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# Gas Accumulation at Inverse Vertical U-bend (IVU) Resulted from Orifice Cavitation

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## 1. Introduction

Gases accumulated unpredictably in a fluid system, such as a safety system of nuclear power plants, affect the performance degradation of cooling system [1]. The accumulated gases also may damage the components of the fluid system. Even if the introduction of gases from outside of the system is not resulted in by the damaged system, the gas accumulation can be generated by separation of the dissolved non-condensable gases during changes of temperature and pressure [2]. However, the mechanism of gas accumulation after the dissolved gas is separated from the flowing water has not been clearly studied.

The following are the representative locations at which gases are liable to accumulate during flow [3]:

- Inverse vertical U-bend (IVU)
- Check, throttle and relief valves
- Branches
- Heat exchangers

The common characteristic of these examples is that they have a point having an elevation locally higher than their vicinities. Bubbles are likely to be trapped at the elevated locations. Also, it is difficult to remove the gases when they are accumulated at these kinds of positions.

Especially, the accumulated gas at the inverse vertical U-bend has higher possibility to intimidate the whole system, as following reasons. First, more amount of the gas can be accumulated at the top of IVU, due to the elevated region is broader and the elevation is higher than the others. Second, unlike the other examples, the accumulated gases are able to escape by increasing the flow velocity. When the large volume of accumulated gas is swept away at once, they can develop a slug and this may trigger more critical problems.

In order to avert the gas accumulation, the accumulative mechanism of non-condensable gases should be understood. In the current study, it was investigated qualitatively how the gases were separated at the orifice by cavitation and accumulated at the IVU.

## 2. Experimental apparatus

The experimental apparatus consists of the water reservoir, pump, turbine flowmeter, orifice and inverse vertical U-bend (IVU), as illustrated in Fig. 1. The reservoir was installed to contain about 0.085 $m^3$ of water. The 2" SCH10 standard pipelines which has about 0.055 m of inner diameter were used to construct the loop of experimental system. The turbine flowmeter was selected in the purpose of measurement of the volumetric flowrate in the range from 0.6 to 10 $m^3/h$. In order to reduce the pressure in sudden during the flow and generate the cavitation phenomena, the orifice was installed before the test section. The orifice was made of stainless steel having the inner diameter of 0.005 m, i.e., the diameter ratio of approximately 0.09.

The test section, i.e., IVU, was made of the transparent acrylic in order to observe the gas accumulation inside IVU. The inner diameter (D) of the flow channel was about 0.055 m which is same with the system pipes. The curvature (R) of the bend was about 0.178 m having 3.5 of ratio between the curvature and inner diameter (R/D). The length (L) of the straight pipes installed at the inlet and outlet of the bend was more than 18 times of the inner diameter.

## 3. Experimental conditions

In the present study, by increasing the flow velocity, the pressure drop of the flow through the orifice was generated. Afterwards, during increase of the differential pressure, the cavitation and gas accumulation phenomena were observed. In addition, with the purpose of studying the process of accumulated gas growth, the water temperature and the differential pressure (or the water velocity) were kept in constant. In this case, the water temperature was 30 °C and the differential pressure between before and after the orifice was 400 kPa.

## 4. Results and discussions

### *4.1. Gas accumulation due to pressure drop*

Fig. 2 shows a correlation between the water velocity and the differential pressure between before and after the orifice. Also, the cavitation, dissolved gas separation and accumulation phenomena based on the pressure difference are illustrated using the colored markers which are show the experimentally measured pressure drops.

