PREDICTION OF WASTE GLASS MELT RATES

Lien-mow Lee
E. I. du Pont de Nemours and Company
Savannah River Laboratory
Aiken, South Carolina 29808

ABSTRACT

Under contract to the Department of Energy, the Du Pont Company has begun construction of a Defense Waste Processing Facility to immobilize radioactive wastes now stored as liquids at the Department of Energy's Savannah River Plant. The immobilization process solidifies waste sludge by vitrification into a leach-resistant borosilicate glass. Development of this process has been the responsibility of the Savannah River Laboratory. As part of the development, a simple model was developed to predict the melt rates for the waste glass melter. This model is based on an energy balance for the cold cap and gives very good agreement with melt rate data obtained from experimental campaigns in smaller scale waste glass melters.

BACKGROUND AND INTRODUCTION

For more than thirty years, the Savannah River Plant (SRP) has been producing for nuclear materials for defense, space, and medical applications. The site spans approximately 300 square miles and is located along the Savannah River near Aiken, South Carolina.

Wastes produced from chemical separation processes have accumulated and are currently being stored in large specially designed underground tanks as a neutralized liquid containing sludge and soluble salts. The sludge consists primarily of hydroxides and hydrous oxides of iron, aluminum, manganese, and fission products.

Since 1974 the Savannah River Laboratory (SRL) has been developing a process to immobilize the waste sludge by vitrification (1, 2, and 3). In the reference process, the waste sludge is pretreated to remove aluminum, soluble salts, and mercury. Glass-forming chemicals are then added as a premelted borosilicate glass frit, and the resulting slurry is fed into a continuous Joule-heated ceramic melter operating at 1150°C. Evolving effluents (mainly steam) are treated by an extensive offgas treatment system which recycles contaminated solids back to the process. The solid portion of the slurry melts and is poured into stainless steel canisters, which are 2 feet in diameter by 10 feet tall.

During the vitrification of defense waste, the production rate is strongly dependent on processing conditions and on the properties of the borosilicate glass formulation. To predict the glass production rate, a simple heat balance model for slurry-fed glass melters has been developed and tested. The model uses only parameters which are easily measured and which will be available during routine operation of the glass melter.

DESCRIPTION OF WASTE GLASS MELTER

A schematic of the DWPF's glass melter is shown in Fig. 1. The melter is cylindrical with a circular cross section. The main containment refractory material is Monofrax K-3 (trademark of Carborundum Company). Other refractory materials surround the K-3 and provide good thermal insulation, especially below the melt pool where sufficient insulation is critical for maintaining constant melt pool temperature. Joule heat is supplied to the pool by passing current through two pairs of flat plate electrodes made of Inconel 690 (trademark of Huntington Alloys, Inc.). Energy can also be applied above the melt pool by Inconel 690 resistance heaters (lid heaters). Lid heaters are used primarily to vaporize the slurry and increase melt flux. They are also necessary for melter startup to bring the melt body to sufficient temperatures to initiate Joule heating with the electrodes. Under normal slurry-fed operation, the lid heaters supply sufficient heat to maintain the melter plenum temperature at 650 to 800°C.

