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Preliminary test facility design of bubble formation and rise velocity in liquid breeder for testing in the ITER

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1. Introduction

A liquid type test blanket module in the International Thermonuclear Experimental Reactor (ITER) has been designed and developed in KAERI [1-5]. Several key technologies such as structure fabrication, He cooling, tritium breeding and extraction have been investigated with the developed test facilities. Among them, the bubble plays a significant role in tritium extraction from the liquid breeder, PbLi. The effect of bubble formation size and rise velocity in the PbLi, was investigated in the present study. In actual liquid breeder, it is difficult to estimate the bubble size and velocity, a preliminary test has been prepared to verify the existing correlations for both parameters.

2. Design progress of the test facility

2.1 Bubble formation in gas-liquid phase

A schematic diagram of the ideal formation of spherical bubble is shown in Figure 1. It is considered vertical porous disk (diameter, d_a) submerged in a viscous fluid (viscosity, η and density, ρ) and gas flowing (density, ρ_g) at constant flow rate, Q.

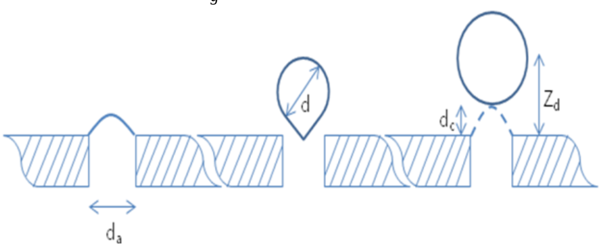

Fig. 1 Schematic diagram of bubble stream formation by P. Snabre(1997)

Most of the theoretical studies bubble volume is derived from a semi empirical model based on a force balance around the bubble at detachment when the bubble is detached from the porous disk [6-8].

$$F_b + F_g + F_P = F_d + F_i + F_\sigma \qquad (1)$$

where buoyancy force, $F_b = (\rho - \rho_g) gV$,

gas momentum force, $F_g = \frac{\pi}{4} d^2{}_a \rho_g W^2{}_g$,

with $W_g = 4Q/(\pi d^2{}_a)$

pressure force, $F_P = \frac{\pi}{4} d^2{}_a (P_g - P)$,

drag force, $F_d = \frac{1}{2}\rho W^2 \frac{\pi d^2}{4} C^*{}_d$,

inertial force, $F_i = \left(\alpha + \frac{\rho_g}{\rho}\right)\rho V \gamma$,

and surface tension force $(F\sigma) = \pi d_a \sigma$,

Here, W_g is gas velocity through the porous disk, W the average velocity of bubble expansion, γ the average bubble acceleration, C_d^* the average drag coefficient, σ the surface tension of liquid, P_g the gas pressure in the bubble and P the average liquid pressure [9].

The force balance (1) at the instant of bubble detachment by neglecting gas momentum $(\rho_g \langle\langle \rho)$, wake effects and recirculation flows near the porous disk $(U \langle\langle W)$ is derived :

$$\rho g V = \frac{\pi}{8} d^2 C^*{}_d \rho W^2 + \pi d_a \sigma + \alpha \rho V \gamma \qquad (2)$$

Where W is the average expansion velocity and bubble average γ is derived from the bubble expansion time $t_b = V/Q$ and the modification distance $Z_d \approx d/2 + d_c \approx 3d/4$ of the bubble center at detachment stage:

$$W \approx \frac{Z_d}{t_b} = \frac{3dQ}{4V} \quad \text{and} \quad \gamma \cong \frac{W}{t_b} = \frac{WQ}{V} \qquad (3)$$

Substituting in the force balance, get the equation [15] :

$$\frac{\pi}{3} d^3 \rho g = \left(\frac{81 C^*{}_d}{16} + 9\alpha\right)\frac{\rho Q^2}{\pi d^2} + \pi d_a \sigma \qquad (4)$$

Experimental data from Miyahara et al. [10, 11] and Al Hayes [12] shows that a drag coefficient ($C_d = 16/\mathrm{Re} + 1$) closes to the large Reynolds number.

