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OPTIMUM FILL VOLUMES IN POT CALCINATION OF RADIOACTIVE WASTES

J. J. Perona

ABSTRACT

The 15,000 MW nuclear economy assumed for the long range study of pot calcination costs reported in ORNL-3192 was used as a basis for calculating optimum fill volumes. An algebraic expression was developed for cost as a function of the normalized radius of the central void space in a partially filled vessel. Minima of this expression were found for acidic and neutralized wastes in 6, 12 and 24-in.-diameter vessels.

Optimum fill volumes decreased as vessel diameter increased, varying for acidic wastes from 99.8% for 6-in.-diameter vessels to 92.5% for 24-in.-diameter vessels. Decreases in costs by using optimum fill volumes instead of the 90% fill volume assumed for all cases in the long range study were small, the largest being an 8% decrease for neutralized wastes in 6-in.-diameter vessels.

NOTICE

In the pot calcination process for solidifying radioactive wastes as carried out at ORNL, the average processing rate decreases as the filling of the calcination vessel progresses. It has been pointed out by M. E. Whatley that there must be an optimum filling point, when calcination vessel costs are balanced off against plant capital costs. It is of interest to the Unit Operations group to know in what range the optimum filling points may lie. Such an optimization based upon expected pilot plant costs would be of little value, because the objectives (and hence the production rate and operating costs) of the pilot plant will be entirely different from those of a production plant.

A better basis for calculating optimum filling points is the set of alternative hypothetical plants used for calculating calcination costs for the wastes from the 15,000 MW nuclear economy assumed in the long range study reported in ORNL-3192.* The variables in this study were vessel diameter and waste composition (acidic or neutralized) for a plant processing Purex and Thorex wastes. Vessels were assumed to be 90% filled in all cases, the 90% point being chosen intuitively as a compromise between good processing rate and good vessel utilization.

In the long range study, yearly capital and operating costs were expressed graphically as functions of plant floor area. While these relationships are not precisely linear, they can be approximated by linear functions with less than 3% error. Capital costs are also a function of shielding wall thickness, but using a constant thickness of 6 ft introduces less than a 10% error in capital costs. Yearly capital costs are then given by

$$CC = 176{,}000 + 84.0\ (A - 1200) \tag{1}$$

and yearly operating costs by

$$OC = 670{,}000 + 330\ (A - 1200) \tag{2}$$

where A = plant floor area, ft.

To simplify the analysis let us consider only those cases where Purex and Thorex wastes are processed in the same sized vessels filled to the same degree. Yearly cost of the vessels can be expressed as

$$VC = \frac{(G_P + G_T)B}{D(x)} \tag{3}$$

where G_P = volume of Purex waste as final solid, gal/year
G_T = volume of Thorex waste as final solid, gal/year
B = cost of individual calcination vessel
D(x) = volume of waste per vessel, gal/vessel

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*J. J. Perona, R. L. Bradshaw, J. T. Roberts, J. O. Blomeke, "Evaluation of Ultimate Disposal Methods for Liquid and Solid Radioactive Wastes. Part II. Conversion to Solid by Pot Calcination," ORNL-3192, September 27, 1961.

The volume of waste per vessel is a function of x, the normalized radial distance from the axis of the cylindrical calcination vessel to the surface of the deposited solid. Specifically,

$$D(x) = 7.48\pi HR^2(1 - x^2) \tag{4}$$

where H = height of solid deposit, ft
R = radius of vessel, ft

Values of G_P and G_T are as follows:

Waste Type	G, gal solid/year
Acidic Purex	10,600
Acidic Thorex	16,200
Neutralized Purex	20,200
Neutralized Thorex	35,900

Values of B are \$500, \$855 and \$2515 for 6, 12, and 24-in.-diameter vessels 10 ft in length.

