characteristics and decreases the insulating strength which increases the spark gap between the tool and work piece. This helps in the uniform flushing of the debris which stabilizes the process and hence increases machining rate and surface finish.

2.2 Experimental setup:

The fig 2.1 shows the description of adding Nano particle into the dielectric.

Fig 2.1 Recirculation system

The next fig shows the powder mixed dielectric

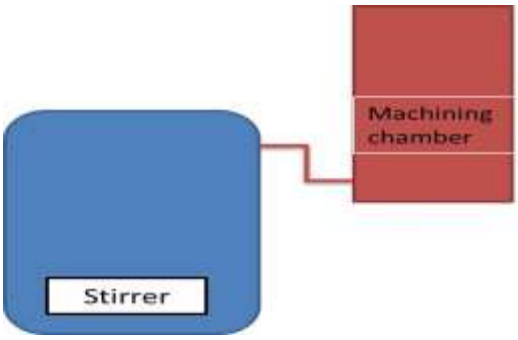

Fig 2.2 Mixing chamber

The real image of same is as follows

Fig 2.3 complete setup

2.3 EDM Working Principle

The working principle of EDM is based on the thermoelectric energy. This energy is produced between electrode and work piece and work piece is submerged in dielectric fluid where electric current passes. The specific small gap between work piece and electrode is called spark gap. This spark gap is filled with insulating gap, The hydrocarbon oil or de-ionized (de-mineralized) water are used as dielectric Schumacher defined the technique of material erosion employed in EDM . It is because ignition of electrical discharges in a dirty, liquid filled gap, when applying EDM, is generally known as ion action identical as found by physical research of discharges in air or in vacuum as well as with investigations on the innovation strength of insulating hydrocarbon liquids.

The working principle of EDM as shown in Fig.3.4 This technique was developed in the late 1940s. The electrode comes closer to the work piece to decrease the spark gap to increase the applied voltage to ionize the dielectric fluid .Electrode and work piece get separated during short discharge at dielectric gap. At very small cross sectional area the dielectric fluid discharges energy into a channel. It cools the two electrodes, and flushes away the material machining from the gap. The discharge energy and the time of spark start get affected due to electric resistance of dielectric. Low resistance results in early discharge. A servo system is that which compares the gap voltage with a reference value and servo system also ensure that the electrode keeps correct spark gap and moves at proper rate, and also protect the electrode if short- circuiting occurs. The feed speed increase when average gap voltage is higher than servo reference voltage. On the other hand the feed speed decreases when the average gap voltage is lower than the reference voltage, which is the used when smaller gap widths causes smaller ignition delay.

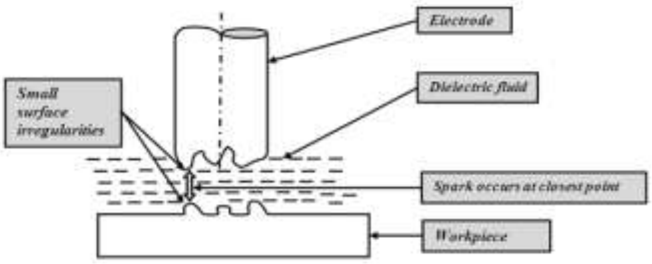

Fig 2.4 Working principle of EDM

In this process there is no direct contact between the work piece and electrode, thus eliminating mechanical stresses, chatter and vibration problems during machining. Different activities are accepted by researchers depend on the interest of the researchers and the availability of the technology. Rajurkar has stated some future trends actions in EDM: machining hard materials, uses powder additives for mirror surface finish, automation and ultrasonic-assisted EDM and control.

3 RESULTS AND DISCUSSION

In this chapter we are discussing about the obtained result of enhanced thermal conductivity and improved MRR with the help of 2D and 3D graphs. And concluded that how much concentration is best suited for best MRR.

3.1 Result on enhancement of thermal conductivity

The copper nano-particle was added in dielectric to enhance their thermal conductivity. Performance of the process has been analysed by conducting experiments in EDM machining.

The thermal conductivity of the fluid was found to be raised with the concentration of nanoparticles and same is presented in Fig. 3.1

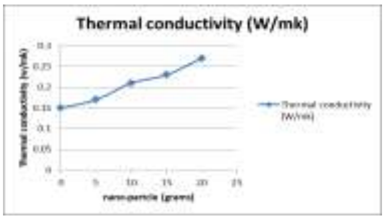

Fig. 3.1 Effect of concentration of nanoparticles on thermal conductivity

Result for the effect of parameters on thermal conductivity is presented above. Fig 5.1 shows the relation between enhancement of thermal conductivity with different concentration of nanoparticles. It can be clearly seen that with increase in concentration of nanoparticles the thermal conductivity increases. The amount of change in thermal conducivity is higher at higher values of concentration and the amount of change in cnhancement of thermal conductivity takes place.