2.2 Rising velocity of bubble

For bubble generated in a stream, in-line hydrodynamic interactions may influence the bubble velocity. The free velocity rise W_o of a single bubble in sluggish flow was acquaint with Hadamard [13] and Rybczynski [14] from the Stokes stream function.

$$W_o{}^2 = \frac{4}{3}\frac{d(\rho - \rho_g)g}{\rho C_d} \quad \text{with} \quad C_d = \frac{8}{\mathrm{Re}}\frac{3\chi + 2}{\chi + 1} \qquad (5)$$

Where χ is the ratio of gas to liquid viscosity and the drag coefficient, $C_d(\chi, \mathrm{Re})$. For a gas phase of week viscosity and density $\left(\chi \approx 0, \rho_g \langle\langle \rho\right)$, the bubble rising velocity in an unbounded viscous fluid shows:

$$W^2{}_o = \frac{4}{3}\frac{dg}{C_d} \quad \text{with} \quad C_d = \frac{16}{\text{Re}} \qquad (6)$$

In the case of a vertical bubble stream rising with a stationary velocity W_b under the low Reynolds number of a long cylinder, the gas volume fraction $\varepsilon = Qd/(W_b V)$ in the gas-liquid column. Substituting the above drag coefficient in equation (6) yields the rise velocity $w_b(\varepsilon)$ of in-line interacting bubble:

$$W_b = \frac{2dg(1+\varepsilon)}{C_d} = W^2{}_O(1+\varepsilon) \qquad (7)$$

2.3 Preliminary test device

A schematic diagram of the preliminary test facility is shown in Fig. 2; outer tank was made from the acrylic panel tank with 52 cm in diameter and 100 cm in height for visual observation. The tank will be filled with a Newtonian water in range of 1.01 ~ 4.04 bar of pressure. The bubble will be formed by blowing air at constant flow rate through a porous disk (inner diameter, $d_a \approx$ 0.2mm). In the top side of the tank, transparent device for installing the camera was prepared to measure the bubble size.

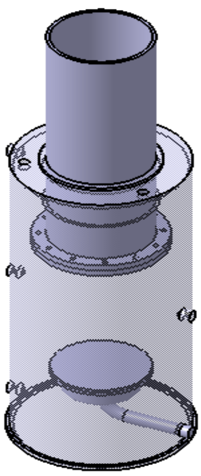

Fig. 2 Design of the test facility for bubble formation and velocity measurement

3. Conclusions

For developing the tritium extraction method from the liquid breeder using the gas blowing, the preliminary test facility has been designed considering the bubble size and rising velocity. To estimate both parameters in the actual extraction facility, some correlations were investigated and they will be compared with the test results using the prepared test facility.

REFERENCES

[1] D.W. Lee, et. al., "Current status and R&D plan on ITER TBMs of Korea," Journal of Korean Physical Society, Vol.49, Dec. 2006, pp S340-S344.
[2] D.W. Lee, et. al., "Preliminary design of a helium cooled molten lithium test blanket module for the ITER test in Korea," Fusion Eng. Des. 82 (2007) 381-388
[3] D.W. Lee, et. al., "Helium cooled molten lithium TBM for the ITER in Korea," Fusion Sci. and Tech. 52 (2007) 844-848
[4] D.W. Lee, et. al., "Design and preliminary safety analysis of a helium cooled molten lithium test blanket module for the ITER in Korea," Fusion Eng. Des., Vol. 83 (2008) 1217-1221.
[5] D. W. Lee, et. al., "Current status on the Korean test blanket module development for testing in the ITER," *Proc. of the KNS Spring Meeting*, Yong-pyoung, Korea, May, 2010.
[6] F. H. Ruddy, A. R. Dulloo, J. G. Seidel, F. W, Hantz, and L. R. Grobmyer, Nuclear Reactor Power Monitoring Using Silicon Carbide Semiconductor Radiation Detectors, Nuclear Technology, Vol.140, p. 198, 2002.
[7] F. H. Ruddy, A. R Dulloo, J. G Seidel, J.W.Palmour, and R. Singh, The Charged Particle Response of Silicon Carbide Semiconductor Radiation Detector, Nuclear Instruments and Methods In Physics Research, Vol.505, p.159, 2003.
[8] J. F. Ziegler, J. P. Biersack, "SRIM-2000, 40: The Stopping and Range of Ions in Matter", IBM-Research, Yorktown, NY 2000.
[9] M. R. Fard, T. E. Blue, D. W. Miller, SiC Semiconductor Detector Power Monitors for Space Nuclear Reactors, Proceedings of the Space Technology and Applications International Forum(STAIF-2004), Feb.8-12, 2004, Albuquerque, NM.
[10] . T. Miyahara, T. Haga, T. Takahashi, Int. Chem. Eng. 23, 524-531 (1983).
[11]. T. Miyahara, T. Takahashi, Int. Chem. Eng. 25, 146-148 (1985).
[12] R.A.M. Al Hayes, R.H.S. Winterton, Int. J. Heat Mass Transfer. 24, 223-231 (1981).
[13] G. Lutz, Semiconductor Radiation Detector, Springer, New York, 1999.
[14] G. F. Knoll, Radiation Detection and Measurement, John Wiley & Sons, New York, pp.612-613, 1999.
[15] S. Ramakrishnan, R. Kumar, N.R. Kuloor, Chem. Eng. Sci. 24, 731-749 (1969).