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Evaluating of Radioactive Gaseous Iodine Filtering System using Bismuth-embedded SBA-15 Mesoporous Silica for Containment Bypass Accidents

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1. Introduction

After the Fukushima nuclear accident, countries using nuclear power have reviewed the safety system of their operating nuclear power plants. This has been done since nuclear power provides baseline power to the grid with the benefit of not contributing to greenhouse gas problems. The predominant regulatory focus is to maintain current nuclear generation and strengthen plant safety systems. Therefore, technologies have been developed and installed to prevent Fukushima type accident/damage to containment buildings. For example, to prevent a serious accident a Containment Filtered Venting System (CFVS) will filter contaminated gases prior to their releases to the outside. This prevents over pressurization of the containment vessel, thereby preventing an explosion.

The main leakage pathways for the release radioactive material from a nuclear reactor is as follows: 1) Leakage of the containment buildings 2) Steam generator tube rupture (SGTR) 3) Interface system loss of coolant accident (ISLOCA), etc. However, a CFVS in the containment building will not be able to perform if the leak occurs from an SGTR or an ISLOCA. For example, when an SGTR occurs, the steam is first sent to the compressor via the steam bypass valve. Should the steam bypass valve fail, as the pressure builds the main steam safety valve (MSSV) is triggered which sends the gaseous materials to the atmosphere, prevent a pressure buildup and explosion. These accidents occur at a very low frequency, but they are potentially dangerous to the public, as radioactive materials are released to the outside, and in some instances contaminating a very large area.

To reduce this risk, previous research [1, 2] suggested a methodology to capture and treat radioactive materials using a radioactive material abatement system. A portable suction and filter system was proposed, which was designed to ensure releases into the air met current criteria. From the radioactive materials to be removed, this paper focuses on the capture of I-129, which has a very long half-life of 1.57×10^7 years and requires strict management due to its high mobility in groundwater [3].

Currently, silver ion-exchanged zeolite (AgX or AgZ) is widely used in CFVS and other filters. Due to the high price and toxicity of silver, silver-based adsorbents cannot be the ultimate answer for gaseous release systems that capture iodine.

Yang et al. have modified the surface of Santa Barbara Amorphous type material (SBA-15) with the thiol group so that the bismuth can stick to the surface of Mesoporous silica, SBA-15 [1,4]. Their research suggests the material can efficiently adsorb radioactive iodine and improve its storage over existing materials.

In this paper, we will use Bi-SBA-15 material for the removal and treatment of gaseous iodine. In addition, future research will develop radioactive iodine reduction techniques by designing experiments to confirm the feasibility of using this material as a filter.

2. Background knowledge and experiment preparation

2.1 Bismuth embedded SBA-15

Yang et al. developed Bismuth-embedded SBA-15 mesoporous silica for the efficient adsorption of radioactive iodine. A significant benefit of SBA-15 is its high hydrothermal stability due to its relatively large pore wall as well as its large mesoporous size [1].

During the synthesis process, the following steps occur: 1) Bismuth forms a Bi-S bond that adsorbs on to the surface of SBA-15 and 2) Next a heat treatment is applied, which converts the material into a Bi2S3 form, to make Bismuth-embedded SBA-15.

Experiments were carried out using this material, and the amount of iodine adsorbed on Bismuth-embedded SBA-15 was measured. For comparison, AgX was also tested under the same conditions. The adsorption amount was about 1.7 times higher than AgX, which was 540 mg-I / g-sorbent [1].

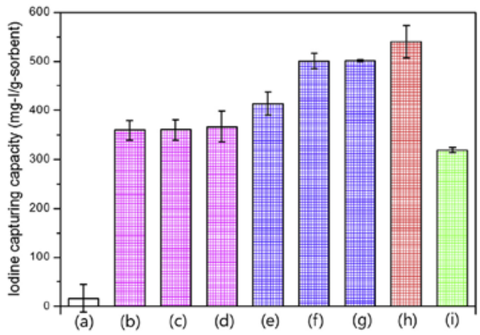

Fig. 1. Iodine capturing capacities in static air for (a) SBA-15, (b) Bi-SBA-15-SH1, (c) Bi-SBA-15-SH2, (d) Bi-SBA-15-SH3, (e) Bir-SBA-15-SH1, (f) Bir-SBA-15-SH2, (g) Bir-SBA-15-SH3, (h) Bir-SBA-15-SH2A, and (i) AgX (tested at 150 °C)[1].

