ANNEX 11

Laminar MHD natural convection cooling in a vertical cylinder

A.I. Iatridis, I.E. Sarris and N.S. Vlachos
Laboratory of Fluid Mechanics and Turbomachines,
Department of Mechanical Engineering, University of Thessaly,
Athens Avenue, 38334 Volos, Greece, Tel/Fax: +30 24210 74090, fluids@mie.uth.gr

PROBLEM DEFINITION

Results of numerical simulations are presented for the laminar and transient natural convection cooling of an initially isothermal quiescent electrically conducting fluid placed in a vertical cylinder in the presence of an axial magnetic field. The fluid is put to motion when the cylindrical wall is suddenly cooled to a uniform lower temperature [1]. For this particular cooling process, the flow is characterised by three sequential almost discrete stages: a) development of momentum and thermal boundary layers along the cylindrical cold wall, b) intrusion of the cooled fluid into the main fluid body, and c) flow and thermal stratification. The particular characteristics of the cooling process were studied for a range of Hartmann, Reynolds and Prandtl numbers for which the flow remained laminar during all stages. The focus is on the effect of the magnetic field and for all the cases studied it is found to decelerate the cooling process and reduce the heat transfer rates. As a consequence of the domination of conduction heat transfer at high magnetic fields, the development of the vertical boundary layer is delayed.

RESULTS AND DISCUSSION

Numerical simulations were performed at various combinations of Hartmann Ha, Rayleigh Ra, and Prandtl Pr numbers. At the initial stage there is no much influence of the magnetic field on the cooling process, as seen in *Fig. 1*, which shows the distribution of isotherms at the initial cooling stage for Ha = 0 and 100. With time passing, the magnetic field tends to delay the cooling of the fluid. The main mechanism of heat transfer in the presence of a strong magnetic field is conduction. The effect of increased Pr on the cooling process is to keep the fluid temperature higher and so the cooling is delayed (see *Fig. 1*). This occurs especially at high Hartmann numbers. When Ra and Pr increase, the increase of the magnetic field delays the cooling process. *Figure 1* shows how heat flows into the vessel, during the initial cooling stage. The most important conclusion isthat the magnetic field delays the cooling process. Furthermore, turbulence develops at increased Ra and Pr values.

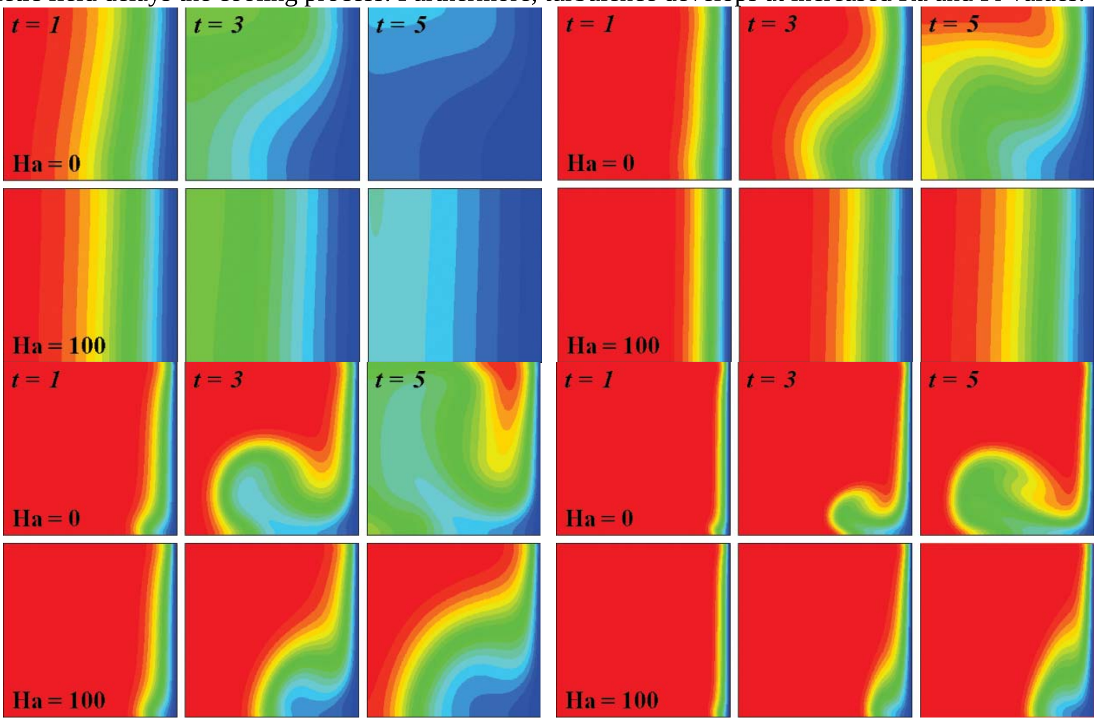

Fig. 1: Distribution of isotherms at the initial cooling stage for Ha = 0 (upper) and Ha = 100 (lower) at (a) Pr = 0.03, Ra = 10^4 (b) Pr = 0.7, Ra = 10^4 (c) Pr = 0.03, Ra = 10^6 (d) Pr = 0.7, Ra = 10^6

