Development of a continuous high throughput electrorefiner for a spent metallic nuclear fuel

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1. Introduction

In the pyrometallurgical reprocessing technology of a spent nuclear fuel, an electrorefining in molten chlorides is the main step [1], and the efficiency of the process is one of the requirements for the treatment of a large volume of uranium in an integrated area [2,3]. So many attempts have been made to enhance the throughput of an electrorefiner [3,4]. The main concepts to enhance their throughput are to increase the cathode area and decrease the physical distance between the electrodes as well as to continuously operate the electrodeposition process without any interruptions. The electrorefiner which has been developed in KAERI consists of a multi channel graphite cathode surrounded by a toroidal rotating anode basket and a flexible screw conveyer to haul the uranium deposit and the noble metal particles independent of the electrodeposition process of uranium. High purity uranium product can be attained through a separate arrangement of the uranium and noble metal collectors. Also, a controlled molten salt flow is necessary to prevent a mixing of the uranium product and noble metal particles.

Hence, in this study, we would like to report on the numerical analysis results of a high throughput electrorefining concept calculated by a commercial CFD code, ANSYS CFX, prior to demonstrating an electrorefining operation. The mixing behavior of the molten salt was calculated according to the process parameters such as the rotation speed of the toloidal anode basket and the central screw agitator.

2. Result and discussion

Based on the assumption that an electrorefined uranium product would be recycled for a fuel, the high throughput electrorefiner in this study is designed to collect the uranium deposit and noble metal fission product particles by individual collectors as shown in Fig. 1. The geometry of the electrorefiner was designed by the built-in ANSYS design modeler version 11.0 of Workbench. With this collector design, a uranium deposit would be harvested in the central uranium collector of Fig. 1 c) ④ and the noble metal fission product particles would fall down into the outer noble metal collector of Fig. 1 c) ⑤, when an ideal fluid flow is provided during an electrorefining operation.

Fig. 2 shows the FEM mesh of a high throughput electrorefiner with 450,335 tetrahedral elements generated by the built-in ANSYS CFX-mesh, and a quarter of the full model was used for the calculation to save on calculation resources since it is an axisymmetry problem. For the calculation of the turbulent flow, the k- model was used, and the material properties and boundary conditions are summarized in Table 1. The size ranges of the uranium deposit and noble metal particles were obtained from a previous report and molybdenum was chosen as a
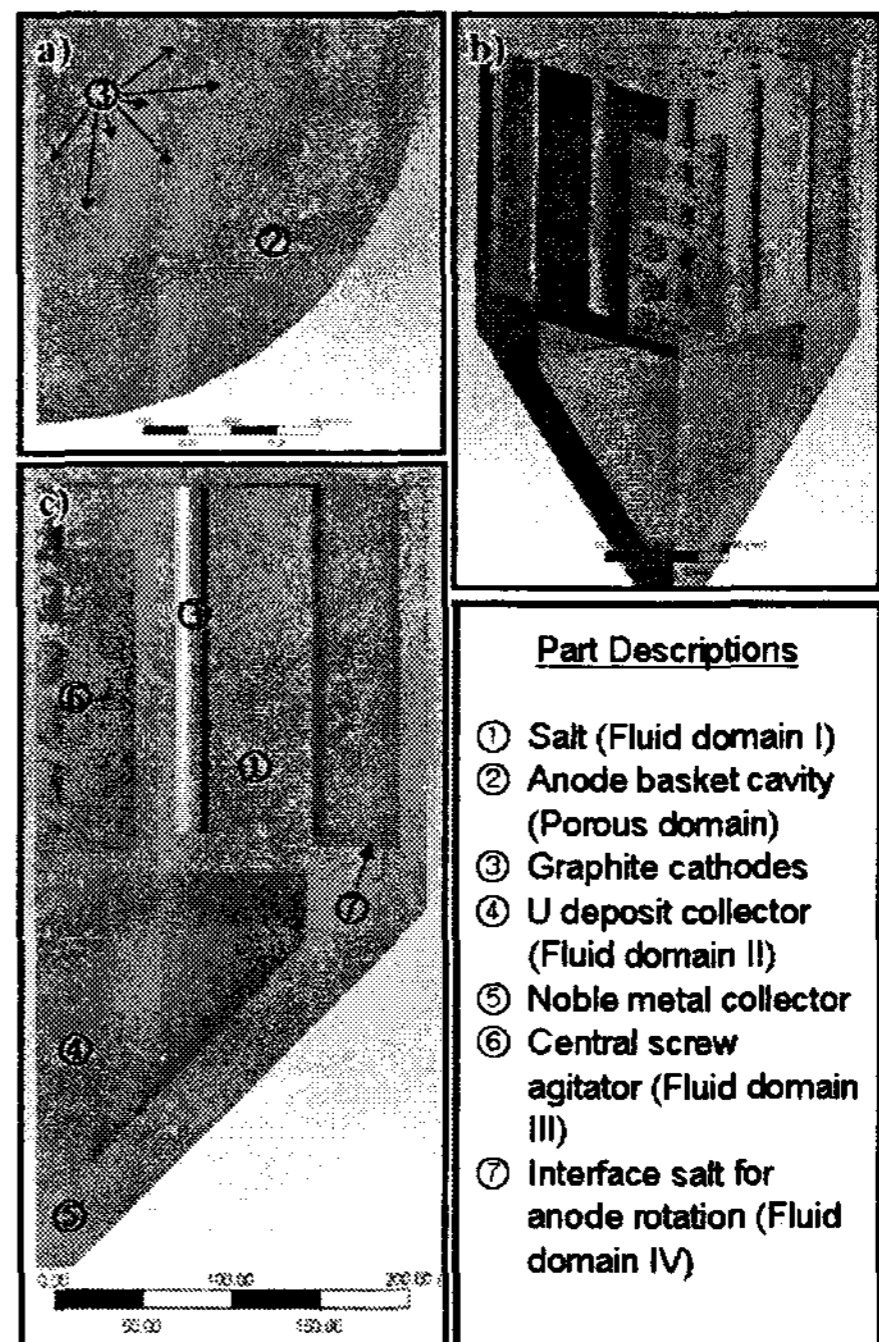

