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NUCLEAR WASTE TREATMENT PROGRAM

PNL--6259

PILOT-SCALE CERAMIC MELTER
1985-1986 REBUILD

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SUMMARY

The pilot-scale ceramic melter (PSCM) developed and tested by Pacific Northwest Laboratory (PNL), has been an important part of the waste vitrification technology programs for the U.S. Department of Energy (DOE). The melter, which was operated from April 1978 through September 1985, performed well over this extended period, producing 34,000 kg of glass for several waste management programs. By mid-1985, several processing problems indicated the need to drain and inspect the melter and make needed repairs. The melter was subsequently dismantled, and the damaged and corroded components were repaired or replaced. The PSCM rebuild ensures that the melter will be available for an additional three to five years of planned testing.

When the PSCM was dismantled and inspected, the melter tank walls, electrodes, and lid refractory were found to be damaged from the corrosion caused by five years of exposure to molten glass and fumes at high temperatures. Measurements indicated that the greatest corrosion occurred to the tank walls near the center of the melter at the glass interface. Corrosion of the refractory used in the tank walls was consistent with the expected corrosion rates for the five years of operation of the PSCM since its last refurbishment and confirmed the suitability of the fused-cast chrome alumina brick for this service.

An analysis of the corrosion products and the failed electrodes indicated that the electrode bus connection welds may have failed due to a combination of chemical and mechanical effects. The electrodes were replaced with a design similar to the original electrodes, but with improved electrical bus connections. The implications of the PSCM electrode corrosion evaluation are that, although Inconel 690 has excellent corrosion resistance to molten glass, corrosion at the melt line in stagnant regions is a significant concern. Future melter designs should address this corrosion problem by placing the electrodes in the walls or by other design modifications that minimize dead area glass contact with Inconel components at the melt line.

Several functional changes were made during the rebuild to bring the PSCM design closer to current melter design philosophy and to improve operational

performance. These changes included increases in wall and floor insulation to better simulate well-insulated melters, a decrease in the lid height for more prototypical plenum and off-gas conditions, and installation of an Inconel 690 trough and dam to improve glass pouring and prevent glass seepage. These modifications will help extend the life of the PSCM and increase its usefulness in further testing.

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INTRODUCTION

The pilot-scale ceramic melter (PSCM) is one of several prototype waste vitrification systems developed and tested by Pacific Northwest Laboratory (PNL). The PSCM is a joule-heated glass melter that is directly fed a slurry of glass formers and simulated high-level waste. Glass becomes an excellent electrical conductor at higher temperatures. By applying a voltage to the electrodes, an alternating electrical current will flow through the glass. Heat is produced in the glass as energy is dissipated by the joule-heating effect. By controlling the voltage applied to the electrodes, the current flow and the resultant glass temperature are controlled. The incoming glass formers and waste are melted together, and the mixture overflows by gravity into a waste canister.

The PSCM, originally designated the calcine-fed ceramic melter (CFCM), was designed to process glass frit and calcined waste material from the spray calciner. The melter was also designed to move east and west on a trolley assembly so that the stationary calciner could be decoupled from the melting process. Figure 1 shows the melter/calciner configuration. It was later demonstrated that eliminating the supernate calcination step and directly feeding a slurry of waste and glass frit to the melter would greatly simplify the waste treatment process (Bjorklund 1981). This configuration is now the reference glass melter mode of operation.

The original melter tank, which was first used in April 1978, was 71 cm wide by 117 cm long for a surface area (excluding electrodes) of 0.76 m^2 . The glass volume was 240 L, and the tank could be tipped to transfer glass out of the melt cavity. The melter construction utilized Inconel 690 and fused-cast chrome-alumina (Monofrax K-3®) block construction in areas in contact with glass for their excellent resistance to corrosion. Because the K-3 has a relatively high thermal conductivity, it was backed by zirconia-alumina paving blocks and other low-conductivity ceramic materials. Between November 1979 and November 1980, the CFCM refractories were replaced and some modifications to

®Monofrax K-3 is a tradename of Carborundum/Sohio Engineered Materials, Refractories Division, Keasbey, New Jersey.

the feed and off-gas systems were made for use in direct slurry feeding studies. At this point, the melter was renamed the PSCM and could no longer be coupled to the calciner.

FIGURE 1. Calcine-Fed Ceramic Melter

PSCM OPERATING HISTORY

The PSCM operated from April 1978 through September 1985 with one major rebuild and rebricking in 1979-1980. Since 1980, there have been several shutdowns during which the lid, electrodes, or other components have been modified. The following sections briefly describe the operational and shutdown periods from 1978 to 1985 emphasizing changes made to the melter from experience gained during operation. The appendix gives a brief chronology of the PSCM experiments and shutdowns from 1978 to 1985.

OPERATIONAL PERIOD 1 (April 1978-October 1978)

At the end of the initial testing, the melter was shut down for about six months for inspection and repair (Dierks et al. 1980). Some widening of the block-to-block refractory joints had occurred on the melter tank walls and the square corners of the discharge throat showed some rounding. No corrosion was detected on the electrodes. The lid was modified to improve the feed nozzle area corrosion resistance by adding a cooling collar to the feed inlet.

