Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

Centrifugal Filtration System for Severe Accident Source Term Treatment

Shuchang Liu[a], Man Sung Yim[a]
[a]*Department of Nuclear & Quantum Engineering, KAIST*
[*]*Corresponding author: msyim@kaist.ac.kr*

1. Introduction

Reactor containment may lose its structural integrity due to over-pressurization during a severe accident [1]. This can lead to uncontrolled radioactive releases to the environment. For preventing the dispersion of these uncontrolled radioactive releases to the environment, several ways to capture or mitigate these radioactive source term releases are under investigation at KAIST. Such technologies are based on concepts like a vortex-like air curtain, a chemical spray, and a suction arm. Treatment of the radioactive material captured by these systems would be required, before releasing to environment.

For current filtration systems in the nuclear industry, IAEA lists sand, multi-venturi scrubber, high efficiency particulate arresting (HEPA), charcoal and combinations of the above in NS-G-1-10, 4.143 [2]. For example, AREVA has used multi-venturi scrubbers for a wet style FCVS [3] and Worley Parsons has developed a dry filtered venting solution using HEPA filters [4].

However, centrifuges are one of the traditional separators, which was not included in the aforementioned list. Considering the flexibility and high efficiency, a centrifuge combined with a multi modular absorbent filtration system is being proposed in this paper.

For absorbents, AREVA uses thiosulfate in the solution and metal fiber in the FCVS. Canada's Emergency Filtered Air Discharge Systems (EFADS) uses a combination of HEPA and charcoal for filtration. Finland uses High Speed Sliding Pressure Venturi (HSSPV) type FCVS which consists of a wet scrubber (filled with water containing sodium hydroxide and sodium thiosulfate), combined with a droplet separator and stainless steel fiber filter [5].

The objective of this paper is to present the conceptual design of a filtration system that can be used to process airborne severe accident source term.

2. Conceptual design

In this section, functional requirements, working principal, and equipment components are described.

2.1 Conceptual Model

The proposed concept is an extension of the idea of a cyclonic separator to be used as a filtration system for removing captured radioactive substances. Cyclonic separators are used in many industrial applications, including the oil refining, dust removal, and vacuum cleaners. The cyclonic separators work on centrifugal and gravitational forces, which cause separation of particles and fluids.

Fig. 1 shows a conceptual design of this system. The direction of the arrows shows the flow direction. The collected radioactive material enters the centrifugal separator from the inlet. The centrifugal separator rotates and directs lighter radionuclides (mainly gases) to the upper compartment, and the heavier radionuclides (mainly liquid and aerosol particulates) to the bottom compartment.

The upper compartment is loaded with granular active carbon (GAC) to filter gaseous radionuclides. The air will be discharged to the environment after passing through active carbon filter. The lower compartment is loaded with NaOH and $Na_2S_2O_3$ solution to absorb the liquid and aerosol particulates. Each compartment may consist of multiple stages to remove radionuclides effectively.

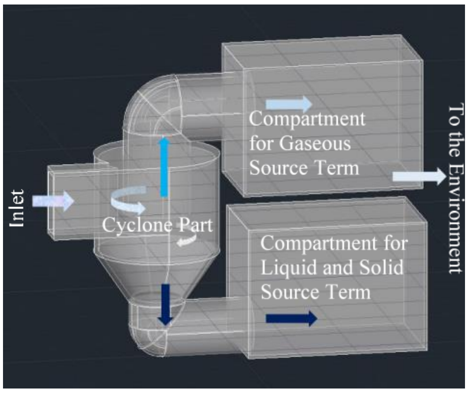

Fig. 1. Conceptual design and work flow of proposed centrifugal filtration system for source term treatment.

2.1 Functional Requirements

The filtration system should ensure that processed radioactive substances, are either sufficiently cleaned to allow direct release back to the environment, or the resulting waste is collectable for further treatment prior to release or disposal. The main objective is to minimize radiological threat of a severe accident to the environment by processing the collected radionuclides.

NUREG 1465 identifies Noble Gases, Iodine, Cesium and Tellurium as top four radionuclides released after 10 hours of a severe accident at light water reactors (LWRs) [6]. After the Fukushima Daiichi Accident, the amount of radioactivity released to the environment was estimated by the Nuclear Industry Safety Agency (NISA) using I-131 and Cs-137 traces [7].

Currently some NPPs have a Filtered Containment Venting System (FCVS) to avoid the over-pressurization of the containment building. The filtration function of the FCVS can form the basis for the function requirements of the proposed filtration system after the collection of radioactive releases. Therefore, in this research, the design specification of FCVS were used to define the design basis for a portion of the filtration system.

Besides the FCVS's ability to filter aerosols, specific attention is being given to its ability to remove organic iodides and iodine-oxide particles as they may contribute significantly to the source term from severe accidents, and are identified as important in NUREG 1465. A significant fraction of the radioactive releases are noble gases. However, no reliable technology exists for efficient retention of these species. Furthermore, the benefits of reducing their quantity to the environment has to be balanced with the drawbacks that could result from radioactivity accumulation in a system designed for their retention.

From this point on, radioactive source term will be limited to the aerosol and iodine.

