CRITICISM MEASUREMENT ON THERMAL CONDUCTIVITY OF NANOFLUIDS

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Abstract
Thermal conductivity is property of material to conduct heat. This study focuses on the preparation and measures the thermal conductivity of nanofluids using transient hot wire method. Generally nanofluids are suspensions of nanoparticles in a base fluid. The nanofluid is produced by mixing the nanoparticles of various size in base fluid like ethanol and water. The nanofluids have high heat transfer rate compared to any other conventional coolants. Hence, the nanofluids have a wide range application in heat transfer process such as nano coolants. The work is completed by using platinum wire of 50μm diameter with a teflon coating of 25μm by transient hot wire techniques. The main advantage of this method is that the wire acts as a heating source as well as a temperature sensor. In the proposed design, the apparatus has an easy calibration of platinum wire and also minimizes the strain effect of the platinum wire.
Index Terms: **Nanofluids, Strain effect, Thermal conductivity, Transient method,**

I. INTRODUCTION

The concept of nanofluid was first studied by Michael Faraday in 1857 on the synthesis and colours of colloidal gold. There are some nanofluids in nature like blood; a biological nanofluid with different nanoparticles for different functions. Modern nanotechnology can produce material with crystallite size less than 50nm. The first measurement of thermal conductivity for nanofluids was done by Choi. Compared to any other conventional coolants, the heat transfer rate is high for nanofluids. The three properties of nanofluid makes it as a coolant (i) high thermal conductivity (ii) high heat transfer rate (iii) high critical heat flux [1].

For the measurement of thermal conductivity Transient hot wire method is used because it reduces the unwanted modes of heat transfer. This method is fast and accurate to measure thermal conductivity of fluids. The principle of this method is based on ideal, constant heat generation of an infinitely long wire dissipating heat into an infinite test medium. In practice, a finite long wire generate heat in finite medium. At the end, thermal conductivity value is determined from the heating power and the slope of the temperature change in a logarithmic time. Effective refrigeration effect can be obtained without refrigerant by using high intensity sound waves [2]. In modern days the research goes on thermoelectric Refrigeration with nanofluids in a mini channel heat exchanger [3].

II. NANOFLUID AND TRANSIENT HOT WIRE METHOD

Nano fluids have a very good thermal management and control. It also has huge application in electronic cooling and space craft thermal management. A.K.Singh reported details about the thermal conductivity of the nanofluid. His paper contains details about the preparation of nanofluid and the various methods involved to check the thermal conductivity of the nanofluid. It also presents how the thermal conductivity depends on the size of the nanoparticles.[1]

Clement Kleinstreuer, and Yu Feng conducted experimental and theoretical studies of thermal conductivity of nanofluid. They mainly focused on spherical shape of the nanoparticles.[4]

Nanofluids have a higher thermal conductivity compared to the same fluid without nanoparticles. An experimental study was performed by S. Lee, S. U. S.Choi, and S.Li. Their experiment was to check the thermal conductivity value of oxide nanoparticles such as Al2O3 and CuO particles. They found that the particle size has an effect on the thermal conductivity. The thermal conductivity values are measured by transient hot wire method. Their experimental results clearly shows that the CuO has high thermal conductivity compared to Al_2O_3. [5]

The transient hot wire apparatus is also applicable for the measurement of thermal conductivity of the polymer solution and poly nanofluids. M.Kostic, Kalyan, and C.Simham recently designed, developed, and fabricated a transient hot wire apparatus for the measurement of thermal conductivity of nanofluids. For getting a higher accuracy value, they used a platinum wire as a hot wire which can be easily calibrated and also have a less strain-gage effect[6]. Particle size is an important parameter that affects the thermal conductivity of the nanofluid. Joohyun Lee, HansulLee, Young-JinBaik and Junemokoo prepared Al_2O_3 nanofluid of different particle sizes and investigated the thermal conductivity using transient hot wire method. [7]

The natural convection have an impact on the hot wire measurement. The proper selection of the temperature range is the important parameter while starting the experiment. Sung Wook Hong, Yong-Tae Kang, Clement Kleinstreuer, and Junemo Koo measured effectively the thermal conductivity of nanofluid. In their experiment, they used an EG-based 1.06 vol % ZnOnanofluid. They investigated theoretically and experimentally, the conduction in the hot wire as well as natural convection. They determined the suitable temperature range and the starting time of the experiment[8].