The red solid line illustrates the theoretically calculated relation of pressure drop with the velocity. When the flow passed through the orifice, the pressure suddenly dropped. The faster the flow velocity, the larger the differential pressure. When the pressure difference became larger than a certain value, the pressure drop at the orifice triggered the cavitation. The black dashed line in Fig. 2 shows the certain differential pressure, i.e., the difference of the atmospheric pressure and the vapor pressure at the temperature of 30 °C. When the pressure drop was less than approximately 100 kPa denoted by

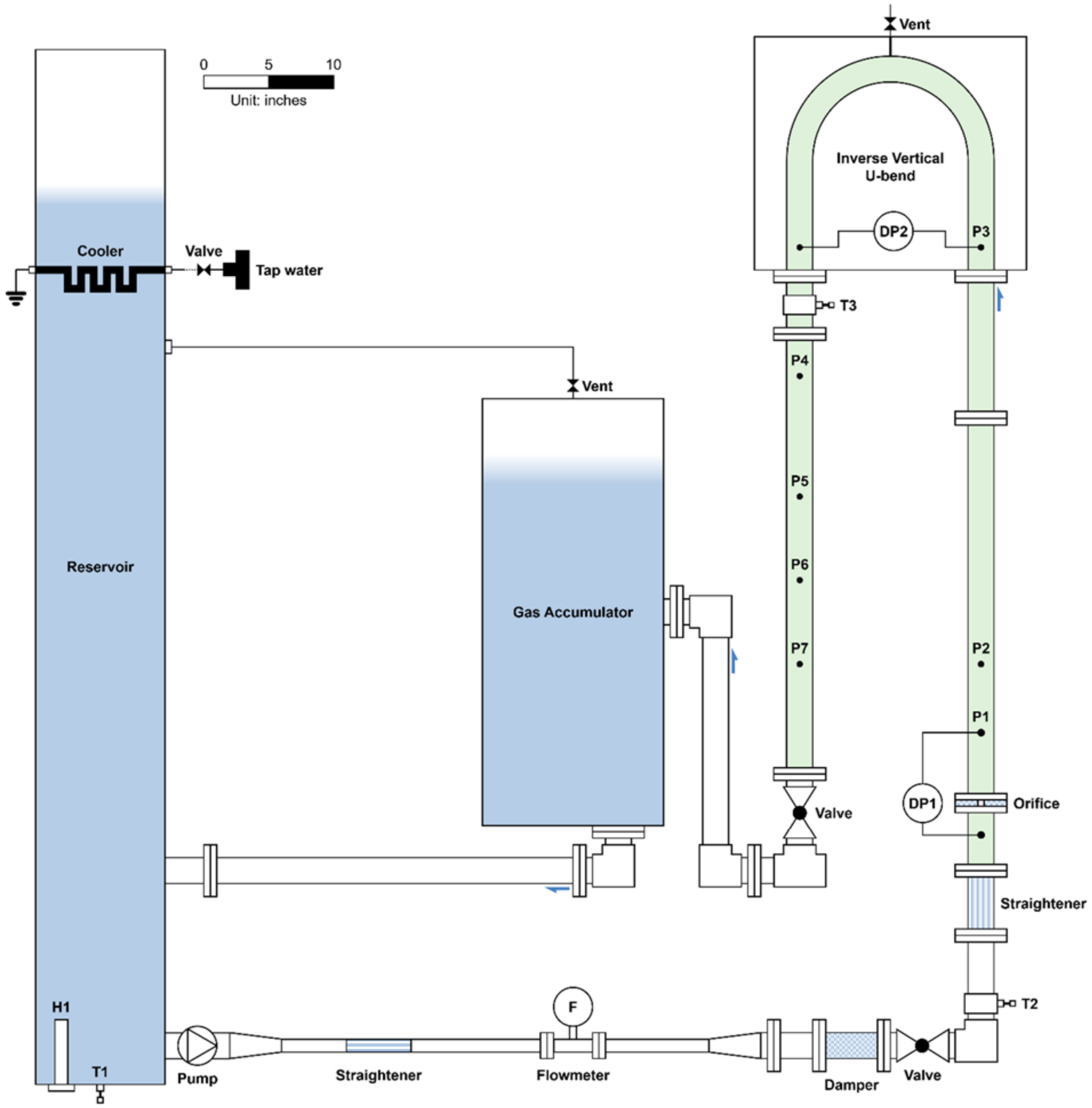


Fig. 1. Schematic diagram of experimental apparatus (green colored region: transparent acrylic).

red markers in Fig. 2, no cavitation and separation occurred. Once the pressure drop exceeded approximately 100 kPa, the cavitation began to occur, as demonstrated by the blue markers. Even though the majority of the cavitation bubbles recovered into the water, the dissolved non-condensable gases were separated with the cavitation and they flowed along the water flow. The amount of the separated gases increased with the increase of the differential pressure. After the pressure drop exceeded a certain value illustrated using the green markers, the separated gases began to be accumulated at the top of IVU.

