Verification of Theoretical Equation for Optimum Design on Vol-Oxidizer Reactor

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1. Introduction

KAERI is developing mechanical head-end process for pyro-processing. Mechanical head-end process consists of disassembling, rod extraction, rod cutting and vol-oxidation on the spent fuel assembly. Also, as a piece of process equipment, a vol-oxidizer which can handle several tens kg HM/batch is developing to supply U_3O_8 powders to an electrolytic reduction(ER) reactor. To install the vol-oxidizer in hot cell, the reactor size should be optimized by the mechanical design. In this paper, we aim at verification of theoretical equation for optimum design on vol-oxidizer reactor. In order to design the reactor size, the volume constants were obtained according to various rod-cuts (cutting hulls + pellets) and theoretical equation was produced by using the volume constants. By using a design SW (Solid-Works) and theoretical equation, the 3D models were designed for reactors. Also, a verification tests were conducted by using the acyls vessel and zry-4(zircaloy-4) tube according to various weight and length. From the results of the verification test, the theoretical equation revealed an accuracy within 0.02~0.04%.

2. Rod-cuts Volume Constants

To obtain rod-cuts volume constant, the size of the rod-cuts is referred to the model of KORI-spent fuel (PWR 14x14, 55,000 MWD/MTD, OD10.75mm).

We measured the variation of the volume in the beaker with 2 liter according to various tube lengths (2, 3, 4, 5, 7, 7, 10 cm). As shown in equation 1 and 2, volume constants were obtained by using the beaker. The bulk and compacted ratios in beaker are shown in Table 1 and Fig. 1. Here, the bulk and compacted volume ratios are determined with or without vibration. The vibration was run for 20 minutes for compacted volume ratios.

$$\text{Bulk volume ratio} = \frac{\text{tube volume}}{\text{volume after cutting}} \qquad (1)$$

$$\text{Compacted volume ratio} = \frac{\text{tube volume}}{\text{volume after vibration}} \qquad (2)$$

(Tube volume is total volume when tubes is piled side by side)

Also, the bulk and compacted ratios can be obtained by the equation 3 and 4 regardless of assembly type and tube length.

Table 1 Bulk/Compacted volume ratio (constant) related to tube length, cm

tube length, cm	bulk volume ratio(constant)	compacted volume ratio(constant)
2.0	1.9910	1.6660
3.0	2.1140	1.7780
5.0	2.3580	1.9760
7.0	2.6590	2.2690
9.0	2.9470	2.5180
10.0	3.0810	2.6320

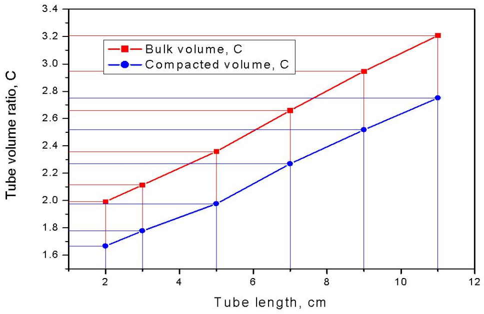

Fig. 1 Slants of volume ratio (constant) related to tube length, cm

$$y_B = y_1 + A_1 \bullet X = 1.702 + 0.1369 \bullet X \qquad (3)$$

$$y_C = y_2 + A_2 \bullet X = 1.405 + 0.1224 \bullet X \qquad (4)$$

(Y_B*: bulk volume ratio,* Y_A*: compacted volume ratio,* Y_1 *and* Y_2*: Y- axis intercept,* A_1 *and* A_2*: slant,* X *: cutting length*)

3. Rod-cuts Volume Equation

The calculation methods for total bulk rod-cuts volume are as follows:

First, a volume of one rod-cut is obtained by multiplying of cutting sectional area ($\pi d^2/4$) and rod-cut length (L_i).

Second, a total piled rod-cuts volume is obtained by multiplying of rod-cut numbers (N_i) and one rod-cut volume ($Li \bullet \pi d^2/4$).

Finally, a total bulk rod-cuts volume (V_t) is obtained by multiplying of total piled rod-cuts volume ($Li \bullet N \bullet \pi d^2/4$) and rod-cuts volume constant (f_i).

