The Design and Performance of a 100-kg/h, Direct Calcine- Fed Electric-Melter System for Nuclear-Waste Vitrification

R. D. Dierks

November 1980

**Prepared for the U.S. Department of Energy
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**Pacific Northwest Laboratory
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THE DESIGN AND PERFORMANCE OF A 100-kg/h,
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Richland, Washington 99352

SUMMARY

This report describes the physical characteristics of a ceramic-lined, joule-heated glass melter that is directly connected to the discharge of a spray calciner and is currently being used to study the vitrification of simulated nuclear-waste slurries. Melter performance characteristics and subsequent design improvements are described. The melter contains 0.24 m^3 of glass with a glass surface area of 0.76 m^2 , and is heated by the flow of an alternating current (ranging from 600 to 1200 amps) between two Inconel-690 slab-type electrodes immersed in the glass at either end of the melter tank. The melter was maintained at operating temperature (900 to 1260°C) for 15 mo, and produced 62,000 kg of glass. The maximum sustained operating period was 122 h, during which glass was produced at the rate of 70 kg/h .

CONTENTS

SUMMARY	iii
FIGURES	vii
TABLES	vii
1.0 INTRODUCTION	1
2.0 MELTER TANK	7
2.1 SIZE	7
2.2 REFRACTORIES	7
2.2.1 Fabrication Sequence	11
2.2.2 Modifications	12
2.3 FREEZE VALVE	13
2.3.1 Original Unit	13
2.3.2 Operation	15
2.3.3 Modifications	16
2.4 ELECTRODES	18
2.4.1 Original Design	18
2.4.2 Modifications	20
2.5 LIDS	23
2.5.1 Original Design	23
2.5.2 Feed Inlet Nozzle	24
2.5.3 Melter Lid Modifications	25
2.5.4 Viewports	26
3.0 DISCHARGE SECTION	29
3.1 THROAT, RISER, AND DISCHARGE TROUGH	29
3.2 DISCHARGE SECTION HEATERS	30

3.3	DISCHARGE TUBES	.	.	.	.	.	.	.	.	30
3.4	FLEXIBLE CANISTER CONNECTING SECTION	.	.	.	.	.	.	.	.	31
3.5	INNER REFRACTORY COOLERS	.	.	.	.	.	.	.	.	31
4.0	SUPPORT SYSTEMS	.	.	.	.	.	.	.	.	33
4.1	CONTAINMENT VESSEL	.	.	.	.	.	.	.	.	33
4.1.1	Size	.	.	.	.	.	.	.	.	33
4.1.2	Cooling Jackets	.	.	.	.	.	.	.	.	33
4.1.3	Melter Cradle	.	.	.	.	.	.	.	.	34
4.2	ELECTRICAL SUPPLY AND CONTROL SYSTEMS	.	.	.	.	.	.	.	.	35
4.2.1	Electrode Power Control	.	.	.	.	.	.	.	.	35
4.2.2	Startup Heater Power Control	.	.	.	.	.	.	.	.	37
4.2.3	Discharge Trough Heater Power Control System	.	.	.	.	.	.	.	.	39
4.2.4	Discharge Face Heater Power Control System	.	.	.	.	.	.	.	.	40
4.2.5	Freeze Valve Heater Power Control System	.	.	.	.	.	.	.	.	43
4.3	FRIT ADDITION SYSTEM	.	.	.	.	.	.	.	.	44
4.3.1	Solids Feeder	.	.	.	.	.	.	.	.	44
4.3.2	Frit	.	.	.	.	.	.	.	.	44
4.3.3	Air Lock	.	.	.	.	.	.	.	.	45
4.4	DATA RECORDING AND INSTRUMENT SENSORS	.	.	.	.	.	.	.	.	46
4.4.1	Automatic Data Recording	.	.	.	.	.	.	.	.	46
4.4.2	Manual Data Recording	.	.	.	.	.	.	.	.	46
5.0	REFERENCES	.	.	.	.	.	.	.	.	55

