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Experimental Analysis of Automatic Cooling Device Using Ferrofluid

Sahib Singh[1], Harry Garg[2]
[1] Sahib Singh-Department of Mechanical Engineering, BFCET, Bathinda, India
[2]Harry Garg - Optical Devices & Systems CSIR-CSIO, Chandigarh, India

Abstract - **Heat is an inevitable byproduct of all the electronic devices and a substantial amount of power is lost in cooling of these devices. The automatic cooling device discussed in this paper utilizes the waste heat and in the presence of magnetic field can be used for cooling applications. This cooling device converts a part of thermal energy into kinetic energy of the fluid does not require any pump for the fluid flow. If a permanent magnet is used, no external power is required for fluid flow.**

Keyterms: **Ferrofluid, Nanofluids, Magnetic Field, Magnetic Fluid, Passive cooling, Automatic cooling device.**

I.INTRODUCTION

A ferrofluid is a temperature sensitive magnetic fluid which means that its magnetization is function of temperature. An external magnetic field imposed on a ferrofluid with varying susceptibility (e.g., because of a temperature gradient) results in a non-uniform magnetic body force, which leads to a form of heat transfer called thermo-magnetic convection[1] and can be controlled by varying ferrofluid properties, the magnetic field strength and also the temperature distribution. This form of heat transfer can be useful when conventional convection heat transfer is inadequate; e.g., in miniature microscale devices or under reduced gravity conditions. It is a passive cooling technique and the heat from the system which otherwise is a waste can be used to induce the flow in presence of a magnetic field. The synergistic effect of magnetization and temperature gradient produces a high performance cooling.

A prototype of a miniature automatic cooling device using ferrofluid has previously been been described by Love et al. [2] & Qiang Li at al.[3] . Strek and Jopek [4] simulated ferrofluid flow in a channel between two parallel plates.

Aminfar et al. [5] have investigated numerically the hydrothermal characteristics of a water based ferrofluid in vertical rectangular duct. The magnetic field is produced by a current carrying wire which is placed along the length of the duct.

Wrobel et al. [7] studied thermo-magnetic convective flow of paramagnetic fluid in an annular enclosure with a round rod core and a cylindrical outer wall numerically and experimentally. Their results show that magnetizing force affects the heat transfer rate and a strong magnetic field can control the magnetic convection of paramagnetic fluid.

Kikura et al. [8] carried out experimental investigations in a cubical enclosure and concentric horizontal annuli under the influence of a varying magnetic field. The permanent magnet was placed at different sides of the enclosure and the effect of magnetic field gradient on the ferrofluid heat transfer was studied.

Lajvardi et al. [9] report an experimental work on the convective heat transfer of ferrofluid flowing through a heated copper tube in the laminar regime in the presence of magnetic field. A series of experiments were conducted to study the effect of external magnetic field and temperature distribution. Their results showed that fluid flow can be controlled by changing the position of the magnet. Significant enhancement on the heat transfer of ferrofluid by applying various orders of magnetic field is observed in this experiment. Also by increasing the ferrofluid concentration, a significant enhancement in heat transfer coefficient is observed.

The present paper reports experimental work on ferrofluid flow in a copper tube loop under the influence of temperature gradient and magnetic field.

II. MECHANISM OF FLOW

The principle of operation is quite simple. In order to understand the mechanism of flow, we must know about the variation of magnetization with temperature. Magnetization decreases with increasing temperature. The temperature at which all the magnetization is lost is called Curie temperature.

The magnetic fluid in the thermal region being at a higher temperature loses its magnetic properties. The cold ferrofluid behind experiences a greater magnetic attraction and due to this greater attraction, the cold ferrofluid pushes the hot fluid, thus resulting in fluid flow. Thus, only requirement for flow is temperature variation within the fluid and magnetic field. Also the flow can be controlled by varying external magnetic field.

III. GOVERNING EQUATIONS

The equations governing the ferrofluid flow under the effect of applied magnetic are Magnetostatic equation, the Mass conservation equation, Momentum equation and the Energy equation in the frame of Boussinesque approximation.

A. Magnetostatic equations

Ferrofluids are non-conducting, so Maxwell's equations are for non-conducting medium and no currents are simplified to

$$\nabla \times \mathrm{H} = 0. \qquad (1)$$

$$\nabla . B = 0. \qquad (2)$$

Magnetic flux density B is given as

$$B = \mu H = \mu_r \mu_0 H, \qquad (3)$$

$$B = \mu_0 (1 + \chi_m) H, \qquad (4)$$

where, $\mu_r = (1 + \chi_m)$ is the relative permeability.

