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Development of ISLOCA Aerosol Pool Scrubbing Test Facility

WooYoung Jung [a*], DooYong Lee [a], BumKyu Kim [a], MinBum Heo [a], Byeonghee Lee [b], Kwang Soon Ha [b]ByungChul Lee [a] and JinYong Lee [a]
[a]*FNC Technology Co., Ltd., Heungdeok IT Valley Bldg. 32F, 13, Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggido, 16954, Korea*
[b] *Korea Atomic Energy Research Institute, (34057) 111, Daedeok-daero 989Beon-gil, Yuseong-gu, Daejeon, Korea*
** Corresponding author: wyj@fnctech.com, +82-31-8005-5936*

1. Introduction

A containment building in a nuclear power plant is one of the key components to prevent the fission products from severe accident being released into the environment. However, there is severe accident scenario called containment bypass accident such as SGTR(Steam Generator Tube Rupture) and ISLOCA(Interfacing System Loss of Coolant Accident) which the fission products can bypass through the containment building and released into the environment. Such these accidents discharge the coolant of the primary system into the auxiliary building due to the pipe break or component damages on the piping system connected to the RCS in a nuclear power plant. As a result, the coolant can be formed a water pool in the auxiliary building. After running out the coolant of the RCS, the core would be damaged and the fission products will be released through the damaged piping system, which can be submerged, to the pool in the auxiliary building. Some fission products may be removed by the piping system and the pool in the auxiliary building. Especially, the amount estimation of filtered fission products can be essential for evaluating the released amount of the fission products into the environment when the carrier gas is injected into the pool. The process called scrubbing is that a liquid volume can remove aerosols carried by a gas stream.[1] The pool scrubbing was heavily examined in the 80's and 90's of the last century.[2] However, several additional issues of the pool scrubbing were introduced to investigate more such as jet injection regime, gas rise hydrodynamics at high velocity injection, scrubbing of fission product vapors, re-entrainment in the long run of a severe accident and the effect of boundary conditions like submerged structures and presence of surfactants.[3,4]

In this study, the test facility will be introduced for evaluating the pool scrubbing efficiency of the aerosol with respect to the variables such as the injected gas flow regime, the direction of the gas injection and the submergence regarding water height of the pool.

2. Test Facility

In this section, ISLOCA aerosol pool scrubbing test facility will be described with respect to main phenomena during the pool scrubbing and scaling parameters. In addition, thermal-hydraulic test results and analysis will be presented.

2.1 Main Phenomena

During the ISLOCA, strong turbulent flow can be expected inside the damaged pipe and the gas flow can be injected into the pool with high velocity under the submerged condition.[1,5]

Inertial impaction, interception and Brownian diffusion can be known as dominant mechanisms of particle removal process during the pool scrubbing. Two types of the conceptual injection flow regime under the submerged condition were introduced as shown in Figure 1.[1]

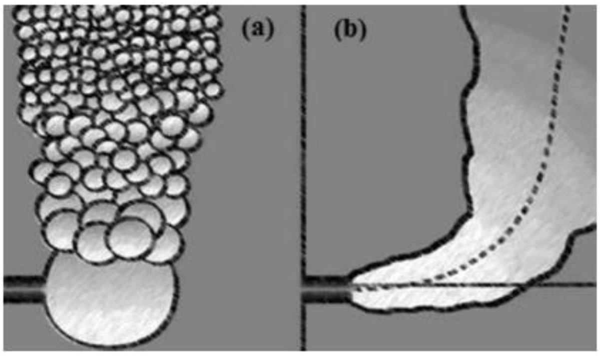

Fig.1. Schematic view of the two conceptual flow regime; (a) Globular Regime; (b)Jet Injection Regime[1]

The transition between globule and jet regime can be defined by Weber number(non-dimensional number) which is based on a threshold defined by critical Weber number.[6] At this point, gas-liquid interface phenomena changes drastically as well as the aerosol removal mechanisms.[2]

2.2 Scaling Parameter

The test facility to measure the pool scrubbing efficiency has been built based on the scaling parameters. The scaling parameters are introduced as follows:

$$Re_{flow} = \frac{\rho D_{duct} U_0}{\mu} \quad (1)$$

where ρ, D_{duct}, U_0 and μ are the fluid density, pipe diameter, fluid velocity and fluid viscosity, respectively.

