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Improvement of separator performance with modified pick-off ring and swirler

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HIGHLIGHTS

- Improved swirlers and 1st POR of a gas-liquid separator are presented.
- Liquid-separation rate, pressure drop and liquid film thickness are measured.
- Performances of separators with the improved swirler and 1st POR are evaluated.
- Applicability of the improved separator to a high quality condition is examined.

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ABSTRACT

The swirler and the 1st pick-off ring (POR) of a gas-liquid separator are improved to reduce the pressure drop, ΔP_T, in the separator while keeping the flow rate of separated liquid, W_{ST}, high. Two swirler designs are presented, i.e. V8 (swirler with eight vanes) and V6 (swirler with six vanes), whose diameters of the hubs supporting the vanes are smaller than that of the normal swirler, N8, and the nose shape of vanes are coned. The swirlers are installed into a one-fifth scale separator with three PORs. The gap width of the 1st POR is reduced to the value of the liquid film thickness in the barrel of the separator and the rear shape of the 1st POR is smoothed. The performance of the downscaled separator with the proposed swirlers and the 1st POR are evaluated under the nominal operating condition of the Hyper BWR and a higher quality condition. As a result, the following conclusions are obtained in the present experimental range: (1) ΔP_T in the separator is reduced by 23% using V8, and V8 gives the same W_{ST} as N8, confirming that the decrease in the hub diameter and the coned-nose shape of vanes are effective, (2) V6 can realize further reduction of ΔP_T (38%) without deteriorating the liquid-separation rate, (3) the reduced gap width of the 1st POR and a tapered shape of the downstream side of the 1st POR are also effective to decrease the pressure drop, i.e. the improved POR decreases ΔP_T by 42% and 54% by combining with V8 and V6, respectively, and (4) the improved separators also show good performances in ΔP_T and W_{ST} at the higher quality condition.

1. Introduction

When uprating the power density of a boiling water reactor (BWR) core, the pressure drop in the steam separator of the BWR may increase, which results in deterioration of the stability of the flow, i.e. the increase in the possibility of density-wave oscillation, and the increase in the load, 20% of which is due to the separator (Nakao, 2007), of the re-circulation pump. Therefore, from the safety and economic point of views, the separator should be improved so as to reduce the pressure drop without degrading the liquid-separation rate, i.e. the ratio of the total flow rate of separated liquid to the total liquid flow rate in the separator inlet.

The separator consists of a standpipe, a diffuser with a swirler and a barrel with three pick-off rings (PORs). The swirler has eight stationary vanes supported by a hub (Jensen et al., 1996; Katono et al., 2014; Ikeda et al., 2003). The swirler vanes apply centrifugal force to a two-phase flow, causing water migration toward the barrel wall and formation of a liquid film flow on the barrel wall. The liquid film flow is discharged from the barrel through the PORs. The pressure drops in a full-scale and a one-fifth scale separator have been experimentally investigated by Iwaki et al. (2010) and Funahashi et al. (2016), respectively. A vapor-water and an air-water system were used in the former and latter, respectively. These studies showed that the swirler and the 1st POR were the

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main sources of the pressure drop in the separator. We also confirmed that the increase in the gas volume flux, J_G, in the barrel from 14.6 m/s to 17.8 m/s increases the total pressure drop by 40% mainly due to the pressure drops in the swirler and the 1st POR. Nakao et al. (2001) assumed that most of the pressure drop in the swirler is caused by the momentum loss, which can be reduced by decreasing the vane angle at the swirler outlet or by increasing the outlet area using a smaller hub diameter. Results of their air-water experiments with improved swirlers implied that the latter improvement is more effective than the former. The improved swirler largely reduced the pressure drop in the swirler. They, however, had to modify the connection between the barrel and the 3rd POR to keep the liquid-separation rate high. Ikeda et al. (2003) carried out numerical simulations of two-phase swirling flows in a separator with a swirler and a single POR by using the two-fluid model. The predicted pressure distribution in the swirler had steep gradients at the swirler inlet and outlet due to the abrupt change in the flow passage area. They therefore changed the shapes of the vanes and hub so as to make the flow passage uniform in the streamwise direction. Iwaki et al. (2010) experimentally demonstrated that this improved swirler gave a large reduction in the pressure drop in a full-scale separator. Jensen et al. (1996) reported that addition of extra vanes increased the pressure drop of a separator. In our previous study (Matsubayashi et al., 2012), we investigated the effects of the number of the vanes on the pressure drop and the liquid-separation rate using the normal swirler having eight vanes and a swirler with six vanes installed in a one-fifth scale separator having a single POR. The six-vane swirler gave a pressure drop much smaller than that of the eight-vane swirler, and the liquid-separation rates for these swirlers were the same. However it remains unclear whether or not the smaller centrifugal force with the six-vane swirler is sufficient to keep the liquid-separation rate in a separator with three PORs high.

