

Filter Pressure-Drop Behavior and Salt-Derived Aerosol Characteristics during Argon Bubbling in the MSTCL Off-Gas System

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1. Introduction

Molten salt reactors (MSRs) employ circulating liquid fuel salts, from which gaseous fission products such as Xe and Kr need to be removed during reactor operation. Inert-gas bubbling using He or Ar has been considered as a method for promoting the removal of these gaseous species from the fuel salt [1]. However, bubble bursting at the molten-salt free surface can generate entrained salt droplets, while vaporized salt species may form fine aerosols through nucleation and condensation during cooling [2]. These salt-derived aerosols can be transported with the carrier gas into the off-gas system and therefore require particulate filtration.

In this study, filter pressure-drop behavior and salt-derived aerosol characteristics were evaluated using an off-gas system connected to a Molten Salt Thermal Convection Loop (MSTCL) containing NaCl–MgCl₂ molten salt. Differential pressure across a two-stage filter was monitored during 105 h of Ar bubbling operation. In addition, aerosol number-size distribution, filter mass loading, particle morphology, and elemental composition were analyzed to characterize aerosol generation and filtration behavior under molten-salt bubbling conditions.

2. Experimental

2.1 Experimental setup and conditions

The MSTCL is a laboratory-scale natural-circulation molten-salt loop constructed at Soonchunhyang University using 1-inch SS316 piping. Its detailed configuration and design specifications have been described in a previous study [3]. Figure 1 shows the MSTCL and the connected off-gas system used in this study. The off-gas system consists of a filter tank, decay tank, gas circulation pump, and preheater and is operated as a closed-loop gas circulation system. Ar bubbling was conducted in the High Temperature Unit (HTU) located in the upper section of the MSTCL. The sparging gas was preheated to approximately 460 °C and injected into the molten salt through a sparger.

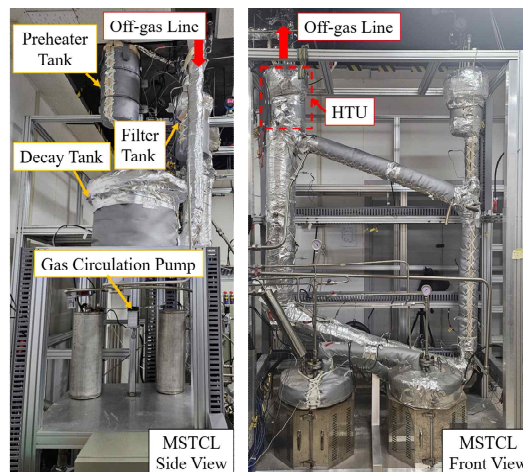


Fig. 1. Experimental configuration of the MSTCL off-gas system.

The experimental conditions for the Ar bubbling and filter pressure-drop test are summarized in Table I. NaCl–MgCl₂ (51:49 mol%) circulated in the MSTCL at 504–580 °C, while Ar was supplied at 2.3 L/min through an eight-hole (Ø1 mm) sparger. The gas temperature at the HTU outlet was approximately 450 °C. The HTU outlet line and filter tank were externally heated to surface temperatures of 600 and 400 °C, respectively; the gas temperature between the filter and decay tanks was approximately 230 °C, and the decay tank and its outlet line were externally heated to surface temperatures of 250 °C. The remaining sections were unheated. Two sintered Hastelloy C-22 filters with nominal pore sizes of 10 and 3 µm were installed in series, with dimensions of Ø39 × 240 and Ø50.4 × 240 mm, respectively, and a wall thickness of 2 mm. The gas passed sequentially through the 10 and 3 µm filters, followed by the decay tank, and was recirculated to the sparger through the gas circulation pump and preheater.

Table I: Experimental conditions for the Ar bubbling test

Parameter	Condition
Molten salt	NaCl–MgCl ₂
Salt composition	51:49 mol%
Salt temperature	504–580 °C
Sparging gas / flow rate	Ar / 2.3 Lpm
Sparger configuration	8 holes × Ø1 mm

2.2 Aerosol Generation and Measurement

Figure 2 shows the expected aerosol generation and transport pathways during Ar bubbling in the HTU. Bubble bursting at the molten-salt free surface can generate salt droplets, while vaporized salt species can form fine aerosols through nucleation and condensation during cooling. These aerosols are transported with the sparging gas from the HTU into the downstream off-gas system.

