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STUDY OF HEAT TRANSFER CHARACTERISTICS OF FERROFLUID

Engineering

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ABSTRACT

Ferrofluid consist of superfine particle having magnetic characteristics whose magnetic properties changes upon changing their temperature up to Curie temperature under the influence of external magnetic field. The nanoparticles are coated with surfactant so as to prevent sedimentation and agglomeration of magnetic particles. A lot of investigations have been done on different types of base fluid like kerosene, distilled water, light oil, diester etc and the effect of different kinds of nanoparticles on the heat transfer characteristics of a ferrofluid have been studied by various researchers This paper is an attempt to review the work done by various investigators who have studied the heat transfer characteristics of a ferrofluid.

INTRODUCTION

Ferrofluid is a colloidal mixture of base liquid and magnetic nanoparticles of size between 10-20 nm. It retains the flow characteristic of common Newtonian fluids, and its magnetic features are similar to those of bulk magnetic materials. Each tiny nano particle is thoroughly coated with surfactant to provide stability to ferrofluid. Since its thermo physical properties can be changed under the influence of magnetic field, it has found many applications in the field of mechanical engineering, bioengineering, and thermal engineering, etc. Upon application of an external magnetic field, the temperature-sensitive magnetic fluid experiences a decrease in magnetization as the local temperature increases, due to which a small magnetic force act on the fluid which lead to flow of the fluid which can transfer heat from small heat generating devices. This paper thus attempts to review the work done by various researchers in studying the flow and thermal characteristics of a ferrofluid.

Mangfei Yang et al.[1] described the experiments involved changing the volume of the ferrofluid and moving the magnet to different positions outside the ferrofluid container. These experiments tested the effect of bringing the heat source and heat sink closer together and using less ferrofluid, and the optimal position for the permanent magnet between the heat source and sink. In the model, temperature-dependent magnetic properties were included into the force component of the momentum equation, which was coupled to the heat transfer module. The model was compared with experimental results for steady-state temperature trends and for appropriate velocity fields. Model calculations showed that the greatest force acted along the axis of the dipole field and that the magnet is best placed midway between the heat source and sink.

Wenlei Lian et al.[2] described thermo magnetic convection of a temperature-sensitive magnetic fluid. A loop was established which include the coupling of magnetic, thermal, and fluid dynamic features. The temperature-sensitive magnetic fluid was simulated in the presence of an external magnetic field and the results of experimental and numerical data were compared to validate the model. The performance of the energy transport device was analyzed to find out the influence of different factors such as input heat load, heat sink temperature and magnetic field distribution along the loop. The results have been discovered that a stable circulation flow can be maintained in a loop-shape channel in the presence of a appropriate external magnetic field and temperature gradient of the magnetic fluid. Amongst several factors inducing the device performance, the magnetic field strength and the fluid temperature difference between the heating section and cooling section are pre-eminent.

K. Shimada et al.[3] performed an experiment which clarifies the effect of the applied magnetic field on the conversion efficiency and the thermo-hydrodynamic characteristics of a system with parallel ducts. The effect of internal angular momentum of particles on the performance of the conversion system was analyzed theoretically and it was concluded that thermo-hydrodynamic characteristics and efficiency of magnetic fluid in new energy conversion system depend strongly on the type of applied magnetic field distribution. The results have found that the efficiency estimated is smaller than the experimental data due to the pressure difference and the saturated value of temperature which is due to the effect of particles aggregating. Thermo-hydrodynamic features of magnetic fluid and its efficiency in new energy conversion systems depend intensely on the type of applied magnetic field distribution.

H. Yamaguchi et al.[4] studied the flow states by conducting a numerical study on a ferrofluid confined in a concentric pipe with an annulus passage. They noticed, when magnetic field strength is increasing then there is corresponding increase in the heat transfer rate. Thus it is inferred that the flow phenomena occurring in the device, reflects the enhancement of the heat transport characteristic.

