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Estimation of the Void Fraction in the moderator cell of the Cold Neutron Source

Jungwoon Choi* and Young-ki Kim
Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon, 34057, Korea
**Corresponding author: ex-jwchoi@kaeri.re.kr*

1. Introduction

Owing to national research demands on cold neutron beam utilization [1], the Cold Neutron Research Facility had been and operated for neuron scientists all over the world. In HANARO, the CNS facility has been operated since 2009.

The actual void fraction, which is the one of dominant factors affecting the cold neutron flux, is difficult to know without the real measurement performed at the cryogenic temperature using the same moderator medium. Accordingly, the two-phase mock-up test in the CNS-IPA (In-pool assembly) had been performed using the liquid hydrogen in terms of the fluidity check, void fraction measurement, operation procedure set-up, and so on for the development of the HANARO-CNS.

This paper presents the estimated void fraction in the different operating conditions and geometrical shape in the comparison with the measurement data of the void fraction in the full-scale mockup test based on the Kazimi and Chen correlation.

2. Void Fraction Correlation

An analytical and experimental investigation of void fraction was studied in the internally heated boiling pools by M.S. Kazimi and J.C. Chen [4]. Their investigation results were concluded as a following correlation under the condition of $V_s/V_\infty \le 2$.

$$\bar{\alpha} = 1 + \frac{0.645(V_s/V_\infty)^{0.35}}{\ln[1 - 0.645(V_s/V_\infty)^{0.35}]}$$

To check the similarity between the fluid dynamic behaviors in different fluid, the volumetric vapor generation per unit liquid volume, j*, and the terminal bubble rise velocity in the internally heated pool, V∞ were calculated as significant factors. The ratio of the vapor fluxes is given by

$$\frac{j_B^*}{j_A^*} = \frac{(\lambda\rho_v)_A}{(\lambda\rho_v)_B}.$$

The terminal bubble rise velocity is given by

$$V_\infty = \left[\frac{\sigma g(\rho_l - \rho_v)}{\rho_l^2}\right]^{1/4}.$$

2.1. Liquid Deuterium CNS in the NBSR

A liquid deuterium cold neutron source has been designed to replace the Advanced LH_2 Cold Neutron Source for the NIST research reactor. During the optimal design of the moderator cell, the void fraction in the LD_2 CNS is estimated by the modified correlation based on the Kazimi and Chen correlation. Applying the mock-up test results, the correlation becomes modified by multiplying of 0.5 [5]. From the modified correlation, the estimated average void fraction is 13%.

2.2. Liquid Hydrogen CNS in HANARO

From the thermosiphon mock-up test results, the void fraction at a heating power of 470W was determined to be about 20% by using a fitting line for the measurements with the heating power [2,3]. Using the HANRO-CNS geometrical dimension, the average void fraction is calculated at 16.4% based on the modified correlation by NBSR. Inhere, if the volumetric vapor generation per unit liquid volume is considered between the different fluids, the multiplying number can be 0.62 instead of 0.5.

When this multiplying number is considered in the modified correlation, the average void fraction is estimated at 20.3%.

2.3. Liquid Hydrogen CNS

When the same approach is applied on the different CNS, the multiplying number is depending on the considering medium, operation pressure, and operation temperature because the physical properties of the working fluid are different on the operating condition.

In the moderator cell design, shown in Fig. 1, the average void fraction in the liquid hydrogen moderator cell is estimated along the longitudinal direction under the saturated temperature at 2 bar(a).

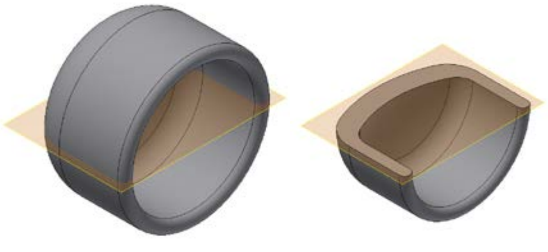

Fig. 1. Schematic moderator cell (M/C) design

The flow area is considered as a horizontal cross section longitudinally with the interval of 10 mm from the top to the middle section. The considering heat load is the summation of the nuclear heat load and non-nuclear heat load which are calculated using a MCNP code and the CFX.

In this calculation, the multiplying number is considered 0.8 and the average void faction is estimated along the heat load as presented in Table I.

Table I: Average void fraction along heat load

Distance from the top of M/C	450W	535W	960W
10 mm	0.261	0.28	0.36
20 mm	0.196	0.21	0.27
50 mm	0.204	0.22	0.28
100 mm (middle)	0.203	0.22	0.29

To apply the Kazimi and Chen correlation, whether the condition of $V_s/V_\infty \leq 2$ is satisfied or not is checked as shown in Table II.

Table II: The V_s/V_∞ ratio along each flow area

Distance from the top of M/C	450W	535W	960W
10 mm	0.72	0.85	1.52
20 mm	0.35	0.42	0.75
50 mm	0.39	0.46	0.83
100 mm (middle)	0.38	0.45	0.81

3. Conclusion

To estimate the average void fraction in the liquid hydrogen, the Kazimi and Chen correlation is used with its modified method suggested by R.E. Williams in NBSR. Since the multiplying number can be changed along the operation condition and working fluid, the different figure is applied to estimate the average void fraction in the different moderator cell shape.

This approach is checked with the void fraction measurement results from the HANARO-CNS mock-up test. When the multiplying number is changed based on j^* comparison between other working fluids, the estimated average void fraction is found to approach the real measured void fraction at the same heat load.

This approach is applied to estimate the average void fraction in the newly designed moderator cell using the liquid hydrogen as a working fluid in the two-phase thermosiphon. From this calculation result, the estimated average void fraction will be used to design the optimized cold neutron source to produce the maximum cold neutron flux within the desired wavelength.

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$\bar{\alpha}$	Average void fraction
V_s	Superficial gas velocity = (volume of gas per second) / (flow area)
V_∞	Terminal bubble rise velocity
j^*	Volumetric vapor generation per unit liquid volume
λ	Heat of vaporization
σ	Surface tension
g	Gravity acceleration
ρ_l	Liquid density
ρ_v	Gas density

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