Though many studies on the improvement of the swirler have been carried out, no attempts have been made to improve the 1st POR. In our previous study (Funahashi et al., 2016), we therefore measured various flow quantities using the one-fifth scale separator with three PORs and found that the liquid film thicknesses at the PORs are smaller than the gap widths under the nominal operating condition and the 2nd and 3rd PORs can separate the liquid passed over the 1st POR even if the liquid film in the 1st barrel becomes thicker than that under the nominal operating condition. We therefore suggested that the reduction of the gap width of the 1st POR would be effective to decrease the pressure drop without deteriorating the separation performance. A preliminary test for this idea was carried out in our previous study (Katono et al., 2015) by using a downscaled model with the normal swirler and two PORs (the 1st and 2nd PORs). The result implied that the gap width of the 1st POR can be reduced down to the film thickness, δ_{99}, for 99% cumulative probability to realize a low pressure drop and a high liquid-separation rate. In addition, a tapered shape of the downstream side of the 1st POR was confirmed to effectively reduce the pressure drop. Since δ_{99} would depend on a swirler design, the gap width of the 1st POR should be set at δ_{99} of the improved swirler. The effects of the improvement of the 1st POR on the pressure drop and the liquid-separation rate, however, have not been investigated for improved swirlers installed in the separator model with three PORs.

In this study, we integrated the above-mentioned improvements for the swirler (Matsubayashi et al., 2012) and the 1st POR (Katono et al., 2015) into the one-fifth scale separator with three PORs. First, we investigated the pressure drop and the liquid-separation rate for two kinds of improved swirlers. One has eight vanes and the other has six vanes, and we measured the liquid film thickness in the 1st barrel. Then we improved the 1st POR based on the measured data of δ_{99} for the improved swirlers and utilized the tapered shape. The pressure drop and the liquid-separation rate of the improved separator will be presented.

2. Experimental

2.1. Experimental setup

Fig. 1 shows the experimental setup, which consists of the barrel of 40 mm inner diameter, the three pick-off rings, the swirler, the diffuser, the standpipe of 30 mm inner diameter, the plenum of 60 mm inner diameter, the gas-liquid mixing section, the water and air supply systems and the upper tank. The PORs are referred to as the 1st, 2nd and 3rd PORs from the bottom to the top. The barrel was made of transparent acrylic resin for flow observation and optical measurement of liquid film thickness. The segments of the barrel between the swirler and the 1st POR, between the 1st and 2nd PORs and between the 2nd and 3rd PORs are referred to as the 1st, 2nd and 3rd barrels, respectively. The test section is a one-fifth model of an actual separator of a BWR.

Air was supplied from the oil-free compressor to the mixing section through the regulator and the flow meter. Water at 298 ± 2 K was supplied using the magnet pump to the mixing section through the wall made of the porous sinter. The liquid flow rate was measured using the flow meter.

The swirler made of acrylonitrile butadiene styrene (ABS) resin was installed in the diffuser to form a swirling flow in the barrel. Its shape (Fig. 2(a)) was based on the actual swirler for ABWR (Katono et al., 2015), i.e. the swirler consisted of eight vanes attached to the hub, whose diameter was 6 mm at the swirler inlet and 15 mm at the outlet. Fig. 2(b) and (c) show improved swirlers with eight vanes and with six vanes, respectively. The hub diameters of the improved swirlers were halved and lower parts of vanes were

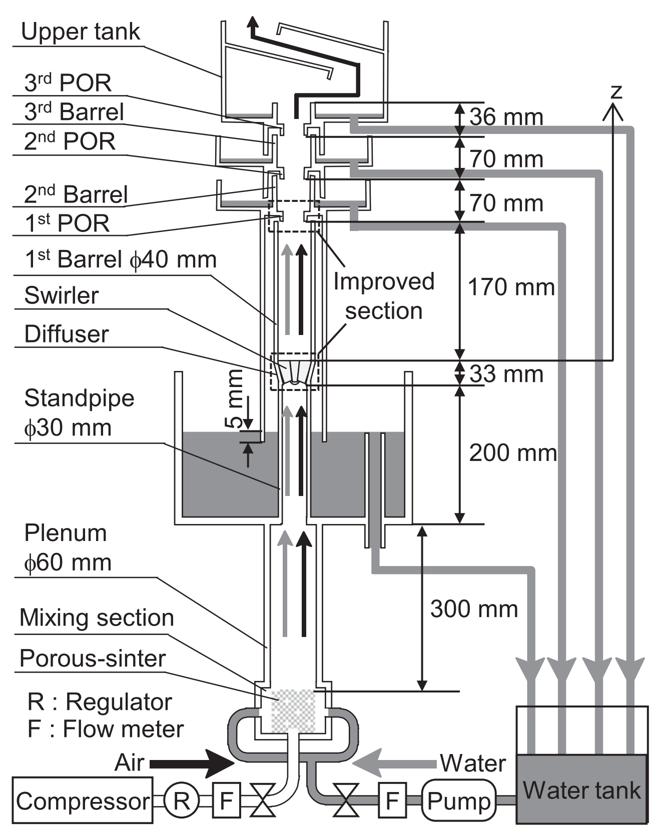

Fig. 1. Experimental setup.