Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2015

Engineering Design of a Double Reactor for Spent Fuel Oxidation

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1. Introduction

Mechanical head-end processing of the spent fuel (SF) disassembly, extraction of the rods, and the shearing of the extracted rods shall be performed in advance as the head-end of the pyro-process, which can recycle the SF of a pressurized water reactor (PWR). An oxidation treatment device is a device used to make a fine powder of U_3O_8 to supply raw material to the electric metal reduction device and supply it to a raw material forming machine.

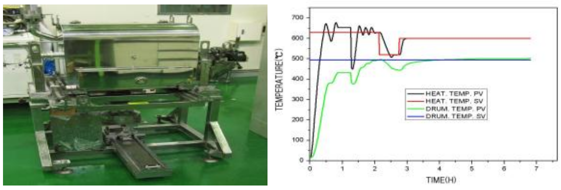
In this study, for a performance enhancement of the oxidation treatment device recovery ratio, the first performance test of the existing device (prototype) oxidation treatment device was carried out. In addition, by analyzing the result, the size of the reactor with a 1 kg HM/batch for a recovery ratio enhancement was decided, and the structure of the reactor was derived as a double structure reactor with a mesh type drum. The principle and structure of this device are as follows.

The pellet of the supplied rods is oxidized in 500℃ reactor A, and penetrates reactor B to form a uniform powder. In addition, if it is rotated in the reverse direction, the powder and hull are separated. The device is composed of a reactor module, driving module, heater module, support module, outlet module, etc.

In addition, by reflecting the enhancements, a vol-oxidizer with a double reactor was designed and manufactured, and a second performance test was carried out. Using a 30 mm hull and simulated powders (balls), as a result of carrying out the enhanced device performance test, the hull recovery ratio was 100%, and the simulated powder recovery ratio was 99% or more.

2. Prototype Oxidizer Performance Test

As shown in Fig. 1-a, an oxidation treatment device performance test was carried out. As a result, there was no reactor gas leak, and the reactor rotation operation, inlet/outlet valve operation, and remote operation test were good. In addition, during the temperature rise test and reaction gas supply, in the 500 °C maintaining test, as shown in Fig. 1-b, the heating rate until being stabilized under a 500 °C atmosphere was 3.3℃/min, which took 150 minutes, and the temperature was maintained constantly for 16 hours. In addition, at input oxygen concentration (O_2) of 50%, the reactor saturation time took 37 minutes, and at O_2 5%, the reactor saturation time took 150 minutes, which was precisely controlled.



(a) test (b) results

Fig. 1. Heating test of prototype device.

3. Prototype Oxidizer Hull Recovery Ratio Test

As shown in Fig. 2, a separation test was carried out on a revolving furnace at 5 rpm, at 500℃, using 132 Zry-4 hulls of 50 mm and 2.5 kg. As a result, the hull recovery ratio was 98%. The reason for the 2% hull not being recovered was because some hulls entered the recovery container in advance by the increased acceleration by the 45° inlet angle and the centrifugal force of the rotating reactor, and by the thermal expansion difference of the screw, which has SUS 304 material, and the rods, which have zircaloy material, were caught inside the reactor.

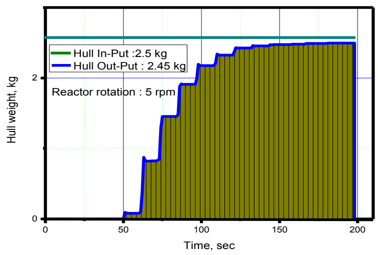


Fig. 2. Recovery efficiency of prototype device.

4. Derivation of Prototype Oxidizer Enhancements

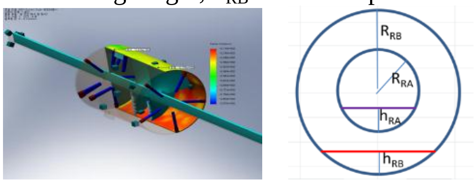
To prevent the screw being caught, in the heat strain equation 1 of Inconel 600 using Solid Works, the heat strain of the screw with SUS 304 material and Inconel 600 and the thermal expansion changes (Fig. 3-a) of the rods with Zry-4 material were calculated and the screw pitch size was decided. The inlet angle was changed from 45° to 37°, and the reactor material was changed from SUS 304 to Inconel 600, which is strong against corrosion. In addition, based on a PWR rod size of 16 x 16 (Ø9.5mm, length 3cm), considering the spent fuel pellet volume and rod volume, the reactor size was decided by equations 2 and 3-b, and the reactor structure was enhanced to a double structure reactor with a mesh type drum.

