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Filtration Characteristics of Long-Term Operation in Vitrification Pilot Facility

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Abstract

One of the most promising technologies for the treatment of low- and intermediate-level radioactive wastes (LILWs) is vitrification technology. Korea Hydro & Nuclear Power. Co. Ltd. (KHNP) has launched the vitrification pilot facility with high temperature filter (HTF) system, which is one of air pollution control technologies with high collection efficiency for particulate matters and no need to cool off-gases below 200℃ before treatment of off-gas. Ion exchange resins(IERs) and dry active wastes(DAWs) are vitrified in cold crucible melter and off-gas is generated during this vitrification process. Particulate matters(PMs) in off-gas were cleaned at first while passing by HTF system. Operation parameters for HTF system was derived from previous mid-term operation of vitrification and a long-term operation was performed in order to evaluate and adjust them. As a results, pressure drop was maintained stably in the range of 50 ± 10 mmAq during the long-term operation and temperature increased with time of operation and was stabilized eventually. PMs collection efficiency by HTF system increased than that of the mid-term operation. Hence, HTF system was operated stably in the long-term operation and its performance was good. The results of the operation will be used as basic data for the design of a future commercial vitrification facility for nuclear power plant.

1. Introduction

Nuclear power plants in Korea produce more than a quarter of the country's electricity and low- and intermediate-level radioactive wastes are generated as wastes. Vitrification technology, which attains remarkable volume reduction and stabilization of treated waste, has been developed for several years in KHNP. Nuclear Environmental Technology Institute (NETEC) of KHNP has constructed a pilot-scale vitirfication plant to demonstrate the feasibility of commercializing this technology. Fig. 1 shows the schematic diagram of the vitrification pilot plant of KNHP-NETEC.

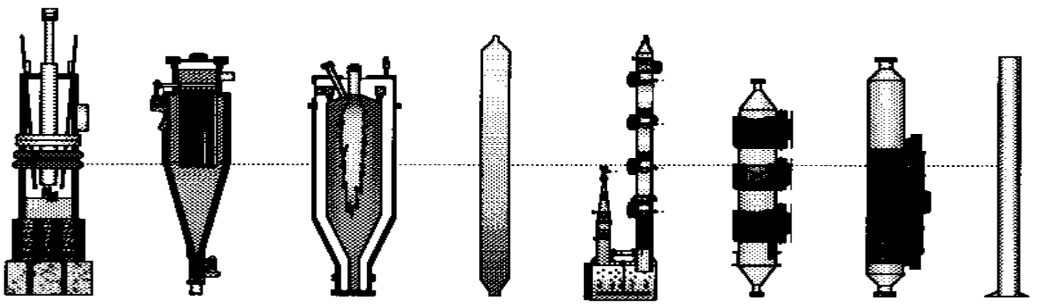
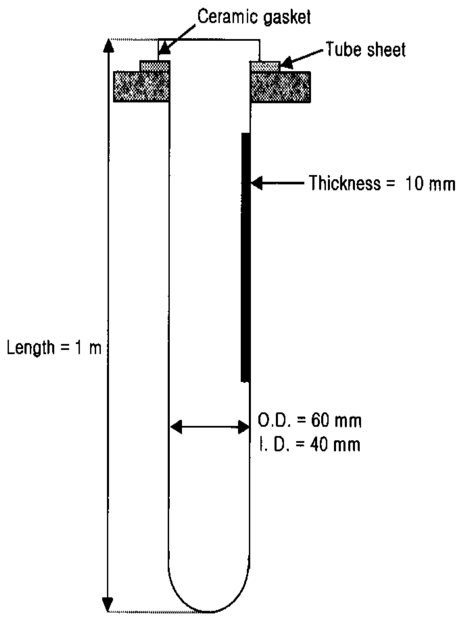


Fig. 1. Schematic Diagram of the Vitrification Pilot facility of KHNP-NETEC.

Major advantage of the vitrification process is that wastes can be introduced directly into the cold crucible melter (CCM) without pre-treatment such as pyrolysis or calcination. The glass products after vitrification have no harmful effect against the environment. During vitrifying the wastes, like conventional incineration, hazardous air pollutants, radioisotopes and particulate matters are to be generated. An off-gas treatment system is installed to remove pollutants such as unburned carbons (CO, HC), acid gases(HCl, SO_2), nitrogen oxides(NOx) and particulate matters and to satisfy Korea emission regulation of environment (SO_2 300 ppm, NO_2 200 ppm, CO 600 ppm, HCl 50 ppm, particulate matters 100 mg/Nm^3). For the removal of radioactive gaseous waste and particulate matters, ceramic candle filters with high collection efficiency and high durability against hot or acidic gases were installed in the off-gas treatment system.[(1)] The purpose of this paper is to apply operation parameters of HTF system derived from the results of a mid-term vitrification operation to a long-term operation and to evaluate those.