FIGURES

1	Calcine-Fed Ceramic-Melter System	.	.	.	.	.	.	3
2	Calcine-Fed Ceramic-Melter System	.	.	.	.	.	.	4
3	Electric Glass Melter	.	.	.	.	.	.	8
4	Melter Tank East-West Cross Section	.	.	.	.	.	.	10
5	Original Bottom Drain Freeze Valve	.	.	.	.	.	.	14
6	Modified Bottom Drain Freeze Valve	.	.	.	.	.	.	17
7	Original Slab-Type Electrode	.	.	.	.	.	.	19
8	Conax Electrical Connector	.	.	.	.	.	.	21
9	Modified Slab Electrodes	.	.	.	.	.	.	22
10	Electrode Power Control	.	.	.	.	.	.	36
11	Startup Heater Power Control	.	.	.	.	.	.	39
12	Discharge Trough Heater Power Control	.	.	.	.	.	.	41
13	Discharge Face Heater Power Control	.	.	.	.	.	.	42
14	Freeze Valve Heater Power Control	.	.	.	.	.	.	43
15	Original Thermocouple Locations	.	.	.	.	.	.	49
16	Modified Thermocouple Locations	.	.	.	.	.	.	52

TABLES

1	Operating History of Calcine-Fed Ceramic Melter	.	.	.	.	2
2	Refractory Thermal Properties	.	.	.	.	11
3	Original CFCM Thermocouple List	.	.	.	.	47
4	Modified CFCM Thermocouple List	.	.	.	.	50
5	Status Log #4--Miscellaneous Data	.	.	.	.	53

1.0 INTRODUCTION

Since 1973 the Pacific Northwest Laboratory (PNL) has been conducting research directed toward the development of ceramic-lined electric melters suitable for the continuous vitrification of nuclear waste slurries (Buel et al. 1979).

This document describes one such melter, which has been designed to continuously accept a calcined nuclear-waste slurry directly from a spray calciner or from other waste calciners, to combine this calcine with an appropriate glass former, and to discharge an interruptible stream of molten glass at a nominal rate of 100 kg of glass/h. The initial startup for this melter was in April 1978, and it was shut down for modification in September of the same year. The melter was restarted in April 1979 and was shut down in November 1979. Approximately 62,000 kg of glass, made from simulated nuclear waste slurries, have been discharged from this melter. Table 1 summarizes the glass production from this melter.

The refractories were removed from the melting tank and the discharge section for examination following the November 1979 shutdown (Dierks et al. 1980). Design changes were completed to improve the refractory performance of the melter tank liner and discharge throat, to improve the performance of the electrodes and the discharge trough, and to adapt the melter for air-lift discharging and direct slurry feeding with alternative power-boosting techniques. Restart of the melter is scheduled for September 1980.

Figure 1 is a photograph of the combined calciner/electric melter facility described, and Figure 2 is a cutaway drawing of the facility.

Briefly, the vitrification process is as follows: simulated aqueous nuclear waste is pumped into a spray nozzle at the top of the calciner. Compressed air atomizes the slurry into a fine mist that drops through the electrically heated spray chamber. Radiant heat from the chamber walls evaporates the water from the mist droplets and calcines the residual metal salts to the oxide forms. The calcine is separated from the water vapor and other gases and drops to the bottom of the calciner. A glass former, or "frit," is continuously metered into the calciner barrel, where it mixes with the calcine

