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EXPERIMENTAL JOULE-HEATED CERAMIC MELTER FOR CONVERTING RADIOACTIVE WASTE TO GLASS

by

Paul H. Chismar

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, South Carolina

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To: Mr. N. R. Grant
RSTD Program Chairman
Oak Ridge National Laboratory
P. O. Box X, Bldg. 7601
Oak Ridge, TN 37830

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Paul H. Chismar

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, SC 29801

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JOULE-HEATED CERAMIC MELTER

ABSTRACT

A small electric melter was developed to implement studies for converting radioactive waste to glass at the Savannah River Laboratory (SRL). The ceramic-lined, joule-heated melter has been in operation for ten months. During this period, simulated, high-level-waste, calcined materials and frit were processed at rates of 2 to 15 g/min. The melt chamber is 7.6-cm wide, 22.9-cm long and 7.6-cm deep. The total power consumption is 3.5 KVA when the glass processing temperature is 1150°C.

A similar unit will be in operation in FY-1979 in the SRL high-level cells.

INTRODUCTION

The Savannah River Laboratory (SRL) is currently involved in a waste vitrification program to develop techniques for disposing of high-level radioactive waste. A joule-heated ceramic melter was developed to implement these studies. A unit of 3200 g (7 lb.) glass capacity was built and operated in a laboratory hood using simulated high-level waste materials (Table I) in combination with different types of frit materials (Table II). The small size of the melter minimizes sampling and transporting of radioactive material to the laboratory high-level cells.

MELTER DESCRIPTION

Two prototype melters were built to gain operating experience and to develop a system of operations. From these prototypes, a continuous-pouring ceramic melter was designed and fabricated.

A plan and a section view of the melter are given in Figure 1. The dimensions of the unit are:

- Melt chamber: 7.6 cm wide, 22.9-cm long, and 7.6-cm deep. The glass depth is maintained at 6.2 cm.
- Overflow chamber: 3.8-cm wide, 12.7-cm long, and 7.6 cm deep.
- Electrodes in the melt chamber: 1.3-cm thick, 7.6-cm wide, and 7.6-cm high.
- Electrodes in the overflow chamber: 1.3-cm thick, 3.8-cm wide, and 7.6-cm high.

Both sets of electrodes are suspended from the top of the refractories and are powered by separate power supplies. This allows each chamber (melt and overflow) to be regulated at different temperatures.

An *Inconel 690* alloy (Huntington Alloys, Inc., Huntington, W. Virginia) pour spout is mounted on the overflow chamber and protrudes into a separately heated pour chamber. This pour chamber is 15.2-cm wide, 10.2-cm deep and 15.2-cm high. Sample containers are placed in this chamber, and an insulating door is closed to control heat losses. The primary container is suspended on trunnions so the entire melter can be pivoted by a motor-driven chain mechanism. A tilt of six degrees is used for continuous pouring, and a fifteen-degree tilt empties about 90% of the glass from both chambers.

The refractory in contact with the molten glass is *Monafrax K-3* fused-cast chrome (27%) alumina, a product of the Carborundum Co., Niagara Falls, NY. These glass contact refractories are 7.6-cm thick and are mounted in a stainless-steel secondary container lined with *Monafrax K* laying cement.

The primary stainless-steel container is 76-cm wide, 60-cm deep, and 33-cm high. The secondary container is placed on a 12.7-cm base of ceramic fiber insulation in the primary container. Insulation between the side walls of the containers varies from 11.5 cm to 15.2 cm in thickness.

A resistance-heater hood with three silicon carbide heaters is mounted on the back edge of the primary container. An insulated operating hood is mounted on the front of the primary container. Both units are hinged so one hood or the other can be positioned above the chambers by a simple pivot motion. An air-cooled feed tube is mounted in the operating hood and receives the simulated calcined waste and frit from a specially designed feeder unit that delivers 20-g slugs of feed material at time intervals from one to sixty minutes.

MELTER CONTROL

The original concept of control was to use temperature feed-back signals or current control. Voltage control without constant adjustments was too unstable. However, temperature feed-back from the refractory had too much lag time, and thermocouples in the glass had a very short life-expectancy. The constant-current control proved to be the most satisfactory control for the system. This unit comprises a phase-angle-firing SCR power unit controlled by a separate controller having a built-in, manual-adjusted, current control and a manual-adjusted power control. The power control alone was not effective because of the low power draw on the unit, but the current control does an adequate job.

