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Study of Kinematic Shock in Inverted U type Pipe of Emergency Core Cooling System

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1. Introduction

In the Generic Letter 2008-01, the void fraction of inverted U-pipes in front of SI(Safety Injection) pumps is very important in analyzing the effect of head loss. The purpose of this paper is to introduce the solution of the problem through the kinematic shock equation. In this work, the behavior of the void packet of the ECCS pipes is illustrated by the equation of kinematic shock equation[1,2]. Specially, the terms of liquid currents are considered in these equations. In other study, the terms are neglected to solve the simplified equation. But in this paper, using the full equation, the terms are considered. The results from this work are compared with Perdu test results[2].

2. Methodology

Some fundamental forms are introduced to illustrate the phenomena of kinematic shock.

2.1. Motion of Void Packet in Simplified form

The movement of the void packet of ECCS pipes is illustrated from Newton Mechanics.
If the void packet is big, the air is similar to a falling object. Also, it have the kinetic energy equivalent to potential energy of hight H.
Here, the void packets experience the falling motion of gravity. Therefore, the falling velocity of void packet in ECCS pipe is followed below;

$$\frac{1}{2}mv^2 = mgH \qquad (1)$$

Where m is mass of falling void packet, v is velocity, g is gravity acceleration, H is vertical length of falling void packet. From Equation (1), the velocity of falling void packet is introduced as following;

$$V=\sqrt{2gH} \qquad (2)$$

The damage possibility of pumps located in front of the SI pump is specified by the depth of void package.
Using equation (1) and (2), a vertical separated flow frame enables the water to accelerate such that

$$U(H) = U_0 + \sqrt{2gH} \qquad (3)$$

The volumetric flow remains constant, hence

$$A_w(H) = \frac{Q_0}{U(H)} = \frac{A_0 U_0}{U(H)} \qquad (4)$$

Where $A_w(H)$ is the vertical cross section of water fall H or the vertical cross section of falling gas volume height H. In addition, Q_0 is the volumetric flow and U_0 is the velocity of water(liquid).

Here, assume the water thickness x would be approximated as a linear function such that the flow area could be represented as below;

$$A_w(H) = \frac{\pi}{4}Dx(H) \qquad (5)$$

Where, D is the diameter of the inverted U pipe.

From equation (4) and (5), as the water accelerates, the thickness change is below;

$$x(H) = \frac{4Q_0}{\pi D U} = \frac{4Q_0}{\pi D(U_0+\sqrt{2gH})} \qquad (6)$$

2.2. Depth of the Kinematic Shock using Simple form

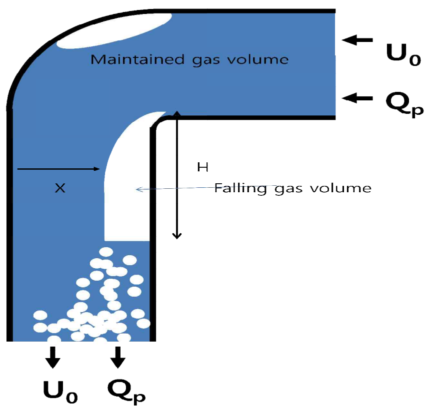

Fig.1 Depth of kinematic shock at the vertical direction in the inverted U pipe

Through the equation (1) ~ the equation(6), it is founded that the water volume is bounded by the bottom of the high point pipe and the location where the water jet plunges into the water filled down-comer where the jet entrains air from the gas volume.
The pattern of the water volume is below;

$$V_w = \int_0^H \frac{\pi}{4}Dx(H)dH = \int_0^H \frac{Q_0}{U_0+\sqrt{2gH}}dH \qquad (7)$$

Here, in order to simplify the dynamic simulation, letting the term of the liquid motion(U_0) of Figure 1 zero. Assume that U_0 is smaller than $\sqrt{2gH}$. Then, this equation is written as;

$$V_w = \int_0^H \frac{Q_0}{\sqrt{2gH}}dH = Q_0\sqrt{\frac{2H}{g}} \qquad (8)$$

From equation (7) and (8), the gas volume is calculated as like equation (9) and modified as like equation (10).

$$V_g = A_0 H - V_w \qquad (9)$$

$$H = \frac{(V_g+V_w)}{A_0} \qquad (10)$$

Where, V_g is the gas volume , A_0 is the cross section of pipe and V_w is the water(liquid) volume within the falling distance of H in Figure 1.

