Determination of Void Fraction in Pipes of Emergency Core Cooling System using Ultrasonic Test

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1. Introduction

In the Generic Letter 2008-01, US NRC issues the gas accumulation of Emergency Core Cooling System (ECCS), containment spray system, and Residual Heat Removal(RHR) system[1,2]. Since 1983, pumps damage has been occurred in PWR[2]. The main reasons are the gas accumulation in the pipe involved in the safety systems [1-3]. Therefore, the evaluation of the gas packet in these pipes in the safety system is very important to protect their pumps and their functions. In 2012, from July 18 to July 19, the containment work down of Wolsung unit 1 was carried out by KHNP Central Research Institute(CRI). In this work, the ideas of detecting the gas accumulation volume and the ultrasonic test (UT) for calculating the void packet volume are introduced. The results of this work will be shown in part of the methodology and the verification.

2. Methodology

In this section, some ideas are introduced the method to carry out UT in pipe in ECCS.

2.1. Ultrasonic Test

In order to survey the gas accumulation in pipes of ECCS using UT, the UT process based on the process in Figure 1is used.

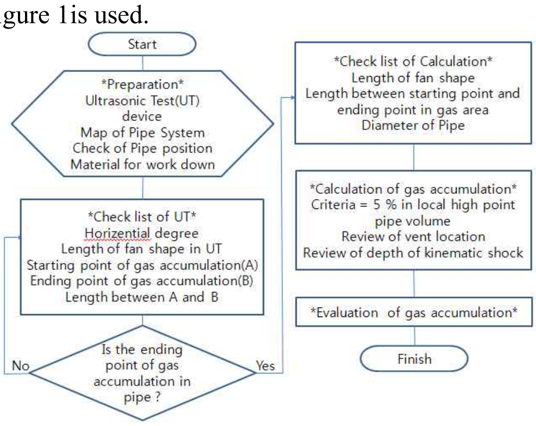

Fig.1 Schematic diagram of UT in the gas accumulation

The main check list of UT work down is consist of the length of fan shape at the void packet cross section, the length of the pipe, starting point of gas area, and ending point of gas area.
In this work, the survey points include the inverted U pipes, horizontal pipes between check valves, and pipes at vent positions.
The survey points are shown in Table 1.

Table 1. Survey positions in ECCS at Wolsung unit 1

No.	Type	Elevation	Diameter (inch,out/in)	Diameter (mm, out/in)
1	Vent	122.098	16/13.94	203.2/177.038
2	Check valves	120.574	12.75/11.06	161.925/140.462
3	Inverted U	123.165	12.75/11.06	161.925/140.462
4	Check valves	120.574	12.75/11.06	161.925/140.462
5	Check valves	114.719	12.75/11.06	161.925/140.462
6	Check valves	114.719	12.75/11.06	161.925/140.462
7	vent	118.898	12.75/11.06	161.925/140.462
8, 9	Inverted U	120.890	12.75/11.06	161.925/140.462

2.2. Evaluation of Gas Packet Volume

In this section, some ideas are introduced to evaluate the gas packet volume in pipe of ECCS. In NEI 09-10, the concept for the calculation of the gas packet volume is simply written without the detail information. However, the detailed calculation method isn't on NEI 09-10. Therefore, in this work, the calculation method is developed using the integral method. The strategy of the calculation methods are shown in Figure 2 and 3.
Figure 2 is shown to illustrate the decrease of the fan shape angle along the pipe length L. Figure 3 is shown to illustrate the calculate of the cross section from fan shape. Finally, in both conditions of slop and non- slop, the cross section areas are integrated along the pipe length L

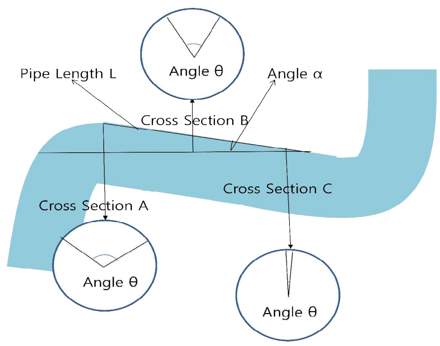

Fig. 2 Calculation of gas volume in pipe in this work

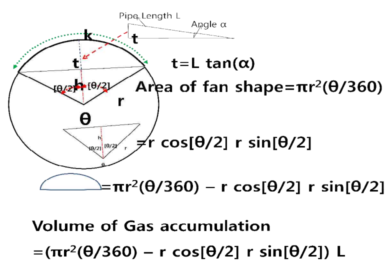

Fig. 3 Calculation of gas cross section in pipe in this work

From Figure 3, it is carried out to calculate the volume of void packet in pipe with slope. In the condition of slope, the calculation formula is introduced as below;

$$dA = \frac{\left(r^2 \sin^2\left(\frac{\theta}{2}\right) - r^2 \cos^2\left(\frac{\theta}{2}\right)\right) 360 + 2\pi r^2}{2 \cdot 360} d\theta \quad (1)$$

