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Recent Advances In Nanofluids

Sayali Dakhole[1], D Yamini D.V.S Anand[2][1] Dr. K.G.Rewatkar[2], Dr. A.R.Bansod

Dr.Ambedkar College, Deekshabhoomi, Nagpur

ABSTRACT: *Various nano materials are being developed in the field of science. There are many present researches which concentrate on nanofluids containing different nanoparticles with various volume concentration and size used in heat transfer applications. Nanofluid is an environmental friendly and also provides better efficiency than the fluids that are being used presently. Nanofluid is a colloidal mixture of nano sized particles in a base fluid to enhance the heat transfer characteristics suited for practical application. Nanofluids area unit embryonic fluids that exhibit thermal properties superior than that of the standard fluid. The application of nanofluids is to attain the thermal properties at the smallest possible concentrations, by homogeneous dispersion and stable suspension of nanoparticles in the host fluids. Nanofluids play very important role in numerous thermal applications like automotive industries, heat exchangers, solar power generation etc. Mostly heat transfer augmentation in solar collectors is one in all the key problems in energy saving, compact styles and completely different operational temperatures. This article includes literature indicating the conventional heat transfer using nanofluids, their physical and chemical properties and analysing the challenges and opportunities of nanofluids in future research work.*

KEYWORDS: *Nanofluids, thermal conductivity, dispersion, colloidal mixture.*

INTRODUCTION

Refrigeration is the technology which makes a major contribution to humanity in many ways including food preservation, control of indoor air quality, gas liquefaction, industrial process control, storage and transport of food and drinks and computer cooling. Without refrigeration, modern life is impossible. In Malaysia, refrigerators are reported to have consumed 20 to 23% of electricity in the residential sector annually since 1997, when the number of refrigerators was around 3.4 million units. However, the number has increased from year to year, reaching with 5.6 million in 2005, and it is predicted that the number will reach 9.2 million by 2015 and 11.3 million by 2020. In line with the increase in the number of refrigerators, the electricity consumption in the residential sector is also estimated to increase by 2015 to about 5254 GWh per year. The Malaysian government has taken the initiative to overcome the high demand for electricity by the residential sector by implementing energy-efficient products including refrigerators. Energy consumption by refrigerators can be improved by using nanoparticles.

Performance of heat transfer equipment can be improved with studies related to a significant increase in heat flux and miniaturization. In many industrial applications such as power generation, microelectronics, heating processes, cooling processes and chemical processes, water, mineral oil and ethylene glycol are used as heat transfer fluid. Effectiveness and high compactness of heat exchangers are obstructed by the lower heat transfer properties of these common fluids as compared to most solids. It is obvious that solid particles having thermal conductivities several hundred times higher than these conventional fluids. To improve thermal conductivity of a fluid, suspension of ultrafine solid particles in the fluid can be a creative idea. Different types of particles (metallic, non-metallic and polymeric) can be added into fluids to form slurries. Due to the fact that sizes of these suspended particles are in the millimetre or even micro meter scale, some serious problems such as the clogging of flow channels, erosion of pipelines and an increase in pressure drop can occur. Nanofluids have attracted much attention recently because of their potential as high performance heat transfer fluids in electronic cooling and automotive. Application of nanoparticles provides an effective way of Improving heat transfer characteristics of fluids. Particles <100 nm in diameter exhibit properties different from those of conventional solids. Compared with micron-sized particles, nanophase powders have much larger relative surface areas and a great potential for heat transfer enhancement. Some researchers tried to suspend nanoparticles into fluids to form high effective heat transfer fluids. Choi[1] is the first who used the term nanofluids to refer to the fluids with suspended nanoparticles. Some preliminary experimental results [2] showed that increase in thermal conductivity of approximately 60% can be obtained for the Nanofluids consisting of water and 5 vol% CuO nanoparticles. By suspending nanophase particles in heating or cooling fluids, the heat transfer performance of the fluid can be significantly improved. The main reasons may be listed as follows:

1. The suspended nanoparticles increase the surface area and the heat capacity of the fluid.
2. The suspended nanoparticles increase the effective (or apparent) thermal conductivity of the fluid.
3. The interaction and collision among particles, fluid and the flow passage surface are intensified.
4. The mixing fluctuation and turbulence of the fluid are intensified.
5. The dispersion of nanoparticles flattens the transverse temperature gradient of the fluid.

PREPARATION METHODS FOR NANOFLUIDS

Various methods have been tried to produce different kinds of nanoparticles and Nano suspensions. There are two primary methods to prepare nanofluids: A. two-step method in which nanoparticles or nanotubes are first produced as a dry powder. The resulting nanoparticles are then dispersed into a fluid in a second step and B. Single-step nanofluid processing methods have also been developed and there are a novel methods also mentioned in this section.