1.1. HTF system

A ceramic candle filter is a kind of rigid bag filter with high efficiency of the particulate matters collection and also long lifetime in condition of high temperature and corrosive gas comparing to other filters. Ceramic materials can resist against high temperature of 900℃ and have no distortion when cleaned by pulsed jet of compressed air. The installed ceramic candle filters have the resistance against hot gases with high concentration of particulate matters and much moisture and have 99.9 % of cleaning efficiency for 1 ㎛ of particles. The filter elements also have 86 % of porosity and 0.4 g/cm^3 of density and its lifetime is longer than any other filters. In general, it has a wide application of facilities emitting high temperature off-gases like as incinerators, coal boilers, melting or pigment processes, processes of glass formulation, metal fume processes and electric power plants. A ceramic candle filter is composed of 44 % of Al_2O_3, 50 % of SiO_2 and 6 % of organic binder and sintered, so it can be self-sustained without the support of bag case.



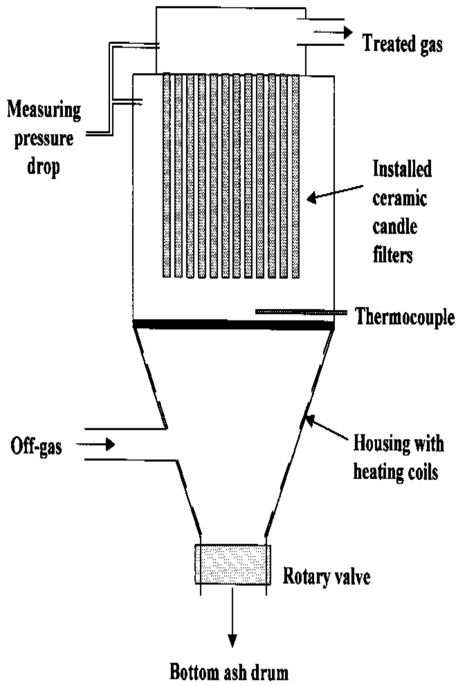


Fig. 2. Schematic Diagram of a Ceramic Candle Filter installed in HTF System.

Fig. 3. Schematic Diagram of HTF System in the Vitrification Pilot Facility

Fig. 2 is the configuration of filter element with 1 m of length, 60 mm outside diameter and 10 mm wall thickness and shows the sealing mechanism between the filter element and the tube sheet. Each filter element has 0.19 m^2 of effective filtration area and can treat 20.5 Am^3/hr of off-gas as its maximum. Filter elements are fixed in the tube sheet through adequate holes and arranged vertically in the filter housing. As in Fig. 3, ceramic candle filters are installed inside HTF system. The HTF system consists of filter housing, pulse-jet cleaning system, hopper, and tube sheet arrangement as shown in Fig. 3. Pulse-jet cleaning system is a device to remove particulate matters on the surface of filter with periodical pulsed jet of compressed air. Particulate matters removed from candle filters are through the hopper inside HTF system and piles up on the bottom ash drum. The bottom ash drum is isolated from HTF system by the rotary valve. The housing of HTF system is electrically heated to about 150 to 200 ℃ to prevent the degradation of filter material and the dust coagulation from the moisture condensation. The cleaning mode of HTF system is changeable depending on the off-gas properties such as flow rate, temperature and concentration of particulate matters, etc.

2. Operation

In general, LILWs generated from nuclear power plants are categorized as DAWs, spent organic IERs, spent filter and borate concentrate. The wastes were simulated with ion exchange resins and dry active wastes for the long-term operation of vitrification. Dry active wastes are combustible and generally composed of protective clothes, shoes cover, vinyl sheet, gloves and papers, etc. Organic ion exchange resins are widely employed in nuclear power plants for liquid waste treatment.[(2)]