SiddharthKominiBabu, K.S.Praveen, B.Raja, and P.Damodharan measured the thermal conductivity using single wire sensor and dual wire sensor. In their experiment, water was chosen as a sample fluid medium. The measurement of thermal conductivity was done using different length of the wires with an accuracy of $\pm 0.25\%$.[9]

B.Merckx, P. Dudoignon, J.P.Garnier, and D.Marchand measured the thermal conductivity of Geo material using simplified hot wire method. Glass bead assemblages of different diameters were preformed to check the role of grain size and saturation of thermal conductivity. They made two measurements, the first one was measured in short time and it was mainly focused on the connection between the wire and the grains of the material in a hydrated state, and the second one is for a long time for the effective measurement of thermal conductivity[10].

NaouelDaouas, Ali fguiri and M.SassiRadhouani worked on numerical solution and an experimental method in order to study the effect of the radiation in transient hot wire thermal conductivity measurement. They estimated the value of the absorption coefficient of the medium. They performed two different experiments with two different temperature ranges [11].

Sandeep Kumar Mechiri, Vasu V, Venu Gopal A, and SathishBabu investigated that the thermal conductivity of the vegetable oils was increased based on composition of hybrid nanoparticles. They prepared a Cu-Zn hybrid nanoparticle with different combinations and dispersed them into vegetable oil. Their results proved that the thermal conductivity value is increased by the increasing the level of the hybrid nanoparticles. They also checked the theoretical values and compared the values with the experimental results [12].

D.Madhesh, and S.Kalaiselvam analyzed hybrid nanofluids as a coolant, which have a very high heat transfer rate compared to any other conventionalcoolant. They prepared a copper-titanium nanocomposite in water .They experimentally investigated the copper-titanium nanofluid in a tubeintube heat exchanger. The convective heat transfer coefficient rate increased by increasing the concentration of the nanofluid and Reynolds number [13].

S. Ravi Babu, and Dr.P. Ramesh Babu fabricated hot wire apparatus for the measurement of thermal conductivity of the fluids. The bias measurement error were based on the calibration with water and the ethylene glycol has been found [14].

Khin Ma MaNyein, Nant Aye Aye Mya, Ye Chan, and Win Win Thar prepared electrically conducting copper nanofluid for the measurement of thermal conductivity using transient hot wire method. They prepared a copper nanofluid in water without inert gas protection. They found the nanoparticle size using XRD analysis [15].

C.Codreanu, N.I.Codreanu, V.V.N.Obrejapresented thermal conductivity on theoretical basis and the experiment was done using transient hot wire method. They made a house computer to control the full experimental setup. The main advantage is that the thermodynamic state of the material under test condition does not change during the measuring process [16].

Hans M.Rodert fabricated a transient hot wire apparatus with platinum wire having diameter of 12.5 μm. Their accuracy level is around 1.5%.The system can be used for wide range of temperature and pressure measurement applications. The precision level will be 0.6 %. Their arrangement of Wheatstone bridge differed from the other transient hot wire systems, and the voltage drop was directly measured from the circuit arrangement [17].

In order to get a highly accurate value of thermal conductivity, special care should be taken to the initial heat supply and the natural convection. Kisoo Han, Wook-Hyun Lee, Clement Kleinstreuer, and Junemo Koo made a study on the natural convection which affected the measurement of thermal conductivity .They checked the thermal conductivity of the pure fluid and the nanofluids, and from the result they found that the natural convection occurred earlier for nanofluid when compared with the basefluid[18].