During the shutdown, an Inconel 690 liner was added to the underflow discharge throat to prevent further corrosion in this area. In addition, feet were welded onto the electrodes to increase the power density on the floor of the melter. This change was intended to improve glass circulation and limit the sludge accumulation on the melter floor. A detailed description of these modifications with sketches and photographs is provided in Dierks et al. 1980. Figure 2 shows the melter configuration with top-entry electrodes and the Mark II lid.

OPERATIONAL PERIOD 2 (April 1979-November 1979)

Following an eight-month operating period in which 51,000 kg of glass was produced, the melter was shut down and examined (Dierks et al. 1980). Significant corrosion had occurred to the lid refractory and feed nozzle area, viewports, and tank refractory. There was no measurable corrosion to the melter floor or the overflow section. The electrodes showed minor corrosion. The

FIGURE 2. PSCM with Top-Entry Electrodes

outer corners of the feet and back edges were still sharp, but the front vertical edges showed a slight rounding. Less than 1% of each electrode mass was missing.

The tank refractory corrosion was serious and required the replacement of the exposed layers of K-3 and zirconia-alumina brick. The horizontal configuration of the K-3 brick allowed attack at the horizontal joints between the brick. Gas bubbles caused "upward drilling" into the bottom face of the upper brick. Although some glass penetrated the K-3, no corrosion could be detected on the zirconia-alumina or Alfrax® backup ceramics. The slab coolers between the tank and the overflow section successfully prevented glass migration into

®Alfrax is a tradename of Carborundum/Sohio Engineered Materials, Refractories Division, Keasbey, New Jersey.

the overflow section of the melter. The zirconia-alumina brick above the K-3 was badly spalled, apparently due to thermal cycling and contact with glass foam or feed material splatter.

The Inconel 690 underflow discharge throat liner was severely attacked; approximately 10% of its mass was lost. In spite of the throat liner, corrosion occurred to the K-3 riser block by upward drilling of trapped gas bubbles between the liner and the brick.

The rebuild of the melter (Bjorklund 1982) sought to correct many of the problems noted above. One of the most significant changes was that the bottom row of K-3 bricks was placed vertically so that there were no horizontal joints beneath the glass surface. The bricks were also cemented together with K-3 mortar. The melter tank interior dimensions were changed to 69 cm by 117 cm, resulting in a melter surface area of 0.73 m^2 and a glass holdup volume of 255 L. The riser section, shown in Figure 3, was fabricated from a single monolithic K-3 block with a 30° upward sloping discharge throat entrance.

A new lid was installed that provided additional plenum space above the tank and better under-lid insulation to minimize lid corrosion. The electrodes were modified (Figure 4) with wedge-shaped feet to prevent sludge accumulation on the electrode feet and to direct some of the electrical current flow away from the tank walls toward the center and floor of the tank. A recording short-to-ground monitor was also installed.

OPERATIONAL PERIOD 3 (November 1980-July 1981)

During this period of operation, direct slurry feeding of the melter was used for the first time. Three melter experiments were made, producing 7300 kg of glass. At the end of the third run, the melter was shut down for inspection and to install a new lid (Bjorklund 1982). Little corrosion of the tank ceramics or electrodes was noted.

During the shutdown from July to November 1981, a new lid (Mark IV) was constructed and installed. The new lid increased the idling freeboard above the glass level from 37 cm to 117 cm and allowed two banks of electrical radiant heaters positioned horizontally in the plenum space to be installed.

a) Front

b) Back

FIGURE 3. Front and Back Views of the Riser Block

FIGURE 4. Electrodes Modified with Wedge-Shaped Feet

The new lid was also equipped with two microwave penetrations in the top for studies on microwave startup and feed rate boosting. Because of the taller lid, the electrodes and tank were modified for side entry of the electrode bus connections.

At the same time, the electrode feet fillets were removed, leaving the original 5 cm x 15 cm feet at the bottom of the electrodes. The electrode bus connections were modified, as shown in Figure 5, so that electrical connections could be made through the sides of the melter box instead of through the lid. Figure 6 shows the melter, lid, plenum heaters, and side-entry electrodes.

OPERATIONAL PERIOD 4 (November 1981-July 1982)

Following the completion of the PSCM-8 run, the melter was drained and inspected (Ethridge 1983). Little glass or sludge remained in the melter; but a significant number of metallic nodules, resulting from processing glass under

FIGURE 5. Electrodes Modified for Side Bus Entry

excessive reducing conditions, were removed from the floor. The throat block and other refractories were still in excellent condition. On the riser block face, a hairline crack ran vertically from the centerline of the throat, but no enlargement was seen anywhere along the crack.

The electrodes showed some corrosion in the portion exposed to plenum vapors. Damage included spalling and pitting. The off-gas port exhibited severe pitting. The spray coating of 80% Ni/20% Cr applied on the previous shutdown was not effective in preventing attack.

The melter was reassembled without major modifications after a brief one-month shutdown. Only the heater units on the freeze valve were replaced.