$$r = t + h = L\tan(\alpha) + r\cos\left(\frac{\theta}{2}\right) \quad (2)$$

$$r - r\cos\left(\frac{\theta}{2}\right) = L\tan(\alpha) \quad (3)$$

$$\frac{r\sin\left(\frac{\theta}{2}\right)}{2} d\theta = dL\tan(\alpha) \quad (4)$$

$$\tan(\alpha) = \text{constant} = T \quad (5)$$

$$dL = \frac{r\sin\left(\frac{\theta}{2}\right)}{2T} d\theta \quad (6)$$

$$\text{Void packet volume} = \iint dA \cdot dL \quad (7)$$

$$\text{gas volume} = \iint \frac{\left(r^2 \sin^2\left(\frac{\theta}{2}\right) - r^2 \cos^2\left(\frac{\theta}{2}\right)\right) 360 + 2\pi r^2}{2 \cdot 360} \frac{r\sin\left(\frac{\theta}{2}\right)}{2T} d\theta\, d\theta \quad (8)$$

$$\text{Gas volume(slope)} = \frac{2\pi r^3 \sin\left(\frac{\theta}{2}\right)}{360 \cdot \tan(\alpha)} + \frac{r^3 \sin\left(\frac{\theta}{2}\right)}{2 \cdot \tan(\alpha)} - \frac{r^3 \sin\left(\frac{3\theta}{2}\right)}{18 \cdot \tan(\alpha)} \quad (9)$$

$$\text{Gas volume(horizental)} = \left(\pi r^2 \left(\frac{\theta}{360}\right) - r\sin\left(\frac{\theta}{2}\right) r\cos\left(\frac{\theta}{2}\right)\right) \cdot L \quad (10)$$

In order to calculate the gas packet volume, it need to calculate the cross section area factor (dA) and the pipe length factor (dL). Equation (1) is shown to illustrate the cross section area factor (dA). Equations (2) ~ (5) are shown to illustrate the pipe length factor (dL).
Finally, the gas volume calculation is carried out by equations (7) ~ (10).

2.3. Verification in Calculation of Gas Packet Volume

In order to check the application capability of the gas volume formula, it is carried out to calculate the volume of a cylinder type vial with the diameter of 5.4cm and the high of 7cm.
In addition, using the clinometers, the detection of pipe slope is simply carried out. In the condition of same volume of liquid in vial, the slope of the vial is changed and detected. At that time, the slope, fan shapes, and the length between the starting point and the ending point of void packet area are used for calculating the volume.
If the equation (9) is correct, in any slope condition, the results of the calculation using equation (9) are same. The quantity of the water in the vial is 114.51cm^3(water dimension, high:5cm, diameter:5.4cm).

3. Result and Discussion

3.1. Ultrasonic Test

Ultrasonic test is suitable for evaluating the gas accumulation. The ultrasonic wave shape between liquid areas is shown a remarkable difference. This feature is efficiently used for calculating the void packet volume.

3.2. Verification and Ultrasonic Test Results

Table 2. Verification of the Void Packet Volume Calculation

No.	angle (degree)	Maximum fan shape (cm)	Water volume (cm^3)	Void packet (cm^3)	Initial void packet (cm^3)
1	0.5	0.9	114.51	45.8	45.8
2	1.0	1.1	114.5	45.81	45.8
3	1.5	1.3	114.503	45.797	45.8
4	2	1.5	114.5	45.81	45.8
5	3	1.6	114.5	45.81	45.8

Table 3. Results from Ultrasonic Test in ECCS at Wolsung unit 1

No.	Diameter (mm, out/in)	Maximum fan shape (mm)	Void Packet (mm^3)	Pipe (mm^3)	Percent Fraction Of Void Packet (%)
1	203.2/177.038	0	0	75818220	0
2	161.925/140.46	75	53337.51	74006845.89	0.07
3	161.925/140.46	65	142419.30	132270191.9	0.11
4	161.925/140.46	135	327597.14	166856305.8	0.20
5	161.925/140.46	140	859827.89	95266768.96	0.90
6	161.925/140.46	145	1644515.1	89874310.34	1.83
7	161.925/140.46	0	0	123096814	0
8	161.925/140.46	155	6294883	529266714.5	1.18
9	161.925/140.46				

From Table 2, the verification of equation (9) is completed successfully. And Table 3 shows that the results of UT are satisfied comparing with the criterion of the gas packet volume 5%. In Wolsung unit1, the maximum void packet fraction is 1.83% at pipes including the check valves. In the inverted U pipes, the maximum is 1.18%.

4. Conclusions

The detailed method of calculating the void packet volume in ECCS using the ultrasonic test is introduced.

The method of the calculation of volume is correct in the verification process (Table 2).

In the part of the criterion of gas volume, all the survey positions are within 5%(Table 3). This UT methodology is simple and efficient for evaluating of the gas accumulation.

REFERENCES

[1] TSTF 10-05, ransmittal of TSTF-523, Revision 0. "Generic Letter 2008-01, Managing Gas Accumulation", June 29, 2010.
[2] Generic Letter 2008-01, "Managing Gas Accumulation ", 2008, US NRC.
[3] NEI 09-10, "Guide lines for Managing Gas Accumulation ", 2009.