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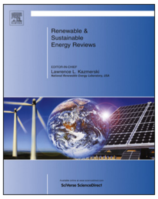

A review of magnetic field effects on flow and heat transfer in liquids: Present status and future potential for studies and applications

A.E. Kabeel [a,*], Emad M.S. El-Said [b], S.A. Dafea [a]

[a] *Mechanical Power Engineering Department, Faculty of Engineering, Tanta University, Tanta, Egypt*
[b] *Industrial Engineering Department, Faculty of Engineering, Fayoum University, Fayoum, Egypt*

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ABSTRACT

The subject of Magneto-hydrodynamic attracted the attention of many research workers in view of its applications to physics, medicine and engineering. The interest in these types of problems stems from the possibility of managing the thermal behaviour or to control the viscous property of the liquids. In this paper, an attempt has been made to present a review work achieved during the recent years worldwide and the state-of-the-art for most important efforts in the study of the phenomenon of the magnetic and electric field effect on liquid flow patterns and heat transfer through it. Magneto-hydro-dynamic (MHD) covers phenomena in electrically conducting fluids, where the velocity field and the magnetic field are coupled. Due to its wide potential, magnetic field effects on flow and heat transfer in liquids and its applications, has been studied extensively. An important discussion for the wider public interest question about the main reasons of the magnetic field effects on flow and heat transfer in liquids is presented.

Contents

1. Introduction

The action at a distance of a magnetic field on the fluid has many practical applications. Examples in the metals processing industry include the control of liquid metals in continuous casting process, plasma welding, electrolytic hall cells for aluminium smelting, electromagnetically supported melts, and many others. Another big application area concerns the nuclear industry, where liquid metal blankets are used for their high heat transfer properties and shielding capabilities under the influence of strong magnetic fields. Also, application of the magnetic field of medical science is one of the important topics in magneto-science. Now, an alternative promising drug instead of that available before and has its side effect, may be at hand by exposing a person to a magnetic field could improve blood flow around their body. The experiment in the hostile environment encountered in all these applications is extremely difficult to perform. Also, the field of MHD is complex as it involves the solution of both the Navier-Stokes equations characterizing fluid flow and Maxwell's equations for the magnetic field. For that reason, mathematical models capable of addressing the MHD problem are practically desirable. This is especially true

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[*] Corresponding author. Tel.: +20 1001543587; fax: + 20 403453860.
E-mail addresses: kabeel6@hotmail.com (A.E. Kabeel), Egypt.emad_mech@hotmail.com (E.M.S. El-Said), salahdafea@me.com (S.A. Dafea).

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in instances where the two fields are strongly coupled. In most situations, analytic solutions of the coupled set of equations do not exist; Numerical techniques provide the only means available for addressing realistic industrial problems.

The study of various magnetic fields and fluid interactions may be divided into two main categories [1]: electrohydrodynamics (EHD), which deals with electric force effects and magnetohydrodynamics (MHD), which deals with the interaction between magnetic fields and fluid conductors of electricity. Today MHD has developed into an extensive engineering and physical science, encompassing astrophysical solar and planetary flows to liquid metal flows in the metallurgical industry. There is no replicated scientific study showing the effects associated with the magnetic field of flow and heat transfer in liquids and their applications in medical and industrial sectors. Schenck [2] reviewed and discussed the issues associated with the exposure of patients to strong, static magnetic fields during magnetic resonance imaging (MRI) and its effects on human health. Electro-Magneto-Hydro-Dynamics (EMHD) addresses all phenomena related to the interaction of electric and magnetic fields with electrically conducting or magnetic fluids. Electric and magnetic flow control, for example, is a challenging area of mathematical and engineering research with many applications such as the reduction of drag, flow stabilization to delay transition to turbulence, tailored stirring of liquids, pumping using travelling EM waves, and many others. The application of electric and magnetic fields in diverse branches of materials science, such as crystal growth, induction melting, solidification, metal casting, welding, fabrication of nano-fibers, fabrication of specialty composites and functionally graded materials, or Ferro-fluids are recently of growing interest. In the steel industry, for example, large electromagnets are used to dampen unwanted fluid motion at free surfaces, control the degree of turbulence, stir the liquid and influence the solidification process. Due to the finite conductivity of biological fluids like blood, MHD also plays a role in biomedical applications like Magnetic Drug Targeting (MDT) and (mmune) magnetic cell separation. In recent years, interest has arisen in using MHD in micro-fluidic devices to stir, cool and pump fluids for, e.g., chromatography or the replication of DNA by Haverkort and Peeters [3]. Fully coupled EMHD systems, that is, in situations where the flow-field is influenced by the electric and magnetic fields and where these fields are in turn influenced by the flow-field, are challenging research subjects with applications in geo- and astrophysics (dynamo, magneto-rotational-instability, etc.). Gerbeth [4] showed that numerical simulations of many important processes (the growth of single crystals, metal casting for aerospace applications, aluminium electrolysis, etc.) require sophisticated tools for coupled fluid flow—heat/mass transfer—electromagnetic fields. Computational EMHD is a vital subject of recent research with a long list of interdisciplinary applications and scientific problems. Kuzmin [5] discussed the results of a CFD simulation as they are never 100% reliable because the input data may involve too much guessing or imprecision, also the mathematical model of the problem at hand may be inadequate, and the accuracy of the results is limited by the available computing power. The reliability of CFD simulations is greater for laminar/slower flows than for turbulent/fast ones, for single-phase flows than for multi-phase flows, and for chemically inert systems than for reactive flows.