The relationship between the magnetization vector M and magnetic field vector H can be written in the form

$$\chi_m H = M, \qquad (5)$$

where, χ_m is the magnetic susceptibility of material is a dimensionless proportionality constant that indicates the degree of magnetization M of a material in response to an applied magnetic field H. The magnetic induction B, the magnetization vector M and the magnetic field vector H are related by the following relation

$$B = \mu_0 (H + M), \qquad (6)$$

where $\mu_0$is a magnetic permeability in vacuum.

B. Equations governing fluid flow

The mass conservation equation is given as:

$$\frac{\partial \rho}{\partial t} + \nabla . (\rho u) = 0. \qquad (7)$$

Ferrofluids are incompressible, i.e. density is constant, and the continuity equation reduces to

$$\rho \nabla . u = 0. \qquad (8)$$

The momentum equation is given by the following equation

$$\rho \frac{\partial u}{\partial t} + \rho (u . \nabla) u = \nabla . \Big[-pI + (\mu(\nabla u + (\nabla u)^T) - \frac{2}{3} \mu (\nabla . u) I \Big] + F. \qquad (9)$$

Since ferrofluid is incompressible fluid, therefore density is constant and the momentum equation reduce to

$$\rho \frac{\partial u}{\partial t} + \rho (u . \nabla) u = \nabla . (-pI + \mu(\nabla u + (\nabla u)^T) + F. \qquad (10)$$

The momentum equation results from the application of Newton's second of motion to the fluid element. The first term on the RHS of the equation represents net pressure force; the second term represents net effect of viscous normal and shear stress. The last term provides the body force on fluid per unit volume. In case of ferrofluids, the body force term in the momentum equation represents the Kelvin body force per unit volume and is given by the following equation

$$F = (M . \nabla) B. \qquad (11)$$

Thus, the momentum equation for ferrofluids reduces to

$$\rho \frac{\partial u}{\partial t} + \rho (u . \nabla) = \nabla . (-pI + \mu(\nabla u + (\nabla u)^T) + (M . \nabla) B \qquad (12)$$

Using value of M and B from (5) and (6) the body force can be written as.

$$F = \mu_0 (\chi_m H . \nabla)(1 + \chi_m) H. \qquad (13)$$

Where χ_m is treated solely as being dependent on the temperature and is given as

$$\chi_m = \frac{\chi_0}{1 + \alpha (T - T_0)} \qquad (14)$$

The energy equation for ferrofluids is the energy equation for an incompressible fluid and obeys the modified Fourier's law is

$$\rho c_p \left(\frac{\partial T}{\partial t} + u . \nabla \mathrm{T} \right) = k \nabla^2 T + \mu \Phi - \mu_0 T \frac{\partial M}{\partial T} \big((\mathrm{v} . \nabla) \mathrm{H} \big), \qquad (15)$$

Where, $\mu \Phi$ is the viscous dissipation is defined as

$$\Phi = \left(2 \left(\left(\frac{\partial u_x}{\partial x} \right)^2 + \left(\frac{\partial u_y}{\partial y} \right)^2 + \left(\frac{\partial u_z}{\partial z} \right)^2 \right) + \left(\frac{\partial u_y}{\partial x} + \frac{\partial u_x}{\partial y} \right)^2 + \left(\frac{\partial u_y}{\partial z} + \frac{\partial u_z}{\partial y} \right)^2 + \left(\frac{\partial u_z}{\partial x} + \frac{\partial u_x}{\partial z} \right)^2 - \frac{2}{3} (\nabla . \mathrm{u})^2 \right) \qquad (16)$$

The last term in the energy Eq. (15) represents the thermal power per unit volume due to the magnetocaloric effects.

IV. EXPERIMENT SETUP

The experimental setup consists of a flow loop, a heating unit, a permanent magnet and a measuring unit. A copper tube 250 mm long 3mm inner diameter and 4.5mm outer diameter is used as a test rig. Five K type thermocouples are used in the setup. Thermocouples T1, T2 and T4 are immersed in the tube at different locations to measure the temperature of the ferrofluid. Thermocouple T5 is immersed in the reservoir and T3 is installed in the copper plate. Before installing, all the four thermocouples are calibrated. Two cartridge type heaters (Fig. 2) of maximum 35 Watt are used to heat the copper plate. The working medium is a hydrocarbon based ferrofluid having a particle size of 13nm having density of .99g/cc and viscosity of 1.87cp. The Curie temperature is 353K.

