Introduction of ARIEL Test facility for Evaluating the Performance of Containment Filtered Venting System

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1. Introduction

The pressure inside the containment can increase substantially, and the integrity of the containment may be threatened during the severe accident, such as Fukushima nuclear power plant accident. So, it requires containment venting in order to maintain the containment integrity. CFVS (Containment Filtered Venting System) is one of the strategies maintaining the integrity of the containment by releasing the high temperature and pressure gas from inside the containment to outside the containment through pipe line by capturing and scrubbing radioactive gases and aerosols. During the releasing process, fission products like radioactive aerosol and iodine are filtered simultaneously by filtration system of the CFVS in order to prevent release of the radioactive material to the environment. The performance of the filtration should be considered that radioactive materials such as cesium and radioactive aerosol are not released outside the environment.

Korea has 23 reactors (19 PWR, 4 PHWR) on 4 sites (Hanbit (6), Hanul (6), Kori (6), Wolsong (1 PWR, 4 PHWR)) providing about 30% of its electricity. Fukushima accidents triggered a discussion on the need to protect from a containment failure by an over pressurization and mitigate an uncontrolled release of activity into the environment. Korean NPP units are planned to be equipped with CFVS, and an open tender is being prepared.

A new CFVS for the light water reactors is developing as a depressurization system of the containments under a severe accident. It consists of pool venturi scrubber, cyclone droplet/particle separator, particulate filter, and molecular sieve filter. The Korea Atomic Energy Research Institute (KAERI) constructed a large-sized test facility, called Aerosol Removal & Iodine Elimination (ARIEL) test facility, to evaluate the performance of the CFVS. In this paper, the ARIEL test facility and test plans to verify the performance of the new Korean CFVS are present.

2. ARIEL Test Facility

2.1 Design Features of CFVS

The new Korean FCVS consists of the four main components, as shown in Fig. 1, which are the venturi scrubber including the pool, the cyclone, the metallic fiber filter, and the molecular.

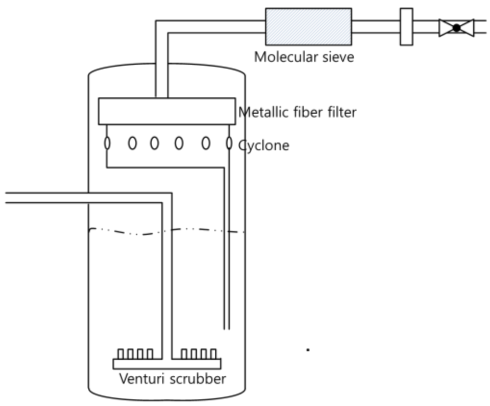

Fig.1. Conceptual design of proposed FCVS system [3]

During the severe accident, if the pressure inside the containment reaches desired set point, the vent valve pipe will be opened by the operator or the operation of the rupture disk. Then, the radioactive gas mixture which consists of steam, gases, and aerosols are discharged to the filtration tank filled with water through the vent pipe. While the mixture gas passes the venturi nozzle, a swarm of droplets coming through the hole in the throat of the nozzle is supplied to the mixture gas. During this process, impaction occurs between the gas and the droplet due to a velocity difference, therefore the radioactive materials are removed from the gas. The mixture gas including the aerosols will pass through a pool of water. While the gases pass through the pool in the form of bubbles, scrubbing process occurs. Also, addition of chemicals is known to augment the scrubbing process for the elemental and organic iodine gases. It results in a scrubbing of gas such as elemental iodine and aerosols. Most of the radioactive aerosol and iodine are removed in the venturi scrubber.

The gas passing the pool still includes tiny aerosol and entrained water droplets. In the cyclone, the heavy particles and hygroscopic moisture of gas are removed by centrifugal force. As shown in the Fig. 1, a number of cyclones are contained in a closed space like a box while the inlet of cyclone is exposed to the gas space such that the mixture gas containing the water droplet and aerosols could pass through the cyclones. The box has several holes for the cyclone inlet. The exit of cyclone is contained in the closed space, at the bottom of which a drain line is connected deep into the pool such that the droplets would drain into the lower part of the water pool.

In next stage, the metallic fiber filter into removes very tiny aerosols and droplets whose size is less than 2 μm. The metallic fiber filter can be the pre-filter and the aerosol filter. The pre-filter consisted of the metallic fiber with a thickness of 6 – 10μm is installed in front of the aerosol filter. The aerosol filter installed after the pre-filter consists of the metallic fiber with a thickness of 2 – 8μm in order to remove the tiny particles. The thickness of the metallic fiber is a parameter affecting the efficiency of the capturing performance; the performance is better as the thickness is thinner.

