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Development of the advanced accumulator for the pressurized water reactor

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ABSTRACT

With the increased requirement for nuclear power generation as an effective countermeasure against global warming, Mitsubishi has developed the advanced pressurized water reactor (APWR) by adopting a new component of the emergency core cooling system (ECCS), a new instrumentation and control system, and other newfound improvements. The ECCS introduces a new passive component called the advanced accumulator which integrates both functions of the conventional accumulator and the low-pressure pump without any moving parts. The advanced accumulator uses a new fluidic device that automatically regulates flow rates of injected water in case of a loss of coolant accident (LOCA). This fluidic device is referred to as a flow damper. The design method of the flow damper and the standpipe was separately published (Shiraishi, 2011). This paper, then, describes the development and experiments with scale models of the advanced accumulator, and the satisfactory results obtained.

1. Introduction

Mitsubishi has developed the advanced accumulator which is a new passive ECCS component of the advanced pressurized water reactor (APWR) (Suzuki et al., 2008, 2009).

Globally speaking, development of passive safety systems for nuclear plants thrived in the 1980s against the backdrop of the Three-mile Island accident in March of 1979 and the Chernobyl accident in April of 1986. At the time, Mitsubishi Heavy Industries, Ltd. (MHI) had been developing a hybrid safety system, namely orchestrating the merits of both passive and active safety systems (Makihara et al., 1993). For the hybrid system, a new device was required to change the flow rate of the ECCS with high reliability and to be maintenance-free for the plant life time. The solution was the advanced accumulator with a new fluidic device, called a flow damper which has no moving parts. Since there are no moving parts, fluidic elements have extraordinary reliability and require no maintenance.

The advanced accumulator was invented using the science of fluidics in 1968 and opened as a basic patent in 1994 (Shiraishi, 1994). It was successfully developed for the next generation PWR and reported in References (Shiraishi et al., 1991, 1992, 1994a,b,c,d; Sugizaki et al., 1992). The development of the advanced accumulator for the APWR was then initiated in 1995 and completed in 1997.

The theory of the flow damper and the standpipe was separately published (Shiraishi, 2011). It describes the principle of the advanced accumulator, and the design methods of the flow damper and the standpipe. This paper, then, reports the development and experimental results with four kinds of scale models of the advanced accumulator, including the 1/2-scale model under the prototype pressure of over 4 MPaG for demonstration.

2. Development of advanced accumulator for APWR

If a large break LOCA (loss of coolant accident) happens, the emergency core cooling system (ECCS) starts to cool the reactor core. The advanced accumulator first works in the ECCS. The roles of the advanced accumulator are as follows depending on the injection processes:

1) Refilling process for large flow injection: The advanced accumulator immediately injects the water equivalent to the volume of the downcomer and lower plenum of the reactor vessel to attain refilling.
2) Reflooding process for small flow injection: The advanced accumulator continues injecting water following the refilling process to maintain water level in the downcomer.

Therefore, the advanced accumulator needs to have a function of automatic changeover of flow rate without any moving parts so that it can inject water at large flow rate first and at small flow rate

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Table 1
Main specifications of the advanced accumulator.

Type	Vertical cylindrical
Number	4
Volume	90 m^3
Design pressure	4.83 MPaG
Design temperature	149 °C
Normal operating pressure	Approximately 4.41 MPaG
Water volume of large flow injection	38 m^3
Water volume of small flow injection	22.2 m^3

later. The duration of small flow injection required is associated with the capacity of Safety Injection (SI) pumps.

The main specifications of the advanced accumulator are shown at Table 1. The volume of the advanced accumulator is determined by summing up water volumes of large- and small-flow injections, gas phase and dead water. The structure of the advanced accumulator for the APWR is shown in Fig. 1. The flow damper installed at the bottom of the accumulator tank is composed of a vortex chamber, large and small flow pipes and an outlet nozzle. The standpipe stands along the wall of the tank and is connected to the large flow pipe at its lower end. The upper end of the standpipe is the inlet port with an anti-vortex cap. Fig. 2 shows the flow damper. The outlet nozzle at the outlet port of the vortex chamber is composed of a reducer, a throat and a diffuser. The outlet pipe concatenates the outlet nozzle and the injection pipe. The bird-eyes view of the safety system of APWR is shown in Fig. 3. The advanced accumulators are indicated by Number 6.