OPERATIONAL PERIOD 5 (August 1982-September 1985)

At its shutdown in September 1985, the PSCM had been in service for nearly five years since its refurbishment in 1980. The melter performed well over this extended period, producing over 34,000 kg of glass. By mid-1985, however, there were several indications that the PSCM was experiencing problems

FIGURE 6. PSCM with Side-Entry Electrodes

resulting from this long period of operation. Visual inspection through the microwave ports revealed that the electrodes were approaching failure. In addition, a portion of the lid refractory had fallen into the melter and the tip of the pour trough was deteriorated, causing glass melt pouring problems.

These conditions did not require the immediate cessation of testing. However, a decision was made in mid-1985 to drain and inspect the melter and make needed repairs. Damaged and corroded components were repaired or replaced to ensure that the PSCM would be available for planned testing over the next three to five years.

A rebuild plan and schedule were prepared and design changes were made to the PSCM during this shutdown. Detailed descriptions of the melter inspection and actual modifications are presented in the following sections. Although changes to the PSCM design were necessary to replace damaged components, the design changes were oriented toward a closer correlation with current melter design philosophy. Functional changes to bring the PSCM design closer to current melter designs included:

- wall and floor insulation increases - This change allowed the PSCM to better simulate a well-insulated melter. Thermowells were installed behind the K-3 brick to monitor heat transfer.
- lid height decrease - The plenum heaters were removed, and the lid was lowered since the extra space needed for heating is not believed to provide any benefit in melter operational performance. This change will give more prototypic plenum and off-gas conditions in the PSCM.
- dam and discharge trough - The PSCM refractory discharge trough was replaced with Inconel 690 and an increased dam was embedded in the refractory between the discharge section and melting cavity to prevent glass seepage. The slope of the discharge trough was increased from 5° to 20° for faster draining.

1985 MELTER INSPECTION

The melter was drained and inspected in September 1985; however, the accumulation of sludge prevented unassisted draining. An air lance was used to clean the drain hole area on the side of the melter tank to initiate glass flow. A 2- to 5-cm-thick layer of sludge and glass remained on the floor of the melter after the glass had drained. No metal nodules of the type seen in previous shutdowns were noted. Significant corrosion had occurred to the melter walls, lid, and electrodes; and the pour trough required replacement.

ELECTRODES

Although the general condition of the electrode faces and feet appeared good, large vertical cracks had formed in the electrodes and significant corrosion was evident on the back sides of both electrodes (next to the wall) near the glass operating level. Figure 7 shows the condition of the electrodes as removed from the melter. In addition, the accumulation of material behind the electrodes, possibly corrosion oxides, had pushed the electrodes away from the tank walls, causing failure of many of the bus weld connections at the top of the electrodes. Figure 8 compares the melter tank and electrodes at the July 1982 shutdown with the September 1985 shutdown.

Sand blasting removed the corrosion products and exposed the severe corrosion that had occurred to the electrodes. (The electrodes are shown again in Figure 9 after sand blasting.) The most severe corrosion can be seen at the bus connections and on the rear of the electrodes at the glass interface level (approximately at the electrode midpoints). As shown in a close-up photograph of the rear of the south electrode (Figure 10), the vertical cracks penetrated the electrode body. The electrode thickness was less than 3 cm in the area of the crack.

A close-up of the front of the south electrode foot shows significant pitting (Figure 11). The condition of the north electrode was similar to that of the south electrode with slightly higher corrosion at the bus connection. The north and south electrodes weighed 187 kg and 174 kg, respectively, after sand blasting. This compares with 195 kg and 193 kg when the electrodes were

a) North - Front

b) North - Back

a) South - Front

b) South - Back

FIGURE 7. Condition of Electrodes as Removed from the PSCM During the 1985 Inspection

a) After 1982 Shutdown

b) After 1985 Shutdown

FIGURE 8. Appearance of Melter Tank After 1982 Shutdown and After 1985 Shutdown

a) North - Front

b) North - Back

a) South - Front

b) South - Back

FIGURE 9. Electrodes After Sand Blasting

FIGURE 10. Back View of the South Electrode

FIGURE 11. Front View of the South Electrode

installed in October 1981 (62,000 kg of glass was produced in 47 months). The total weight decreased by 6.8% since the electrodes were last modified and installed in November 1981. This compares with a 0.4% decrease in weight between November 1980 and July 1981 (7300 kg of glass was produced in 8 months).

Previous corrosion studies of Inconel 690 in melter environments have indicated very good corrosion resistance under reducing conditions. PNL laboratory tests on a wide assortment of glasses indicated static corrosion rates of 0 to 15 $\mu\text{m}/\text{day}$ as shown in Table 1 (Brouns and Partain 1986).