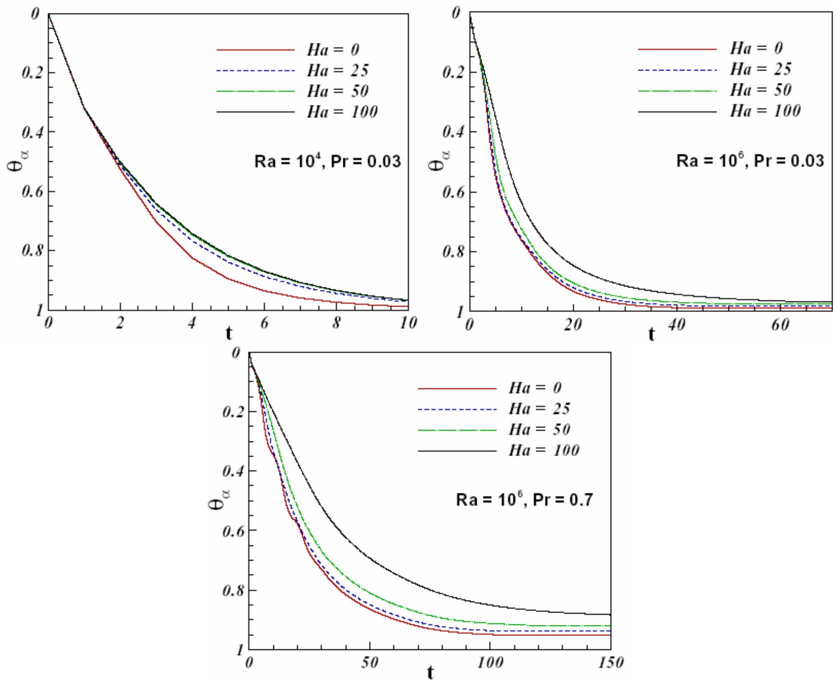

Fig. 2: Average temperature in time, for (a) Pr = 0.03, Ra = 10^4 (b) Pr = 0.03, Ra = 10^6 (c) Pr = 0.7, Ra = 10^6

An interesting detail is that at increased Ra, the changes in the magnetic field have a stronger effect on the fluid temperature, as indicated by the mean fluid temperature θ_a in *Fig. 2*. Increasing Ra and Pr delays the cooling and it is obvious that when Ra, Pr, and Ha are high, the temperature is kept at even higher levels and for longer time.

Figure 3 presents the radial distribution of fluid temperature for Ha = 100, showing that it decreases with time. It is concluded that when Pr increases, the temperature is kept at high levels. Furthermore, when Pr is high, the temperature decreases slower, and a larger part of the fluid is kept at higher temperature.

The present analysis focused on the effect of the imposed magnetic field, which was expected to reduce the fluid motion and, consequently, decelerate the cooling. It is observed that, at the initial stage of the development of the boundary layer on the cylindrical wall, there is no significant influence of the magnetic field. In the next stage of thermal intrusion of cold fluid, a significant reduction in heat transfer is observed in the presence of the magnetic field, while at the final stage of thermal stratification, the cooling rate of the fluid depends on the combination of Rayleigh, Prandtl and Hartmann numbers. This is related to the cold vortices emanating from the vertical boundary layer [2]. Finally, it should be noted that the present results were based on the assumption of axisymmetry and, thus, the study of possible three-dimensional effects is proposed for future work.

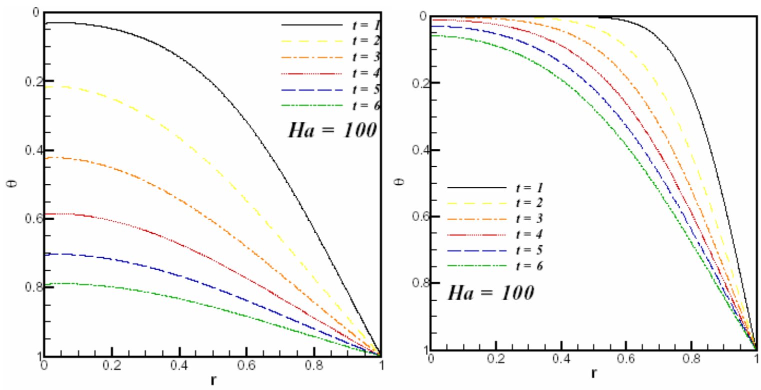

Fig. 3: Radial distribution of temperature for Ha=100, Ra=10^4 at (a) Pr = 0.03 (b) Pr = 0.7

REFERENCES

[1] W. Lin and S.W. Armfield, “Scaling laws for unsteady natural convection cooling of fluid with Prandtl number less than one in a vertical cylinder”, Physical Review **E72**, 016306 (2005).

[2] I. E. Sarris, A. I. Iatridis, C. D. Dritselis, and N. S. Vlachos, “Magnetic field effect on the cooling of a low-Pr fluid in a vertical cylinder”, Physics of Fluids **22**, 017101 (2010).