Some reviews and studies have been published about MHD or EMHD and their applications in different fields [6–8]. Nevertheless, this paper presents a critical review work of the highlights that have been achieved during the recent years for most important efforts in the study of magnetic field effects on flow and heat transfer in liquids and their applications, which have developed on medical and industrial fields.

2. Response to external magnetic field

Increasing evidence of the importance of the magnetic field influence on the heat and flow of liquids and also the response of liquid particles in the presence of a magnetic field need detail discussion. The properties of the liquids such as thermal conductivity and viscosity can be changed under an applied external magnetic field. When stationary transverse magnetic field is applied externally to a moving electrically conducting fluid, electrical currents are induced in the fluid. The interaction between these induced currents and applied magnetic field produces a force known as Lorentz force which tends to retard the flow of conducting fluid and changes the transport phenomena of heat [9]. Baranwal and Deshmukh [10] introduce the basic principle of Magneto rheological fluid (MRFT) is that very small suspended particles having magnetizing properties are introduced in the base fluid. When a magnetic fluid is applied to this fluid, these particles form a chain aligned in the direction of the field which creates a resistance to the fluid flow. Resulting, an increase in the fluid viscosity takes place. According to this phenomena, the effect is probably caused by the response of red blood cells (RBC) which can be easily explained as follows. In the presence of a strong magnetic field, the red blood cells form chains that align themselves with the field lines where convoys of red blood cells line up behind a leading cell. This process could enable the cells to pass through the blood in a more streamlined fashion, thus reducing the blood's viscosity.

For another example, the ferromagnetism particles in a homogeneous liquid, each with its embedded magnetic moment, are analogous to molecules of a paramagnetic gas. In the absence of an applied field, the particles are randomly oriented, and the fluid has no net magnetization. However, for ordinary field strengths the tendency of the dipole moments to align with the applied field is partially overcome by thermal agitation [11].

It is well known that MHD pressure drop reduction is an important issue in the fluid mechanics. The MHD pressure drop is caused by the generation of a resistive electromagnetic force, which in turn increases the friction force because of the resultant flattened velocity distribution due to induced by Lorentz force [12].

From the above review, it is concluded that, the thermal and flow management of liquids under magnetic field is a central design and enhancement consideration for many engineering technologies, from the complex to the commonplace to satisfy the demand for faster development in industrial and medical fields.

3. Magnetic field effects on flow and heat transfer

3.1. Effects on flow field behaviour

Many researches are done to study the magnetic field effect on viscous properties of liquids. Rivero et al. [13] studied the flow of a liquid metal past a localized magnetic field in a rectangular duct and compared with some experimental results. The calculated field was validated with a different magnetic system, where the same kind of magnets was used. For $Re < 2050$, the laminar model fits better to the experimental data than turbulent models, while for $Re > 2050$ the turbulence models present a better agreement but still do not reproduce the behaviour accurately in the whole region. Nevertheless, results suggest that the dynamics of vortex patterns as Re is increased may be due to the transition from a laminar to turbulent regime.

A three-surface-multi-layered channel is one of the possible methods for reducing the MHD pressure drop. Aoyagi et al. [14] evaluated experimentally and numerically the liquid metal MHD flow in a three-surface-multi-layered channel was conducted to confirm the extent of MHD pressure reduction in the channel. The MHD flow was tested using a Bi–Sn eutectic alloy (MHD liquid) and an open annular channel under up to 5 T magnetic field.

YaoHui et al. [15] studied experimentally and numerically the initial responses and evolutions of the flow pattern and lift coefficient