To measure the efficiency of the filtration, the decontamination factor (DF) is usually used, as the ratio of the initial amount of a nuclide in a stream (specified in terms of concentration or activity of radioactive materials) to the final amount of that nuclide in a stream following treatment by a given process [8], where

$$\mathrm{DF} = \frac{\text{Initial amount}}{\text{Final amount}} \qquad (1)$$

And

$$\text{Efficiency} = \left(1-\frac{1}{\mathrm{DF}}\right)\times 100\% \qquad (2)$$

Different countries use different DF requirements for FCVS to measure its filtration efficiency. Table 1 shows the DF requirements in different countries. Table 2 below shows the leading FCVS vendors' filter design parameters.

Table 1: Different countries DF requirements [5] [9]

Country	Aerosol	Molecular iodine
France	>10	>10
Germany	>1000	>10
Finland	>100	Not required
Sweden	>100	>500
Switzerland	>1000	>100
Netherland	>1000	>10
Slovenia	>1000	>100
Belgium	>1000	>100

With respect to the filter performance, more than 99.9% (DF>1,000) retention for aerosols and 99% (DF>100) for molecular iodine was considered sufficient when the first FCVS were implemented in the 1980s and 90s (such DF values were set as target values by some regulators). [5] Based on the statement as well as the data in Table 1, the most frequently identified DF was chosen. For Iodine, a DF of 100 was selected, while for aerosols a DF of 1000 was selected.

Table 2: Filter designs summary by different vendors [1]

	Aerosols	Elemental Iodine	Organic Iodine
AREVA High speed sliding pressure venting	>10,000	>500 >1000	>50
Westinghouse Filtra-Multi-Venturi-Scrubber	>1000	>10,000	>5
IMI Filtered Containment Venting System	>10,000	>1000	>1000
EdF Sand-bed Filters	>1000	>10	N.D.
Westinghouse Dry Filtration System	>10,000	<1000	>40
Worley Parsons Dry Filtration System	>20,000	>>2000	>2000

2.3 Components and Dimensions

To clarify the flexibility of this system, it should be noted that the centrifuge can be either permanently installed or be a "mobile asset". For example, the centrifuge filtration system can be installed in a truck that can easily enter the site during a severe accident situation. The Korean Gijiang-gun Fire Station currently owns and operates a Rosenbauer Panther 8x8 truck which is equipped with a spray arm. This truck is under consideration for demonstrating potential mobility of the proposed centrifuge filtration system. Table 3 shows the parameters of the truck as the design (size) constraints of the proposed filtration system. Table 4 shows the dimension of the designed filtration system.

Table 3: Parameters of the truck [10]

Dimensions	Length 13,289mm / Width 3,028mm / Height 4,031mm
Total Weight	50,885 kg
Passengers	2
Engine Horsepower	1,400HP →(Volvo 700HP x 2) EURO-5
Maximum Speed	122km/h / (0 ˜ 80km/h within 24 seconds)

Table 4: Proposed physical design limits of the portable centrifuge system

Total Height	4000mm
Inlet Dimensions	Length 2500 mm / Width 600mm / Height 1500mm
Upper Outlet Radius	750mm
Outlet Radius	750mm
Body Radius	1500mm

3. Summary

Most if not all of the requirements of the scenario for applying this technology near the containment of an NPP site and the environmental constraints were analyzed for use in the design of the centrifuge filtration system. This article proposes a combination of centrifuge separation/filtration with an absorbent module for the preliminary conceptual design. Next, simulation and validation will be conducted to refine the design and assess its performance.

REFERENCES

[1] A. Wolski, E. Lukanov, V. Papazov, A. Wirries, Design and operation of European Containment Filtered Venting Systems, International Society for Nuclear Air Treatment Technologies, Jun. 22-24, 2014, St. Louis, MO.
[2] J. Hammer, A. Ritter, Filtered Containment Venting System at Swiss NPPs and KKL in particular, Swiss Federal Nuclear Safety Inspectorate ENSI, Jan. 15, 2014, Ft. Lauderdale.
[3] Filtered Containment Venting Systems, Areva, Presentation to US Nuclear Regulatory Commission (NRC), Jul. 12, 2012.
[4] P. Bakardzhiev, E. Ivanov, A. Wolski PhD, D. Markov PhD, G. Pichurov PhD, E. Lukanov, CFD Thermal Analysis of Aerosol Filters Used in Severe Accident Containment Venting Systems, Sep. 2015, BgNS, Sozopol.
[5] OECD/NEA/CSNI Status Report on Filtered Containment Venting, Nuclear Energy Agency Committee on The Safety of Nuclear Installations, Jul.2nd, 2014.
[6] NUREG-1465, Accident Source Terms for Light-Water Nuclear Power Plant, final report, Feb. 1995.
[7] M. Baba, Fukushima Accident: What happened? Radiation Measurements, Vol. 55, pp.17-21, 2013.
[8] NUREG-0017, Rev. 1, T. Chandrasekaran, J. Y. Lee, C. A. Willis, Calculation of Release of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized Water Reactors, Apr. 1985.
[9] C. Hillrichs, D. Vignon, P. Felten, Review of European Filtered Containment Venting System.
[10] http://www.rosenbauer.com