H. Yamaguchi et al.[5] examined the effect of magnetic field on the heat transfer mode in considering the flow and temperature fields of a ferrofluid flowing inside a square cavity in which a partitioned wall was placed in the middle of the space. They concluded that when Rayleigh number dependent electric field is applied, the flow mode with four vortices or two vortices generated , and when there is no magnetic field, the flow mode with four vortices retains and at lower region of Rayleigh number when the buoyancy (due to the gravity) and the magnetic body force coexists, the heat transfer characteristics are low. However, by increase of Rayleigh number the heat transfer can be largely improved and shows higher value when a strong magnetic field is applied.

Giti Karimi-Moghaddam et al.[6] studied the thermo magnetic convection in different heat loops under external magnetic field. On the basis of dimensional analysis in terms of geometric length scales, ferrofluid properties, and the strength of the imposed magnetic field, characterization of thermo magnetic convection (of different heat loops under the influence of the external magnetic fields) is done. They developed a one-dimensional theoretical model to characterize the thermo magnetic circulation loop using scaling arguments in terms of physical parameters. In parallel to this theoretical analysis, they conducted supporting numerical simulations using COMSOL. They concluded that a series of theoretical and numerical studies have been carried out to analysis the performance of a single phase, steady-state partially heated thermo magnetic circulation loop in the presence of an external magnetic source, containing a temperature sensitive ferrofluid. A one-dimensional theoretical model was developed to characterize the thermo magnetic circulation loop in terms of the physical parameters such as the geometric length scales, ferrofluid properties, and the strength of the imposed magnetic field. Matsuki et al.[7] developed an automatic cooling loop which consists of an electromagnet, a heat source, a heat sink and a loop-shape tube which contains a temperature-sensitive magnetic fluid. The setup is done in such a way that magnetic fluid was exposed to an external magnetic field, and a thermal field kept flowing in the loop without mechanical parts. The magnetic fluid is less sensitive to the fluid temperature as magnetic fluid has high curie temperature than the curie temperature of the temperature fluid.

Love et al.[8] exposed a simple 2-mm-diameter glass tube with a 40-mm-long column of MF to a uniform magnetic field and a thermal field. They choose temperature-sensitive Mn-Zn ferrite magnetic fluid as a working fluid due to its low Curie temperature. The fluid was observed to move at a speed of 1–2 mm/s. They constructed constitutive thermal, magnetic, and fluid dynamic equations associated with the magneto caloric pump and validate their finite element model with a series of experiments. When they use their finite element model, they observed that experimental data the simulations results agree to each other. Their starting results show a good match between the model and experiment as well as approximately an order of magnitude increase in the fluid flow rate over conventional magnetite-based ferrofluid operating below 80 degrees C. Finally, as a practical demonstration, they describe a novel application of this technology: pumping fluids at the "lab-on-a-chip" microfluidic scale. Yamaguchi et al.[9] studied the temperature sensitive fluids. They numerically observed the performance of an energy conversion device with the help of a temperature-sensitive magnetic fluid. Their experimental setup was in such a way that a disc was exposed to magnetic and thermal fields and a fluid was driven to circulate around the disc. Heat was converted to the kinetic energy of the magnetic fluid and the disc was forced to rotate by the flowing fluid.

Fumoto et al.[10] developed an automatic cooling loop which consists of a magnetic fluid, an earth magnet, a heat source, and a heat sink. A circulation flow of fluid was maintained inside the loop and the flow rate of fluid was measured using an ultrasonic liquid flowmeter. They also examined the relationship between the temperature difference and magnetic energy.