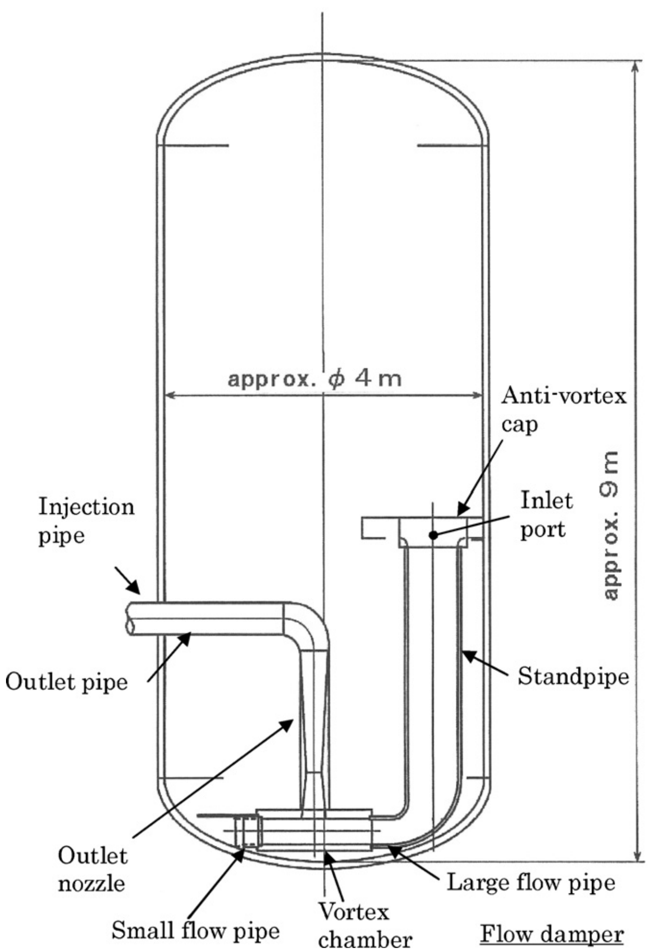

Fig. 1. Structure of the advanced accumulator. The accumulator tank contains the flow damper at the bottom and the standpipe along the side wall. The outlet nozzle is connected to the injection pipe by the outlet pipe.

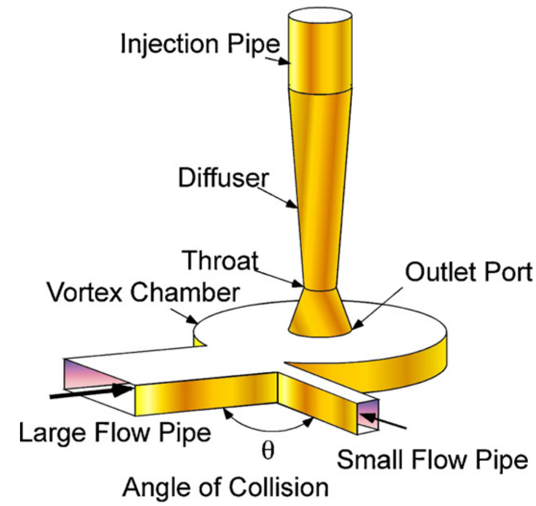

Fig. 2. Mechanical configuration of the flow damper. It consists of large and small flow pipes, a vortex chamber, and an outlet nozzle which is composed of a reducer, a throat and a diffuser. The reducer is between the outlet port and the throat.

The phenomena we expect in the advanced accumulator are as follows:

1) In the large flow phase, water level in the accumulator tank is higher than the inlet port of the standpipe. Water in the accumulator tank flows into both the inlet port of the standpipe and the small flow pipe. Water in the standpipe flows into the large flow pipe. Both flows from the large and small flow pipes collide with each other in the vortex chamber. The conflux goes straight to the outlet port of the vortex chamber without a vortex formed. Thus, large flow rate comes out. The flow in the flow damper is that of typical pipe flow which has the general properties for pipe flow. Reynolds number of the prototypical flow is very large so that viscosity effect can be negligible. The critical section determining the flow rate is at the throat whose cross sectional area is the minimum. The potential of cavitation at the throat is, therefore, the governing phenomenon to be considered.
2) During flow changeover, water level in the accumulator tank is close to the inlet port of the standpipe. Sharp changeover of flow rate is preferable for reliable injection. So prevention of formation of a vortex and a water fall on a water surface just above the inlet port of the standpipe is an important function of the anti-vortex cap. The changeover of flow rate starts just when water level in the accumulator tank comes down to the lower edge of the skirt of the anti-vortex cap, and flow sharply stops entering into the standpipe. Water column in the standpipe first undershoots and then recovers due to its inertia during the changeover. So prevention of gas leakage through the standpipe is another important function of the standpipe. A strong and steady vortex is quickly formed in the vortex chamber.
3) In the small flow phase, water level in the accumulator tank is lower than the inlet port of the standpipe. Water in the accumulator tank flows into only the small flow pipe. Water is preserved and almost stationary in the standpipe to prevent gas leakage through it. A strong and steady vortex continues until the end of the small flow injection. The viscosity effect can be negligible for the strong vortex flow in the chamber of the flow damper. The potential of cavitation at the center of the vortex is the important phenomenon to be considered.