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Extension of A VOF based CFD Code to MHD Free Surface Flows

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Abstract: Important MHD free surface characteristics were analyzed using a modified MHD-extended commercially available incompressible non-MHD FLOW-3D code. The MHD flow operating conditions for liquid lithium concepts under NSTX operating conditions were simulated and discussed. These results show how and which MHD force has an important effect on the proposed lithium flow concepts.

1. Introduction

In the APEX study[1], free surface flowing liquid lithium walls have been proposed as a potential tool for particle control and for high heat flux removal[2]. Lithium is believed to improve plasma performance by reducing recycling and improving edge control, and allowing stable tokamak operation with increased elongation under reactor conditions. Moreover, flowing lithium wall helps to reduce the thermal stress and consequent failure rates of the first solid wall. These physics and technology benefits provide incentives for exploring flowing liquid lithium walls.

There are many codes and studies available to simulate the free surface flow[3]. However, most of them do not take into account MHD effects. Therefore they cannot be directly used to calculate fluid flows in nuclear fusion devices where significant MHD interaction occurs due to a strong reactor magnetic field. In this paper, numerical models that implicated in a VOF method CFD FLOW-3D code for the simulation of MHD effects are discussed. Some examples, such as the MHD free surface lithium flow under NSTX condition based on the proposed concepts of soaker hose and film flows are analyzed and presented.

2. Model

While extending a non-MHD CFD code to MHD regimes, it requires that the electric potential or the induced magnetic field to be solved separately and coupled with the Navier-Stokes-Maxwell equations. This is what being coded now. However, in several particular cases MHD force can be viewed as an additional source term of body force such as in an axi-symmetric flow. Here, the most two important mechanisms leading to MHD drag are described. These include induced currents caused by a toroidal field gradient along the flow direction and a toroidal electric current produced by the normal field, which both result in the opposing Lorentz force. If only magnetic field components of B_x and B_y are considered, the body forces by wall acts only in the momentum equations of x and y direction, which are written as:

$$\frac{\partial u}{\partial t}+\frac{1}{V_F}\left\{uA_x\frac{\partial u}{\partial x}+vA_y\frac{\partial u}{\partial y}+wA_z\frac{\partial u}{\partial z}\right\}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+g_x+f_x+F_{emx} \tag{1}$$

$$\frac{\partial v}{\partial t}+\frac{1}{V_F}\left\{uA_x\frac{\partial v}{\partial x}+vA_y\frac{\partial v}{\partial y}+wA_z\frac{\partial v}{\partial z}\right\}=-\frac{1}{\rho}\frac{\partial p}{\partial z}+g_y+f_y+F_{emy} \tag{2}$$

where g is the gravity acceleration, f is the viscous frictional force, where the Lorenz force per unit volume is:

$$\vec{F}_{em}=\vec{j}\times\vec{B} \tag{3}$$

where $\vec{j}$ is the induced current density and from Ohm 's law for moving media:

$$\vec{j}=\sigma[\vec{E}+\vec{U}\times\vec{B}] \tag{4}$$

$\vec{U}$ is the velocity vector; $\vec{B}$ is the magnetic field and $\vec{E}$ is the electric potential. More description of the model will be given in the final paper.

3. Results

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Numerical analysis was performed to study the details of lithium free surface characteristics under a surface normal field, field gradient and geometrical effects. As shown in Figure 1, lithium flow has thickened significantly as it approaches the NSTX inboard divertor. This is due to the MHD drag caused by a normal surface field gradient changing from 0.06 T to 0.03 T over a flow distance of 20 cm. On the other hand, as shown in the left-hand side of the figure, droplet splashes are found if a sharp joint is made to connect the center stack and the inboard divertor.

The effect of radial field on a soaker hose idea is also studied. In this concept, a small flow is fed into the surface by a differential pressure between the flow inside a duct and outside vacuum boundary. The flow is pushed away from the surface through an inward force generated from the interaction of the toroidal field and the applied external current in the poloidal direction as shown in Figure 2. If a radial field exists the interaction between the radial field and the external current produces a preferential toroidal force and flow as shown in Figure 3.

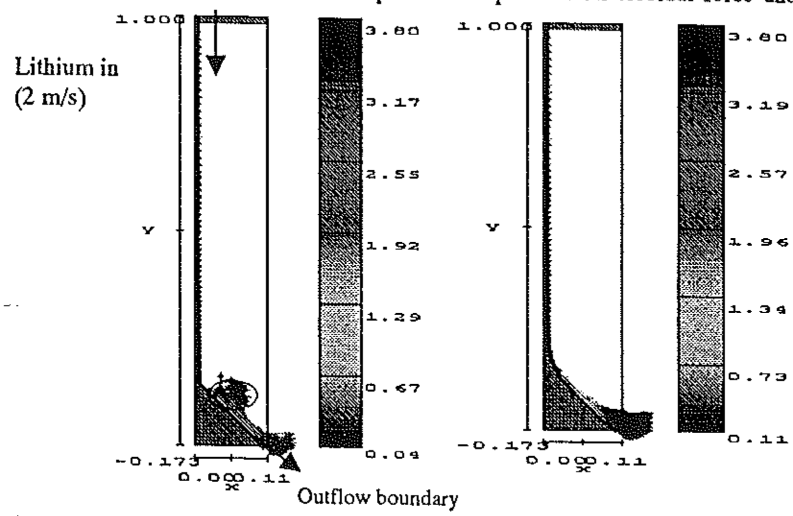

Figure 1. Velocity vector of lithium proceeds over the two kind connections between center stack (the straight portion) and inboard divertor (the inclined plate)(under NSTX condition. (unit: meter/s)

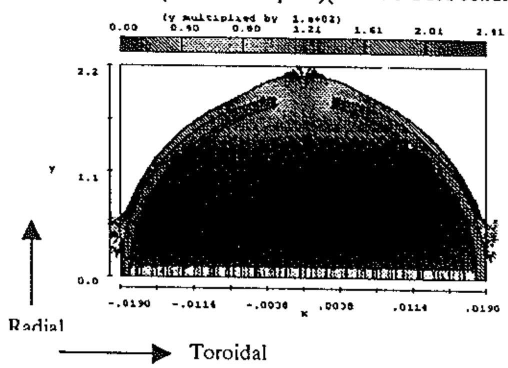

Figure 2 Interaction between the toroidal field and an applied external current caused flow to flow away from the free surface. Lithium velocity is shown. (B_T =0.15 T, B_r=0 T)

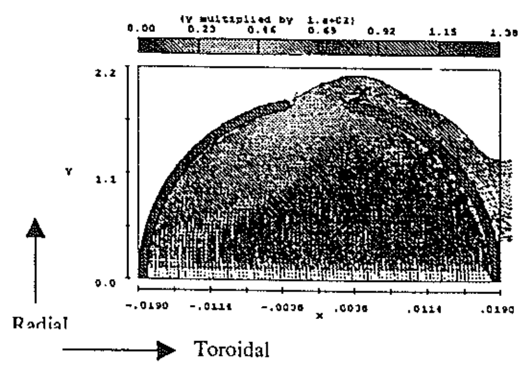

Figure 3 Interaction between the radial field and an applied external current creates a preferential flow. Lithium flows toward right-hand side of the channel. (B_T =0.15 T, B_r =-0.1T)

Acknowledgement

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