Inconel electrode corrosion data from other development melters confirm the favorable laboratory corrosion resistance of Inconel 690. The Savannah River Plant (SRP) small cylindrical melter (SCM) was examined in 1982 and showed excellent electrode corrosion resistance. However, portions of the melter constructed from Inconel 690 above the melt line experienced severe corrosion (Allen, Iverson, and Plodinec 1985). The SRP large slurry-fed melter

TABLE 1. Comparative Static Corrosion Rates of Candidate Electrode Materials

Material	Corrosion Rate, $\mu\text{m/day}$ ^(a)					
	Static Testing at 1050°C		Static Testing at 1150°C		Powered at 0.78 A/cm ² (1050°C)	
	Flux Line	Submerged	Flux Line	Submerged	Flux Line	Submerged
Inconel 690	0 to 15	0 to 5	0 to 7	0 to 7	4 to 11	0 to 9
Inconel 601	4 to 18	0 to 15	0 to 42	0 to 33	18	18
Tin oxide	5 to 15	2 to 9	11 to 18	0 to 15	--	--
304-L	9 to 58	0 to 69	31 to 203	9 to 100	90	90

(a) Ranges measured for six different glass compositions in seven-day static tests.

(LSFM) was shut down and examined in 1984 after two years of operation at 1100 to 1150°C (Iverson and Bickford 1985). The largest decrease in electrode thickness was 0.6 cm (8 $\mu\text{m/day}$) near the top of the electrodes. A corrosion rate of 29 $\mu\text{m/day}$ was seen on Idaho National Engineering Laboratory (INEL) melter electrodes after 18 weeks at 1000 to 1100°C (Gombert and Pong 1980). However, the glass contained significant calcium fluoride. While none of these electrode corrosion data show the severe attack experienced in the PSCM, many accounts indicated significant corrosion of exposed Inconel 690 surfaces in the plenum areas.

Barnes and Larson (1981) found a maximum corrosion rate of 3 $\mu\text{m/day}$ for the electrodes in the PSCM in 1980 after three years of operation. While the submerged electrodes experienced little corrosion, the Inconel materials in the plenum showed severe corrosion due to halides and sulfates in the feed stream (Dierks et al. 1980). This corrosion by oxidizing materials may have application to the corrosion experienced at the rear of the PSCM electrodes.

Table 2 gives the results of corrosion product analyses on samples taken around the PSCM electrodes during the 1985 rebuild. Corrosion products removed from below the south electrode bus bar show much higher Fe and Mn to Cr ratios than Inconel 690. Corrosion product samples from both electrodes showed Ni and Cr levels significantly below Inconel 690. The F, Cl, and S levels in the corrosion products were below 0.2% in all but the north electrode corrosion

TABLE 2. Analysis of Electrode Corrosion Products

Sample Locations	Concentrations, %									
	Al	Cr	Fe	Mn	Ni	Na	Si	F	Cl	S
Sludge tank bottom	4.23	8.48	8.54	0.75	1.82	7.80	15.80	0.04	0.16	0.02
South electrode (5 cm below bus bar)	4.98	2.12	21.00	4.96	6.72	4.91	7.55	0.03	0.06	0.54
North electrode bus bar	2.51	21.60	10.30	2.15	7.72	3.81	7.80	0.01	0.03	0.20
Inconel 690	0.20	30.00	9.40	0.14	60.00	--	0.13	--	--	--

sample, which was 0.5%. The F, Cl, and S levels were close to the concentrations of these elements in the sludge removed from the melter floor. Although these analyses are indicative of corrosion, they do not give strong evidence of a particular corrosion mechanism. Unfortunately, most of the corrosion material was sand blasted from the backs of the electrodes before samples were taken and these analyses are inconclusive.

A possible mechanism for the severe corrosion seen at the rear of the electrodes is suggested by the appearance of the electrodes after sand blasting. As the electrodes were pushed away from the walls, the mechanical stress (and possibly heating and cooling cycles) opened small cracks at the cooling channel welds on the back of the electrodes and breached the vertical holes drilled for weight factor and specific gravity measurements. The cooler stagnant area behind the electrodes allowed an accumulation of oxidizing salts, especially at the melt line, which accelerated the attack of the Inconel 690.

LID SHELL AND REFRACTORY

As can be seen in Figure 12, a portion of the lid refractory material above the overflow section had fallen into the melter tank. This photograph shows exposed Inconel hangers on the west wall of the upside-down lid. Lack of support for this section of refractory is credited with its failure. In the

FIGURE 12. Lid Refractory

previous lid design, the west wall extended over the melter tank with no support from below. The Inconel 690 hangers failed to hold the lid ceramic to the shell and part of the lid fell into the melter tank. This problem was addressed by using ceramic hangers in the new lid design.

MELTER TANK REFRACTORY

The K-3 brick on the melter walls showed some corrosion consistent with the five-year operating life of the melter refractory. Figure 13 shows that the K-3 brick was attacked both above and below the glass line. East to west wall measurements taken in 1980, 1981, and 1985 showed erosion/corrosion of the walls and indicated that the walls had shifted east with reference to the melter tank flanges. Figure 14 shows the east and west wall profiles at a point 53 cm south of the north wall (5 cm north of the tank centerline). The same figure also shows the total corrosion at the same location when the east and west wall measurements are combined. These measurements indicate the most severe corrosion of the brick occurred 25 to 30 cm above the melter floor.

FIGURE 13. East Wall of Melter Tank

FIGURE 14. Changes in Melter Wall Measurements

Figure 15 shows the total change of the east and west walls at six locations along the melter tank. The north-south locations of the measurement points are given in Table 3. These measurements show that the corrosion was more pronounced at the center of the tank than on the ends near the electrodes.