POWER REQUIREMENTS

The power requirements of the small melter are dependent on heat losses because of the physical structure of the melter. As compared to a large melter, where heat loss to the glass drawn off is a large factor, those losses to a small melter are not a significant factor.

Insulation was applied to this small melter to cut the thermal losses from the structure. The insulation helped to prevent thermal shock to the ceramic bricks and also reduced the current density on the electrode to a permissible level of operation.

Power is supplied by a 480-volt, 3-phase transformer that has a 208-volt, 2-phase output. The two output single phases are isolated from each other and from ground.

START-UP TECHNIQUE

For an experimental melter, start-up and restart-up can be frequent due to design changes, power outages, etc. Overhead silicon carbide resistance heaters and suspended electrodes add flexibility to this design. To obtain an operating status with a joule-heated ceramic melter, it is necessary to melt the glass charge between the electrodes. This initial heating is done with a separate power supply which allows the resistances heaters to slowly heat the ceramic refractory bricks and the glass charge to a temperature where the current is conducted through the glass between the electrodes. When this joule-heating becomes self-sustaining, the resistance heaters are turned off and allowed to cool.

The resistance-heater hood is then removed and the operating hood is placed over the chambers. This insulated hood reduces the heat loss and allows gas-samples to be collected. This hood also provides a mounting for the air-cooled feed tube.

Both chambers are then slowly brought up to operating temperatures. The specially designed feeder is moved over the feed tube and the melter is ready to operate as a continuous pouring unit.

FIGURE 2 shows the melter operating in a laboratory hood.

MELTER OPERATION

Premixed feed is loaded into the hopper above the melter and is delivered by a special feeder to the melt surface. The molten glass passes through two 1.2-cm channels (throats) in the center refractory brick to the overflow chamber. The glass rises and is poured into stainless steel beakers by tilting the melter. Filled beakers are slow-cooled in the brick fort beside the melter.

Melting rates were determined by measuring the rate of feed addition (g/delivery) and dividing by the time required for disappearance of the batch into the melt. However, these raw values had to be corrected for differences in surface coverage. Feeds containing sodium carbonate quickly spread across the entire melt surface with a great deal of frothing. Feeds without sodium carbonate stayed in a conical pile (angle of repose $\sim 30°$ from the horizontal, ~ 2 in. across at the base). Thus, melting rates were normalized by dividing by the area initially covered by the batch. The melting rates reported here are the maximum rates which could be achieved in the small-scale melter.

A melting rate less than 6 g/(in.^{2}-hr) implies a residence time greater than the 24 hours currently specified in the reference process. Thus, lower melting rates are unacceptable.

The foam factor, an empirical parameter defined for this work, is a useful measure of foam stability. This parameter characterizes foam behavior in terms of the surface clearing time, normalized to unit weight. The surface clearing time is the time required for the melt surface to clear after a batch of feed is delivered to it. The surface clearing time is usually about twice the time used in determining the melting rate. The foam factor is derived from this by dividing by the weight of the batch, and has units of minutes/g.

INITIAL EXPERIMENTAL RUNS

Initial small melter experiments have demonstrated that only high aluminum and average sludge-glasses produce persistent foams at 1150°C (Table III). The foam persistence of average sludge melts increases with the sodium carbonate content of the feed (Table IV). Foaming causes a decrease in the melting rate. Foam persistence is probably due to the presence of ferrite-spinel crystals which increases the effective viscosity of the molten liquid in the foam. The melting rates were increased by increasing the melt temperature, by using other low-melting glass-formers (sodium borate, for example) along with sodium carbonate, or by reducing the titanium oxide content of the frit. For all tests with glass frit, the frit was ground finer than 10 mesh (2 mm). Surface coverage was non-uniform in all cases. Because the melting rates assume uniform coverage over the area covered by the batch, the calculated melting rate numbers reported are biased toward the low (conservative) values.