The result of these experiments along with input and output parameters are shown in the Table 4.2. All the reading was taken according to Design of experiments (DOE).To understand the interaction of input parameters with respect to output parameter, graphs were drawn of output vs. input parameters for which three other parameters were kept at fixed level. To understand the effect of responses with interaction of 2 parameters together, 3-D graphs were drawn using the Design Expert software 7.0.0.

In these graphs two other parameters were kept at fixed level and the graph was drawn between the specific parameters, effect of which was to be studied.

As per design expert software, the following combination is taken for the experimentation Eastman et al.(Eastman et al. 2001) also found 40% increase in thermal conductivity.

3.2 Discussion on effect of various parameters and their interaction on enhancement of k or Material Removal Rate

3.2.1 Effect of discharge current

The variation of material removal rate with discharge current is shown in Fig 5.2 From the graph it can be seen that MRR increases with the increase in the discharge current. This is due to the increase in the spark energy and power.

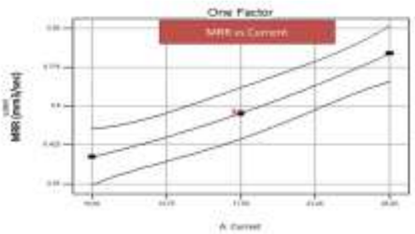

Fig.3.2 Effect of Current on MRR

The rate of heat generation in inter-electrode gap increases with increasing discharge current. When powder is mixed with the mineral oil there are lot of current conducting particles present in the discharge gap and because of this the breakdown voltage of the mineral oil becomes lower.

3.2.2 Effect of concentration of nano-particle

The variation of material removal rate with concentration of powder is shown in Fig.3.3. From the graph it can be seen that MRR initially increases with the increase in the concentration of copper powder but after certain concentration it starts decreasing.

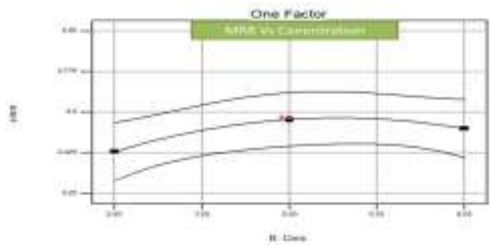

Fig.3.3 Effect of Concentration on MRR

As mentioned earlier when powder is mixed into the oil there are a lot of current conducting particles in the discharge gap and because of this the breakdown voltage of the oil becomes lower. So the process of electrical discharge becomes easier and MRR increases but after certain concentration of powder in the oil MRR starts decreasing because the powder starts sedimenting and is not properly flushed from the discharge gap which adds to the already present debris form the work piece. Due to improper flushing of the debris and powder the MRR starts decreasing.

3.2.3 Effect of Duty cycle

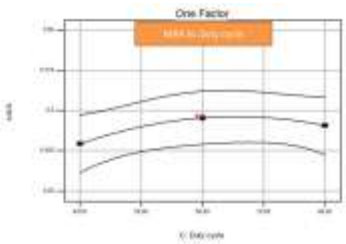

Fig.3.4 Effect of Duty cycle on MRR

The variation of material removal rate with duty cycle can been seen from Fig. 5.4 it can be seen from the figure that there is small but continuous increase in MRR with the increase in the duty cycle. In present work the percentage change observed in MRR for PMEDM with unit change of duty cycle is 0.46% higher than the values observed for conventional EDM.

At higher duty cycle ignition conditions improve due to strong heat, since the pulse interval is shortened as the pulse duty factor rises with simultaneous growth in the amount of removed material.

3.3 MRR variation with interaction of concentration and current

The variation of MRR with interaction of concentration and current can been seen from the Fig. 5.5 The MRR increases with increase in current and MRR is first increasing and then decreasing after an optimum value of concentration.

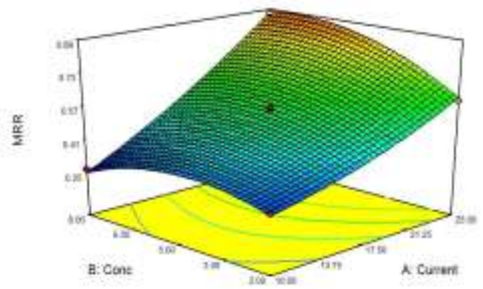

Fig.3.5 Variation of MRR with Current and Concentration

The amount of change in MRR with current is higher at higher values of concentration and the amount of change in MRR with concentration is higher at higher values of current. So it can be inferred that the maximum MRR can be obtained at high values of current and at the optimum value of concentration.

3.4 MRR variation with interaction of concentration and duty cycle

Variation of MRR with interaction of duty cycle and concentration can been seen from Fig. 5.6 MRR increases with increase in duty cycle while with increase in concentration MRR increases till the optimum point and then decreases.