Part Descriptions

① Salt (Fluid domain I)
② Anode basket cavity (Porous domain)
③ Graphite cathodes
④ U deposit collector (Fluid domain II)
⑤ Noble metal collector
⑥ Central screw agitator (Fluid domain III)
⑦ Interface salt for anode rotation (Fluid domain IV)

Fig. 1. Geometry of high throughput electrorefiner and part descriptions
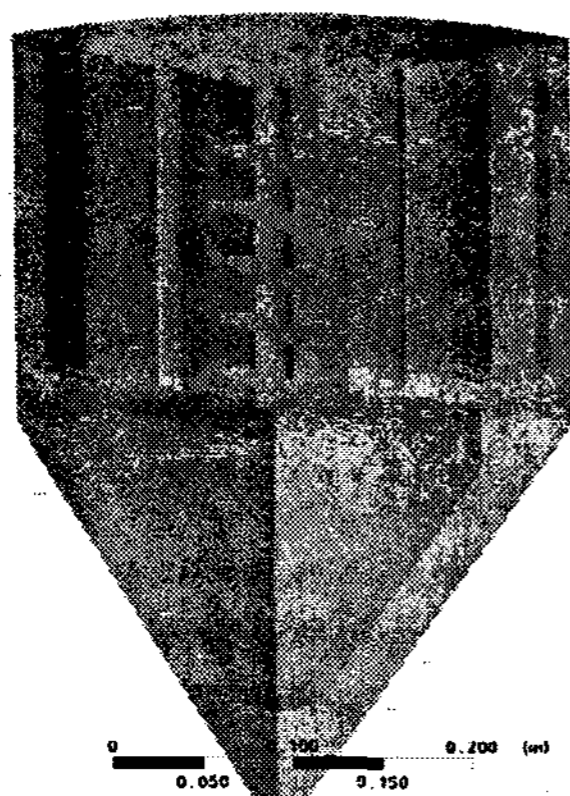a) Top view   b) Isometric view
c) Side view