2.1. Parameters

The mid-term operation of about 50 hours was conducted in four stages according to changes of operation parameters in order to derive operation parameters of HTF system for the long-term operation. The simulated waste was fed into CCM at the rate of 12 kg/hr. The mixing ratio of simulated waste, ion exchange resin : dry active waste was 1 : 2. During the operation, important off-gas parameters such as flow rate, temperature and pressure drop, etc were measured continuously every stages by on-line.[(3)] Fig. 4 shows the temperature inside HTF system and pressure drop measured during the mid-term operation. At the stage 1, cleaning pressure, cleaning frequency and pulse-jet duration time of HTF system were 2 bar, 2 min and 0.25 sec, respectively. Pressure drop was maintained stably in the range of 70 ± 10 mmAq. At the stage 2, cleaning frequency was changed to 6 min. and then pressure drop steeply increased to 100 mmAq. In accordance with the reduced cleaning frequency from 6 min. to 3 min at the stage 3, pressure drop decreased to 70 mmAq and then increased steeply with time again. At the last stage, the decrease of pressure drop resulted in 4 bar of cleaning pressure. Pressure drop was 30 ± 10 mmAq. Temperature of housing was fixed to 200 ℃ for preventing the degradation of filter material and the particle coagulation from the moisture condensation.

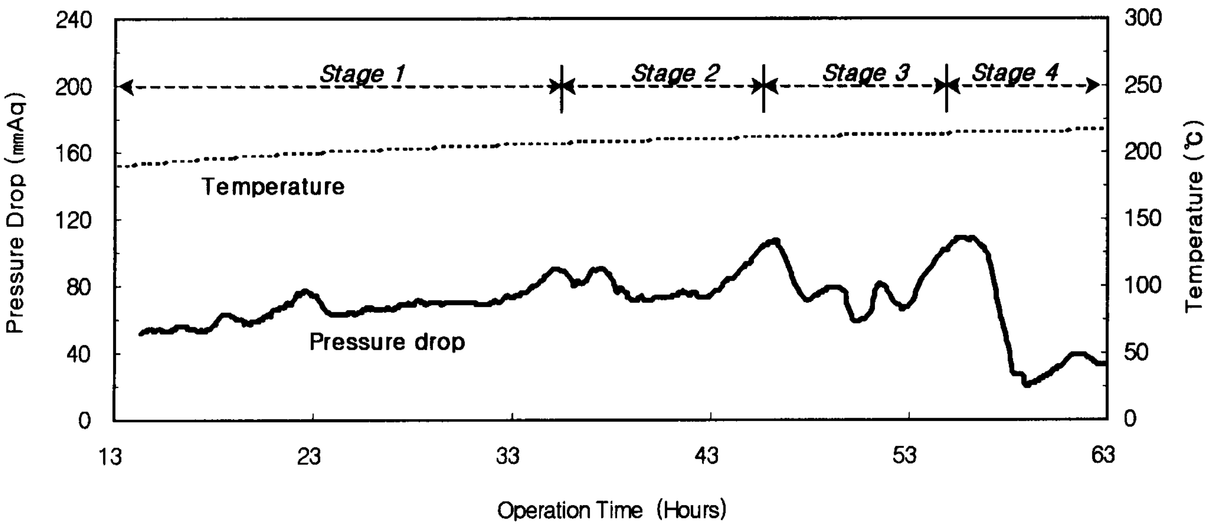


Fig. 4. Temperature and Pressure Drop during the Mid-Term Operation.

Temperature inside HTF system is shown in Fig. 4. The gentle increase of temperature was the result of increased waste feeding and flow rate of off-gas. From the results of the mid-term operation, the optimum operation parameters of HTF system were derived as follows: 4 bar of cleaning pressure, 3 min of cleaning frequency and 0.25 sec of pulse-jet duration time. The increase of operation time, variation of waste feeding and flow rate of off-gas were considered. Table 1 shows operation parameters applied to HTF system for the mid-term and the long-term operation.

Table 1. Operation Parameters of HTF System for the Mid-Term and the Long-Term Operation

Parameters / Operation	Number of filters installed	Temperature	Pulse-jet duration time	Cleaning Frequency	Cleaning pressure
Mid-term operation	32	200℃	0.25 sec	3 min.	2 ~ 4 bar
Long-term operation	32	200℃	0.25 sec	3 min.	4 bar

Total filtration area of HTF system was 6.08 m^2 and expected face velocity for the design was calculated as 0.3 m/min. The face velocity is relatively low value in comparison with 0.7 to 1.2 m/min of face velocity for conventional municipal waste incinerators and 1.8 to 2.4 m/min for oxygen furnaces. Generally, low value of face velocity for a design is often used when the particle size distribution includes a significant fraction of sub-micrometer particulate matters or when the dust loading is higher than before.

