Analytical Study on Supersonic Two-Phase Flow Nozzle

Khine Tun Naung, Hayato TAJIMA, Hideaki MONJI

Department of Engineering Mechanics and Energy, University of Tsukuba
1-1-1, Tennodai, Tsukuba, Ibaraki 305-8573

ABSTRACT
This paper describes the numerical analysis and experimental equipment of two-phase nozzle flow, which is commonly applied to ejector of air-conditioning system. Two-phase flow nozzle is a device that converts thermal energy to kinetic energy. Gas and liquid have different properties, especially density. So the flow acceleration and velocity are varied and it is called velocity slip. It can cause energy losses. The efficiency of nozzle can be increased by reducing this phenomenon. In order to overcome this phenomenon, it is needed to analyze the microbubble in the nozzle of supersonic two-phase flow. It is predicted that microbubble is effective because of its properties. The main content in this paper is the comparison of analytical data by using STAR-CCM+ and practical data for supersonic two dimensional microbubble flows.

INTRODUCTION
At present air-conditioning and refrigeration systems use the ejector as an energy converting device for depressurizing circulating refrigerant. A typical modern ejector consists of a convergent-divergent nozzle. This nozzle transforms the thermal energy of the high-pressure liquid flow at the inlet to the kinetic energy of supersonic liquid-gas flow at the outlet. Velocity slip between gas and liquid reduces the efficiency of nozzle.

Microbubble is miniature gas bubble. It can reduce the energy losses of two-phase flow because of less velocity flow.

ANALYSIS
The main equation was obtained from the momentum and continuity equations as shown below

\[ u \frac{\partial u}{\partial x} + \frac{1}{\rho} \frac{\partial p}{\partial x} = 0 \] (1)

By integrating (1), it got energy equation.

\[ \frac{1}{2} \dot{u}^2 + \int \frac{1}{(\alpha - 1) \rho_l} dp = \text{const} \] (2)

Continuity equations for gas and liquid are

\[ \frac{\partial}{\partial x} \alpha \rho_g u = \dot{m} \] (3)

\[ \frac{\partial}{\partial x} (1 - \alpha) \rho_l u = -\dot{m} \] (4)

The amount of CO₂ changed from liquid to gas is

\[ \dot{m} = -\frac{\partial}{\partial x} \left(1 - \alpha \right) \rho_l u C_s \] (5)

\[ C_s = \frac{\text{Re}^4}{\rho^{26}} \] (E: Henry constant)

\[ C_s; \text{maximum percentage of CO}_2 \text{ dissolved in water} \]

Substitute (5) into (3) and (4) and divided by gas to liquid

\[ \frac{\alpha \rho_g + (1 - \alpha) \rho_l C_s}{(1 - \alpha) \rho_l (1 - C_s)} = \text{const} = B \] (6)

By solving (6),

\[ \frac{1}{(\alpha - 1) \rho_l} dp = \frac{p}{\rho_l} + \frac{p_0}{\rho_0} \left(B \ln p - \frac{k(1 + B)p^n}{n} \right) \] (7)

By substituting (7) into (2),

\[ \frac{1}{2} \dot{u}^2 + \frac{p}{\rho_l} + \frac{p_0}{\rho_0} \left(B \ln p - \frac{k(1 + B)p^n}{n} \right) = \text{const} \] (8)

By using the result of equation (8), it can predict the initial pressure in upper tank and the amount of carbon dioxide. Calculation result from the equation (8) and STAR-CCM+ analysis result are compared. STAR-CCM+ is one of the numerical analysis software.

NUMERICAL ANALYSIS (STAR-CCM+)
The model is shown in table. 1 and the boundary condition is shown in table.2. We assumed that at the throat pressure is 1 atm and volume fraction 0.1, 0.2 and 0.3. Then initial pressure is got by using equation (8) and sound speed of homogeneous two-phase flow is assumed. According to initial pressure, velocity of single phase flow at the throat can be calculated by STAR-CCM+. At last we compared the two conditions of sound speed of homogeneous two-phase flow and velocity at the throat.

RESULT
Velocity at the throat and sound speed of homogeneous two phase flow are calculated. Velocity must be larger than sound speed at the throat for supersonic condition. We got supersonic condition of volume fraction at 0.2 and 0.3 in the throat and then at 0.1, it’s not supersonic flow as shown in figure.3.

CONCLUSION
We considered for the supersonic was appeared or not at the throat by using calculation method and numerical analysis software STAR-CCM+ and
compared two results. The supersonic flow can be generated in the situation inlet pressure is 0.27MPa (α =0.3), 0.31MPa (α =0.2).

REFERENCES

Table 1. The chosen model for STAR-CCM+ analysis

<table>
<thead>
<tr>
<th>Analytical method</th>
<th>Uniform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equation</td>
<td>Reynolds average n-s equation</td>
</tr>
<tr>
<td>Type of solver</td>
<td>Separated method</td>
</tr>
<tr>
<td>Turbulent model</td>
<td>Standard k-ε</td>
</tr>
<tr>
<td>Wall theory</td>
<td>high y+ wall treatment</td>
</tr>
</tbody>
</table>

Table 2. Boundary condition

<table>
<thead>
<tr>
<th>Inlet (Stagnation inlet)</th>
<th>Turbulent strength</th>
<th>Pressure (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.01</td>
<td>0.27, 0.31, 0.43</td>
</tr>
<tr>
<td>Outlet (Pressure outlet)</td>
<td>Turbulent strength</td>
<td>Pressure (MPa)</td>
</tr>
<tr>
<td></td>
<td>0.01</td>
<td>0.10, 0.11, 0.15</td>
</tr>
</tbody>
</table>

Fig. 1 Experimental apparatus

Fig. 2 Nozzle

Fig. 3 The result for two kind of analysis

Fig. 4 Velocity distribution by STAR-CCM+