Md. Jahangir Alam, Mohammad Ariful Islam, and KeishiKariya, Akio Miyara measured the thermal conductivity for cis-1, 1, 1, 4, 4,4-hexa fluoro-2-butene.They measured it at the liquid phase and the vapor phase for an eco-friendly refrigerant [19].

G.Paul, M.Chopkar, I.Manna, and P.K.Dasdid a scientific investigation about the thermal conductivity of the nanofluid. They presented a brief review on the different methods for the measurement of thermal conductivity of nanofluids. From their review, the most commonly used method is the transient hot wire method. They prepared ethylene glycol and water based nano-ceramic (ZrO_2 and TiO_2) nanofluid using physical preparation method or two step method. From their results, they found that nano-ZrO_2has high thermal conductivity value [20].

M.A.Ahmed, M.Z.Yusoff, K. C. Ng, and N.H.Shuaib performed a convective heat transfer of SiO_2 –water based nanofluid flow in channels with different shapes experimentally and numerically. Their selection of the channel shapes were trapezoidal, sinusoidal and straight [21].

L.SyamSundar, G.O.Irurueta, E.VenkataRamam, Manoj K Singh, and A.C.M.Sousa prepared a nanodiamond-cobalt oxide nanocomposite and checked the thermal conductivity and the viscosity. The nanocomposite material was produced using in-situ growth technique and chemical co-precipitation between cobalt chloride and sodium borohydrate. The size of the composite was measured using DLS method. Their results showed that the hybrid nanofluidswere better than the single nanoparticles based nanofluid [22].

KyosukeFujiura and his team determined the thermal conductivity of hydrates of semiclathrate and that of aqueous tetrabutylammonium bromide (TBAB) and tetrabutylammonium chloride (TBAC) at 1 atm pressure and between 223 and 303 K. They selected a parylene-coated probe in the transient hot wire method [23].

Haoran Li, Li Wang,Yurong He, YanweiHu,Jiaqi Zhu, and Baocheng Jiang investigated ethylene glycol+ZnOnanofluids and measured its viscosity and thermal conductivity. They used X-ray diffraction to measure the structure of the nanoparticles [24].

N.A.Usri, W.H.Azmi, RizalmanMamat, K.Abdul Hamid, G.Najafi checked the thermal conductivity of Al_2O_3 nanoparticles in Ethylene Glycol and Water mixture. They used a 13nm size particle with three different volume ratio of water and ethylene glycol. Their result shown that the thermal conductivity value decreased while the value of Ethylene glycol was increased due to the property of Ethylene glycol [25].

III. SYNTHESIS OF NANOFLUID

Choi made the first nanofluid by mixing nanoparticles with fluids. There is a rapid development in preparation of nanofluid .There are two fundamental methods, namely the two step process and the chemical approach. In two step process, the nanoparticles are produced as a dry powder by an inert gas. Then the nanoparticles are mixed into a fluid. Chemical approach includes chemical precipitation, chemical vapour deposition, thermal spray and micro emulsions. In Chemical approach using wet technology, surface functioned nanoparticles of metals dispersible in a medium such as a water, can produce monodispersed nanostructures.

The other method is Laser ablation that is single step techniques which simultaneously produces and disperse nanoparticles directly in the base fluid. Large variety of nanofluids can be produced using this method. The method was useful for further splitting the nanoparticles in the nanofluid and to have an idea on the effect of particle size on thermal conductivity. Another single step method is microwave irradiation method, which is a quick method for the production of nanofluid [1].