Two-Step Method:

This method is most widely used for preparing nanofluids. Nanoparticles, nanofibers, nanotubes, or other nanomaterials used in this method are first produced as dry powders by chemical or physical methods. Then, the nano-sized powder will be dispersed into a fluid in the second processing step with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling. Two-step method is the most economic method to produce nanofluids in large scale, because nanopowder synthesis techniques have already been scaled up to industrial production levels. Due to the high surface area and surface activity, nanoparticles have the tendency to aggregate. The important technique to enhance the stability of nanoparticles in fluids is the use of surfactants. However, the functionality of the surfactants under high temperature is also a big concern, especially for high-temperature applications. Due to the difficulty in preparing stable nanofluids by two-step method, several advanced techniques are developed to produce nanofluids, including one-step method. In the following part, we will introduce single-step method.

One-Step Method: The nanoparticles may agglomerate during the drying storage, and transportation process, leading to difficulties in the following dispersion stage of two-step method. Consequently, the stability and thermal conductivity of nanofluids are not ideal. In addition, the production cost is high. To reduce the agglomeration of the nanoparticles, one-step methods have been developed. There are some ways for preparing nanofluids using this method including direct evaporation condensation [3, 4], chemical vapour condensation [3], and single-step chemical synthesis.

Other Novel Methods: Wei et al developed a continuous flow micro fluidic micro reactor to synthesize copper nanofluids. By this method, copper nanofluids can be continuously synthesized, and their microstructure and properties can be varied by adjusting parameters such as reactant concentration, flow rate, and additive. CuO nanofluids with high solid volume fraction (up to 10 vol%) can be synthesized through a novel precursor transformation method with the help of ultrasonic and microwave irradiation [5]. The precursor $Cu(OH)_2$ is completely transformed to CuO nanoparticle in water under microwave irradiation. The ammonium citrate prevents the growth and aggregation of nanoparticles, resulting in a stable CuO aqueous nanofluid with higher thermal conductivity than those prepared by other dispersing methods. Phase-transfer method is also a facile way to obtain mono disperse noble metal colloids [6]. Phase transfer method is also applied for preparing stable kerosene based Fe_3O_4 nanofluids. Oleic acid is successfully grafted onto the surface of Fe_3O_4 nanoparticles by chemisorbed mode, which lets Fe3O4 nanoparticles have good compatibility with kerosene [7]. In a water cyclohexane two-phase system, aqueous formaldehyde is transferred to cyclohexane phase via reaction with dodecyl amine to form reductive intermediates in cyclohexane. The intermediates are capable of reducing silver or gold ions in aqueous solution to form dodecyl amine-protected silver and gold nanoparticles in cyclohexane solution at room temperature. Feng et al. used the aqueous organic phase transfer method for preparing gold, silver, and platinum nanoparticles on the basis of the decrease of the PVP's solubility in water with the temperature increase [8].

ADVANTAGES OF NANOFLUIDS

Nanofluids cause drastic change in the properties of the base fluid so, the following benefits are expected to get on.

- Due to nano size particles, pressure drop is minimum.
- Higher thermal conductivity of nanoparticles will increase the heat transfer rate.
- Successful employment of nanofluid will lead to lighter and smaller heat exchanger.
- Heat transfer rate increases due to large surface area of the nanoparticles in the base fluid.
- Nanofluids are most suitable for rapid heating and cooling systems.
- Due to nano size particles, fluid is considered as integral fluid.
- Good mixture nanofluids will give better heat transfer.
- Microchannel cooling without clogging. Nanofluids are not only a better medium for heat transfer in general but they are also ideal for microchannel applications where high heat loads are needed.
- Cost and energy saving. Successful employment of nanofluids will result in significant energy and cost savings because heat exchange systems can be made smaller and lighter.

THERMAL CONDUCTIVITY OF NANOFLUIDS:

Choi [8] established the field of nanofluids in 1995, and in 2001 measured thermal conductivity enhancement of 160 per cent for MWCNT's dispersed in poly (a-olefin) oil. Several groups have measured thermal conductivities far in excess to those predicted by the Maxwell model, while it has been hypothesised that small particle size, and hence large surface area is important. Research conducted on copper oxide nanoparticles by two different groups reported that the nanofluid containing larger particles exhibited higher thermal conductivity. Das et al. [9] reported that nanofluids exhibit a strong dependence on temperature, with a correlation between higher conductivities and higher temperatures. The uniqueness of nanoparticles and nanofluids is that no current model, applicable to larger particles, can estimate the enhancement of nanoparticles because of the breakdown at continuum at the nano size.