Measurements of individual bottom row K-3 brick confirmed that 0.8 to 1.5 cm of material had corroded from the east and west walls in a band 10 to 20 cm high centered about 30 cm above the melter floor. Thus, the maximum wall corrosion occurred about 10 cm below the nominal 40-cm glass operating level. Corrosion of the walls was most severe just below the glass surface where the largest convection currents are present due to convective heat transfer to the cold cap.

The K-3 refractory corrosion rates have been measured by a number of investigators (Brouns and Partain 1986) in commercial and defense glass. Between 1050°C and 1150°C, the static corrosion rates were generally between 10 and 20 $\mu\text{m/day}$ at the melt line and less than 10 $\mu\text{m/day}$ below the glass surface. The PSCM K-3 corrosion rate in the 1600 days of operation since the PSCM was last rebricked in 1979-1980 was 4 to 8 $\mu\text{m/day}$ based on the wall and individual block measurements. This indicates that the PSCM K-3 corrosion resistance was satisfactory and within expected performance limits.

Some glass penetrated the K-3 brick layer, especially on the west wall (Figure 16). The zirconia-alumina brick was not attacked and prevented the glass from penetrating further.

The melter K-3 floor brick also required replacement, although corrosion was less severe there than on the walls. Measurements of the degree of corrosion on the floor were not possible because the sludge was removed from the floor by chipping. The refractory materials beneath the K-3 brick were in good condition, although glass had penetrated the K-3 layer in the freeze valve area. Figure 17 shows the melter tank after the walls and the K-3 floor blocks were removed. The glass that had penetrated the K-3 floor brick is the black patch in the center of the tank.

FIGURE 15. Total Change in Melter Wall Measurements

TABLE 3. Reference Points for Wall Corrosion Measurements

<u>Location (a)</u>	<u>Distance from North Wall, cm</u>	<u>Distance from South Wall, cm</u>
1	13	103
2	23	93
3	53	63
4	63	53
5	93	23
6	103	13

(a) See Figure 15 for locations.

FIGURE 16. Melter Tank After K-3 Wall Removal

FIGURE 17. Melter Tank After Wall and Floor Removal

RISER BLOCK

Width measurements indicated that the riser block was subjected to the same erosion/corrosion as the rest of the east and west walls (Figure 18). The riser block also exhibited a 1.3-cm concave band about 10 cm below the glass level approximately 15 cm high. Figure 19 shows the throat entrance as it appeared in the 1982 shutdown and after the riser block was removed in 1985. The throat entrance widened from an original 5.0 cm, to 6.4 cm in 1982, and to 7.4 cm in 1985. The throat entrance was considerably wider at the bottom when removed in 1985. Although there was no indication of upward drilling by gas bubbles on the upper surface of the throat, Figure 19 shows that the throat entrance also grew vertically by about 1.5 cm.

FIGURE 18. Riser Block Measurements

OVERFLOW TROUGH

The Inconel tip on the pour trough was removed in June 1985 because of corrosion. The main K-3 portion of the pour trough was in good condition, although there was fracturing of the trough at the overflow face. The entire trough was removed to replace the pour tip. Figure 20 compares the trough as it appeared in the 1985 shutdown with its "as-installed" appearance.

a) 1982

b) 1985

FIGURE 19. Riser Block Throat Entrance After 1982 Shutdown and After the Riser Block Was Removed in 1985

a) 1980

b) 1985

FIGURE 20. Glass Discharge Trough as Installed (1980) and After the 1985 Shutdown

DESIGN CHANGE DETAILS

Details of the design changes to the PSCM are presented below with sketches or drawings where applicable. Design changes were made to the melter tank, overflow section, electrodes, and lid. A photograph of the modified PSCM is shown in Figure 21.

HEAT TRANSFER

Heat transfer calculations were made to determine the refractory configuration necessary for the PSCM to simulate the heat transfer characteristics of a well-insulated recently constructed furnace design such as the radioactive liquid-fed ceramic melter (RLFCM). To correlate the heat transfer data, the peak heat fluxes through the back wall, floor, and side wall of the RLFCM were calculated from steady-state temperature data. Then, several combinations of ceramic materials were used to calculate equivalent heat fluxes in the PSCM. The peak heat fluxes through the RLFCM surfaces are shown in Table 4.

The iterative solution using various combinations of Duraboard®, Alfrax-66, zirconia-alumina, and K-3 brick in the PSCM resulted in the configuration shown in Table 5.

MELTER CAVITY MODIFICATIONS

Figure 22 is an east-west cross section of the melter tank looking north. The sketch shows the brick layout, overflow trough and riser block, and the north electrode. The major differences between this design and the previous design is that zirconia-alumina brick was used to raise the floor 10 cm and an additional 1.25 cm (1/2 in.) of Duraboard was added to the melter walls. The new melter tank with the floor and riser block in place is shown in Figure 23. Figure 24 shows the melter tank after the walls were installed, but with the wall support forms still in place.