For the filter pressure-drop test, the pressures upstream and downstream of the filter tank and the differential pressure across the filter tank were continuously measured during 105 h of operation. The filters were weighed before and after the experiment to determine the mass gain resulting from aerosol collection.

Aerosol measurements were conducted separately from the filter pressure-drop test. Gas was sampled from the off-gas line at the top of the HTU, and the aerosol number-size distribution was measured over an aerodynamic diameter range of 0.006–10 μm using an HR-ELPI⁺ (Dekati Ltd., Finland). In addition, particles collected on the filters were analyzed by SEM-EDS to characterize their morphology and elemental composition.

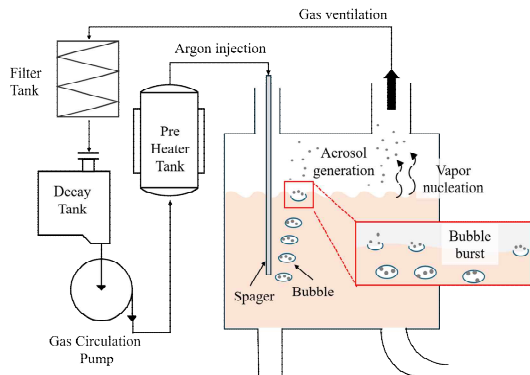


Fig. 2. Expected aerosol generation and transport pathways in the HTU during Ar bubbling.

3. Results and Discussion

3.1 Filter pressure-drop behavior

Figure 3 shows the differential pressure across the two-stage filter during 105 h of Ar bubbling operation. The differential pressure remained relatively low during the initial period and began to increase after approximately 75 h as aerosol deposition progressively increased the filter resistance. During this period, intermittent sharp decreases were also observed, which are interpreted as temporary recovery of gas-flow paths due to local restructuring or partial detachment of the deposited layer. Subsequent aerosol deposition increased the flow resistance again, resulting in repeated rise-and-drop behavior. After approximately 100 h, the pressure drop increased rapidly and reached about 0.38 bar at 105 h, which is interpreted as

accelerated filter clogging during the later stage of operation. The filter mass changes before and after the experiment are summarized in Table II. The first-stage 10 μm filter showed a mass gain of 0.38 g, whereas the second-stage 3 μm filter gained 0.05 g. Thus, most of the measured filter mass loading occurred on the first-stage filter.

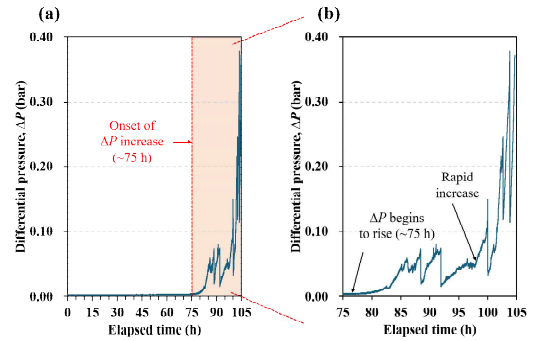


Fig. 3. Differential pressure across the two-stage filter during 105 h of operation: (a) overall trend and (b) enlarged view of the pressure-drop increase.

Table II: Filter mass changes after the experiment

Filter	Before (g)	After (g)	Mass gain (g)
10 μm	520.73	521.11	0.38
3 μm	780.82	780.87	0.05

3.2 Aerosol Size Distribution and Characteristics

Figure 4 shows the aerosol number-size distribution measured during Ar bubbling. A distinct aerosol population was observed in the ultrafine particle region, with the highest number concentration appearing at approximately 0.01 μm . In addition, Figure 5 shows that aerosols collected on the second-stage 3 μm filter exhibited chain-like agglomerates and crystalline particles on the order of several hundred nanometers. Considering the ultrafine size distribution together with the observed nanoscale morphology, these results suggest the presence of fume-type aerosols formed through vaporization, nucleation, and condensation of salt species.

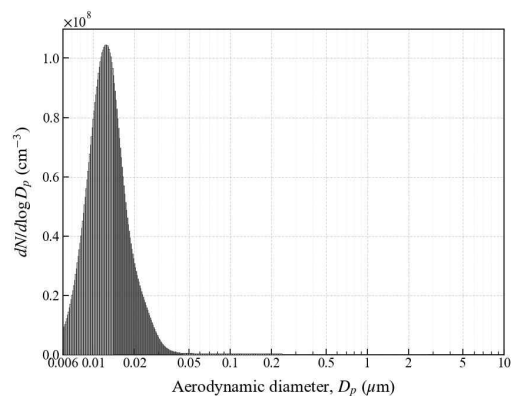


Fig. 4. Aerosol number-size distribution measured at 1-s intervals during Ar bubbling.

