Chapter - 6

Summary and Conclusions
6.1 Summary and Conclusions

Liquid metal MHD power conversion systems of gravity type have been recently proposed for variety of low grade heat sources, fast breeder and fusion reactors. These systems are based on Faraday's law of induction extended to electrically conducting liquids. They contain high-density liquid metal and a suitable thermodynamic fluid. These systems have large conversion efficiency in view of isothermal expansion in the riser (as against adiabatic expansion of steam in turbine of Rankine cycle).

Two-phase vertical upward liquid metal flows occur in the riser of these systems and liquid metal flow in the downcomer pipe containing MHD generator. The overall efficiency of the power conversion depends upon the interaction of the phases. The flow is complicated due to bubbly, slug and churn flow in the riser.

Extensive literature surveys of various two-phase models based on air-water, steam-water and to a limited extent liquid metal have been done. It is found that most of the studies in two-phase flows have been confined to mixture (or diffusion) model, where the two- phases are considered as a single fluid with the empirical relation of the void fraction. Even though the diffusion model is simple, compared to two-fluid model, many important characteristics of the two-phase flow are lost. In the case of liquid metal flows, very little work has been carried out related to two-phase flows.

In order to study two-phase flows in LMMHD riser, a one-dimensional, steady state, two-fluid model is developed. The equations consist of a one-dimensional continuity equation for each phases, combined momentum equation, vapour momentum equation and appropriate drag force for multibubble, churn and slug flow along with virtual mass force and related transport and thermodynamic relations. Taital et al. classification has been assumed to determine transition from one flow to other.
Effects of variation of void fraction and phase velocities of the fluid across the cross section of the pipe have been studied based on Ishii et al. model by modifying relative velocity and incorporating appropriate coefficients in the conservation equations. Bubble size at the mixer orifice exit has been calculated using Kumar et al. equations. A numerical code in Fortran is developed for solving these equations by using 4th order Runge-Kutta method. The code is tested for numerical stability, sensitivity to the input slip values etc.

In order to verify the accuracy of the model, experiments have been carried out in a nitrogen-mercury experimental facility at Bhabha Atomic Research Centre. Void fraction, slip and pressure at different locations were determined for the mass fluxes varying from 0.125 and 2.302 kg/sm² for nitrogen and 5.52 × 10³ to 12.26 × 10³ kg/sm² for mercury. Experimental data of void fraction slip and pressure at different location of nitrogen-mercury facility have been compared with predicted values based on the model developed. The agreement is reasonably good.

Based on this model, a 230 kWe LMMHD PC system suitable for Solar-Waste heat has been designed. Appropriate equations for the flow in the mixer, riser, separator, downcomer and MHD generator have been solved. End losses due to recirculating currents at the entrance and exit of the generator have been taken into account. Extensive optimisation have been done by varying geometry, flow rates and electrodynamic parameters like load factor magnetic field intensity, voltage, electrical power etc. The optimised system consists of two loops of LMMMD HD PC connected in series. Loop-1 operating with Lead at 350 °C and Loop-2 operating with Lead-Bismuth (25 % of Bismuth) at 215 °C. Steam at 430 °C enters Loop-1 after receiving thermal energy of 2.5 MW from the Regenerator, Solar Tower and Incinerator Waste Heat. The net efficiency of conversion from thermal to electrical is 9.2 % with a voltage of 3.4 V and current of 84 kA.
6.2 Recommendations of scope of future studies

The flow is not fully developed near the entrance region of the riser. In this region accurate modelling requires three-dimensional analysis. Formulation of the three-dimensional equations with appropriate initial conditions is quite complicated and at present very little work has been carried out. On the other hand, when the flow is fully developed in the case of circular pipe, the flow become essentially two-dimensional and is functions of radial and axial co-ordinates. As a first step, the present one-dimensional analysis should be extended to two-dimensional in the fully developed regions. This gives us information regarding transverse variation of fluid variables. Thus, better modelling of drag and virtual mass force can be achieved.

In order to obtain the two-dimensional solutions, turbulence has to be taken into account explicitly unlike one-dimensional equation, where it is accounted in the frictional pressure drop. Appropriate $k-\varepsilon$ model for turbulent two-phase flows have to be solved. Along with better modelling, detailed experiments have to be carried out to obtain void distribution, pressure distribution etc. in the riser for validate the model. With the availability of better two-phase flow models, accurate design and scale up studies of LMMHD PC systems can be carried out. In addition these studies will give us deeper understanding of the processes taking place in the two-phase flows in general.