There are steady state and transient methods for the measurement of thermal properties. Although steady-state methods are simple theoretically, these involve rather elaborate technique practically, including thermal guard to eliminate lateral heat flow and electronic control system to enable stable condition during the test. Transient methods provide fast measurement and reduce unwanted modes of heat transfer. Most thermal property measurements of nanofluids have been done using transient method of measurement. The measurement of thermal diffusivity and thermal conductivity is based on the energy equation for conduction. Zhang[10], Zhang, et al. [11] have used transient short hot wire method to simultaneously measure thermal conductivity and thermal diffusivity of Au/toluene, Al_2O_3/H_2O, carbon nano fibre/H_2O[10] and ZrO_2/ H_2O, TiO_2/H_2O CuO/H_2O[11]. Murshedet al. [12-13]have used double hot wire method to measure thermal diffusivity of nanofluids. Literature reported thermal conductivity for various nanofluids is shown in table below.

Table 1. Thermal conductivity of different Nanomaterials[13]

Sr.no	Nanomaterials	Thermal conductivity (K) in W/mk
1	Water	0.61
2	Ethylene glycol	0.26
3	Al_2O_3	3.5
4	CuO	20
5	ZrO_2	2
6	SiO_2	1.4
7	Fe_3O_4	9.7
8	Au	317
9	Ag	429
10	Al	257
11	Fe	80.2
12	Carbon nanotubes	2000
13	diamond	600

Theoretical study on nanofluids containing Al_2O_3, CuO and Cu particles were investigated [14]. The results showed 60% improvement in heat transfer is observed corresponding to the base fluid HE-200 oil/water, with 5%

volume dispersion. Further investigations on CuO, Al_2O_3 suspension on water/ethylene glycol [15] showed 20% improvement in heat transfer with 4% volume dispersion. Similar results were observed in steady state parallel plate technique by Xuan and Li, where 12% enhancement in effective thermal conductivity is observed. Further researches showed 20% [20] and enhancement by various researchers [15-17]. Cu nano particles suspended with transformer oil and water was investigated by Eastman et.al and results showed promising results. SiC nano particles of 26nm are suspended on deionized water/ ethylene glycol (EG) was investigated using transient hot wire method by [18-19]. Fe based nanofluid was investigated [20], by dispersing Fe nano particles of 10nm in ethylene glycol. The results showed that Fe, SiC nanofluid is not promising compared to the base fluid even though Fe is a good thermal conductive material. The many investigators reported that agglomeration of particles plays a vital role in the study of thermal conductivity of the material. From the aforementioned discussion, we find that the existing experimental and numerical data from different research communities vary extensively. In context to the above discussions, the international nanofluid property benchmark exercise (INPBE) also justified the thermal conductivity of the nanofluids based on the experimental and theoretical studies [21]. The major results reported are there is an enhancement of 5% to 10% of thermal conductivity of nanofluids based on the base fluid (water, PAO).

EXPERIMENTAL SETUP AND TEST PROCEDURE

This section provides a description of the facilities developed for conduction experimental work on a refrigerator. The technique of charging and evacuation of the system is also discussed here.

Experimental methodology: The temperature of the refrigerant inlet/outlet of each component of the refrigerator was measured with copper – constantan thermocouples (T type). The thermocouple sensors fitted at inlet and outlet of the compressor, condenser, and thermocouples/temperature sensors were interfaced with a HP data logger via a PC through the GPIB cable for data storage. Temperature measurement is necessary to find out the enthalpy in and out of each component of the system to, investigate the performance. The inlet and outlet pressure of refrigerant for each of the component is also necessary to find out their enthalpy at corresponding state. The pressure transducer was fitted at the inlet and outlet of the compressor and expansion valve as shown in Fig.1. The pressure transducers were fitted with the T-joint and then brazed with the tube to measure the pressure at desired position. The range of the pressure transducer is -1 to + 39 bars. The pressure transducers also been interfaced with computer via data logger to store data. A service port was installed at the inlet of expansion valve and compressor for charging and recovering the refrigerant. The location of the service port is shown in Fig. 1. The evacuation has also been carried out through this service port. A power meter was connected with compressor to measure the power and energy consumption.