$$\lambda = \alpha(T_2 - T_1) \bullet L \quad (1)$$

(λ: heat strain, α: thermal expansion coefficient, T_2: increased temperature), T_1: initial temperature, L: length)

$$V(L,R,h) = L\{R^2 \cos^{-1}\{\frac{(R-h)}{h}\} - (R-h)(2Rh-h^2)^{1/2} \quad (2)$$

(R_{RA}: reactor A radius, R_{RB}: reactor B radius, h_{RA}: reactor A cladding height, h_{RB}: reactor B powder height)



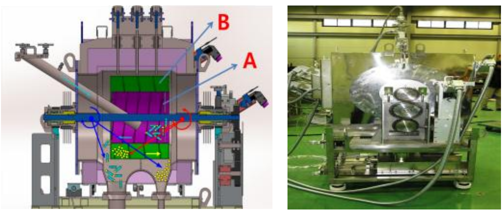
(a) thermal analysis (b) double reactor

Fig. 3. Thermal analysis of tube and reactor size.

5. Vol-oxidizer with Double Reactor

Fig. 4-a shows an oxidation decladding double reactor structure with an improved hull and powder recovery ratio and pellet oxidation efficiency. As you can see in Fig. 4-a, the cut rods inserted into the inlet are inserted into rotating reactor A and react at 500℃, and the pellet inside the cut rods is oxidized and the powder drops to reactor B to form a uniform and stable oxidized powder. Also, if you rotate the double reactor in the reverse direction, the powder and hull are separated.

As shown in Fig. 4-b, by reflecting the enhancements, the oxidation decladding double reactor was designed and manufactured. The size of the device is 150mm in length, 120mm in width, and 160mm in height, and is composed of reactor module, driving module, heater module, support module, outlet module, etc., and is made by considering remote operation and maintenance.



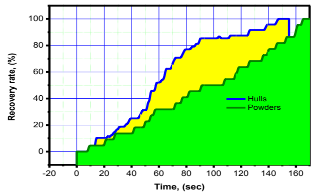
(a) double reactor (b) vol-oxidizer

Fig. 4. Improved reactor and device.

6. Enhanced Vol-Oxidizer Performance Test

Using the oxidation decladding double reactor, the device performance test was carried out. Instead of the powder, 110g of copper balls with Ø3 mm was used, and as a result of scale measurement of the recovery ratio against the insertion amount, the powder recovery ratio was 100%. (Fig. 5-a, Fig. 5-c). In addition, as shown in Fig. 5-b, using 53 cut zircaloy (Zry-4) hulls (Ø9.5x L30mm) corresponding to 1kg of spent fuel, the recovery ratio measurement test was carried out. As a result of the measurement, the recovery time took about 150 seconds, and 100% was recovered (Fig. 5-c).

(a) powders(balls) (b) tubes(zry-4)



(c) recovery efficiency

Fig. 5. Recovery efficiency of tube and powders**.**

7. Conclusions

For an oxidation decladding device enhancement and performance test, the temperature rise test and hull recovery ratio performance test were carried out with the existing single reactor structure oxidation treatment device (prototype with 1 kgHM/batch) to derive the enhancements of the oxidation decladding considering the pellet inlet angle, reactor structure, remote capability, etc. In addition, a 1kg/batch oxidation decladding double reaction device with an enhanced hull/powder separation and recovery ratio and pellet oxidation efficiency was designed and manufactured. As a result of a separation recovery test of the hull (length 30mm) and stainless balls (SUS: diameter 3mm) of the enhanced device, it was verified that the hull separation recovery was 100% and the powder separation recovery was 100%. We obtained the oxidation test evaluation data and design data using an enhanced oxidation decladding double reaction device.

ACKNOWLEDGEMENT

This study was carried out with support from the 2012 government (Ministry of Education, Science and Technology) funding (Nuclear Energy Technology Development Project, No. 2012M2A8A502569

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