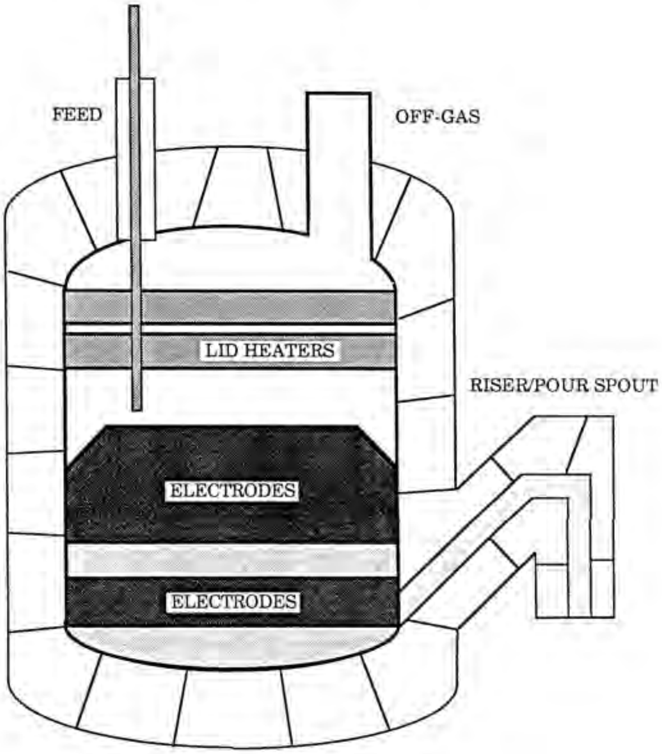

Fig. 1. Slurry-Fed Melter.

MODEL DERIVATION

The model is based on a simple heat balance around the cold cap on the surface of the glass melt. The glass production rate is assumed to be equal to the total heat received, divided by the heat consumption per pound of feed multiplied by the solids loading in the feed. The heat received includes the radiant heat from the lid heaters and refractory walls, and the energy from natural convection from the glass melt.

The radiant energy received by the cold cap may be estimated by considering the energy balance for the frit during melter startup, i.e., when the slurry feed rate and Joule heating are both zero. At this circumstance, the frit receives energy from the lid heaters and melter walls. The energy given up by the frit consists of energy irradiated by the frit and energy lost by conducting through the frit and the melter wall. The energy balance for the frit during startup can be expressed by equation 1.

$$4\,\sigma\,\varepsilon_1 F_{14} T_1^4 A_1 + \sigma\,\varepsilon_4 T_4^4 A_4 F - \sigma\,\varepsilon_4 T_4^4 A_4 - \frac{T_4 - T_0}{\dfrac{T_4}{k_4 A_4} + \dfrac{T_5}{k_5 A_5} + \dfrac{T_6}{k_6 A_6} + \dfrac{T_7}{k_7 A_7}} = 0 \qquad (1)$$

Subscripts 1 and 4 refer to lid heater and frit, respectively, subscripts 5, 6, and 7 refer to different layers of melter insulation, and:

σ is the Stefan-Boltzmann constant
ε is the emissivity of radiating surface
T is the absolute temperature
A is surface area
F is the fraction of radiation energy emitted from the frit which is again received by the frit due to radiation from the melter wall to the frit
l is the thickness of the insulation
k is the thermal conductivity of the insulation
F_{14} is the view angle from the lid heaters to the frit surface.

The first term in the left-hand side of equation 1 is the radiant energy received by the frit from the lid heaters. The third and the fourth terms represent the radiant energy emitted from the frit, and the energy loss from the frit due to conduction through the melter wall. The second term represents the radiant energy the frit receives from the melter wall, which is expressed as a fraction of the energy emitted from the frit. This point requires further explanation.

Let us consider the melter plenum as a thermodynamic system which includes melter walls and the glass surface but excludes the lid heaters. Assuming there is no air inleakage, there are only two energy streams which transfer across the system boundary. They are the energy input through the lid heaters and the energy emitted by conduction through the melter walls. At steady state, these two streams are equal to each other. For energy transfer within the system, let us consider the glass surface. At steady state with no air inleakage, the energy emitted from the glass is equal to the energy it receives from the melter wall. In other words, the energy received by the glass from the melter wall is proportional to the energy it emits, with a proportionality constant equal to one. Since all melters have some air inleakage, some portion of energy is lost to the air inleakage. Therefore, only a fraction of the energy which the glass emits is returned to it from the melter wall. This is why the radiant energy the frit receives from the walls is expressed as a fraction of the energy it emits.