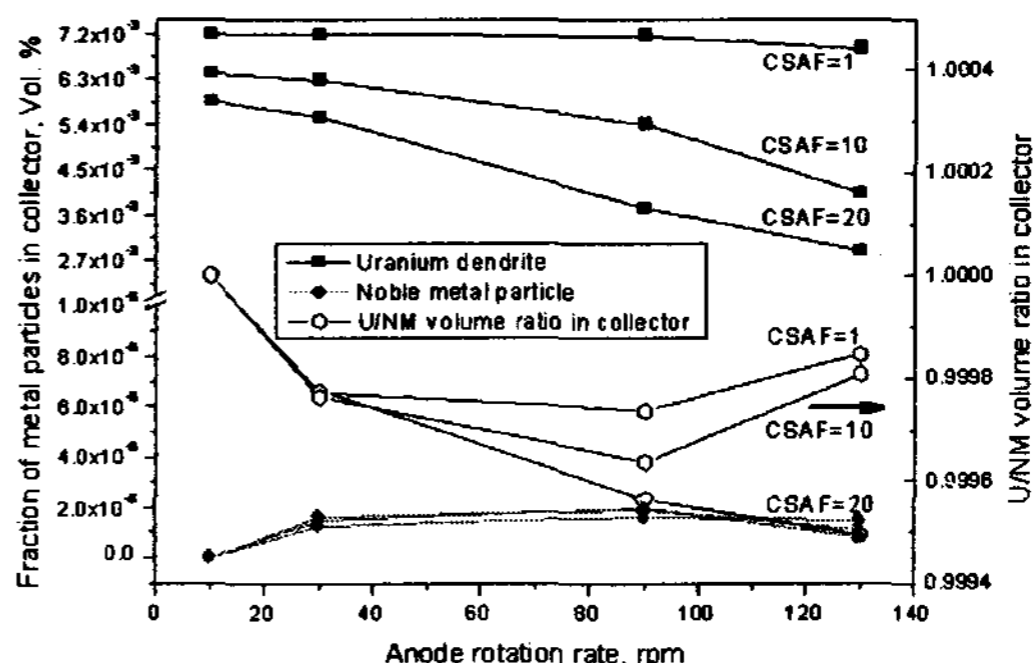Fig. 2. FEM mesh of the high throughput electrorefiner

Fig. 3. Calculated volume fraction of the metal particles in the deposit collector as a function of the anode rpm (void fraction of anode cavity : 0.5, rpm of central screw agitator : 30, CSAF=cross sectional area factor)

representative noble metal in the spent nuclear fuel. The design criteria of the high throughput electrorefiner in this study is to treat 20kgU/24hr which means 0.2315 g of uranium dendrite is generated during 1 second on the cathode surface. In the same manner, the noble metal generation from the anode basket is calculated as 0.002315 g/s because the LWR spent fuel contains around 1% of noble metals. Prior to the experimental validations, separation behavior between the noble metal particle and uranium dendrite was investigated by calculating the volume fractions of each metal particle in the deposit collector as shown in Fig. 3. It is very difficult to define the CSAF of the uranium deposit due to its dendritic geometry, so various CSAFs from spherical to critical shapes were applied to observe how they affect the distribution behavior of the metal particles. The volume fraction of the uranium dendrite in the deposit collector decreased with the anode rpm as well as the CSAF, whereas the noble metal fraction tended to increase. This leads to a decrease of the U/NM volume ratio in the deposit collector which eventually decreases the purity of the final uranium product. The fraction of the uranium dendrite decreased more rapidly with the anode rpm as the CSAF increased. Uranium dendrite travels further through a molten salt before settling into a deposit collector as the drag force increases. The drag force of the uranium dendrite is also proportional to the CSAF.

3. Conclusion

Numerical simulation and assessment were performed for a high throughput electrorefining concept. The fine uranium dendrite tended to be affected by the molten salt flow and a significant amount of the uranium dendrite with a high surface area could pass over the deposit collector at a higher rotation rate of the central agitator or anode basket. It was numerically confirmed that a separate design of the deposit and the noble metal sludge collector is effective to recover a high purity uranium product if appropriate processing conditions are provided.

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