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Experimental Study on Head Degradation in a Reactor Coolant Pump for a Small Modular Reactor under Two-Phase Flow Conditions

Byeonggeon Bae[a*], Tae-Kyoon Kim[a], Hyuntae Lim[a], Jihoon Lee[a]
[a]*Korea Atomic Energy Research Institute, 989, Daedeok-daero, Yuseong-gu, Daejeon, 34057, South Korea*
[*]*Corresponding author: bgbae@kaeri.re.kr*

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1. Introduction

A small modular reactor (SMR) currently under development can eliminate large break loss of coolant accident (LBLOCA) because the steam generator, reactor coolant pump (RCP), and pressurizer are integrated into the reactor and there are no large pipes. However, a small break of loss of coolant accident (SBLOCA) can occurs due to the rupture of safety injection connection pipes or instrumentation pipes. When the SBLOCA occurs in a primary system of the SMR, two-phase flow occurs due to rapid pressure drop and leakage of a primary coolant. When two-phase flow occurs in the primary system, the head of the RCP decreases, significantly reducing a pump performance and making it difficult to form a normal flow rate. Since a primary coolant flow rate is one of the important factors in operation of the reactor, it is necessary to predict a head degradation under two-phase flow conditions. Until now, a nuclear safety analysis code for the commercial pressurized water reactor (PWR) has been applying the head degradation data obtained from the past by Aerojet Nuclear Company (ANC) for a MOD-1 semiscale pump [1]. However, there is no head degradation data of the RCP for the SMR under two-phase flow conditions. In this study, the two-phase flow experiment was performed in the RCP of the SMR, data on the head degradation with a void fraction was presented, and this was compared with the experimental results of the RCP for the PWR.

2. Experimental facility

The experimental facility consists of a model pump, a booster pump, a water tank, an air injection system, a void fraction measuring system, instruments, as shown in Fig. 1. The model pump is a mixed-flow type with the same hydraulic part as the RCP that will be applied to the SMR. Air is injected from an air compressor of 6 kgf/cm^2 through an air dryer and a filter, and the gas flow rate is controlled by the mass flow controller. The supplied water and air pass through the mixer to form a homogeneous two-phase flow. The void fraction measurement system consists of two quick closing valves (QCVs) in a main flow path and one QCV in a bypass flow path. When measuring the head of the pump, two-phase flow flows into the main flow path and the bypass flow path is blocked. When measuring the void fraction, the bypass flow path is opened and the main flow path is blocked. The void fraction is measured by measuring the stagnant water level in the pipe between two QCVs of the main flow path using a level gauge. Information on the main measuring instruments is shown in Table I.

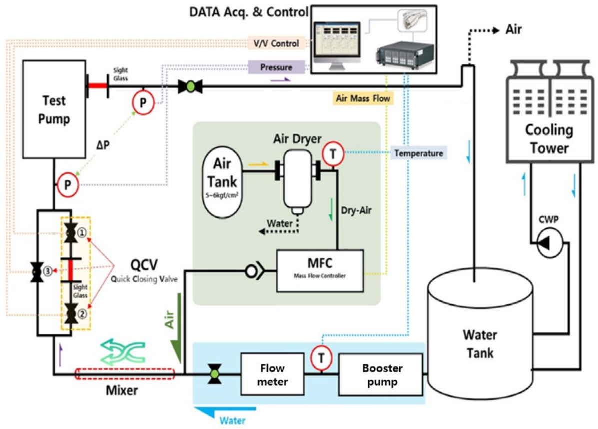

Fig. 1. Schematic diagram of the experimental facility

Table I: Information on measuring instruments

Instruments	Measurement range	Measurement accuracy
Venturi flowmeter (water)	0~1,000 m^3/h	±0.5% of reading
Mass flow controller (air)	0~150 m^3/h	±2.0% of full scale
Pressure transmitter (suction)	-1~3 kgf/cm^2	±0.04% of span
Pressure transmitter (discharge)	0~5 kgf/cm^2	±0.04% of span
Level gauge	0~300 mm	±0.5mm
Thermometer	0~80°C	±1.3°C
Electromagnetic detector	0~20,000 rpm	±1 rpm

3. Experimental conditions

The experiment was conducted for two rotation speed conditions (low, high). Since there is a risk of damage to the pump when the void fraction is high, the experiment was conducted at two rotation speeds up to the void fraction of approximately 5%. Then, the two-phase flow experiment was continued with a higher void fraction condition (up to 30%) for a conservative rotation speed condition. First, the flow rate and head are measured at the rated operating point of single-phase flow, which is a normal operating condition. After then, the head is measured according to the change in the void fraction. The experiment was repeated five times for each experimental condition to confirm the reproducibility, and the experimental data was averaged over approximately 60 sec. The suction pressure was kept constant at 1.5 kgf/cm^2 to prevent cavitation.

