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Pool Scrubbing Efficiency for Elemental Iodine with Self-priming Scrubber Nozzle Used in Containment Filtered Venting System

Woo Young Jung [a], Jong Chan Lee [a,], Hyun Chul Lee [a], Gyu Tae Kim [a], Doo Yong Lee [a*]
[a] *FNC Technology Co., Ltd, Heungdeok IT Valley 32th floor, 13, Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, 151-742 Korea*
[*] *Corresponding author: dylee@fnctech.com*

1. INTRODUCTION

There are several pathways for activity release to the environment defined in NEA/CSNI report. One of the defined pathways is Containment Filtered Venting System (CFVS) when severe accident occurs. CFVS can considerably reduce the release of the radioactive fission product from the containment in a nuclear power plant(NPP) to the environment. Although most iodine is released as a form of suspended aerosols from RCS to the containment atmosphere, liquid phase and gaseous iodine is also formed in the containment atmosphere [1].

One of the iodine absorbers is introduced as active charcoal filter which can have 90-99% of the iodine removal efficiency [2]. However, moisture and water droplets can reduce the filtering efficiency of the active charcoal filter. Therefore, the submerged scrubbing nozzle in a pool was suggested and tested as an alternative component about the active charcoal filter on CFVS.

The scrubbing nozzle was designed as a part of a development of Korean CFVS shown in Figure 1.1. The nozzle was tested in order to study the aerosol scrubbing performance previously. The results present that the scrubbing efficiency of the nozzle was increased with the increment of the throat velocity of the nozzle [3].

Iodine removal efficiency in non-submerged and submerged self-priming venture scrubber was evaluated by experimental study. It introduces iodine removal efficiency in terms of the scrubber type which was 85~99%. The effects of the inlet concentration, gas flow rate were studied [4].

Other recent study shows elemental iodine filtering efficiency using only a self-priming venture scrubber which was 41-66% [5]. These recent studies were performed under the condition using air as a main carrier gas.

Fig. 1.1. Schematic of scrubbing nozzle

In this study, the developed self-priming scrubbing nozzle was tested under the conditions based on the CFVS operational condition using elemental iodine. The scrubbing efficiency through the submerged nozzle located in the scrubbing liquid pool will be presented and analyzed in terms of test variables to affect the iodine scrubbing efficiency.

2. TEST LOOP

The elemental iodine test loop consists of three parts. One is to provide the thermal hydraulic conditions such as system pressure, temperature, composition of carrier gas and etc. The other is for generating elemental iodine and injecting the generated iodine into the test loop. Another is for sampling the generated elemental iodine from the test loop.

Figure 2.1 and figure 2.2 shows the schematic and overview of elemental iodine test loop respectively. The developed scrubbing nozzle is located at the main test section and it is submerged inside the scrubbing liquid with chemicals. The thermal-hydraulic conditions for the test cases have been achieved by a steam generator and an air compressor with control valves. The hydrogen ion concentration (pH) of the scrubbing liquid inside the main test section has been controlled by Sodium-Hydroxide (NaOH) and Sodium Thiosulfate ($Na_2S_2O_3$).