Lujun Zhou et al.[11] They introduced a newly designed thermomagnetic motor .In order to get heat-to-power energy output ,they used an elaborate gearing module into the thermo magnetic convection . They examined the rotation characteristics of the thermo magnetic motor with a digital video camera system. The performance of the rotor and temperature profiles of the magnetic fluid is provided by considering a series of operational conditions. They discussed the constitutive thermal, magnetic, and fluid dynamic relationships of the device by considering the previously collected data. After performing the experiment, the operation mechanism of the thermo magnetic motor is better understood, the performance of the device is improved, and the reliability of the device is promoted for different application purposes.

Sheng Lun Hung et al.[12] numerically studied the flow pattern of a magnetic fluid. They performed the experiment by filing the magnetic fluid within an annulus whose inner cylinder is moving at a constant rotational speed, while the outer cylinder is stationary but under the influence of a non-uniform external magnetic field. Hartmann number is taken as a reference to characterize the strength of magnetic field. As the Hartmann number increases, the fluid elements experiences the greater resistance to enter the region with magnetic field. The strength and size of the recirculation cell depend on the reference Hartmann number, the number and size of the discrete regions without external magnetic field. They concluded that the entry of fluid element with the magnetic field in the region will depend on the presence and absence of the external magnetic field. This will generate the recirculation cell, the shear stress on the moving inner cylinder increases with the reference Hartmann number and the span of the single external magnetic field region, the magnitude of the shear stress on the stationary outer cylinder may increase or decrease with the reference Hartmann number depending on the external magnetic field configuration.

M. Petit et al.[13] studied on Liquid cooling of electronic devices. It is already known that a liquid flow can be created without any mechanical part with the help of the ferrofluid which has low Curie temperature. They studied about the creation of a pressure drop in a straight tube filled with a MnZn ferrofluid and submitted to a magnetic field. The experimental setup is instrumented with thermocouples. They concluded that a without any moving mechanical pieces and taking advantage of a thermomagnetic coupling in a ferrofluid, hydrostatic pressure can be successfully created . Magneto-convective motion decrease the temperature gradient in the ferrofluid because of this pressure is limited, so this static pressure is due to the temperature dependence of the magnetic properties of Mn–Zn ferrite colloids. The reduction of the pressure is probably also due to an agglomeration of the magnetic particles.

D. Zablotsky et al.[14] compared the results of numerical and experimental investigation of thermo magnetic convection in a temperature sensitive ferrofluid containing Mn–Zn nanoparticles under the influence of strong non-uniform magnetic field generated by permanent magnets. Results were compared in three aspects: magnetic intensification as dependent on the temperature difference, on the magnet shift, and averaged vertical flow velocity. Simulation was done in turbulent convection using RANS equation solver implemented in ANSYS CFX with SST k–w two-equation closure model. It was found that maximal thermo magnetic intensification was achieved when magnets were positioned as near as possible to the warm (cooled) end and when heat source was located into the region of maximal magnetic field intensity.

Fatih Selimefendigil et al.[15] studied a lid driven square cavity heated from below with two rotating cylinders under the influence of a magnetic source were numerically simulated. They investigated the effects of Reynolds number, angular speed of the cylinders, the ratio of the angular velocities, the ratio of the cylinder diameters and the strength of the magnetic dipole source on the fluid flow and heat transfer characteristics of the lid driven cavity heated from below. They concluded that the flow and thermal patterns are effected with Reynolds number and magnetic dipole source which adds an inhomogeneous magnetic body force, Local and averaged heat transfer enhancement are observed as the Reynolds number increases, the external magnetic field acts in a way to decrease the local heat transfer in some locations and increase it in some others. Averaged heat transfer first increases then decreases as the value of the magnetic dipole strength increases.

CONCLUSIONS

The following conclusions can be drawn from the papers reviewed in this study.

1. Increase in heat transfer rate is observed with increase in magnetic field strength.
2. Heat transfer is an increasing function of Reynolds number.
3. With increase of Rayleigh number, there is substantial improvement in heat transfer characteristics of a ferrofluid.
4. As the Hartmann number increases, the fluid element experiences the greater resistance to enter the region with magnetic field.

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