Weber Number is defined as

$$We = \frac{\rho_g v_g^2 d_{in}}{\sigma} \quad (2)$$

where ρ_g , ν_g, d_{in} and σ are the gas density and velocity, nozzle diameter and water surface tension respectively.

The critical Weber Number is

$$We_c = 10.5 \cdot \sqrt{\frac{\rho_l}{\rho_g}} \quad (3)$$

where ρ_l is the liquid density.

2.3 Test Facility

The ISLOCA aerosol pool scrubbing test facility consists of three parts such as gas supply system, aerosol system and test section (pool scrubbing part shown in Figure 2. The pool scrubbing test facility is connected from the test facility for measuring aerosol deposition inside a pipe which is previously built(cloud mark). The configuration of the test facility is presented in Figure 3.

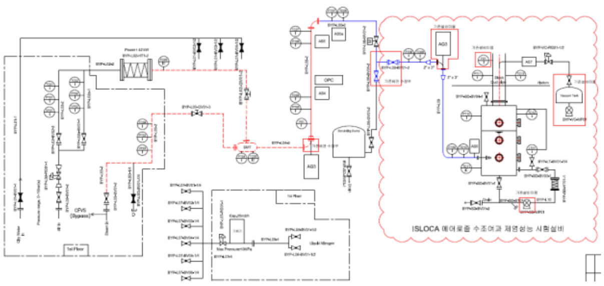

Fig.2. Schematic diagram of ISLOCA Aerosol Pool Scrubbing Test Facility

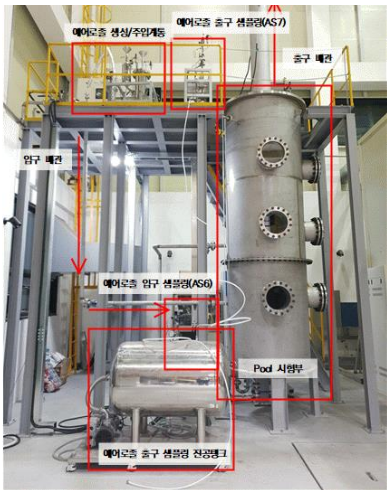

Fig.3. Configuration of ISLOCA Aerosol Pool Scrubbing Test Facility

The gas supply system can provide main flow of the tests up to 0.15kg/s(steam) and 0.22kg/s(compressed air). The thermal-hydraulic boundary conditions of the test such as pressure and flow rate can be built by the motor-driven valve and regulator. Temperature of the test is controlled by pre-heater and heating jacket. The available boundary conditions of the test are described in Table I.

Table I: Test Boundary Condition

Variables	Range	Note
Pressure	1 ~ 5 bar(a)	Inlet Pipe
	1 ~ 1.3bar(a)	Pool
Temperature	20 ~ 152 ℃	Inlet Pipe
	20 ~ 107 ℃	Pool
Flow Rate	Max. 0.22kg/s	Air
	Max. 0.15kg/s	Steam

The aerosol system consists of two components (aerosol generation/injection system and aerosol sampling). In order to measure the pool scrubbing efficiency, the test materials should be injected to the pool. The aerosol (SiO_2, solid, spherical, 0.7μm) mixed with ethanol will be used as test material. The aerosols (SiO_2+Ethanol) can be injected by the two fluid nozzle. The aerosol is pressurized by high pressure nitrogen. After this the nozzle atomizes the aerosol into the inlet of the pool using another nitrogen gas (high temperature) with evaporating the ethanol. As result, the main flow from the gas supply system can be mixed with the aerosol before reaching the pool. The schematic diagram of the aerosol generation/injection can be shown in Figure 4.