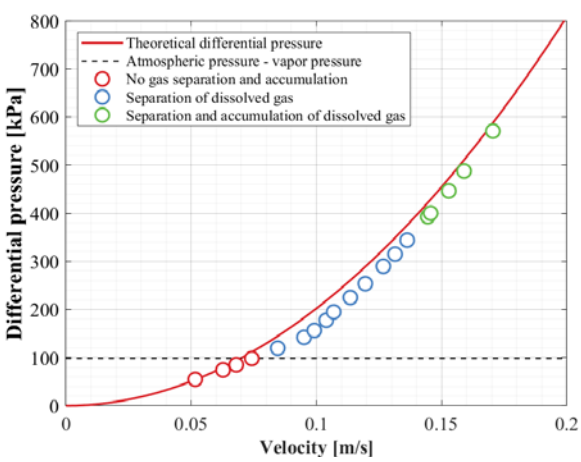


Fig. 2. Theoretical and experimental correlations between water velocity and differential pressure.

*4.2. Growth mechanism of gas accumulation*

Fig. 3 shows growth images of the accumulated gases during the constant differential pressure of 400 kPa.

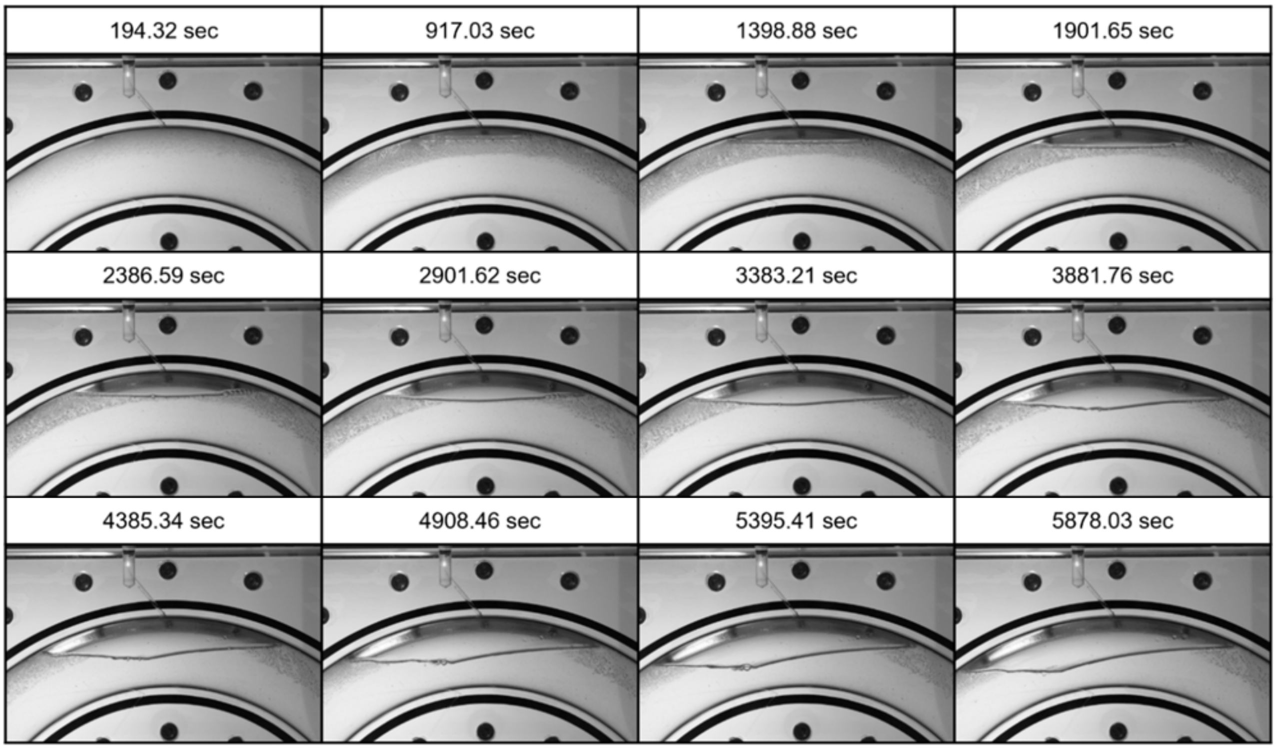


Fig. 3. Growth of accumulated gases at 400 kPa of orifice's differential pressure (water velocity: 0.146 m/s).

Basically, the size of bubbles produced by cavitation is very small, as shown in Fig. 4(a). Because the small sized bubbles are rarely affected by buoyancy, the vast majority of the bubbles were swept out by the flow and got away from the IVU, as demonstrated in Fig. 4(b). However, some bubbles were attached to the pipe's inner wall by friction. They merged with the other flowing bubbles and grown in size. When their size had grown above a certain level, the bubbles were detached and began to be accumulated from the top of IVU under the influence of buoyancy. Once the gas-water interface was formed at the top of IVU, not only the merged bubbles, but also the small sized flowing bubbles collided with the interface and grew the accumulated gas. Due to the flow velocity was very slow at about 0.146 m/s, the accumulated gas grew with a horizontal interface before about 2,000 sec.