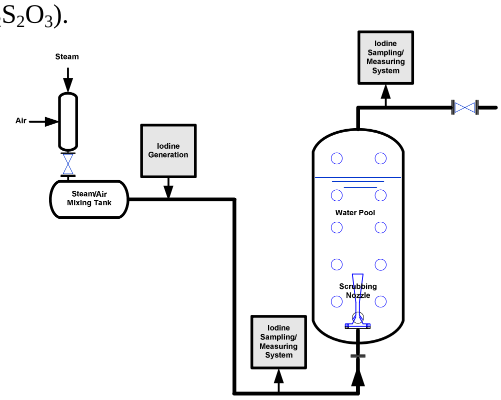

Fig. 2.1. Schematic of elemental iodine test loop

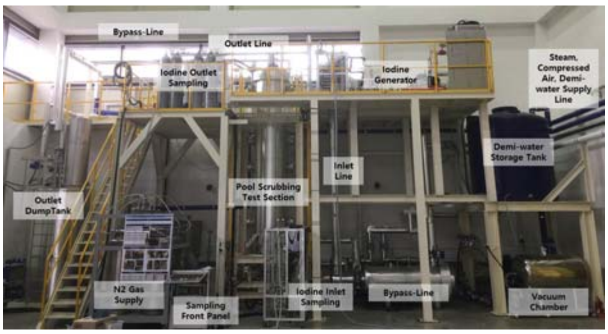

Fig. 2.2. Schematic of elemental iodine test loop

2.1 Elemental Iodine Generation System

Gaseous elemental iodine (I_2) has been used to control the elemental iodine concentration on the system carrier gas. The gaseous iodine has been generated by the sublimation process from a bead type of the iodine. The sublimation chamber has been heated and insulated by a heating jacket in order to control the amount of the generated elemental iodine. When gaseous iodine is generated, it has been mixed with pressurized argon gas(Ar) and injected into the elemental iodine test loop. All lines of the generating system were heated and the temperature of the fluid has been controlled in order to prevent the steam condensation in the main test loop.
Figure 2.3 shows the sublimation chamber of the elemental generation system.

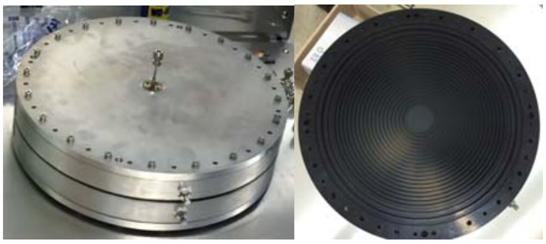

Fig. 2.3 Sublimation chamber

2.2 Elemental Iodine Sampling System

The sampled gaseous elemental iodine can be analyzed by ion-selective electrode (ISE) for on-line measurement and UV-Vis for off-line measurement. However, these cannot be used under the high pressure and temperature conditions. Therefore, when the sampling is performed, the pressure is dropped by a critical orifice and injected into the sampling liquid. All sampling lines until a critical orifice are heated for preventing steam condensation.

Figure 2.4 shows the schematic of the elemental iodine sampling column. The ISE electrode is located at one port of sampling column and the sampling liquid is cooled down by coolant at the surface of the column. The ISE was calibrated before starting the every test.

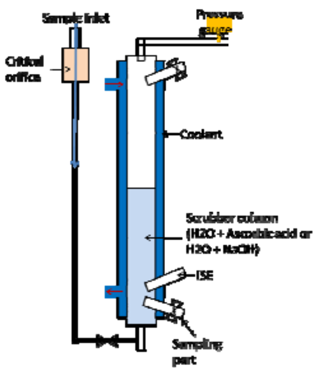

Fig. 2.4 Elemental iodine sampling column

The test conditions are decided by the combination of the test parameters and its range listed in Table 2.1.

Table 2.1 Test variables and range of elemental iodine

Variable	Range	Remark
Elemental Iodine Carrier gas	0%, 50%, 70%, 100%	Steam mass fraction
System Pressure	250, 400, 600kPa(g)	
Carrier Gas Flow Rate	151, 191, 203 m^3/h	Steam 100 wt%
System Temperature	Depend on System Pressure	Saturated steam temperatrue
Scrubbing Liquid Level	Min. and Max.	
Scrubbing Liquid hydrogen ion concentration(pH)	12, 10	Initial value of test cases

3. TEST RESULTS

Various tests have been performed to evaluate the scrubbing efficiency of the submerged nozzle with chemicals in the pool for the elemental iodine. The test parameters of the scrubbing efficiency can be carrier gas (steam, air and steam mixture), nozzle inlet pressure and temperature, hydrogen ion concentration (pH) and the water level of the scrubbing pool.

Reference conditions of the tests have been decided in order to compare the influence of the parameter. The reference conditions of the test cases are presented in Table 3.1.

Table 3.1 Reference conditions of test cases

Variable	Range	Remark
System Pressure	400 kPa(g)	
Scrubbing Liquid Level	Min.	
Scrubbing Liquid pH	12	Initial value of test cases
Duration	2 hr	

The reference tests have been conducted in terms of the carrier gas such as air, steam mixture (50 wt%), and steam. Figure 3.1 shows the scrubbing efficiency of the submerged nozzle in the pool against those steam mass fraction. The reference test case using air had the highest scrubbing efficiency and the lowest one was the steam mixture case in these tests. One of the reasons why the air case had the highest scrubbing efficiency among them is because the inlet iodine concentration was higher than the other reference cases. The steam case shown in figure 3.1 can be explained by the steam condensation effect in the pool and/or the effects from the droplets generated by non-condensable gas from the scrubbing nozzle.