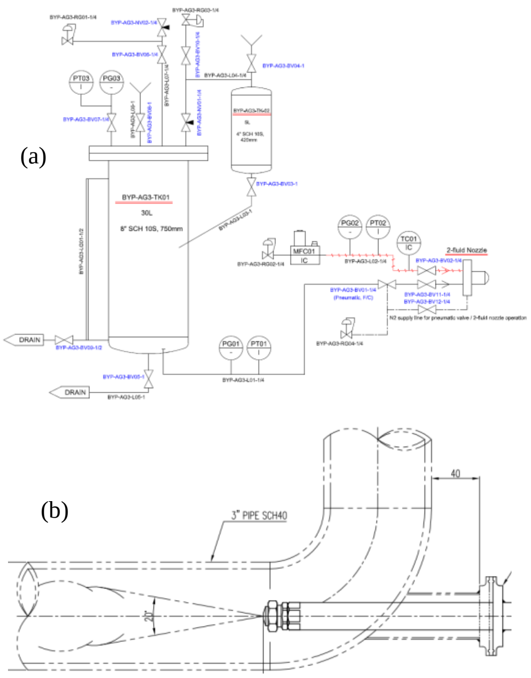

Fig. 4. Schematic diagram of Aerosol Generation/Injection System; (a) Aerosol Generation System; (b) Aerosol Injection

The test flow reaches the pool via a 2-inch pool inlet pipe which is connected to the pool horizontally. The main flow with the aerosols is sampled just before reaching the pool by the aerosol sampling system. Using the sampled aerosol mass with sampled flow rate can be converted as an inlet aerosol concentration of the pool.

The test section which is a pool is a stainless steel vessel with flat head. The dimension of the pool is Φ1200mm x 3800mm(Inner diameter and inner height respectively). The inlet of the pool is located at 1000mm high of the pool bottom plate due to change the injection direction and to reduce wall effect when the gas is injected. In addition, the 6 sight glasses are located in terms of the elevations from the nozzle center in order to observe the bubble dynamics. The pool configuration is presented as Figure 5.

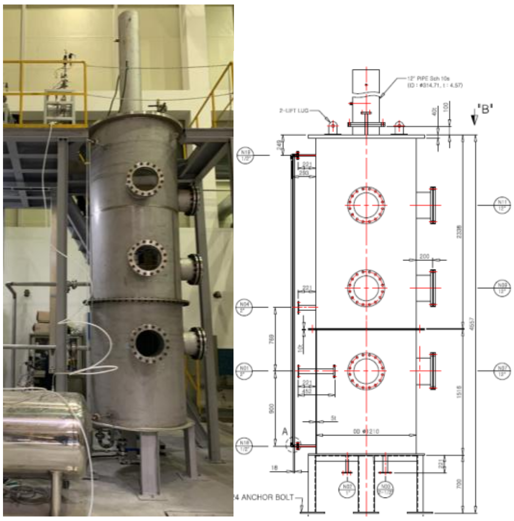

Fig. 5. Pool Configuration of the test facility

The test section has a stack(Φ300mm) which is the outlet of the pool. At the stack, the aerosol passes through the pool scrubbing can be measured by another sampling system which is performed by the same principle with the inlet sampling system unless the sampling flow rate controlled by a vacuum pump. The aerosol sampling systems of the inlet and outlet are described in Figure 6.

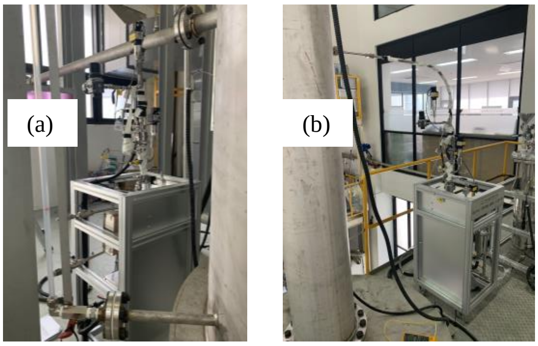

Fig. 6. Configuration of Aerosol Sampling System; (a)Inlet of the pool; (b) Outlet of the pool

The aerosol sampling filter which collects the aerosol is located at the closest point where the sampling probe is to minimize the possible aerosol loss on the sampling line.

The inlet nozzles are selected to produce the gas flow regime under the submerged condition. There are four different sizes which has diameter of 25mm, 15mm, 12mm and 8mm respectively presented as Figure 7(a). In addition, the direction of the injection can be changed from horizontal to vertical using the component shown in Figure 7(b).