The yearly total costs of processing the Purex and Thorex wastes are given by

$$TC = 846{,}000 + 414\ (A\text{-}1200) + \frac{(G_P + G_T)B}{D(x)} \tag{5}$$

and now A must be expressed as a function of x. From the long range study report

$$A = 100 \times (\text{number of lines}) + 200\ (F_P + F_T + 1.0)^{1/2}$$
$$+ 200 + 27 \times (\text{number of vessels per day}) \tag{6}$$

where F = off gas factor (see appendix A, ORNL-3192)

The first term in eq 6 gives the floor area required for calcination equipment, the second term the area for evaporation and off gas equipment, and the last two terms the area for testing and decontamination. The number of processing lines is given by

$$L = \frac{1}{7600}\ \frac{t_P(x)G_P + t_T(x)G_T}{D(x)} \tag{7}$$

where $t_P(x)$ = cycle time for processing an individual vessel with Purex waste, hours

and 7600 is the number of operating hours in a year, assuming 15% downtime. Explicitly,

$$t_P(x) = k_{1,P}R^2(1 - x^2 + 2x^2 \ln x) + k_{2,P} \tag{8}$$

where $k_{1,P}$ = experimentally determined constant characteristic of Purex waste, hours/ft^2

$k_{2,P}$ = part of cycle time other than filling time (e.g. calcination, melting, freezing, and handling), hours

Values for k_1 are:

Waste Type	k_1
Acidic Purex	280
Acidic Thorex	266
Neutralized Purex	118
Neutralized Thorex	115

In assigning values to k_2, 3 hours was assumed for calcination and 8 hours for handling or changeout, making a total of 11 hours. In addition the possibility of more than one filling was allowed for neutralized wastes, which melt during calcination, and 2 hours was assumed for melting and freezing in between fillings. Thus values of k_2 would be 11 hours for filling once, 13 hours for filling twice, and 15 hours for filling three times.

The equation for total yearly costs can now be expressed as a function of x as follows:

$$TC = 432{,}000 + 82{,}800\,(F_P + F_T + 1.0)^{1/2} + \frac{(G_P + G_T)(B + 31.9)}{7.48\pi HR^2(1 - x^2)} +$$

$$+ 5.45\,\frac{NR^2(1 - x^2 + 2x^2 \ln x)(G_P k_{1,P} + G_T k_{1,T}) + (G_P k_{2,P} + G_T k_{2,T})}{7.48\pi HR^2(1 - x^2)} \qquad (9)$$

where N = number of filling cycles.

Taking the derivative of TC with respect to x and setting the equation equal to zero, we obtain

$$1 - x^2 + 2 \ln x = -\,\frac{(G_P + G_T)(B + 31.9) - 5.45\,N(G_P k_{2,P} + G_T k_{2,T})}{5.45\,NR^2(G_P k_{1,P} + G_T k_{1,T})} \qquad (10)$$

Equation 10 was solved for several cases of interest and the results are given in Table 1.

Table 1. Optimum Filling Points as a Function of Calcination Vessel Diameter and Waste Composition

Waste Composition	x, Normalized Radius of Void Space 6-in.-dia	 12-in.-dia	 24-in.-dia
Acidic Purex-acidic Thorex	0.047	0.20	0.275
Neutralized Purex-Neutralized Thorex	< 0.01	0.033	0.067
Neutralized Purex filled twice-neutralized Thorex filled twice	0.024	0.147	0.210
Neutralized Purex filled three times-neutralized Thorex filled three times	0.073	0.24	0.31

It is economical to fill larger diameter vessels less than smaller diameter vessels, because cost per gallon of space is less in larger vessels and because initial rates are higher and final rates lower in larger vessels. For all cases shown in Table 1 vessels would be filled past the 90% point ($x = 0.316$) assumed in the long range study. However, costs would not be significantly cheaper. Using equation 9 to calculate total costs for the case of acidic Purex-acidic Thorex in 24-in.-diameter vessels, a cost of 0.866×10^{-2} mills/kwh_e was calculated for $x = 0.316$ and 0.864×10^{-2} mills/kwh_e for $x = 0.275$. For the case of neutralized Purex-neutralized Thorex in 6-in.-diameter vessels, in which the largest difference between optimum filling point and the 90% point occurs, the cost decrease by filling to the optimum point is about 8%.

In the long range study a second filling cycle was shown to decrease costs for neutralized wastes. The cost for three filling cycles for the case of 24-in.-diameter vessels is about the same as for two cycles. The desirability of multiple filling cycles is strongly dependent on the validity of assumed values for k_2 and must be determined by actual pilot plant experience.

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