The molecular sieve box is located outside the CFVS vessel to remove the organic iodine. The gas passing the metallic fiber filter goes to the molecular sieve in order to remove the iodine. The molecular sieve plays a role in filtering organic iodine. The molecular sieve consists of the synthetic zeolite, silver zeolite is used so that the radioactive iodine is removed in the high temperature process. There are a lot of uniform tiny holes, therefore the gas coming from the molecular sieve will pass the holes to remove the iodine.

Finally, an orifice and valve is installed before the entrance of the molecular sieve. The location of orifice has to be optimized as it will change the volumetric flow into the molecular sieve, which would affect the amount of molecular sieve, which is quite expensive as it contains Ag.

2.2 1:1 Full height CFVS test facility: ARIEL

The large-scaled performance tests have been performed such as ACE, JAVA, etc. KAERI constructed a large-sized test facility, called Aerosol Removal & Iodine Elimination (ARIEL) test facility, to evaluate the performance of the new Korean FCVS. It consists of a test vessel, thermal-hydraulic, and aerosol/iodine generation and measurement parts as shown in Table 1.

The retention test of aerosol/iodine will be performed in the ARIEL test facility, which is a scaled-down, full height, reduced diameter mock-up of the new Korean CFVS, as shown Figure 2. The key components of the CFVS are the pool venturi scrubber, cyclone droplet/particle separator, metallic fiber filter, and molecular sieve. Each of these has various phenomena associated with them. However, the major scaling parameters for designing a test facility are a gas residence time and pressure drop [4]. To verify the performance of FCVS, two test facilities would be used. One is based on scaling analysis with three venturi nozzle out of total 60 venturi nozzles. Another is based on scaling analysis with one nozzle out of total 60 venturi nozzles.

Table 1. Summary of ARIEL Facility

Part	System	Main Equipment
Test Vessel	Performance Test Components	CFVS Pressure Vessel
		Scrubber Nozzle
		Cyclone
		Metal fiber filter
Thermal-hydraulic	Gas Supply System	Steam Boiler Unit
		LN2 Storage Tank & LN2 Evaporator Unit
		Air Compressor Unit
		Air & N2 Heater
		Air & N2 Reservoir
	Storage & Drain System	Suppression Tank
	Cooling System	Steam Condenser
		Circulation Pump
		Cooling Tower
		Strainer
Aerosol/Iodine Generation & Measurement	Aerosol/Iodine Generation & Measurement	Aerosol/Iodine Injector
		Sampling Bottle
		Suction Chamber/pump

Fig.2. The 1:1 height, reduced diameter scale CFVS facility ARIEL to determine aerosol and iodine retention

Table 2. Capacity of the Test facility

Parameter	Value
Maximum operating pressure	10 bar a
Maximum operation temperature	170 ℃
Steam generator capacity	5000 kg/hr
Nitrogen generator capacity	1800 kg/hr
Air supply capacity	1800 kg/hr

Table 2 shows the capacity of the FCVS test facility. The maximum operation pressure in front of the inlet nozzle is 10 bars and the temperature is about 170 ℃. The test section can be operated from ambient pressure up to 10 bars by a pressure control system. The steam generation capacity is up to 5000 kg/hr, in order to simulate the high stream mass fraction. Nitrogen and air can be supplied up to 1800kg/hr.

The fluid, gas and wall temperatures, the absolute, gauge and differential pressures along the test section and the flow rates at the inlet and outlet of the test section can be measured. The water level swell is monitored online during the test by a special guided radar probe. The whole test section can be heated to compensate for heat losses, to prevent steam condensation and to reduce aerosol/iodine losses at cold walls.

3. Performance evaluation of CFVS

3.1 Thermo-hydraulic test

In ARIEL, several thermal hydraulic tests were performed using nitrogen gas without aerosol/iodine feeding at the selected test conditions. In this experiments, fluid, gas and wall temperatures, the absolute, gauge and differential pressures along the test section and the flow rates at the inlet and outlet of the test section were measured. The water level swell was monitored online during the test by a special guided radar probe. The normalized level swell is obtain by the change of the water level divided by the initial water level.

Figures 3 to 5 show the some thermal hydraulic test results which are the change of the inlet pressure which is located in front of the venturi nozzle, the pressure drop through the pool including venturi nozzle, and the normalized level swell, respectively.

During the severe accident, if the pressure inside the containment is reached to specific opening value, the vent pipe will be opened and the high pressure gas releases to the CFVS. Through the dynamic test, it was confirmed that components in CFVS are functioning normally during the transient process. It also needs some time to reach normal operation from start-up. So, the measuring parameters are the change of the scrubber pool height, the pressure at each component, and the time to reach the normal operation condition from start-up. It can be seen in figures 3,4,5 from 0 to about 100s.