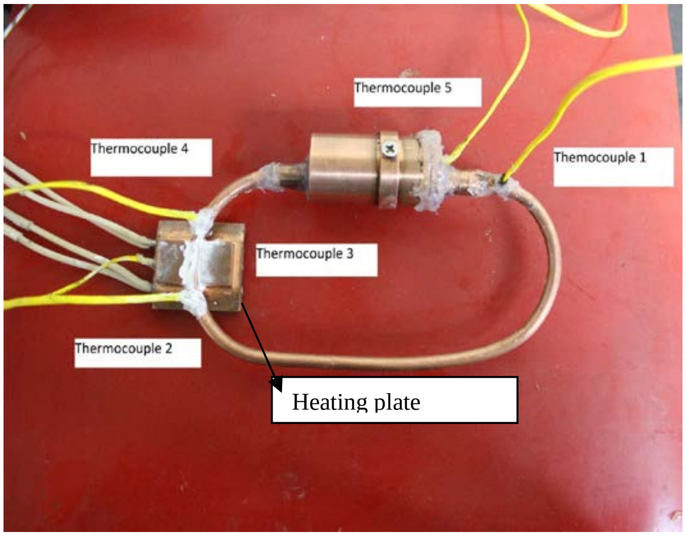

Fig. 1 Experimental setup showing position of thermocouples

Fig. 2 Cartridge type heater

V. RESULTS AND DISCUSSIONS

The cooling device consists of a ferrofluid, copper tube loop, permanent magnet, a heat source to form a passive cooling device. In such a device, a magnetic body force rises due to combined effect of temperature gradient and magnetic force is responsible for the flow of magnetic fluid. Ferrofluid in the thermal region being at a higher temperature experiences a decrease in magnetization and fluid far from the heat source being colder as experiences a greater magnetic force as compared to the hot one and gives a push to the hot fluid resulting in flow.

From Fig.3 it can be seen that, maximum temperature of 71.5℃ is observed at the thermocouple T3, which is the steady state temperature of in the absence of the magnetic field. Fig.4 shows that when the magnetic field is applied, the temperature starts dropping. This drop in temperature indicates fluid flow due to magnetic body force. The fluid flow is in anticlockwise direction. The flow and temperature approach a steady state after a short span of time; resulting in a maximum temperature of 64 ℃ at T3; drop of 7.5℃ . Temperature at T1 increases after the application of magnetic field. This is due to the fact that T1 being away from the heat source is at a relatively lower temperature of 46℃. The magnetic field induces the fluid flow and a higher temperature fluid replaces the low temperature fluid in the thermocouple region T1. A temperature drop of 5.5 degree and 7.4 degree is observed at T2 and T4 respectively.

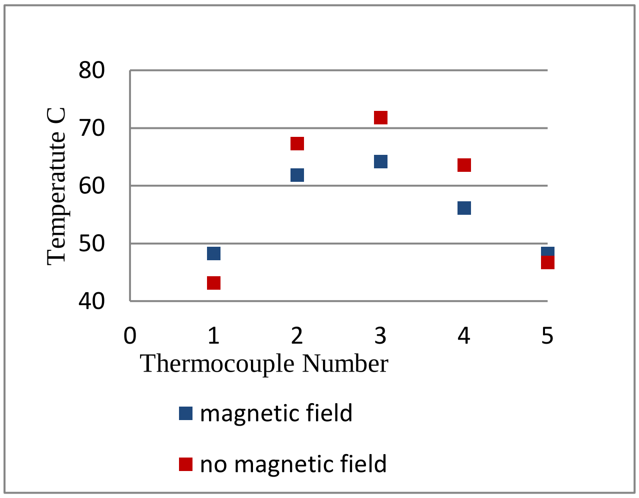

Fig. 3 Temperature difference at different thermocouples in the presence and absence of magnetic

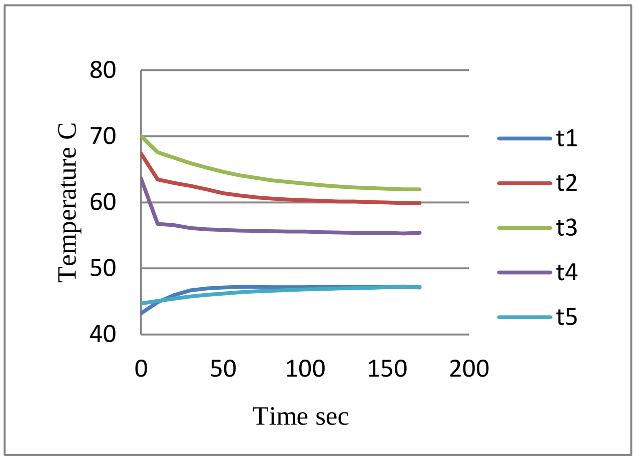

Fig. 4 Variation of temperature with respect to time on the application of magnetic field