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FIGURE 21. Modified PSCM

TABLE 4. RLFCM Calculated Heat Fluxes

<u>Melter Surface</u>	<u>Heat Flux, W/m²</u>
Melter west wall	3062
Melter north and south walls	3646
Melter floor	2205

TABLE 5. Recommended Refractory Materials for PSCM Rebuild

<u>Metal Surface</u>	<u>Material</u>	<u>Original Thickness, cm</u>	<u>New Thickness, cm</u>
Melter west wall	Monofrax K-3	10.0	10.0
	Zirconia-alumina brick	7.5	7.5
	Alfrax-66	7.5	6.4
	Duraboard	1.25	2.5
Melter north and south walls	Inconel electrode	5.0	6.4
	Monofrax K-3	10.0	10.0
	Alfrax-66	7.5	7.5
	Duraboard	1.25	2.5
Melter floor	Monofrax K-3	10.0	10.0
	Zirconia-alumina brick	6.4	16.5
	Ramming mix	7.5	7.5
	Duraboard	2.5	2.5

Only the K-3 bricks were removed from the melter floor. The existing ramming mix, Duraboard, and zirconia-alumina brick were left intact. A 10-cm layer of zirconia-alumina brick was added on top of the existing zirconia-alumina and K-3 brick was installed on top of that. In the melter cavity walls, an additional 1.25-cm (1/2-in.) layer of Duraboard was added and the single layers of zirconia-alumina, Alfrax-66, and K-3 brick were replaced. One of the used K-3 wall blocks was reinstalled in the west wall so that additional long-term corrosion data could be obtained on the next rebricking. No changes were made to the melter tank shell.

- K-3 Refractory
- Zirmul Refractory
- Ramming Mix
- Alfrax 66 Castable Refractory
- Alfrax 57 Castable Refractory
- Duraboard Insulation

FIGURE 22. Melter Cavity and Overflow

FIGURE 23. Melter Floor and Riser Block

Figure 24. Melter Walls In Place

The net result of these changes to melter operation will be lower heat losses through the PSCM walls and floor and increased refractory and electrode temperatures. Mixing patterns will be closer to those of better-insulated melters, giving similar refractory corrosion and crystal formation rates. Minor increases in the PSCM corrosion rates are expected but are outweighed by the improved melter performance. The new tank dimensions are 115 cm by 74 cm. The melt surface area is 0.76 m^2 after the area occupied by the electrodes is subtracted. The new glass volume is 288 L.

OVERFLOW SECTION MODIFICATIONS

The overflow riser block was replaced because of corrosion. The design of the discharge throat is very similar to the previous riser block throat (Figure 25). The vertical riser hole was moved about 3 cm closer to the melt cavity to increase the overflow glass temperature slightly, and the block was keyed to mate with the dam and overflow trough.

The overflow trough was fabricated entirely from Inconel 690 instead of K-3 brick (Figure 26). The new trough was welded to a 1.3-cm (1/2-in.) block, which, in turn, was welded to a 0.6-cm (1/4-in.) Inconel 690 dam plate as shown in Figure 27. The Inconel trough assembly is expected to be more reliable than the previous design. The overflow trough slope was increased from 5° to 20° to match the RLFCM design. A thermowell attached to the trough will monitor the actual trough temperature, which will be used as a process control parameter. The fire brick surrounding the overflow section was left intact. The air coolers were reinstalled on the east side of the dam with additional insulation between them.

The new Inconel 690 dam will enhance PSCM performance by permitting a higher glass discharge temperature, thereby improving glass pouring. Without the dam, the previous PSCM throat and riser had to be operated at a temperature low enough to prevent the molten glass in the melter tank from seeping through the east wall brick into the discharge area. The dam will provide a barrier to prevent molten glass from penetrating into the discharge area so the throat and riser can be operated at a temperature where the glass viscosity is lower for better flow from the discharge trough.

FIGURE 25. Front and Side Views of Modified Riser Block

FIGURE 26. New Overflow Trough

FIGURE 27. New Overflow Trough and Dam

ELECTRODES

The electrode design (Figure 28) is similar to the previous design, but uses 6.4-cm (2-1/2-in.) Inconel 690 plate instead of 5-cm (2-in.) plate. The thicker plate was available and avoided a 16-week vendor delivery time. The electrode foot is 13 cm wide; the previous foot was 15 cm wide. The 6.4 cm x 13 cm foot will give the same foot-to-face current density as the present RLFCM electrodes.

The electrodes are about 15 cm taller in the center to allow the power bus bar to be connected directly to the electrode instead of welded to an attaching plate as in the previous design. Figure 29 shows the electrodes as installed in the melter tank. The new design provides greater structural strength between the electrode and the bus bar than the welded design.

FIGURE 28. New Electrode Design

The bus bar connections are offset from the center of the electrodes because the east wall of the melter tank has been shifted to the east by about 8 cm. The bus connection penetrations in the north and south tank walls were not changed. A thermowell was added to each electrode to provide temperature data for heat flux calculations and materials evaluation.

FIGURE 29. New Electrodes as Installed in the Melter Tank

LID DESIGN MODIFICATIONS

The new melter lid (Figure 30) covers both the melter cavity and the overflow section. The one-piece lid design eliminates the need for a lid support flange that extended from north to south above the overflow section. The support flange had warped severely, was a source of inleakage, and did not provide adequate lid refractory support; it was removed from the melter during the inspection phase.