MELTER PERFORMANCE

The melter has been in operation for ten months. Three shutdowns have occurred during this period; once due to a power failure, and twice for repairs and changing the power transformer unit. Evidence of current leakage between the chambers through the channels could be observed by temperature variations of the glass in the chambers and by current readings on the electrode input leads. Serious electrode damage caused shutdown of the melter. Erosion in the channels between the chambers was greater than would be expected from normal erosion due to glass flow. The electrode damage and extraordinary erosion were attributed to this current leakage. A new transformer was installed and repairs were made to the melter. Since the unit was restarted, no apparent current leakage has been detected from input current readings, and the glass temperatures have been evenly distributed across the chambers. The constant-current controls maintain a glass temperature within ten degrees of the desired temperature at all times. The temperatures on the air-cooled primary container range from 80 to 120 degrees centigrade. All design changes have been incorporated in the melter to be installed in the SRL high-level cells.

ACKNOWLEDGMENT

M. J. Plodinec of the Savannah River Laboratory developed the empirical foam factor for this system.

TABLE I. Composition of Simulated Sludges

Component	Composition, Wt. % High Iron	Average	Composite	High Aluminum
Fe_2O_3	71.6	48.9	33.7	6.1
Al_2O_3	6.5	29.0	49.4	87.6
MnO_2	4.8	13.1	11.0	5.0
CaO	4.9	3.4	3.5	0.4
NiO	12.2	5.6	2.4	0.9

TABLE II. Frits

Component	Composition, Wt % 21	21A	21B	21BX
SiO_2	52.5	62.3	60.4	68.3
Na_2O	18.5	3.3	6.3	7.1
B_2O_3	10.0	11.9	11.5	13.0
TiO_2	10.0	11.9	11.5	-
CaO	5.0	5.9	5.7	6.4
Li_2O	4.0	4.7	4.6	5.2

TABLE III. Effect of Sludge on Foam Persistence

Sludge[a]	T, °C	Foam Factor	Melting Rate, g/(in.^{2}-hr)
Composite	1150	0.4	7.9
	1180	0.3	8.0
High Iron	1150	0.8	10.4
	1180	0.5	10.4
High Aluminum	1150	2.6	4.3
	1180	1.1	5.8
Average	1150	2.2	5.2
	1180	0.6	8.3

a. All melts contained 25 wt % of the indicated sludge, and the equivalent of 75 wt % Frit 21, made from Frit 21B and sodium carbonate.

TABLE IV. Average Sludge Melts

Frit Form	Sludge Amount	T, °C	Foam Factor	Melting Rate, $g/(in.^2\text{-}hr)$
21A + Na_2CO_3	27.5	1150	2.0	3.3
(85% Na_2O from Na_2CO_3)		1180	1.0	4.9
21B + Na_2CO_3	27.5	1150	2.2	5.2
(70% Na_2O from Na_2CO_3)		1180	0.7	8.9
21 (No Na_2CO_3)		1150	0.8	43.2
		1180	0.6	52.0
21B + Na_2CO_3	25	1150	2.2	5.2
		1180	0.7	8.3