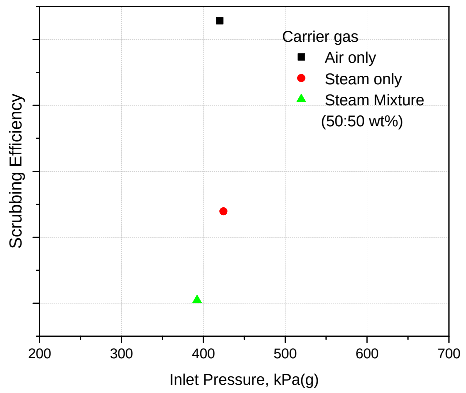

Fig. 3.1 Elemental scrubbing efficiency against the steam mass fraction of the reference cases(inlet pressure: 400kPa(g), pool water level : 0.7m from top of scrubbing nozzle, pH of the pool: 12)

In addition, figure 3.2 shows the results from the comparison between two different steam mass fraction cases. Filled triangle presents one of the reference cases and the empty triangle shows the scrubbing efficiency from the case using 80wt% mass fraction condition. This shows the same tendency with figure 3.1. The results show that when the steam mass fraction was increased, the scrubbing efficiency was also increased due to the steam condensation.

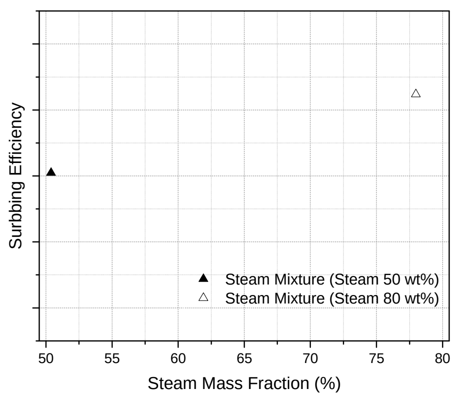

Fig. 3.2 Elemental iodine scrubbing efficiency against the steam mass fraction (inlet pressure: 400kPa(g), pool water level : 0.7m from top of scrubbing nozzle, pH of the pool: 12)

There are three different pressure conditions which have been performed in terms of the pressure at the inlet of the scrubbing nozzle and the results of these tests presented in figure 3.3. The tendency of the results presents when the pressure was increased, the efficiency was also increased. The reason why is because the nozzle was designed with the condition when the pressure is increased, the gas flow rate through the nozzle is also increased. This means that the scrubbing efficiency of the nozzle itself in the pool is increased when the pressure is increased. Therefore, the scrubbing efficiency had a similar performance with the aerosol cases studied previously.

Figure 3.4 shows the iodine scrubbing efficiency against the pool water level in terms of the carrier gas. The tendency of the efficiency was increased when the pool water level was increased. The reason why is because when the water level is increased, the residence time of the bubbles from the nozzle outlet to the surface of the water is increased.

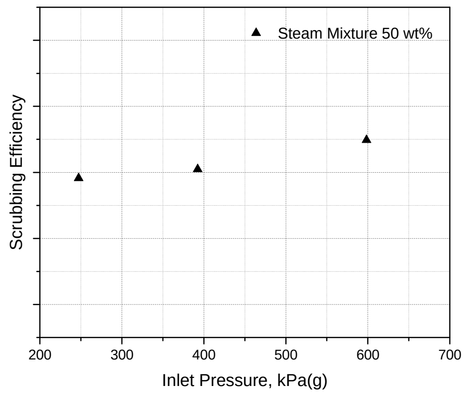

Fig. 3.3 Elemental iodine scrubbing efficiency against the inlet pressure (pool water level: 0.7m from top of scrubbing nozzle, pH of the pool: 12, steam mixture(50 wt%)