IV. METHODOLOGY

The important design parameters are (i) radius of the hot wire,(ii)material of the wire, (iii)length of the wire,(iv)thickness of the insulating material,(v)length of the sample ,(vi) radius of the sample. Platinum has a higher thermal conductivity compared to the nichrome hot wire. So platinum is selected as a hot wire for this experimental setup. Radius of the hot wire is another important parameter for the design. The commercially available radius sizes are 25.4µm and 50.8µm. For the present application 12.5µm radius is selected.

Teflon has been selected as the insulating material because the Teflon has high chemical resistance, corrosion resistance, and stress cracking at high temperature. The thickness of the insulating material for the present application is 25.4µm.

Length of the platinum wire (L) is 0.1484m and the length of the sample (L_s) is 0.170m.The overall sample volume (V_c)is 35ml. A cross section of the apparatus is shown in the figure. The major components in the assembly are the base plate, cell cap with wire and the outer cell. Threaded hole in the base plate connects to the center plate for the purpose of easy assembly and disassembly of the cell. The outer cell act as a sample fluid reservoir. The inner cell has a semicircular hot wire holder with an alignment ring. In a cell cap the hotwire guiding block, sliding tube, tension spring, and the spring rod are attached. A locking nut is fastened on the spring rod and mounted at the top of the cell cap. The spring rod and the locking nut act as a nut and bolt arrangement in the cell. The locking nut is designed and fabricated to a specific weight and is used for calibration of the platinum wire. An inverted L shape gauge is mounted on the holder for the purpose of calibrating the hot wire tension and gives the guide movement to the spring rod.

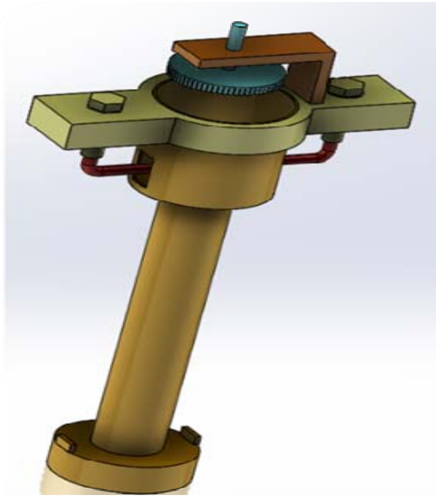

Fig 1. Full View of Transient hot wire apparatus

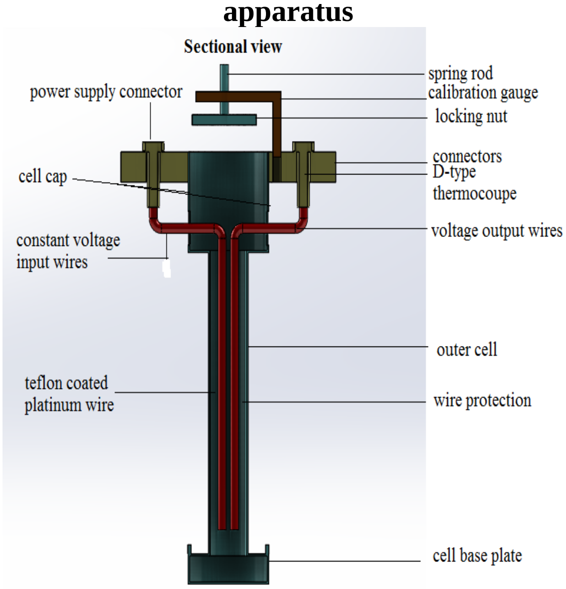

Fig2 Section view of Apparatus

The two copper wires are mounted on the alignment ring and finally that alignment ring will be attached to the end of the hot wire. The electrical and the thermocouple wires are connected in the cell through the opening at the middle section. The thermocouple wire holder, calibration holder are mounted at the middle of the cell cap. There are three thermocouples used, and they are mounted on the semicircular wire holder at the angle of 15^0,45^0, and 75^0 along with the length of the test sample to check the fluid temperature. The thermocouple wire is bent towards the hot wire through the hole of the semicircular wire holder.

