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# Study of Heat Transfer Control with Magnetic Field Using Higher Order Finite Difference Scheme

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**Abstract.** The control of convective heat transfer from a heated circular cylinder immersed in an electrically conducting fluid is achieved using an externally imposed magnetic field. A Higher Order Compact Scheme (HOCS) is used to solve the governing energy equation in cylindrical polar coordinates. The HOCS gives fourth order accurate results for the temperature field. The behavior of local Nusselt number, mean Nusselt number and temperature field due to variation in the aligned magnetic field is evaluated for the parameters $5 \leq Re \leq 40$, $0 \leq N \leq 20$ and $0.065 \leq Pr \leq 7$. It is found that the convective heat transfer is suppressed by increasing the strength of the imposed magnetic field until a critical value of $N$, the interaction parameter, beyond which the heat transfer increases with further increase in $N$. The results are found to be in good agreement with recent experimental studies.

**AMS subject classifications**: 76D05, 65N06

**Key words**: Higher Order Compact Scheme, forced convection, magnetic field, low $R_m$ approximation.

## 1 Introduction

Magnetic fields are now being employed in control of fluids and in metallurgical processing where liquid metals are involved. The principal effect in action being the Lorentz force produced in the electrically conducting fluid in magnetic field. Further, the magnetic field is useful to eliminate unwanted recirculation bubble or turbulent motion of fluid.

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When an electrically conducting fluid moves in presence of a uniform external magnetic field, electric current is produced in the fluid, which slowly dissipates in the fluid in the form of heat energy via Ohm's law. The dissipation of heat energy in the moving fluid causes considerable modification in the thermal convection and fluid flow structure. In particular it is known that rate of fluid flow gets damped due to the imposed uniform magnetic field. Hence it is of particular interest to investigate the nature of heat transfer in the presence of MHD effects [1]. Fluid flow control using magnetic field is based on a solid physical foundation. This has scope for technology that aids in a better heat transfer control. Applications like fusion technology have made hydromagnetic flows of electrically conducting fluid and their heat transfer more important in recent years. The study of magnetic heat transfer over a sphere has been explored experimentally by Boynton [2]. Uda et al. [3] experimentally studied MHD effects on heat transfer of liquid Lithium flow in an annular channel. Yokomine et al. [4] investigated heat transfer properties of aqueous KOH solution ($Pr \approx 5$) in their experimental study and concluded that there is a degradation of heat transfer with magnetic field. The electromagnetic enhancement of heat transfer has also been found [5]. The heat transfer from the side-wall of a duct through which an electrically conducting fluid flows within a strong transverse magnetic field [6] and the heat transfer around a circular cylinder placed in a rectangular channel subject to the externally applied magnetic field [7] have been investigated in recent times. The magnetic effect on forced convection around a circular cylinder embedded in a porus medium has also been investigated [8]. An experimental study [9] provided the evidence that an externally applied magnetic field can help to suppress vortex shedding. In this regard, numerical studies have been conducted later to understand the flow instability that is present in the wake using magnetic fields and it was found that depending on the magnitude of applied magnetic fields in the two-dimensional flow region, the vortex shedding can be suppressed or eliminated and as a result the flow becomes stabilized [10–12].

Higher Order Compact Schemes (HOCS) are becoming more popular in recent days due to their higher order of accuracy in results in addition to unconditional stability of the numerical scheme. These schemes capture the flow phenomena very accurately in coarser grids itself when compared to upwind schemes and also some second order accurate finite difference schemes [13–15]. In this paper, control of heat transfer from a heated circular cylinder immersed in a steady stream of viscous incompressible and electrically conducting fluid which is under the influence of an externally imposed magnetic field is studied using higher order finite difference scheme. The behavior of local and mean Nusselt numbers is then compared with recent experimental results.

## 2 Formulation of the problem

The forced convective heat transfer problem is formulated as steady, laminar flow in axis-symmetric cylindrical polar coordinates. The center of the cylinder is chosen at origin