If equation (8) is inserted into equation (10), equation(10) is rewritten as;

$$H = \frac{\left(V_g+Q_0\sqrt{\frac{2H}{g}}\right)}{A_0} \qquad (11)$$

Letting $H_1 = \sqrt{H}$, equation (11) is modified into secondary equation (12) and the solution is simply written as (13).

$$H_1^2 - U_0\sqrt{\frac{2}{g}}H_1 - \frac{V_g}{A_0} = 0 \qquad (12)$$

$$H_1 = \frac{1}{2}\left[U_0\sqrt{\frac{2}{g}} + \left(\frac{2U_0^2}{g} + \frac{4V_g}{A_0}\right)^{1/2}\right] \qquad (13)$$

2.3. Depth of the Kinematic Shock using Full equation

In section 2.1, the current term U is neglected under assuming it is very small. But the term should be considered, if it is enough to affect to the falling water.
Integrating Equation (7), it is converted to equation (14)

$$V_w = \int_0^H \frac{Q_0}{U+\sqrt{2gH}}\,dH = Q_0\sqrt{\frac{2H}{g}} + \frac{Q_0U}{g}(\log(\sqrt{2gH}+U) \qquad (14)$$

Using equation (9) and (10), equation (14) is written as;

$$H = \frac{\left(V_g + Q_0\sqrt{\frac{2H}{g}} + \frac{Q_0U}{g}(\mathrm{bg}\ (\sqrt{2gH}+U)\right)}{A_0} \qquad (15)$$

From equation (15), letting $H_1 = \sqrt{H}$,

$$H_1^2 - U_0\sqrt{\frac{2}{g}}H_1 - \frac{V_g}{A_0} + \frac{Q_0}{A_0}\left(\frac{U\mathrm{bg}\ (\sqrt{2g}H_1+U)}{g}\right) = 0 \qquad (16)$$

Here, fourth term of equation (16) is written as Taylor's expansion;

$$\frac{Q_0}{A_0}\left(\frac{U\mathrm{bg}\ (\sqrt{2g}H_1+U)}{g}\right) = \frac{\mathrm{bg}\ (UQ_0A_0)}{gA_0} + \frac{\sqrt{2g}Q_0H_1}{gA_0} - \frac{Q_0H_1^2}{UA_0} + \frac{2\sqrt{2g}Q_0H_1^3}{3U^2A_0} - \frac{gQ_0H_1^4}{U^3A_0} + \cdots (17)$$

Taylor's expansion is considered up to the second term. Then equation (16) is converted into equation (18) and (19).

$$H_1^2 - U_0\sqrt{\frac{2}{g}}H_1 - \frac{V_g}{A_0} + \left(\frac{\mathrm{bg}\ (UQ_0A_0)}{gA_0} + \frac{\sqrt{2g}Q_0H_1}{gA_0} - \frac{Q_0H_1^2}{UA_0}\right) = 0 \qquad (18)$$

$$H_1 = \frac{1}{2}\left[\left(U_0 - \sqrt{U_0}\right)\sqrt{\frac{2}{g}} + \left(Q_0 - \sqrt{Q_0}\right)\sqrt{\frac{2}{g}} + \left(\frac{4Q_0U_0}{g} + \frac{4V_g}{A_0}\right)^{1/2}\right] \qquad (19)$$

2.4. Approximation of Full Equation

In the previous section, the solution of full equation was introduced. Equation (18) can be changed as equation (20).

$$H_1^2 - U_0\sqrt{\frac{2}{g}}H_1 - \frac{V_g}{A_0} + \left(\frac{\mathrm{bg}\ \ (UQ_0A_0)}{gA_0}\right) = 0 \qquad (20)$$

The solution of equation (20) is expressed as following;

$$H_1 = \frac{1}{2}\left[\left(U_0 - \sqrt{U_0}\right)\sqrt{\frac{2}{g}} + \left(\frac{4Q_0U_0^2}{g} + \frac{4V_g}{A_0}\right)^{1/2}\right] \qquad (21)$$

3. Result and Discussion

3.1. Comparison between Simple form and Full form

The kinematic shock is very sensitive to the void packet velocity but is not by the void packet area. However, the kinematic shocks depend on the falling object dynamic. The sensitivity is shown in Figure 2, 3, and 4.