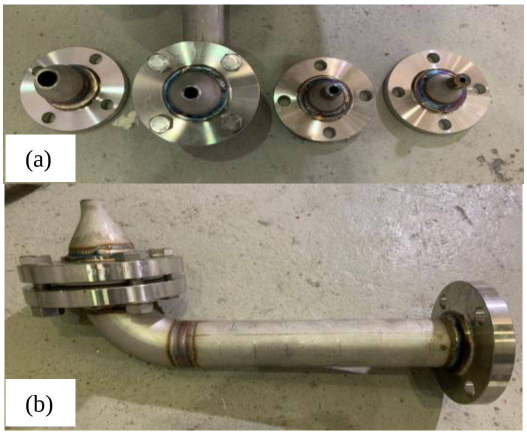

Fig. 7. Configuration of Nozzle Component; (a) 4 types of nozzles; (b) Nozzle components to change direction

There are several controlling processes based on PLC(Programmable Logic Controller) with PID control such as pre-heater power control for supplied air and nitrogen of the system and water in the pool regarding the measured temperature of the instrumentation. In addition, the motor driven valve and the pumps for water circulation and vacuum tank are also controlled at the PLC.

The thermal-hydraulic variables such as pressure, temperature and flow rate can also be monitored by PLC. The measuring points of the system pressure and temperature are the location of the aerosol injection, the pool inlet, the inside of the pool and the outlet of the pool.

In addition, the volumetric flow rate is measured at the outlet of the gas supply system which can be converted to mass flow rate using the pressure and the temperature measured at the same location with the flow meter. Otherwise, the sampling flow rate for air is obtained as volumetric flow rate using MFC(Inlet sampling) and MFM(Outlet Sampling). In terms of steam as using a carrier gas, condensate of the steam flow can be converted to the mass flow rate for calculating the aerosol concentration at the sampling point. All obtained data can be saved by the PLC.

2.4 Thermal-hydraulic Test

The two types of the thermal-hydraulic test were performed for estimating the ability of the test facility. The compressed air was used to develop the test boundary condition with 15mm diameter nozzle. The tests were performed under the maximum and minimum pressure condition. The jet flow regimes were observed from both tests. The test results of the maximum pressure condition were presented in Table 2. The measured Webber Number was about 5.95×10^7 which was much higher than the calculated critical Weber Number. This means that the jet flow regime was developed.

The configuration of the jet flow regime is presented in Figure 8.

Table 2: Test Results(Max. Pressure Condition)

Variables	Range	Note
Pressure	4.98 bar(a)	Pool inlet
Temperature	18.05℃	
Flow Rate	0.183kg/s	
	112.93m³/h	
Flow Re#	235,291	
Flow Velocity	177.52m/s	Nozzle
Water Level	1180mm	Base on Nozzle
We_c	133.033	
We	5.95×10^7	

Fig. 8. Configuration of the jet flow regime(Max. pressure condition)

The results from the minimum pressure condition were shown as Table 3.

Table 3: Test Results(Min. Pressure Condition)

Variables	Range	Note
Pressure	1.22 bar(a)	Pool inlet
Temperature	17.53℃	
Flow Rate	0.024kg/s	
	64.94m³/h	
Flow Re#	30,950	
Flow Velocity	102.08m/s	Nozzle
Water Level	1180mm	Base on Nozzle
We_c	270.744	
We	1.76×10^7	

The configuration of the jet flow regime is presented in Figure 9.

The flow regime of Figure 9 seems like the form of globule regime. However, Weber Number of the test was also much higher than the critical Weber Number. Therefore, the additional test should be performed in order to develop the boundary condition for globule regime condition. ($We<We_c$)

Fig. 9. Configuration of the jet flow regime(Min. pressure condition)

3. Conclusions

ISLOCA aerosol pool scrubbing test facility is introduced in order to investigate the pool scrubbing efficiency. The thermal-hydraulic tests were performed for estimating the ability of the test facility. The jet flow regime was observed from both tests with the same submerged condition. To evaluate the pool scrubbing efficiency, the tests using the aerosol(SiO_2, 0.7μm) will be conducted using air or steam flow as a carrier gas.

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