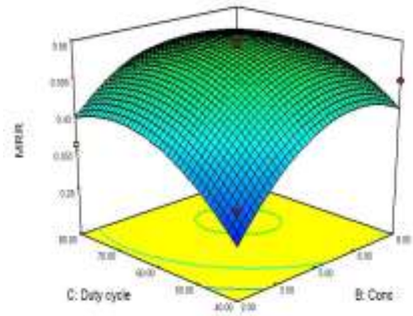

Fig. 3.6 Variation of MRR with Duty cycle and Concentration

3.5 MRR variation with interaction of Current and Duty cycle

Amount of change in MRR with change in duty cycle is higher at higher values of concentration. Amount of change in MRR with change in concentration is also higher at higher values of duty cycles shown in fig 5.7.

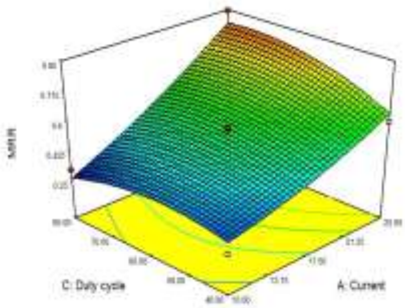

Fig 3.7 Variation of MRR with Duty cycle and Current

4. CONCLUSIONS

In this work, experimental study of enhanced thermal conductivity of dielectric by introducing EDM to find the Material Removal Rate (MRR) and Tool Wear Reduction (TWR) were analyzed. It is conducted that the increase in thermal conductivity has significant impact on different parameters of EDM. The major findings are summarized as follows:

- ✓ Based upon the following experimental setup, we found that as we add copper nanoparticles powder in the dielectric (kerosene) it increases between 13 to 32% enhancement in the thermal conductivity.
- ✓ So as we add copper nanoparticles in dielectric it increases the MRR and decrease the TWR.

REFERENCES

- ✓ Eastman, J. A., Choi, S. U. S., Li, S., Yu, W., and Thompson, L. J. (2001). "Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles." Applied Physics Letters, 78(6), 718-720.
- ✓ Keblinski, P., Eastman, J. A., and Cahill, D. G. (2005). "Nanofluids for thermal transport." Materials Today, 8(6), 36-44.
- ✓ Biercuk, M. J., Llaguno, M. C., Radosavljevic, M., Hyun, J. K., Johnson, A. T., and Fischer, J. E. (2002). "Carbon nanotube composites for thermal management." Applied Physics Letters, 80(15), 2767-2769.
- ✓ Choi, S. U. S., and Eastman, J. A. "Enhancing thermal conductivity of fluids with nanoparticles." International mechanical engineering congress and exhibition, San Francisco, CA, 1995.
- ✓ Eastman, J. A., Choi, S. U. S., Li, S., Thompson, L. J., and Lee, S. "Enhanced thermal conductivity through the development of nanofluids." Fall Meeting of the Materials Research Society (MRS), Boston, USA, 1996.
- ✓ Keblinski, P., Phillpot, S. R., Choi, S. U. S., and Eastman, J. A. (2002). "Mechanisms of heat flow in suspensions of nano-sized particles (nanofluids)." International Journal of Heat and Mass Transfer, 45(4), 855-863.
- ✓ Li, C. H., and Peterson, G. P. (2006). "Experimental investigation of temperature and volume fraction variations on the effective thermal conductivity of nanoparticle suspensions (nanofluids)." Journal of Applied Physics, 99(8), 084314.
- ✓ Liu, M. S., Lin, C. C., Huang, I. T., and Wang, C. C. (2006). "Enhancement of thermal conductivity with CuO for nanofluids." Chemical engineering and technology, 29(1), 7277.
- ✓ Liu, M. S., Lin, M. C., Huang, I. T., and Wang, C. C. (2005). "Enhancement of thermal conductivity with carbon nanotube for nanofluids." International communications in heat and mass transfer, 32(9), 1202-1210.
- ✓ Masuda, H., Ebata, A., Teramae, K., and Hishinuma, N. (1993). "Alteration of Thermal conductivity and Viscosity of Liquid by Dispersing Ultra-fine Particles." Netsu Bussei (Japan), 7(4), 227-233.
- ✓ Xie, H., Wang, J., Xi, T., and Liu, Y. (2001). "Study on the thermal conductivity of SiC nanofluids." Journal of the Chinese Ceramic Society, 29(4), 361-364.
- ✓ Assael, M. J., Chen, C. F., Metaxa, I., and Wakeham, W. A. (2004). "Thermal Conductivity of Suspensions of Carbon Nanotubes in Water." International Journal of Thermophysics, 25(4), 971-985.
- ✓ Patel, H. E., Das, S. K., Sundararajan, T., Sreekumaran Nair, A., George, B., and Pradeep, T. (2003). "Thermal conductivities of naked and monolayer protected metal nanoparticle based nanofluids: manifestation of anomalous enhancement and chemical effects." Applied Physics Letters, 83(14), 2931-2933.
- ✓ Lee, S., Choi, S. U. S., Li, S., and Eastman, J. A. (1999). "Measuring thermal conductivity of fluids containing oxide nanoparticles." Transactions of the ASME. Journal of Heat Transfer, 121(2), 280-289.