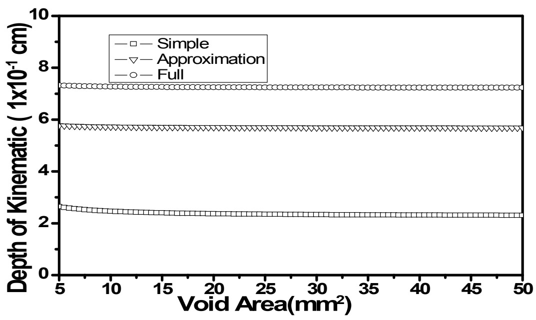

Fig. 2 Kinematic shocks under void packet area

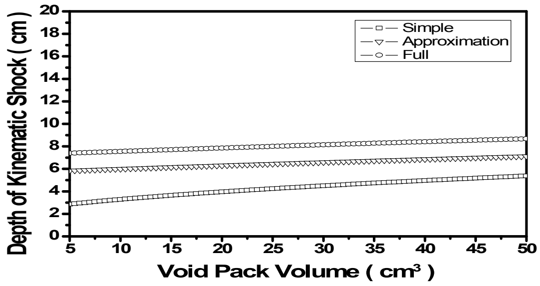

Fig. 3 Kinematic shocks under void packet volume

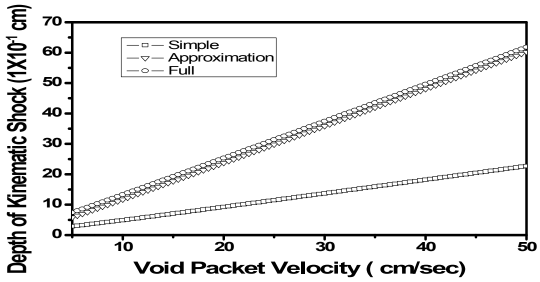

Fig. 4 Kinematic shocks under void packet velocity

3.2. Comparison between The modeling in This Work and Other Experimental Example.

In order to verify this work, this result is compared with the Perdu Test experiment example.

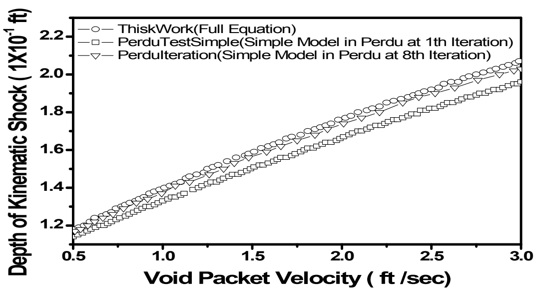

Fig. 5 Kinematic shocks under the Perdu conditions

The verification of full equation is carried out by the comparison with Perdu Test example.
Generally, Perdu test simple model is calculated by many iterations of simple form developed by Perdu experimental lab. Figure 5 shows that the full equation of this work is in good agreement with the result of many iterations of Perdu simple model. The only one-step calculation of this work is completely matched with the multi-step calculation of Perdu Test.

4. Conclusions

The new method of calculating the depth of the kinematic shock in U-type pipe in ECCS is introduced. The kinematic shock is strongly depended on the void packet velocity. In the part of verification, the difference between this work and Perdu experiment result is nothing in the condition of many iterations of Perdu simple model. In conclusion, this work's method is more efficient than Perdu simple model because of the use of only one-step calculation.

REFERENCES

[1] TSTF 10-05, Transmittal of TSTF-523, Revision 0. "Generic Letter 2008-01, Managing Gas Accumulation", June 29, 2010.
[2] Perdu Test Report, "Simplified Equation for Gas Transport To Pumps", January 21, 2010, NEI Workshop.