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Experimental study on aerosol scrubbing efficiency of self-priming venturi scrubber submerged in water pool

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A B S T R A C T

Scrubber nozzles are key pieces of equipment used to remove aerosols in a wet-type filtered containment venting system (FCVS). This study deals with the aerosol scrubbing efficiency of a scrubber nozzle operating in self-priming mode. The scrubber nozzle that has been developed in this work consists of a reducer, a throat, a diffuser, a liquid suction slit, and an end cap with a rectangular section area. The aim of this study was to characterize scrubbing efficiency under various thermal hydraulic and aerosol conditions including nozzle inlet pressure (250–600 kPa(g)), nozzle inlet temperature (102–164 °C), nozzle inlet flow rate (air: 42–132 m^3/h, steam: 112–269 m^3/h), submergence from the nozzle exit (0.7–2.7 m), aerosol size (0.5, 0.7, 3 μm), nozzle inlet aerosol concentration (0.1–3 g/m^3), and steam mass fraction in the main carrier gas (0–1). Aerosol scrubbing efficiency was measured based on the inlet and outlet aerosol concentrations of the scrubbing vessel with isokinetic sampling systems including a glass microfiber filter. Experimental results show that the scrubbing efficiency increased with increasing aerosol size, steam mass fraction, nozzle submergence, and inlet aerosol concentration. We also showed that the scrubbing efficiency increased with an increase in inlet pressure at low scrubber nozzle submergence. However, at higher scrubber nozzle submergence, the nozzle inlet pressure did not significantly influence the scrubbing efficiency. The aerosol scrubbing efficiency with the developed self-priming scrubber nozzle submerged in the pool was over 97% for various thermal–hydraulic conditions. Thus, the experimental results can be used to design a wet scrubber system considering upstream conditions such as operation of the FCVS.

1. Introduction

The Fukushima Daiichi Nuclear Power Plant accident was primarily caused by the tsunami following the Tohoku earthquake on March 11, 2011. This event prompted the installation of mitigation systems to minimize radiation release to the environment and the development depressurization strategies. Filtered containment venting systems (FCVSs) have been developed to protect against containment failure and minimize the discharge of radioactive materials to the environment. The FCVSs currently in service around the world have various configurations and are generally classified as either wet-type or dry-type. In a wet-type system, a scrubber nozzle is the key element used to eliminate the particulate aerosol and gaseous species from the contaminated gas stream because water is an effective filtration media. Also, additional equipment such as a metal fiber filter can be installed to eliminate iodine species or fine aerosols. In a dry-type system, a deep bed filter (such as a metal fiber, ceramic, or a sand bed) is installed as the main retention stage (OECD/NEA, 2014).

During light water reactor (LWR) severe accidents, core degradation results in the release of both radioactive and non-radioactive aerosols. Aerosol particles, elemental iodine, and organic iodine are considered when performing source term evaluations for FCVSs.

In FCVS devices, the scrubber nozzle that delivers the contaminated gas steam through a water pool can be classified as an orifice, a sparger, a vent, or a Venturi nozzle. Among all of the different scrubber nozzles, the Venturi scrubber is one of the most efficient filtering devices to simultaneously remove particulate aerosols between 0.1 and 300 μm (Tri-mer Co., 2012) and gaseous species like SO_2, I_2, and CH_3I (Wei-yi et al., 2011) from the contaminated gas stream.

Lehner (1998) introduced two classifications of Venturi scrubbers to supply the scrubbing liquid: the forced feed method through pumps and the self-priming method based on the pressure difference between liquid hydrostatic pressure in the water pool and gas static pressure in the throat. The self-priming Venturi

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Nomenclature

C_{SiO_2}	SiO_2 concentration (g/m^3)
m_{SiO_2}	Sampled aerosol mass (g)
t	Sampling time (sec)
$\dot{V}_{air}$	Flow rate of air (m^3/s)
$m_{SiO_2,inlet}$	Inlet sampled aerosol mass (g)
$m_{SiO_2,outlet}$	Outlet sampled aerosol mass (g)
t_{inlet}	Inlet sampling time (sec)
t_{outlet}	Outlet sampling time (sec)
$\dot{V}_{air,inlet}$	Inlet flow rate of air (m^3/s)
$\dot{V}_{air,outlet}$	Outlet flow rate of air (m^3/s)
m_{cw}	Mass of condensed steam (g)
ρ_{steam}	Density of steam at sampling system conditions (g/m^3)
$\dot{V}_{steam,inlet}$	Inlet flow rate of steam (m^3/s)
$\dot{V}_{steam,outlet}$	Outlet flow rate of steam (m^3/s)
$\dot{V}_{total}$	Flow rate of air and steam mixture (m^3/s)
η	Aerosol scrubbing efficiency in the water pool (%)
DF	Decontamination factor [−]
$\Delta\dot{V}_{total,inlet}$	Flow rate of air and steam mixture at inlet (m^3/s)
$\Delta\dot{V}_{total,inlet}$	Flow rate of air and steam mixture at outlet (m^3/s)
ΔC_{SiO_2}	Uncertainty of SiO_2 concentration (g/m^3)
Δm_{SiO_2}	Uncertainty in sampled aerosol mass (g)
Δt	Uncertainty in sampling time (sec)
$\Delta\dot{V}_{air}$	Uncertainty in flow rate of air (m^3/s)
$\Delta\dot{V}_{steam}$	Uncertainty in flow rate of steam (m^3/s)
Δm_{cw}	Uncertainty in mass of condensed steam (g)
$\Delta\eta$	Uncertainty in aerosol scrubbing efficiency in the water pool (%)
ΔDF	Uncertainty in decontamination factor [−]