The square microwave insertion ports were removed from the lid. The feed port was moved to the center of the melter tank and the off-gas and emergency vent ports are now in the south-east and north-east corners of the plenum. The off-gas and emergency vent nozzles are 15 cm in diameter instead of the previous 10 cm. Also, the height of the plenum space has been decreased. The height of the plenum above the melt surface is now about 60 cm, which is similar to the RLFCM. Additional ports were added for instrumentation.

FIGURE 30. Modified Melter Lid Design

A large section in the center of the lid is removable to allow for better tank access and sampling. The underside of the new melter lid shell before installation of refractories is shown in Figure 31.

As shown in Figure 32, the lid refractories are now supported by ceramic anchors. The anchors are attached to the lid shell by Inconel 690 clips. This modification will provide better support and corrosion resistance than the Inconel hangers used in previous lids. Figure 33 shows the lid insert that covers the overflow area.

FIGURE 31. Modified Melter Lid Shell

FIGURE 32. Modified Melter Lid with Ceramic Anchors

ELECTRICAL/INSTRUMENT CHANGES

The main power cables to the melter electrode were in only fair condition and posed a safety concern. The cable insulation was brittle and had deteriorated from exposure to heat, especially near the melter. Past practice had been to replace only the cable section nearest the melter with a short spliced section. Localized heating and failure have occurred at the splices in the past. For these reasons, the entire cable was replaced and a junction box was added near the melter for easier replacement of that cable section during future shutdowns.

All of the internal melter thermocouples and thermowells were replaced. A thermocouple termination panel was installed near the melter. The existing thermocouple cable runs to the data acquisition equipment were left intact, but the thermocouple leads near the melter that have deteriorated because of exposure to heat were replaced. As with the electrode cables, only a short length of thermocouple cable will be replaced during future shutdowns.

FIGURE 33. New Overflow Area Insert

OFF-GAS SYSTEM MODIFICATIONS

No major changes were made to the off-gas system, although the off-gas nozzle and the emergency vent nozzle diameters were changed from 10 cm to 15 cm for increased flexibility. It was necessary to modify the emergency vent line and the jumper between the melter lid and the venturi scrubber because of the changes to the lid. The venturi scrubber and other off-gas equipment were not modified.

STRUCTURAL SUPPORT MODIFICATIONS

Calculations were made to determine if the current structural support would limit any proposed design changes because of the increased melter weight. The calculations exposed an oversight in the melter design upgrade of five years ago. Before this shutdown, the melter sat in a carriage assembly that rolled along a track on the second floor. The carriage members that transmit the weight from the melter/carriage assembly to the rails were not adequately oversized to safely support the existing melter and carriage weight. In addition, the rebuild added about 180 kg to the melter assembly.

Since it is no longer necessary to move the melter along the track or to tip the melter, the carriage was mounted on I-beams attached directly to the floor. This modification was a simple, low-cost means to correct this safety problem, and it also raised the melter high enough to permit filling full-size 3-m-tall canisters.

CONCLUSIONS

The PSCM operated for 5.5 years between 1978 and 1985, producing over 57,000 kg of glass. Corrosion of the tank refractories and the Inconel 690 electrodes necessitated shut down and repair of the melter in 1985. The PSCM was rebuilt maintaining the same basic design but with enhancements to the lid, electrodes, and overflow area. The following conclusions can be drawn from the melter disassembly and rebuild project:

- The type and configuration of the melter tank ceramics are suitable for melter use with the glass types tested. Corrosion of the K-3 refractory used in the melter walls was consistent with expected corrosion rates for the five-year operation of the PSCM.
- A portion of the melter lid fell into the melter cavity during later operation. The melter lid refractory failed because of inadequate vertical support at the walls and failure of the Inconel 690 anchors welded to the lid. The anchors were replaced with more corrosion-resistant ceramic anchors and Inconel 690 clips. The new lid will extend the useful life of the PSCM and enhance its operation for the remaining tests.
- The electrodes failed at the upper bus connection and showed severe corrosion at the glass melt interface. Corrosion was worst where cooling channels had been machined into the rear of the electrodes, penetrating into the vertical holes drilled for weight factor and specific gravity measurements. The severe electrode corrosion may have been due to a combination of oxidizing material buildup and mechanical stress at the channel welds on the rear of the electrodes. The new electrode design alleviates the bus failure problem, but a configuration where the electrodes are inserted in the wall to prevent attack at the rear may be a better design.
- The overflow trough was modified because of corrosion to the Inconel 690 pour tip. The ceramic components were replaced with an Inconel

690 trough and dam. This change will increase the corrosion resistance in the overflow area and will prevent glass from seeping into the overflow area from the melter tank. Glass seepage has been a common mode of failure for several melters at PNL.

