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Numerical study of cavitating flow of magnetic fluid in a vertical converging–diverging nozzle

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Abstract

The fundamental characteristics of the two-dimensional cavitating flow of magnetic fluid in a vertical converging–diverging nozzle under a strong nonuniform magnetic field are numerically investigated to realize the further development and high performance of the new type of a two-phase fluid driving system using magnetic fluids. The numerical results demonstrate that effective two-phase magnetic driving force and fluid acceleration are obtained by the practical use of the magnetization of the working fluid.

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Keywords: Cavitation; Multiphase flow; Liquid metal MHD; Internal flow

1. Introduction

The precise investigation of cavitation or two-phase flow phenomenon of magnetic fluid is very interesting and important not only as the basic studies on hydrodynamics of magnetic fluids, but also for finding solutions to problems related to the development of practical engineering applications of magnetic fluids, such as a new fluid driving system or energy conversion system using two-phase flows of magnetic fluid which was proposed by one of the authors [1].

The principle of such a fluid driving system is schematically depicted in Fig. 1. In this system, the flow is accelerated in the region of the converging nozzle, and the cavitation inception is induced at the downstream point of the throat of a diverging nozzle due to a pressure decrease. Furthermore, the flow is additionally accelerated not only by the pumping effect of the cavitation bubbles, but also by the rise of magnetic pressure induced by the unbalance of magnetic body forces in the single- and two-phase flow regions under a nonuniform magnetic field.

In the present study, two-dimensional characteristics of cavitating flow of magnetic fluid in a converging–diverging nozzle with phase change are numerically investigated to demonstrate the further development and high performance of the two-phase fluid driving system or fluid transport applications.

2. Governing equations

The calculation is carried out using the two-dimensional generalized curvilinear coordinate system (ξ, η) as shown in Fig. 1; ξ and η denote the transverse and

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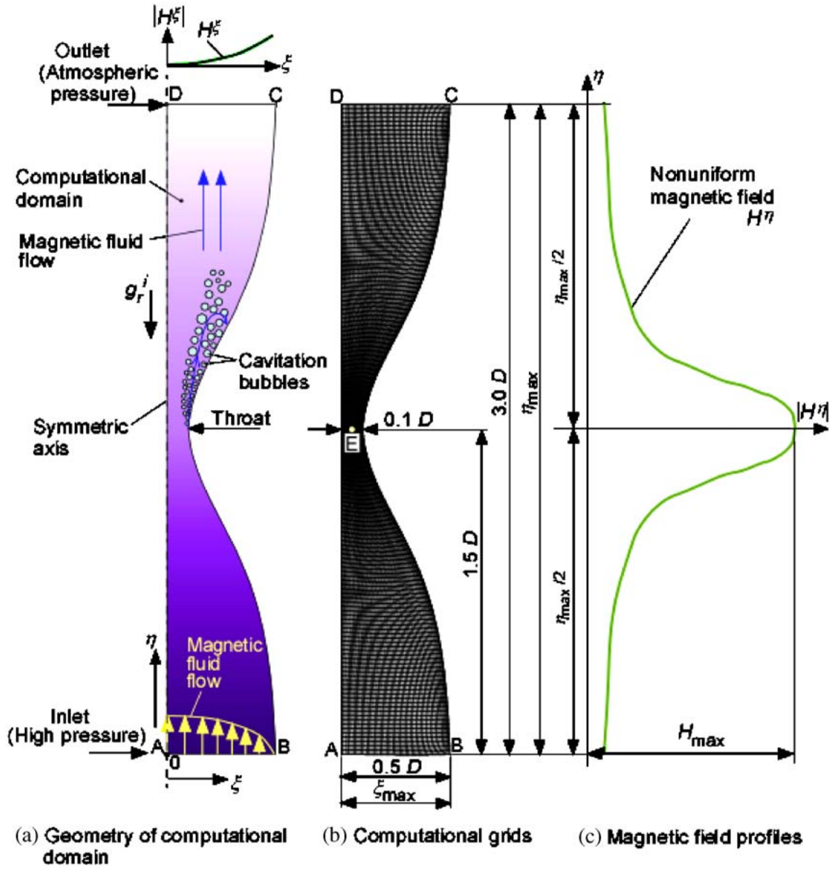

Fig. 1. Schematic of computational system.

longitudinal coordinate, respectively. The model for analysis simulates the cavitating flow of magnetic fluid passing through the converging–diverging nozzle in a vertical duct. The nonuniform magnetic field is applied in the longitudinal η-direction, which is parallel to the mainstream of working fluid flow. The governing equations of the cavitating magnetic fluid flow, taking into account the effect of nonuniform magnetic field based on the unsteady two-dimensional thermal nonequilibrium two-fluid model [2], are derived as follows.

The mass conservation equation for gas and liquid phases is

$$\frac{\partial}{\partial t}\left(\alpha_m \rho_m\right) + \nabla_j\left(\alpha_m \rho_m u_m^j\right) = \Gamma_m, \tag{1}$$

where the subscript m denotes the gas phase ($m = \mathrm{g}$) or liquid phase ($m = \mathrm{l}$), t is the time, α_g and α_l are the gas- and liquid-phase volume fraction ($\alpha_\mathrm{g} + \alpha_\mathrm{l} = 1$), respectively, ρ_g and ρ_l are the gas- and liquid-phase density, respectively, u_g^j and u_l^j are the gas- and liquid-phase contravariant velocity, respectively, Γ_g and Γ_l are the gas- and liquid-phase generation density, respectively. The superscripts and subscripts (i, j, k) denote the contravariant and covariant components, respectively, and the subscripts g and l denote the gas and liquid phases, respectively.

The combined equation of motion for a total gas and liquid phase is

$$\begin{aligned}
&\frac{\partial}{\partial t}\left(\alpha_\mathrm{g}\rho_\mathrm{g}u_\mathrm{g}^i + \alpha_\mathrm{l}\rho_\mathrm{l}u_\mathrm{l}^i\right) + \nabla_j\left(\alpha_\mathrm{g}\rho_\mathrm{g}u_\mathrm{g}^i u_\mathrm{g}^j + \alpha_\mathrm{l}\rho_\mathrm{l}u_\mathrm{l}^i u_\mathrm{l}^j\right) \\
&\quad = -g^{ij}\nabla_j p_\mathrm{l} + \mu_0\alpha_\mathrm{l}M^j\nabla_j H^i + \beta_\mathrm{T}g^{jk}\nabla_j\nabla_k u_\mathrm{l}^i \\
&\qquad + \frac{1}{3}\left(\beta_\mathrm{T}\nabla_j\nabla_k u_\mathrm{l}^k\right)g^{ij} + \left(\alpha_\mathrm{g}\rho_\mathrm{g} + \alpha_\mathrm{l}\rho_\mathrm{l}\right)g_r^i,
\end{aligned} \tag{2}$$

where the second term of the right-hand side of Eq. (2) represents the magnetic body force term in two-phase flow, H^i is the contravariant vector of magnetic field, M^j is the contravariant vector of magnetization, g^{ij} is the fundamental metric tensor, p is the absolute pressure, μ_0 is the permeability in vacuum, and g_r^i is the contravariant vector of gravitational acceleration.