4. Experimental results

The results of the head degradation according to the increase in the void fraction are shown in Fig. 2. In Fig. 2, the X-axis represents the void fraction, and the Y-axis is the ratio of the head under two-phase flow conditions to the head in single-phase flow conditions. The head degradation for the void fraction at the low rotation speed condition was greater than that at the high rotation speed condition. This is because the head appearing at the low rotation speed of the pump is smaller, so the compressibility of bubbles is relatively smaller, and thus the effect of bubbles on the head degradation is greater [2]. In addition, since the flow velocity at the low rotation speed condition is relatively low, there is less mixing of gas and liquid, which leads to the formation of larger bubbles, which has a significant impact on the degradation in the pump performance. That is, in the void fraction of 1 to 5%, the head degradation tended to be more conservative at the low rotation speed among two rotation speed conditions. An additional experiment was conducted for conditions with the void fraction higher than 5% for the low rotation speed condition.

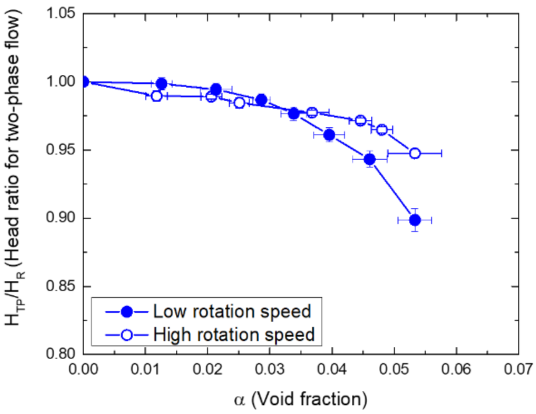

Fig. 2. Head degradation according to the void fraction

The circled symbols in Fig. 3 represent the experimental results for the void fraction up to 30% at the low rotation speed condition. The head dropped sharply when the void fraction around 7%, and when the void fraction exceeded 10%, the head gradually decreased to around 30% of the rated head. At the void fraction of 30%, the head was reduced to 16% of the rated head. In addition, the result of this experiment was compared with the experimental data of the ANC MOD-1 pump [1] and the CE/EPRI pump [3] related to the RCP for the PWR in a previous study. Table II summarizes the impeller type and specific speed for each pump. The specific speed is a dimensionless number defined by the pump's rotation speed, flow rate, and head, and is used to determine the impeller type and characteristics of the pump. It can be confirmed that the pump for the SMR used in this experiment has a lower void fraction at which the head decreases rapidly than the results of other pumps.

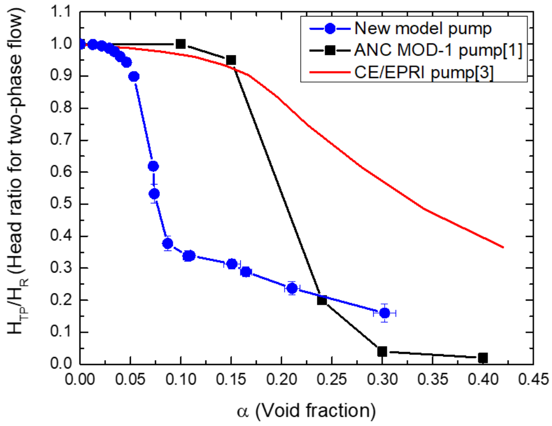

Fig. 3. Comparison of the head degradation under two-phase flow conditions for several reactor coolant pumps

Table II: Hydraulic characteristics of several reactor coolant pumps

	Impeller type	Specific speed (rpm,m^3/min, m)
New model pump	Mixed	1063
ANC MOD-1[1]	Radial	136
CE/EPRI[3]	Mixed	630

5. Conclusions

The measurement of the head for the void fraction was performed by changing the void fraction up to 30% on the RCP for the SMR. The experimental results showed that the threshold for the void fraction at which the head decreases rapidly was approximately 7%, and that the head dropped to about 16% of the rated head at the void fraction about 30%. From a conservative point of view, it is recommended that there is a risk of damage or failure of the pump when the void fraction exceeds 7% be considered when applying the experimental data to the nuclear safety analysis code.

REFERENCES

[1] Lane, Jeffrey W., et al., Performance Assessment of the Two-Phase Pump Degradation Model in the RELAP5-3D Transient Safety Analysis Code, Nuclear Technology 161.3, pp.277-285, 2008.

[2] Johann Friedrich Gülich, Centrifugal Pumps, Third Edition, Springer, 2014.

[3] Hunter, J. A., and Harris, P. A., Performance of Small Nuclear Reactor Primary Coolant Pumps under Blowdown Conditions.[PWR], Idaho National Engineering Lab., 1978.