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APPENDIX

OPERATIONAL HISTORY OF PSCM

APPENDIX

OPERATIONAL HISTORY OF PSCM

<u>Run ID #</u>	<u>Date</u>	<u>Years</u>	<u>Comments</u>
Startup	4/24/78	0	Mark-I lid installed.
CFCM-1	5/8/78	--	
CFCM-2	5/24/78	--	
CFCM-3	6/1/78	--	
CFCM-4	6/26/78	--	
CFCM-5	9/20-30/78	--	First multiday test.
Shutdown	10/24/78	0.5	Mark-I lid removed.
Startup	4/13/79	--	Mark-II lid installed, electrode feet added, throat liner installed.
CFCM-6	4/18-27/79	--	
CFCM-7	6/4-30/79	--	
CFCM-8	11/5-9/79	--	
Shutdown	11/30/79	1.13	Mark-II lid removed, CFCM tests produced 61,500 kg of glass in 1266 h of operation.
Startup	11/28/80	--	Mark-III lid installed, refractories replaced, electrode bus changed.
PSCM-1	12/12-19/80	--	First liquid slurry test, TDSM-131 with coal, 220 kg of glass produced.
PSCM-2	3/23-27/81	--	Propane boost, TDSM-131 with coal, 2872 kg of glass produced.
PSCM-3	7/19-24/81	--	TDSF-131 with formate, 2400 kg of glass produced.
Shutdown	7/28/81	1.80	Total glass produced = 7292 kg.
Startup	11/14/81	--	Mark-IV lid installed.

Run ID #	Date	Years	Comments
PSCM-4	12/7-11/81	--	TDSF-131 with formate, 2709 kg of glass produced.
PSCM-5	1/25-31/82	--	Lid heating, TDSF-131 with formate, 3338 kg of glass produced.
PSCM-6	3/21-26/82	--	Lid heating, TDSF-165 with formate, 40% solids, 4125 kg of glass produced.
PSCM-7	5/17-21/82	--	DWPF-165 with formate, 50% solids, 2750 kg of glass produced.
PSCM-8	6/14-24/82	--	Lid heating, high Al-165 with formate, 7630 kg of glass produced.
Shutdown	6/24/82	2.41	End of SRL program support; 27,844 kg of glass produced.
Startup	7/24/82	--	
PSCM-9	8/2-5/82	--	WV-131S, about 2238 kg of glass produced.
PSCM-10	8/82	--	WV-131S, HWVP instrument test, about 72 h, about 900 kg of glass produced.
PSCM-11	11/15-19/82	--	NCAW/frit-82-10, 220 kg of glass produced, HWVP-5.
PSCM-12	12/21/82	--	Nonfeed reboil test for 17 h, fed for 11 h, 43 kg of glass produced, HWVP-6 NCAW/82-10 frit.
PSCM-13	1/17-19/83	--	HWVP-7, 48 h, NCAW/82-10, 182 kg of glass produced.
PSCM-14	3/24,25, 28-31/83	--	WV dry fed test, 4400 kg of glass produced, WV washed sludge at 30 wt%.
PSCM-15	5/17-26/83	--	WV Hydrox, waste at 30 wt%, 3650 kg of glass produced.
PSCM-16	8/22-29, 31, 9/1/83	--	WV nitric acid waste at 30 wt%, 3000 kg of glass produced.
PSCM-17	9/26-30/83	--	HWVP, CAW, 694 kg of glass produced.
PSCM-XX	7/9-10/84	--	MCC test, filled 36 1/4-scale cans with SRL-TDSF-165 glass, dry fed, 3500 kg of glass produced.

<u>Run ID #</u>	<u>Date</u>	<u>Years</u>	<u>Comments</u>
PSCM-18	8/1/84	--	WV short test to test off-gas equipment, 300 kg of glass produced.
PSCM-19/ 19E	8/21-31, 9/1, 19-21/84	--	WV with zeolite (30 CV), chemical glass formers, 0.5 moles nitric acid, 2870 kg of glass produced.
PSCM-20	4/1-10/85	--	8 FRG canisters filled, #8 feed used, 240 h of operation, 2000 kg of glass produced.
PSCM-21	5/31-6/11/85	--	WV-205 feed, 296 h of operation, 3170 kg of glass produced.
PSCM-22	7/15-8/2/85	--	HW-39 glass composition, 10 1/2-scale canisters filled for SRL, 427 h of operation, 6800 kg of glass produced.
Undesignated	9/11-12/85	--	2 FRG canisters filled, 400 kg SRL 131 frit/calcine (dry fed), 30 h of operation.
Shutdown	9/13/85	--	34,367 kg of glass produced since last shutdown.

SUMMARY

Total operating time = 5.55 years = 48,700 h.

Total liquid feeding time = 0.40 years = 142 days = 3410 h.

Total glass produced = 119,500 kg = 262,900 lb.

Glass produced from liquid-fed operation = 57,600 kg = 126,750 lb.

ACRONYMS

CAW Purex current acid waste
 DWPF Defense Waste Processing Facility (Savannah River Laboratory)
 FRG Federal Republic of Germany
 HWVP Hanford Waste Vitrification Program
 MCC Materials Characterization Center
 NCAW neutralized Purex current acid waste
 PSCM pilot-scale ceramic melter
 SRL Savannah River Laboratory
 TDSF Savannah River waste - formatted (Bjorklund 1982, p. 18)
 TDSM Savannah River waste - modified (Bjorklund 1982, p. 18)
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