Here, the out-diameter of rod-cut differs according to kind of spent fuel assembly. However, even if kind of spent fuel assembly changes, a rod-cuts volume constant is fixed. As shown in equation 5, the rod-cuts volume equation was produced by using the volume constant, length, numbers and cutting sectional area on the rod-cuts.

$$V_t = f_i L_i N_i \frac{\pi D^2}{4} \qquad (5)$$

(*V_t: total bulk rod-cuts volume, f_i: rod-cuts volume constant, L_i: rod-cut length, N_i: rod-cut numbers, $\pi d^2/4$: cutting sectional area*)

4. Reactor 3D Modeling

By using a design SW (Solid-Works), the 3D models were designed according to lengths and weights of the rod-cuts for reactors. Also, in order to manufacture the acyls vessel, we conducted 3D modeling. The purpose of 3D modeling is to optimize the reactor size that is placed in a hot cell. The design conditions for reactor are as follows:

1) Boundary condition : inside diameter-300mm
2) Reactor is filled with rod-cuts up to 50%
3) Model of KORI-spent fuel (PWR 14x14, 55,000 MWD/MTD, OD10.75mm)

As shown in Fig. 2, in order to design the reactor, we used the rod-cuts volume equation and considered the weights (spent fuel: 5 kg, 20 kg, 50 kg, 100 kg) and lengths (3 cm, 5 cm, 7 cm, 10 cm) on the rod-cut. Fig. 3 is the reactor size that is designed by using the design SW (Solid-Works) according to rod-cuts length at SF 5 kg HM/batch.

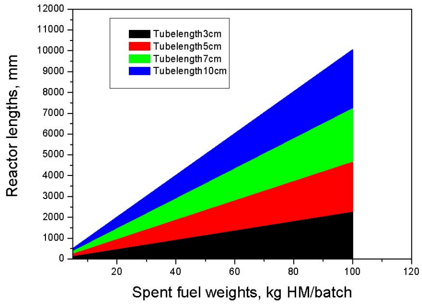

Fig. 2 Reactor lengths related to tube lengths, cm

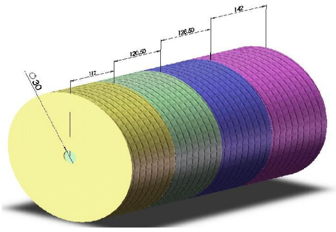

Fig. 3 Reactor sizes related to tube lengths at SF. 5 kg HM/batch.

5. Verification

As shown in Fig. 5, in order to verify this theoretical equation, the acryl reactors with a scale of centimeters that can be filled with the rod-cuts were manufactured. Also we manufactured the rod-cuts with various weights (spent fuel: 5 kg, 10 kg, 20 kg) and lengths (3 cm, 5 cm, 7 cm, 10 cm). Here, the material of the rod-cuts is zry-4(zircaloy-4) tube and the out-diameter of the rod-cuts is 10.75mm. The rod-cuts were filled in the acryl reactors and the volumes were measured according to a variation of their weights and lengths for verification. Fig. 5 is a picture which the acryl reactor is filled to the rod-cuts. As shown in the Fig. 6, the theoretical equation revealed an accuracy within 0.02~0.04%.

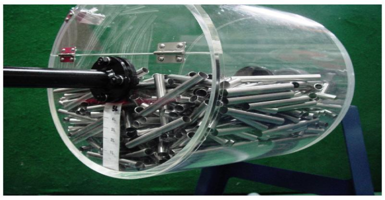

Fig. 5 Rod-cuts volume in acryl reactor (weight: 20kg, length: 100mm).

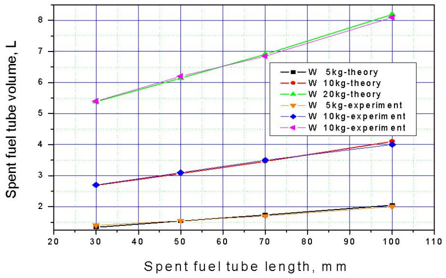

Fig. 6 Rod-cuts volumes related to lengths and weight, liter.

4. Conclusions

The rod-cuts volume constants were obtained according to various rod-cuts. The size of the rod-cuts is referred to the model of KORI-spent fuel (PWR 14x14, 55,000 MWD/MTD, and OD10.75mm). The rod-cuts volume equation was produced by using the volume constants, length, numbers and cutting sectional area on the rod-cuts. Even if a type of spent fuel assembly changes, a rod-cuts volume constant is fixed. Also, the rod-cuts volume can be calculated by the theoretical equation. By using a design SW (Solid-Works) and theoretical equation, the 3D models were designed according to lengths and weights on the rod-cuts for reactors. In order to verify this theoretical equation, the acryl reactors with a scale of centimeters that can fill to the rod-cuts were manufactured. As a result, the theoretical equation revealed an accuracy within 0.02~0.04%. A theoretical equation which can calculate the volume with various weights and lengths of the rod-cuts can be used for design on optimum volume for a reactor of vol-oxidizer.

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