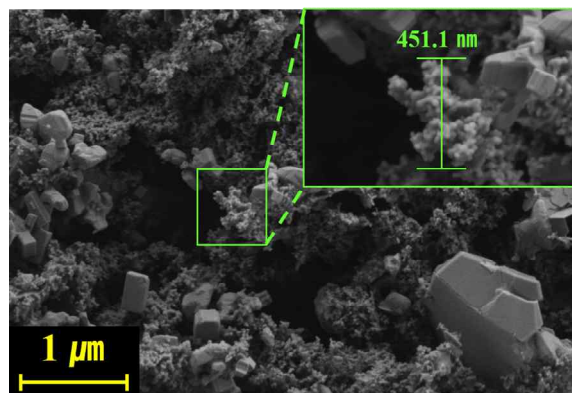


Fig. 5. SEM images of aerosols collected on the 3 μm filter

Figure 6 shows aerosols collected on the first-stage 10 μm filter. Droplet-like particles approximately 20–40 μm in size were observed together with chain-like agglomerates. Point EDS analysis showed that the droplet-like particle at P1 contained 23.46 wt% Na and 13.96 wt% Mg, indicating a relatively Na-rich composition, whereas the chain-like particle at P2 contained 9.37 wt% Na and 22.19 wt% Mg, indicating a relatively Mg-rich composition.

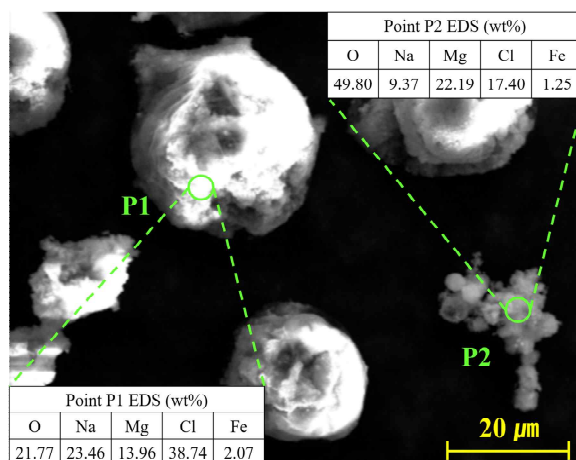


Fig. 6. SEM image and point EDS analysis of aerosols collected on the 10 μm filter.

The observed differences in particle morphology and composition indicate the presence of at least two distinct aerosol populations. The relatively large droplet-like particles are interpreted as mist-type aerosols generated by bubble bursting at the molten-salt free surface [2]. Because these particles originate from the direct dispersion of molten-salt droplets, their composition is expected to more closely reflect that of the bulk molten salt than that of vapor-derived particles [4]. In contrast, the ultrafine particles and chain-like agglomerates are interpreted as fume-type aerosols formed through vaporization of salt species followed by nucleation and condensation during cooling. Differences in the volatilization and condensation behavior of salt species can result in compositional fractionation during fume formation [2]. Therefore, the

contrasting Na/Mg compositions observed at P1 and P2, together with the distinct particle morphologies, further support the interpretation of different aerosol formation pathways during Ar bubbling.

4. Conclusion

In this study, the pressure-drop behavior of a two-stage filter and the characteristics of salt-derived aerosols were evaluated under Ar bubbling conditions in the MSTCL off-gas system. The filter differential pressure began to increase after approximately 75 h and showed a nonlinear increase, with a rapid rise after approximately 100 h. After 105 h of operation, mass gains of 0.38 g and 0.05 g were measured for the 10 μm and 3 μm filters, respectively, indicating substantially greater mass loading on the first-stage filter.

Aerosol size-distribution and morphology analyses revealed distinct ultrafine and droplet-like particle populations. The ultrafine particles and chain-like agglomerates were interpreted as fume-type aerosols, whereas the larger droplet-like particles were interpreted as mist-type aerosols. Their different morphologies and Na/Mg compositions further support the interpretation of different aerosol formation pathways associated with vaporization–nucleation–condensation and bubble bursting. Future work will focus on the reproducibility of the pressure-drop behavior, the effects of filter configuration, and size-resolved chemical analysis to further clarify aerosol composition and formation pathways.

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