The cell parameters are L=0.170m, V_c=35 ml, the insulating material thickness is 25.4µm, and the diameter of the wire is 50.8µm[4].

V. MATHEMATICAL MODEL

Mathematically, the hot wire method is an ideal, infinitely long, continuous dissipating heat of heat flux (q) at time, t=0in an infinite fluid medium. The assumptions are, only conduction takes place in a fluid medium, uniform heat dissipation all over the wire. The governing equation taken from the Fourier's equation for 1D (one dimensional) transient heat conduction in a cylindrical coordinates,

$$\frac{1}{\alpha}\frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) \quad (1)$$

In above equation $T=T_0+\Delta T$ is the temperature of the medium at time t, and the radial distance is r.T_0 is the initial temperature and the $\Delta T$is the temperature difference..Applying the boundary condition in the equation(1),

$$\lim_{r\to 0}\left\{r\left(\frac{\partial T}{\partial r}\right)\right\} = -\frac{q}{2\Pi k_f} \text{ at } t = 0 \text{ and } r = 0 \quad (2)$$

$$\lim_{r\to\infty}\{\Delta T(r,t)\} = 0 \text{ at } t \geq 0 \text{ and } r = \infty \quad (3)$$

Where ρ_f and $C_f$are density and specific heat of the medium. Neglect higher order terms, the equation (2) will become as

$$\Delta T = T(r,t) - T_0 = \frac{q}{4\Pi k_f}\left\{-\gamma + \ln\left(\frac{4\alpha t}{r^2}\right)\right\} \quad (4)$$

Where γ=0.5772 is the Euler's constant.
For the constant fluid medium, the properties are fixed and arbitrary radius 'r' after differentiating the above equation, it is eliminated and finally the equation(4) will be

$$k_f = \frac{q}{4\Pi}\frac{1}{d(\Delta T)/d\ln(t)} \quad (5)$$

This shows that the thermal conductivity is directly proportional to the heat source and is inversely proportional to the temperature difference with the natural logarithm of time.

The advantage of this method is its simplicity and low cost of construction .The wire itself is used as a heat source and as a temperature sensor for the measurement of thermal conductivity. Another advantage is that convection heat transfer rate will be minimized [4].

VI. DATA ACQUISITION

Thewheatstone bridge circuit is used to measure the resistance value of the platinum hot wire. The platinum wire acts as one of the arms in the wheatstone circuit. First the bridge will be balanced until the voltage output value is of 10-15µV .The balancing of the circuit will be performed for a particular period of time, using constant input voltage of 0.1 V to minimize the heating of the platinum wire at the initial bridge balancing. After the bridge balancing a constant voltage input V_{in} at start time t=0, is applied to platinum hot wire, thus resulting in the unbalancing of the circuit due to the resistance change of the platinum hot wire. The input voltage(V_{in}) and the output voltage (V_{out}) are measured using computer acquisition system .The various signals are measured using data acquisition hardware. The six signals that are measured are the bridge input voltage, bridge output voltage, hot wire voltage drop and the three signals from the thermocouples mounted along the length of the hot wire cell at the top, middle, and the bottom. A measured data is developed using LabView software. The bridge output voltage and time are stored simultaneously. The post processing of the acquired data is used to calculate the resistance change, temperature change, heat input and the thermal conductivity of the test sample[4].

VII. CONCLUSION

The review was performed about the thermal conductivity measurement of nanofluid. For the measurement of thermal conductivity transient hot wire method is used. This paper contain details about the design parameters of the transient hot wire apparatus, also has information about various parameters affecting the thermal conductivity value of the nanofluid.

The thermal conductivity of the nanofluid depends on the various parameters like size of the nanoparticle, structure of the nanoparticle and the selection of the base fluid. A research mainly focused on the parameters which affects the thermal conductivity of nanofluid and preparation of the hybrid and nanocomposite nanofluids will be done in future.

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