2.2 Radioactive material suction and filtering system

If a radioactive material is leaked due to a major accident, it is necessary to capture it, to prevent its spread, and to have a visible system that the public can understand.

Previous research [5] has suggested and studied systems for reducing the leakage of radioactive materials from containment buildings. This research investigated ways to prevent the spread of radioactivity by capturing radioactive materials. The system mainly consists of a suction part, a filter and a treatment system.

This study has prioritized the elements of a containment accident. As such, it was determined that the location of the main safety valve, in the auxiliary building, is where a leak may occur, and should be analyzed first. Based on leakage data in the literature, the physical factors that the suction apparatus would be exposed will be investigated. The released radioactive materials entering the suction part are firstly filtered through a cyclone separator. Then, the radioactive materials are physically and chemically filtered through a HEPA filter and gaseous iodine filter which is made with Bismuth-embedded SBA-15.

2.3 Conceptual design of filter using Bismuth embedded SBA-15

The filter for gaseous iodine adsorption can be divided into specific designs based on the capture capacity; 1) The filter chamber/cylinder filled with Bismuth embedded SBA-15 and 2) The thick disk or plate type with a honeycombed grid (Fig. 2). Both methods are basically aimed at increasing the surface area where the iodine can be adsorbed.

The degree of pressure drop is quite different between the two filter types. In general the greater the degree of filtration, the greater the pressure drop and the decrease in air speed. Therefore, it is necessary to set the filter system parameters based on the gas release conditions and the design of the suction apparatus.

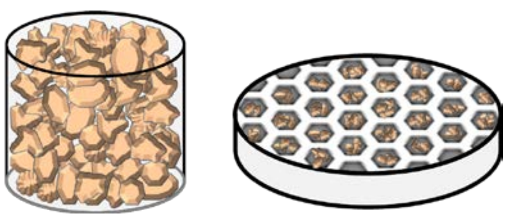

Fig. 2. Conceptual design of Bi-SBA-15 filter
(Cylindrical shape and disk shape)

2.4 Experiment setup for filter verification

In previous studies, adsorption efficiency of Bismuth embedded SBA-15 was compared with AgX in a specific temperature and static condition. However, the actual adsorption situation is not static but a flow. In order to confirm its feasibility as a filter, it is necessary to analyze the filter's performance in a non-static condition. This includes changes in temperature and pressure difference. A schematic diagram of the experimental apparatus for verifying the Bismuth embedded SBA-15 filter is shown in Fig. 3.

In the current experiment setup, the gas passes through the filter once, but individual elements or the combined structure can be changed to improve its overall efficiency. Since it is necessary to adjust the temperature and flow rate of the iodine gas for the experimental conditions, a heater and temperature controller will be used and the pressure will be regulated using the pump after the filter. Before and after the filter, both a pressure and flow gauge will be installed to confirm the fluid condition. Using the filter's change in mass, after the experiment, it is possible to measure the adsorption capacity of the filter as the concentration, temperature, and pressure change. These results will confirm the effectiveness of the filter under test conditions.

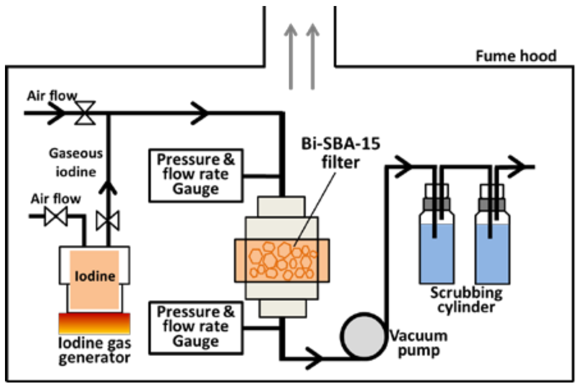

Fig. 3. Experiment setup to capture gaseous iodine

3. Conclusion

This study is the beginning of a system to prevent leakage of radioactive material when containment bypass accident occurs. This paper suggests a filter system for iodine adsorption and an experiment setup for verifying the effectiveness of using Bi-SBA-15 filter in various conditions. If the iodine adsorption performance is predicted to be good, the proposed filtering system can contribute to mitigate the effects of environmental radiation

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