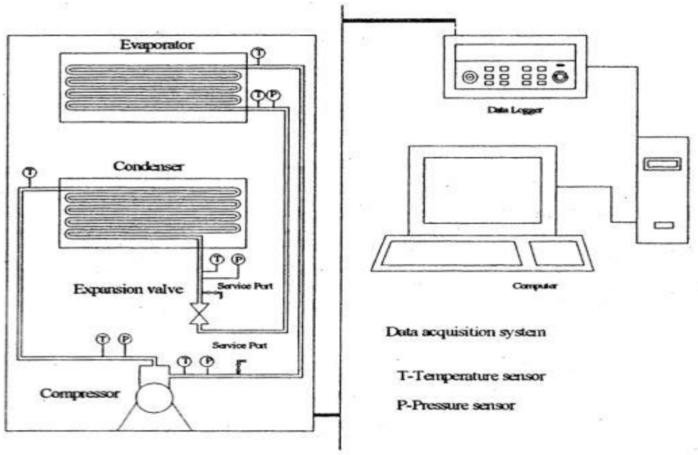

Fig.1 Experimental apparatus

Preparation of nanolubricants: Preparation of nanolubricants is the first step in the experimental studies on nanorefrigerants. Nanofluids are not simply liquid solid mixtures. Special requirements are even, stable and durable suspension, negligible agglomeration of particles, and no chemical change of the fluid. Nanofluids can be prepared using single step or two step methods. In the present study two step procedure is used. Commercially available nanoparticles of aluminium oxide (manufactured by Sigma Aldrich) with average size <50nm and having density 0.26 g/cc were used for the preparation of nanolubricant. Mass fraction of nanoparticles in the nanoparticle–lubricant mixtures is 0.06%. An ultrasonic vibrator (Micro clean 102, Oscar Ultrasonics) was used for the uniform dispersion of the nanoparticles and it took about 24 hours of agitation to achieve the same. Experimental observation shows that the stable dispersion of alumina nanoparticles can be kept for more than 3 days without coagulation or deposition.

System Evacuation: Moisture combines in varying degree with most of the commonly used refrigerants and reacts with the lubricating oil and with other materials in the system, producing highly corrosive compound. The resulting chemical reaction often produces pitting and other damage on the valves seals, cylinder wall and other polished surface of the system. It may cause the deterioration of the lubricating oil and the formation of sludge that can gum up valves, clog oil passages, score bearing surface and produce other effect that reduce the life of the system. Moisture in the system may exist in solution or as free water. Free water can freeze into the ice crystals inside the metering device and in the evaporator tubes of system that operate below the freezing point of the water. This reaction is called freeze up. When freeze up occurs, the formation of ice within the orifice of the metering device temporarily stops the flow of the liquid refrigerant .To get rid of the detrimental effect of moisture Yellow jacket 4cfm vacuum pump was used to evacuate the system. This system evacuates fast and better which is deep enough to get rid of contaminant that could cause system failure. The evacuation system consists of a vacuum pump, a pressure gauge and hoses. The hoses were connected with the service port to remove the moisture from the system. When the pump is turned on the internal the pressure gauge shows the pressure inside the refrigerator system.

System Charging: Yellow jacket digital electronic charging scale has been used to charges R600a into the system. This is an automatic digital charging system that can charge the desired amount accurately and automatically. The charging system consists of a platform, an LCD, an electronic controlled valve and charging hose. The refrigerant cylinder was placed on the platform which measures the weight of the cylinder. The LCD displays the weight and also acts as a control panel. One charging hose was connected with the outlet of the cylinder and inlet of the electronic valve and another one was connected with the outlet of electronic valve and inlet of the service port. Using this charging system refrigerants were charged into the system according to desired amount.

Test Procedure: The system was evacuated with the help of vacuum pump to remove the moisture and charged with the help of charging system. The pressure transducers and thermocouples fitted with the system were connected with the data logger. The data logger was interfaced with the computer and software has been installed to operate the data logger from the computer and to store the data. The data logger was set to scan the data from the temperature sensor and pressure sensor at an interval of 5 minutes. A power meter was connected with the refrigerator and interfaced with the computer and power meter software was installed. The power meter stores the instantaneous power and cumulative energy consumption of the refrigerator and cumulative energy consumption of the refrigerator. The pressures and temperatures of the refrigerants from the data logger were used to determine the enthalpy of the refrigerant. All equipments and test unit was installed inside the environment control chamber where the temperature and humidity was controlled. The dehumidifier has been used to maintain desired level of humidity at the control chamber.

Conclusion

Heat transportation phenomenon are immensely important in the industrial as well as scientific field. Nanofluid is an environmental friendly and also provides better efficiency than the fluids that are being used for the same purpose for improved heat conduction due to unit embryonic fluids. Smallest possible concentrations, homogeneous dispersion and stable suspension of nanoparticles makes it the best suitable candidate for host in fluids. Different kinds of nanofluids with their thermal conductivities and specific standard procedure adopted are discussed here.

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