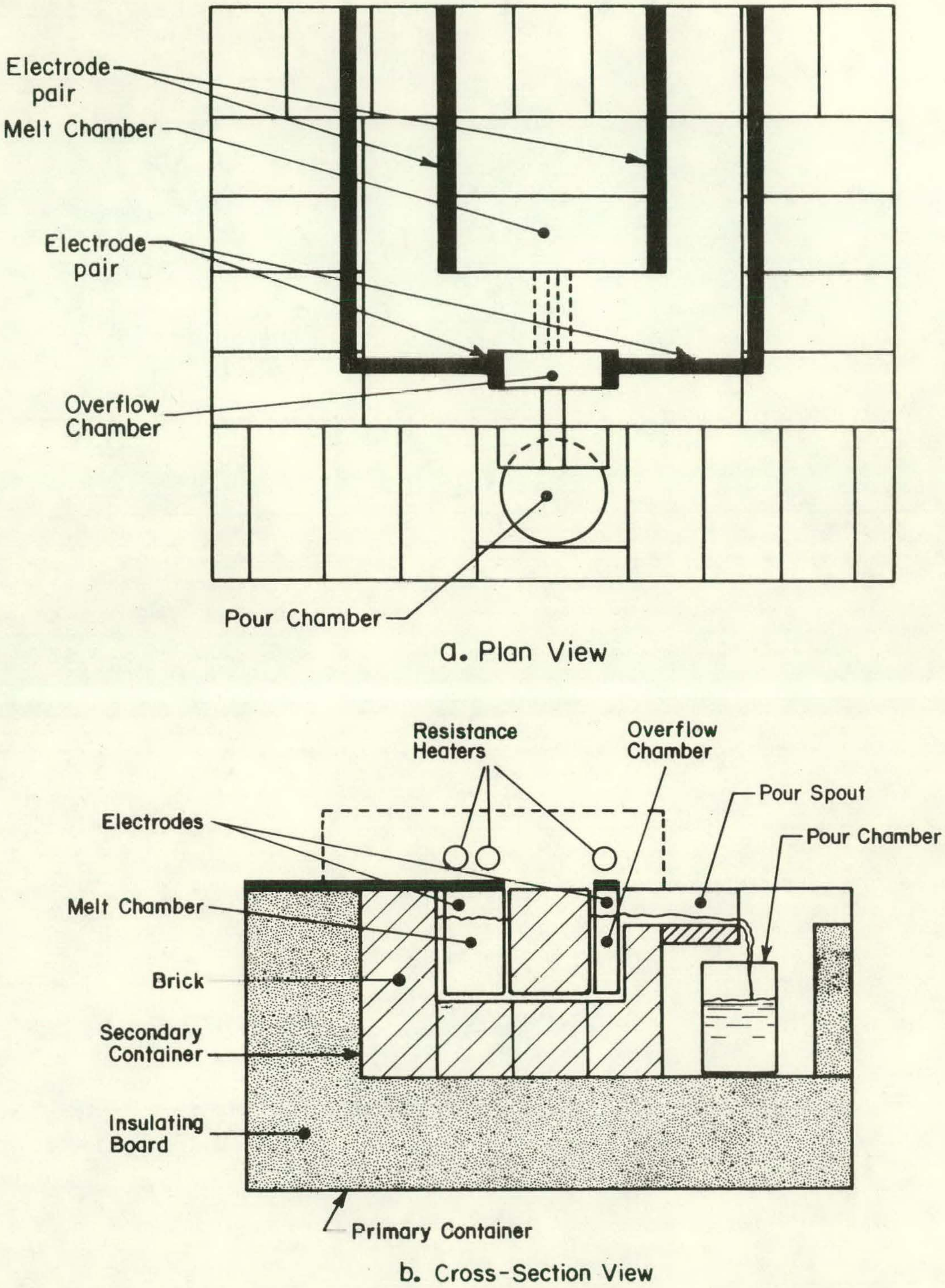

FIGURE 1. Plan and Cross-Section Views of Melter

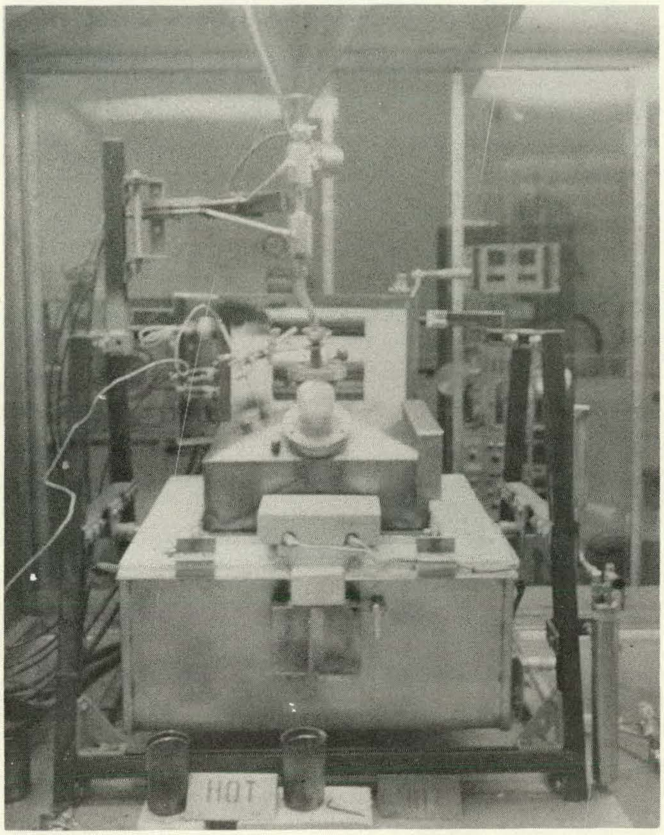

FIGURE 2. Small Scale Electric Melter