STEADY STATE NUMERICAL MODEL FOR CRITICAL TWO-PHASE FLOW IN NOZZLE

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Summary This paper presents a steady state two-phase flow model including new choking criterions for one-dimensional conservative systems. As a first step, this model is used to study the flow in the motive nozzle of an ejector. Mechanical disequilibria and momentum exchange between phases is taking into account and numerical scheme uses SIMPLE algorithm. Numerical results are compared to experimental and previous numerical results from literature.

INTRODUCTION

The steady state flow of compressible fluid through convergent-divergent nozzles covers various important flow phenomena like the occurrence of critical flow conditions, transition from subsonic to supersonic flow or the occurrence of flow discontinuities. One phenomena still of interest is the choking condition in a critical flow such as in supersonic ejectors. Supersonic ejectors are widely used in a range of applications such as aerospace, propulsion, refrigeration and many thermal systems. In this paper, a one-dimensional compressible steady state two-phase flow model is presented with new choking criterions that are directly related to optimal flux conditions developed by [1]. As a first step, this model is used to study the flow in the motive nozzle of an ejector.

NUMERICAL MODEL

This is a one-dimensional two-fluid single pressure model using one temperature and mechanical disequilibria between phases in which no phase changes occurred. The procedure used for the calculation of the flow field is the standard SIMPLE algorithm developed for steady state flow conditions. A constant liquid density and perfect gas law for compressible component are assumed. In addition, droplets in gas flow for momentum exchange between phases are assumed to be uniform. In order to take account of the mechanical disequilibria, the slip ratio between phases must be obtained using drag source term.

With these assumptions, the following four equations model is obtained:

$$\frac{\partial}{\partial x}\sum_k \left(f_{Mk}\right) a_s \alpha_1 \rho_1 u_1 = 0$$

$$\frac{\partial}{\partial x}\sum_k \left(f_{Mk} s_k\right) a_s \alpha_1 \rho_1 u_1^2 + \frac{d}{dx}\left(a_s p\right) = p\frac{\partial a_s}{\partial x}$$

$$\frac{\partial}{\partial x}\left[A\alpha_1\rho_1 u_1\left(\sum_k \left(f_{Mk} s_k^2\right)\frac{u_1^{\;2}}{2} + \sum_k \left(f_{Mk} f_{Tk}\right)\frac{C_{p1}P}{R_1\rho_1}\right)\right] = 0$$

$$\frac{\partial}{\partial x}\left(A\alpha_2\rho_2 u_2^2\right) + \frac{\partial}{\partial x}\left(a_s\alpha_2 p\right) = \Gamma_{2,J} + \Gamma_{2,J}^c$$

where $\Gamma_{2,J}$ is the drag force between phases, $\Gamma_{2,J}^c$ is the force cause by the variable section, and s_k the slip ratio.

NUMERICAL RESULTS

At the inlet of the nozzle, homogeneous equilibrium flow is assumed from reservoir. For this reason, each phase have the same temperature and pressure. The inlet volume fraction is imposed. For the outlet boundary condition a constant exit pressure is applied. The initial conditions in the nozzle are identical with the upstream reservoir conditions which imply that the transient calculation starts with a strong discontinuity at the nozzle exit. The model has been validated with experimental data from Elliot and Weinberg [2] and compared to numerical results from Städtke [3].

Elliot and Weinberg comparison

Experimental results were obtained using a 1.27 m experimental nozzle. Authors show one pressure profile and a table resuming experimental results obtained for different mass flow ratio such as mass flow rate, exit velocity, and thrust measurement. Inlet conditions for all tests are p_0= 10.3421 (MPa), T_0=293K and an exit pressure of 0.1013 MPa. The

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Figure 1.1 shows that numerical pressure profile is in good agreement with experimental results. For this test, mass flow ratio is 39.1 and experimental mass flow rate is 67.33 kg/s. The numerical mass flow rate obtained is 67.64 which give an error of 0.45%.

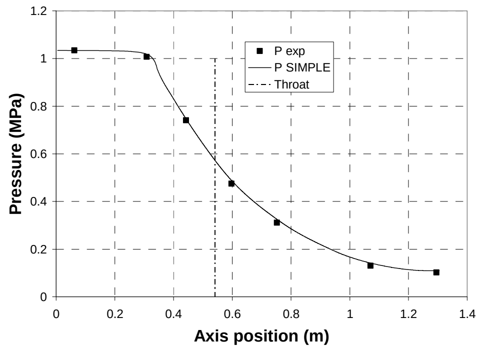

Figure 0.1: Pressure profile in the nozzle.

Städtke comparison

The ASTAR nozzle geometry presented by Städtke [3] is used to compare numerical results. For this case, fixed upstream reservoir pressure and temperature of p_0 = 1 MPa, T_0 = 400 K, $u_1 = u_2$ is used with a mass flow rate ratio (F_{Mk}) of unity and an exit pressure of 0.6 MPa. Numerical results obtained with this scheme are in good agreement with those of [2] as shown on Figure 1.2. Total mass flow rate obtained by [2] is 5.68 kg/s compared to 5.70 kg/s obtained with this model which implied a difference of 0.35%.

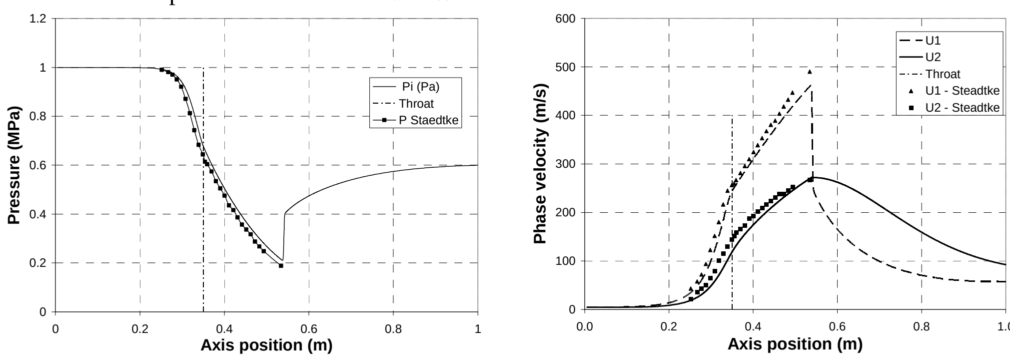

Figure 0.2: Pressure and velocity profiles in the ASTAR nozzle.

CONCLUSIONS

Multiphase systems present significant scientific challenges and the choking phenomenon has to be taken into account properly to achieve an accurate model of two phase flow. More results are obtained concerning super-critical behavior in comparison with mono-phase compressible flow. This numerical scheme give good results and the numerical study have given a lot of information about critical two-phase flow behavior. It also shows that steady state models are achievable for critical two-phase flow. Such an approach is in some cases simpler that using transient models which involve much more complex propagation phenomenon.

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