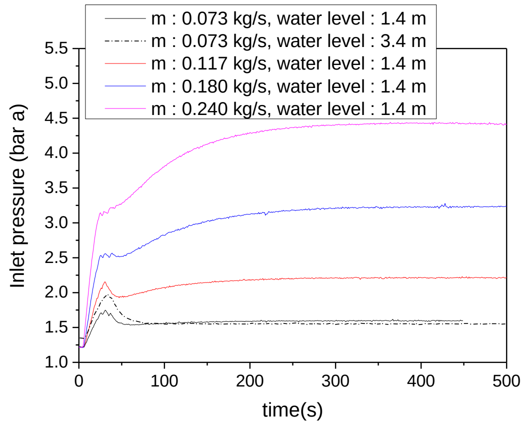

Fig.3. Change of inlet pressure

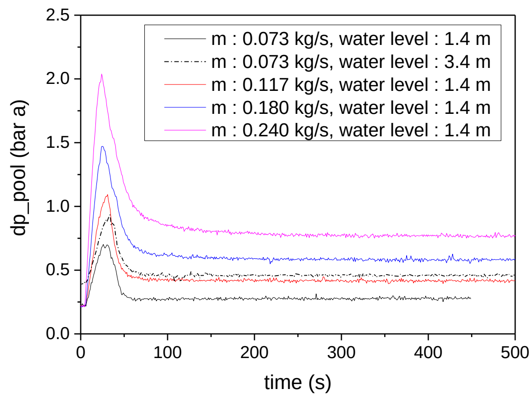

Fig.4. Pressure drop at the pool with mass flow rate

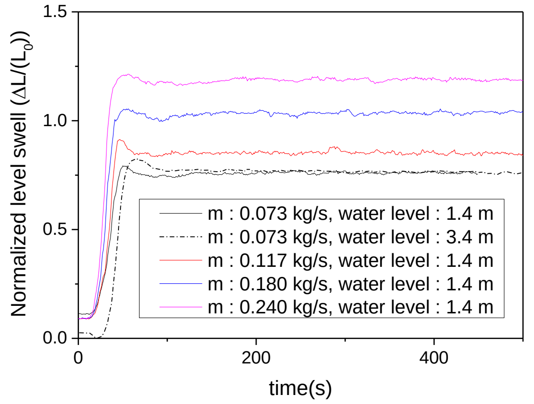

Fig.5. Normalized level swell in CFVS

3.2 Test matrix

Further thermo-hydraulic test will be performed to characterize the pressure and temperature behavior and to use for detailed test planning. The experiments to observe the non-condensable gas effect in the scrubber pool will be performed using steam/nitrogen gas.

Aerosol removal test, elemental/organic iodine removal test should be performed to evaluate the performance of Korean FCVS.

The aerosol and the elemental/organic removal tests will be performed at the same conditions as thermal hydraulic test. The decontamination factor (DF) of FCVS is measured. In order to simulate the most severe case, the test will be performed at the maximum aerosol concentration condition. Non-soluble particle (SiO_2) will be used. As the change of the vessel temperature and the pressure, the particles are re-suspended from the scrubber pool and a surface of each component. So, re-suspension test will be performed after aerosol removal test. All tests are planned lasting 2 hours to collect an appropriate number of aerosol and I_2 samples at the inlet and especially at the outlet, respectively. Although the remove efficiency of iodine in scrubber pool is dependent on pH, this effect would not be observed in this performance test. However, the pH scale of scrubber solution is maintained higher than 9 using the chemical additive. Furthermore, the pH of the scrubber solution will be monitored online during the test by a pH electrode device. Also, the temperature of pool, the mixture level swell, and the pressure, will be is measured. As the change of the vessel temperature and the pressure, the iodine is re-volatilized from the scrubber pool and a surface of each component. Re-volatilization of iodine test will be performed after elemental/organic iodine removal test.

4. Conclusions

In severe accidents, the discharge of corium would lead to substantial releases of fission products in the form of aerosols and gases, which are simultaneously released with steam and non-condensable gases. Release of the gaseous species in sufficient quantities from containment to environment generates a risk for public health. The filtered containment venting systems (FCVS) can considerably reduce the leakage of radioactive materials to the environment.

Aerosol Removal & Iodine Elimination (ARIEL) test facility, to verify the performance of the FCVS was constructed. The experimental CFVS was a scaled-down, full height, reduced diameter mock-up of Korean CFVS. The ARIEL test facility consists of five parts; a performance test facility, gas supply facility, storage & drain facility, cooling facility, and aerosol/iodine generation and measurement facility. The maximum operation pressure in front of the inlet nozzle is about 10 bars and the temperature is around 170 ℃. The steam generation capacity is up to 5000 kg/hr, and nitrogen and air can be supplied up to 1800kg/hr. We are planning to conduct thermal-hydraulic tests, aerosol removal tests, and elemental/organic iodine removal tests to verify the performance of the new Korean FCVS.

ACKNOWLEDGEMENTS

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