Based on actual operating data, 50% of the radiation energy emitted from the glass is again received by the glass. This factor was calculated from Eq. 1 using lid heater and plenum temperature data obtained from experiment. From Eq. 1, we can express the total radiant energy received by the cold cap, or, by Eq. 2.

$$Q_r = 4\,\sigma\,\varepsilon_1 F_{14} A_1 T_1^4 + \sigma\varepsilon_4 T_4^4 A_4 F - \sigma\varepsilon_4 (373.2)^4 A_4 \qquad (2)$$

The first and the second terms on the right hand side of Eq. 2 represent the radiant energy received by the cold cap from the lid heaters and the melter wall, respectively. The last term represents the radiant energy emitted from the cold cap which is insignificant compare to the first two terms.

The energy which the cold cap receives from the melt pool is due to natural convection and can be expressed by Eq. 3.

$$Q_n = hA(T_g - 373.2) \qquad (3)$$

where: h is the heat transfer coefficient
T_g is the glass pool temperature
A is the cold cap surface area

The heat transfer coefficient, h, that is required for calculating natural convection can be obtained from correlation involving the Grashof and Prandtl numbers [4].

$$\frac{hD}{k} = 0.54 \left[\frac{g\,\beta\,(T_g - 100)D^3\rho^2}{\mu^2} \cdot \frac{C_p\mu}{k}\right]^{0.25} \qquad (4)$$

where: D is cold cap diameter
k is thermal conductivity of glass
g is gravitational acceleration constant
ρ is density of glass
μ is viscosity of glass
C_p is specific heat of glass
β is volumetric thermal expansion coefficient

All of the variables in Eq. 4 can be independently measured. Therefore, Eq. 4 can be used to calculate the heat transfer coefficient, h. Once the heat transfer coefficient is calculated, the heat transfer to the cold cap due to natural convection, Q_n, can be calculated from Eq. 3.

The total energy received by the cold cap is calculated as the sum of Q_r from Eq. 2 and Q from Eq. 3. The melt rate is then calculated by dividing the rate of energy receipt by the cold cap by the energy required to produce glass per unit weight of feed, and then multiplying this result by the percent solids in the feed.

The correlation simplifies the model a great deal. Without it, we would need to obtain solutions for continuity equations, momentum equations, and energy equations. These equations are nonlinear and coupled, and require elaborate programming for computation. This is one reason SRL has an extensive physical modeling program for melter study. The model described in this paper is simple; the calculation takes less than 15 seconds on an IBM PC.

RESULTS

The comparison between the measured and the calculated melt rate using frit 165 is given in Table I. The key variables affecting melt rate such as glass pool temperature, plenum temperature, percent solids in the feed, and percent cold cap coverage are also included in Table I. It can be seen that the agreement between the measured and the calculated melt rates is quite good. A similar comparison for frit 131 is given in Table II. Again, the agreement is very good.

TABLE I

Actual Vs. Predicted Melt Rates for Frit 165

Bulk Glass Temperature°C	Average Plenum Temperature°C	Slurry, % Solids	Measured Melt Rates, lb/hr/ft/ft	Calculated* Melt Rates, lb/hr/ft/ft
1112	738	35	5.6	5.0
1135	722	36	6.0	5.0
1135	725	37	5.5	5.3
1145	724	39	5.4	5.7

* 95% cold cap coverage.

TABLE II

Actual vs. Predicted Melt Rates for Frit 131

Bulk Glass Temperature°C	Average Plenum Temperature°C	Slurry, % Solids	Measured Melt Rates, lb/hr/ft/ft	Calculated* Melt Rates, lb/hr/ft/ft
1200	680	39	7.7	7.4
1200	700	39	7.7	7.7
1170	705	39	7.7	7.2
1150	654	38	7.4	5.9
1175	656	32	6.5	5.2
1150	620	39	5.1	5.7
1150	635	39	6.6	5.9
1160	660	32	5.5	5.0

* 95% cold cap coverage.

CONCLUSION

A simple heat balance model for a slurry-fed glass melter has been developed and tested. The model uses only parameters which are easily measured and which will be available during routine operation of the glass melter.

The predictions of the model have been compared to actual experimental data. The measured and calculated values for the melt rate agree within 10%. The model has also been applied to production-scale melters to suggest ways to improve performance.

ACKNOWLEDGMENT

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