2.2. Long-Term Operation

The long-term operation of about 120 hours was conducted totally. With the exception of heating and cooling of CCM, the pure feeding and combustion of the operation was performed only for about 94 hours. Installed filter elements were ceramic candle filters and were already used for 115 hrs before the long-term operation. Most of parameters were similar to that of the mid-term operation. The cleaning operation of HTF system was simultaneous with waste feeding and was conducted continuously. During the operation, the operation parameters such as cleaning pressure and cleaning frequency, etc were not changed.

2.3. Analysis Method

To evaluate the stability of the long-term operation, we measured several parameters such as pressure drop, temperature, flow rate and concentration of particulate matters in the off-gas. All the measured data were recorded on data acquisition system and indicated on the real-time indicator.(4) Pitot tube inside housing measured pressure drop of HTF system. A thermocouple and a flow meter measured temperature and flow rate, respectively and recorded continuously. To analyze collection efficiency of particulate matters, isokinetic sampling was conducted at the inlet and the outlet of HTF system. The Korean Standard Sampling and Analysis Methods was applied for the sampling.(3) The sampling of particulate matters was replicated two times during operation. Collection efficiencies for particulate matters were calculated from data of isokinetic sampling. Collection efficiency by filtration is given the following expression.[5]

$$\text{Collection Efficiency} = \frac{(C_{in} - C_{out})}{C_{in}} \times 100\ \%$$

Where C_{in} = Concentration of particulate matters in off-gas before filtration (g/Nm^3)

C_{out} = Concentration of particulate matters in off-gas after filtration (g/Nm^3)

3. Results

Operation parameters were measured, and through the analysis of the operation parameters acquired during the long-term operation, we get a few important results. The results are shown as follows:

3.1. Pressure drop & Temperature

Fig. 5 shows pressure drop variation inside HTF system during the long-term operation. The pressure drop was maintained in the range of 50 ± 10 mmAq as in Fig. 5 and no steep increase or decrease was occurred. Under the influence of the residue layer of dust, pressure drop increased gently but was stabilized. The result showed a similar tendency toward pressure drop curve of the mid-term operation.[6] The results of temperature measurement are shown in Fig. 6. In the long-term operation, temperature of off-gas through HTF system was similar in shape to the results of the mid-term operation and was showed as a stable curve in the range of 200 to 300 ℃. Temperature increased with time of operation and was stabilized eventually. Apparently, no physical damage was observed and there was no consideration of thermal cracking for ceramic candle filters.[7]

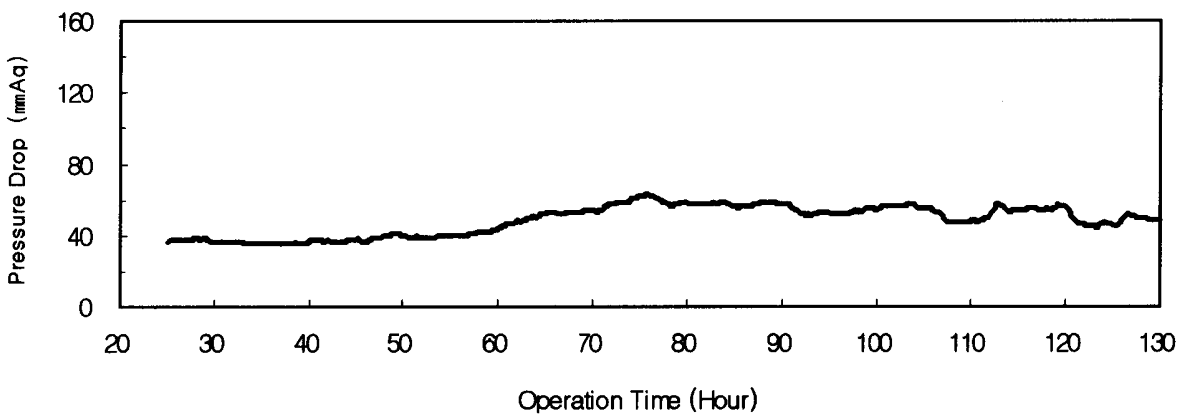


Fig. 5. Pressure Drop Variation of HTF System during the Long-Term Operation.