The more the volume where the accumulated gas accounted for, the narrower the flow path at the IVU formed. This phenomenon caused the pressure drop between before and after the accumulated gas. As a result, secondary flow occurred behind the outlet-side interface. Accordingly, it was observed that the bubbles passing through this region did not escape the IVU, returned back and joined the accumulated gas.

## 5. Conclusions

In order to investigate the accumulative principles of dissolved gases, it was observed how the pressure drop in the orifice affects the gas accumulation. When the pressure of the water flowing through the orifice reduced less than the vapor pressure, the dissolved gas began to be separated. The pressure drop increased more than a certain value, the gas was accumulated at the IVU. Additionally, the growing process of gas accumulation phenomenon was visualized.

With the intention of more precise research, the following topics are planned to carry out in near future.

- Various orifices having different inner diameter will be used for generating various pressure drop at same velocity condition.
- By image processing, the amount of accumulated gas and the accumulative rate will be quantified.

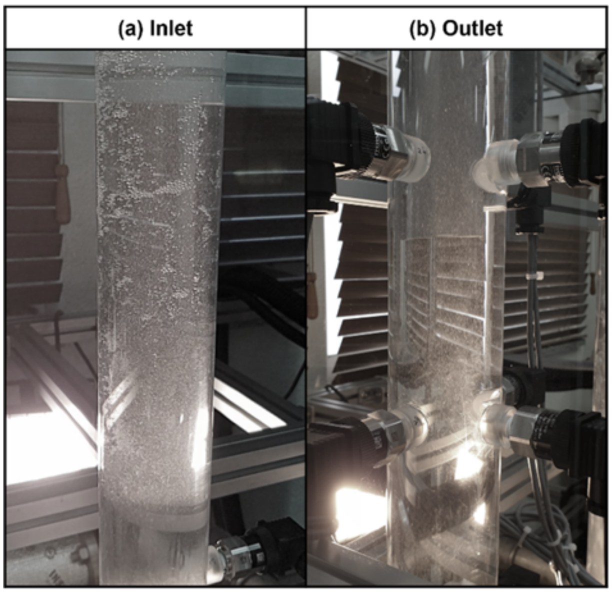


Fig. 4. Images of the straight pipes installed at the inlet and outlet of IVU.

- Gas accumulation after the dissolved gas separation generated by heating will be observed.

## REFERENCE

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[3] Nuclear Energy Institute, Guidelines for Effective Prevention and Management of System Gas Accumulation, NEI 09-10 (Rev 1a-A), Dec., 2010.