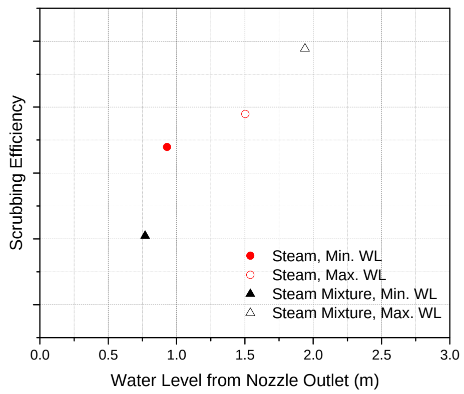

Fig. 3.4 Elemental iodine filtering efficiency against the pool water level (Inlet pressure: 400kPa(g), pH of the pool: 12, Mixture: steam 50 wt%)

Figure 3.5 presents the trend of hydrogen ion concentration (pH) from the initial to the end of the each test case. The filled and empty triangle represents the initial condition of the scrubbing liquid which is over pH 12 and around pH 10 with the mixture carrier gas respectively. Both tests have been performed under the conditions which are same as the reference test conditions except the condition of the initial pH in the pool during 2 hours. The trend of the hydrogen ion concentration (pH) is that when the pH in the pool is increased, the pH variation from the initial to the end of the tests is decreased.

Figure 3.6 shows the test results of the scrubbing efficiency in the pool against the initial pH in the pool of the reference case using steam mixture. These results are from the cases presented in figure 3.5. When the initial pH of the pool is increased such as over 12, the scrubbing efficiency of the submerged nozzle in the pool is increased.

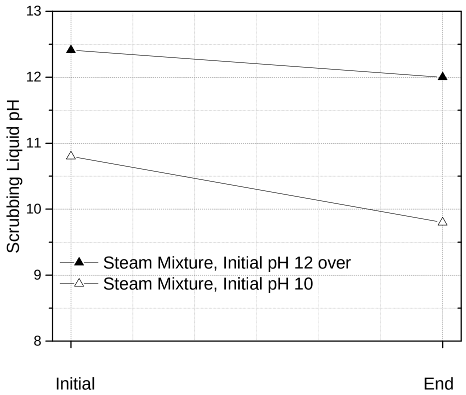

Fig. 3.5 Scrubbing liquid pH trend from initial to end of the test cases (Inlet pressure: 400kPa(g), pool water level: 0.7m from the top of the scrubbing nozzle Mixture: steam 50 wt%)

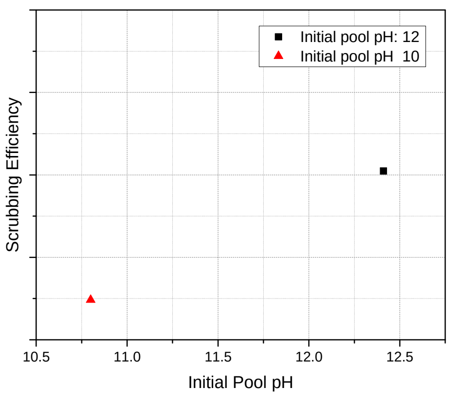

Fig. 3.6 Elemental iodine scrubbing efficiency against the initial pool pH (Inlet pressure: 400kPa(g), pool water level: 0.7m from the top of the scrubbing nozzle, Steam mass fraction 50 wt%)

4. CONCLUSION

The submerged scrubbing nozzle in the pool with chemicals used for the CFVS has been developed for scrubbing elemental iodine. Elemental iodine filtering efficiency of the nozzle with the scrubbing liquid has been measured and analyzed by the conducted several test cases. The major findings are follows:
(1) The scrubbing efficiency of the nozzle in the pool for elemental iodine (I_2) increases due to the steam condensation.
(2) The scrubbing efficiency of the nozzle in the pool for elemental iodine (I_2) decreases due to the generated droplets.
(3) The scrubbing efficiency of the nozzle in the pool for elemental iodine is increased when the inlet pressure of the nozzle is getting higher due to the increase of the flow rate through the nozzle.
(4) The scrubbing efficiency of the nozzle in the pool for elemental iodine increases when the water level is getting higher due to the increase of the residence time of the bubble from the nozzle.
(5) The scrubbing efficiency of the nozzle in the pool is increased when the initial pH of the pool is increased.

ACKNOWLEDGEMENT

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