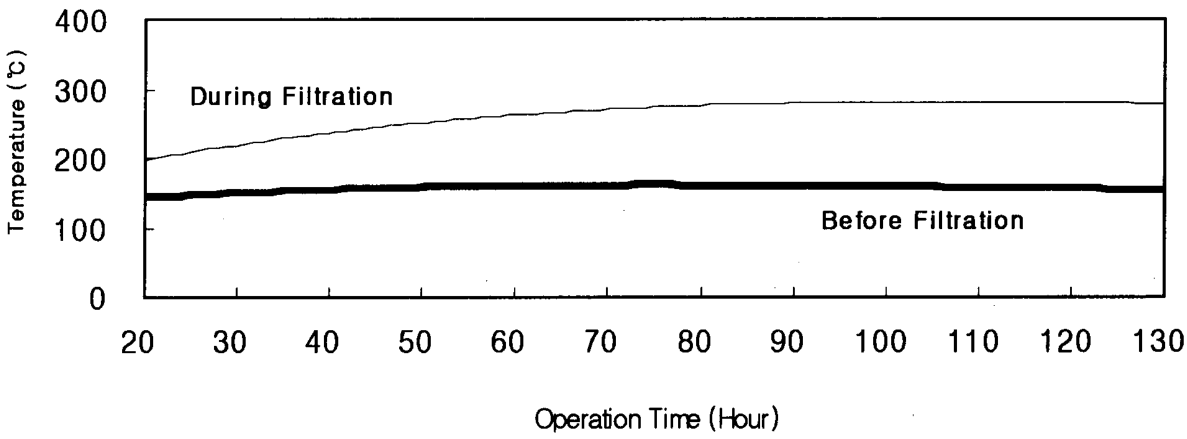


Fig. 6. Temperature of Off- Gas through HTF System during the Long-Term Operation.

3.2. Concentration & Collection Efficiency

Fig. 7 shows concentration of particulate matters during the mid- and the long-term operation. In the long-term operation, concentrations of particulate matters in off-gas were lower than that of the mid-term operation.

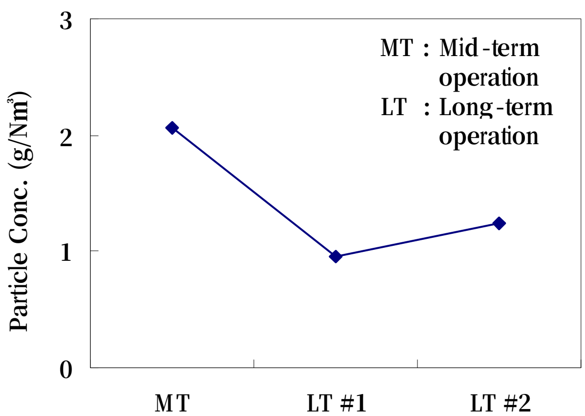


Fig. 7. Concentrations of Particulate Matters in Off-Gas during the Mid- and the Long-Term Operation.

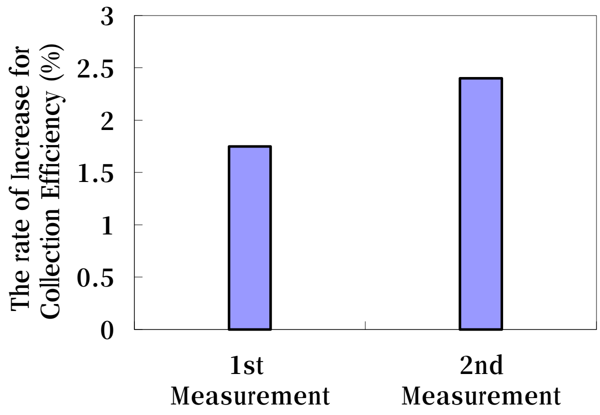


Fig. 8. The Rate of Increase for Collection Efficiency of the Long-Term Operation comparing with the Mid-Term Operation.

Collection efficiencies derived from measurements of concentration were higher than 99.5 % and increased more than the results of the mid-term operation as in Fig. 8. The rate of increase for collection efficiency was more than 2 % on average.

4. Conclusions

The long-term operation of vitrification was performed to evaluate operation parameters derived from previous mid-term operation. The results derived from the operation may be summarized as follows:

1. Pressure drop increased gently with time of operation but eventually reached to the steady state.
2. Off-gas temperature through HTF system was a stable curve in the range of 200 to 300 ℃ during the operation.
3. Concentrations of particulate matters in the long-term operation were lower than that of mid-term operation.
4. Collection efficiencies of the long-term operation showed some improvement in comparison with that of the mid-term operation.

In conclusion, the stability and the good performance of HTF system were confirmed in the long-term operation. The application of parameters derived from the mid-term operation of vitrification was very appropriate for the long-term operation. Finally, all the results from the operation will be used as basic data for the future operation and the design of a future commercial vitrification facility for nuclear power plants. Further experiments to adjust parameters to maintain negative pressure of whole process will be carried out in the future.

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