VI. CONCLUSION

Ferrofluid flow characteristics have been investigated in the presence of magnetic field and temperature gradient. From the results of the experiment it is observed that a there is a significant decrease in the temperature when the magnetic field is applied. This decrease in the temperature is attributed to fluid flow. As in this cooling device, flow occurs itself without any external power consumption, such a device can effectively be used in thermal management of electronic devices. This device is maintenance free as it does not involve any mechanical moving parts.

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NOMENCLATURE

Symbol	Physical Quantity
ρ	density (kgm^{-3})
T	temperature (K)
u	velocity (ms^{-1})
k	thermal conductivity
M	magnetization vector (A m^{-1})
B	magnetic Induction (Wb m^{-2})
H	magnetic field, (A m^{-1})
F	Kelvin Body Force (Nm^{-3})
μ	permeability of medium, Hm^{-1}
μ_0	permeability of air or vacuum = $4\pi 10^{-7}$Hm^{-1}
χ_m	total magnetic susceptibility
χ_0	differential magnetic susceptibility of the ferrofluid,
α	thermal expansion coefficient of the fluid
T_0	reference temperature, K

REFERENCES

[1] R.E. Rosenweig, “Ferrohydrodynamics,” *Cambridge University Press*, London, 1985**.**

[2] L J. Love, J.F. Jansen, T.E. Mcknight, Y. Roh, T.J. Phelps, “Ferrofluid induced flow for microfluidic applications,” IEEE Trans. Mechatronics, vol.10, pp. 68-76, 2005.

[3] Qiang Li, W. Liang, H. Sun, JF. Jansen, “Investigation on operational characteristics of a miniature automatic cooling device,” *International Journal of Heat and Mass Transfer*, vol. 51, pp.5033-5039, 2008.

[4] T.Strek, H.Jopek, “Computer simulation of heat transfer through ferrofluid,” *Journal of Solid State Physics* 244 (2006) 1027-1037.

[5] H. Aminfar , M.Mohammadpourfard, S.Ahangar Zonouzi, “Numerical study of the ferrofluid flow and heat transfer through a rectangular duct in the presence of a non-uniform transverse magnetic field,”*Journal of Magnetism and Magnetic materials,* vol. 327, pp. 31-42, 2013.

[6] H Yamaguchi, I Kobori, Y Uehata, K. Shimada, “ Natural convection of magnetic fluid in a rectangular box,” *Journal of Magnetism and Magnetic materials*, vol. 201, pp. 264-267, 1999.

[7] W. Wrobel, E. Fornalik-Wajs, J.S. Szmyd, “Experimental and numerical analysis of thermo-magnetic convection in a vertical annular nclosure,” *International Journal of Heat and Fluid Flow,* vol.31, pp. 1019-1031, 2010.

[8] H. Kikura, T. Sawada, T. Tanahashi, “Convection of a magnetic fluid in a cubic enclosure,” Journal *of Magnetism and Magnetic materials*, vol. 122, pp. 315-318, 1993.

[9] Maryamalsadat Lajvardi , JafarMoghimi-Rad, IrajHadi, AnwarGavili, Taghi Dallali Isfahani, Fatemeh Zabihi, Jamshid Sabbaghzadeh, “Experimental investigation for enhanced ferrofluid heat transfer under magnetic field effect,” *Journal of Magnetism and Magnetic Materials* vol. 322, pp.3508-3513, 2010.

[10] A.Jafari , T. Tynjala, S.M. Mousavi, P. Sarkomaa, “Simulation of heat transfer in a ferrofluid using computational fluid dynamics technique,” *International Journal of Heat and Mass Transfer,* vol. 29, pp. 1197-1202, 2008.

[11] A.Gavili, M.Lajvardi, J.Sabbaghzadeh, “The effect of magnetic field gradient on ferrofluids heat transfer in a two dimensional enclouser,” *J. Compu. Theo. Nanoscience.*

[12] Frank P. Incropera, David P. DeWitt, “Fundamentals of Heat and Mass Transfer,” *John Wiley India*, 2007