scrubber is simpler, can be operated at high-temperature, is easy to install, can remove a mixture of gas and solid or liquid particles (Economopoulou and Harrison, 2007), and requires no power for operation. Therefore, it can be applied in FCVSs as the filtration component.

As shown in Fig. 1, the principal mechanism to remove aerosol particles in the self-priming scrubber nozzle is based on inertial impaction. These aerosols continue their flow path and collide with the atomized liquid droplet in the nozzle throat. The particulate aerosol no longer follows the free stream gas and is finally captured in the liquid droplet. The liquid does not directly form droplets at the entrance of the throat, but takes a film-like shape. The injected water is initially in the form of a liquid jet and is scattered by the shear stress of the gas. Droplets are formed at the end of the throat due to the surface tension of the liquid.

The present research involves an experimental study of scrubbing efficiency of particulate aerosols in a self-priming scrubber nozzle submerged in a water pool. The self-priming scrubber nozzle used in this study employs a Venturi-based mechanism and consists of a reducer, throat, diffuser, liquid suction slit, and end

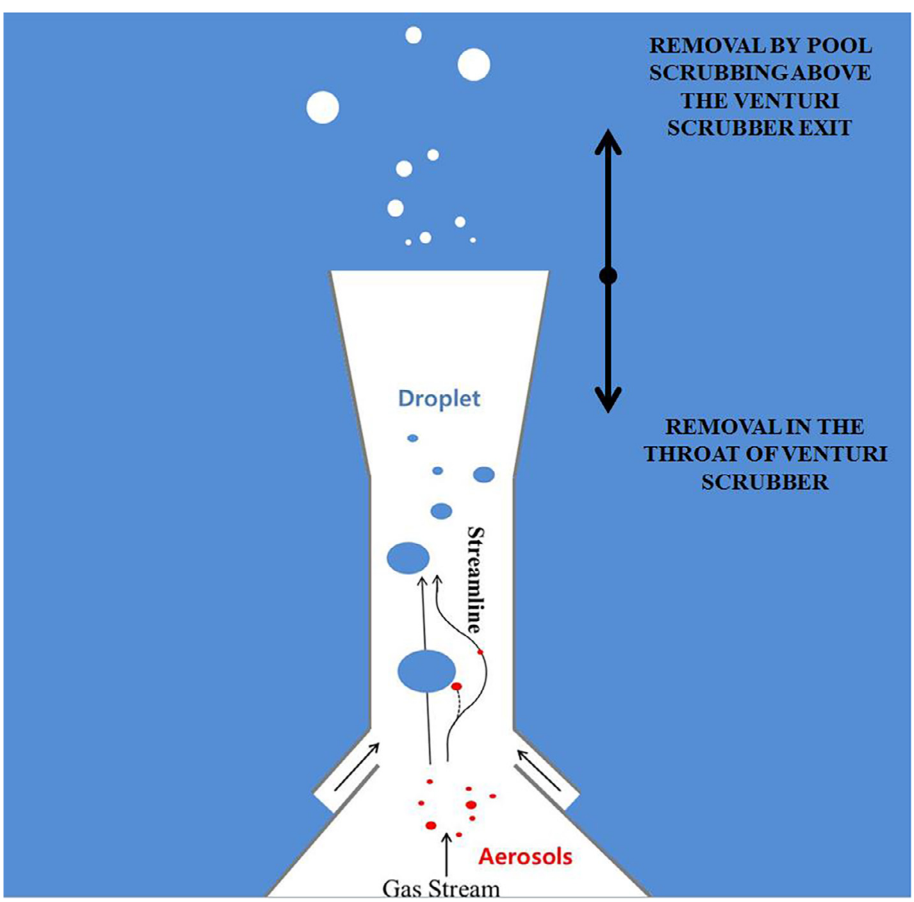

Fig. 1. Major removal mechanism of aerosols in a Venturi scrubber.