TABLE 1. Operating History of Calcine-Fed Ceramic Melter

Operating Dates		Activity	Hours	Feed(a)	Frit(a)	Glass Temp., °C	Glass Rate, kg/h	Current, amps	Power, kW	Glass, kg
From	To									
4/21/78	4/25/78	Startup	110	PW7a	76-199	975	---	0-200	0-34	364
5-08	5-08	CFCM-1 ^(b)	8	PW7a	76-199	~950	---	200-300	30-40	---
5-24	5-26	CFCM-2	15	PW7a	76-199	~850-900		250	31-36	623
6-01	6-01	CFCM-3	7	PW7a	76-199	~980	10-40	350	35	155
6-23	6-23	CFCM-4a	4	PW7a	76-199		50	400	50	190
6-24	6-26	CFCM-4b	4	PW7a	76-199	975	60	300	40	230
6-27	6-27	CFCM-4c	3	PW7a	76-199	975	80	330	50	215
6-29	6-29	CFCM-4d	4	PW7a	76-199	900	50	380	50	10
9-08	9-08	CFCM-5	3	SRP-COMP	411	~1045	30	270	28	0
9-11	9-11	CFCM-5	3	SRP-COMP	411	970-1190	30		40	60
9-14	9-14	CFCM-5	7	SRP-COMP	411	~1000	50		35	250
9-19	9-29	CFCM-5	245	SRP-COMP	411	~1150	20-45	700-800	40-50	9039
10-23-78	10-24-78	Drain & Shutdown	18	PW7a	76-199	~1120	---	500-0	38-0	---
Total "ON" Time: 6 months, 4380 hours			431 h							11,136

END PERIOD 1 OPERATION

10-24-78 4-13-79 Melter Modifications: Added Inconel-690 "feet" to electrodes, chipped sludge from melter tank, installed Inconel-690 throat liner, increased feed inlet pipe and nozzle from 10 cm to 15 cm, replaced the 10-cm feed inlet sleeve through the lid insulation with an Inconel-601 cone tapering at 45° from 58 cm OD, added cooling jacket to upper 8 cm of feed inlet cone.

4-13-79	4-17-79	Startup	100	SRP-TDS	411	0-900	---	0-700	0-40	418
4-17	4-22	CFCM-6	106	SRP-TDS	411	1025-1170	35-70	700-970	39-52	3550
4-22	4-27	CFCM-6	133	SRP-TDS	211	1075-1215	60-80	920-1000	63-76	7450
6-04	6-10	CFCM 7	137	SRP-TDS	211	1150	60-70	960	50	5900
6-10	6-14	CFCM-7	102	SRP-TDS	211	1250	60-75	950-1150	60-80	6100
6-14	6-17	CFCM-7	75	SRP-TDS	211	1280-1260	75-85	1150-1200	75-90	5400
6-17	6-23	CFCM-7	145	SRP-TDS	211	1250	70	1000	60-75	6700
6-23	6-30	CFCM-7	155	SRP-TDS	211	1275	70	1150	85	10600
11-05	11-09	CFCM-8	110	SRP-TDS	211	1150	60	700-800	40-65	4302
11-30-79	11-30-79	Drain & Shutdown	4	SRP-TDS	211	~1175	---	~1050	85	
Total "ON" Time: 7 1/2 months, 5475 h			1063 h						TOTAL	61,500

END OF PERIOD 2 OPERATION

(a) See Dierks et al. (1980) for waste and frit types.

(b) Denotes an experimental run number for the melter.

FIGURE 1. Calcine-Fed Ceramic-Melter System

FIGURE 2. Calcine-Fed Ceramic-Melter System

and drops onto the surface of the molten glass in the melter tank. Alternating current passing through the molten glass between two massive electrodes maintains the glass at 1100⁰ to 1200⁰C and supplies the heat necessary to fuse the metal oxides and the glass-former into a homogeneous glass material.

As the molten glass accumulates in the melter tank, it flows out of the tank through an underflow throat, up a riser passage, along a discharge trough, off of a discharge lip and into a receiving canister. The melter can be tipped approximately 3⁰ forward to decrease the inventory of glass in the melter tank, or 2⁰ backward to stop the flow of glass from the discharge trough. This enables the receiving canister to be replaced without interrupting the calciner operations and also minimizes "stringing" of the glass from the discharge lip when the calciner operation is interrupted.

The primary objective of this particular electric melter is to demonstrate the compatibility of a spray calciner and an electric melter in a combined system, and to determine their interaction during periods of upset, nonuniform feed composition and component failure. The melter is designed to utilize the output from a full-scale calciner that had been built to demonstrate the feasibility of a calciner/in-can melter system (Mikols et al. 1973), and yet not interfere with the orderly pursuit of the in-can melter development program. Thus, as is shown in Figures 1 and 2, the melter rests in a wheeled cradle that enables the melter to be positioned directly under the calciner in an operating mode when the calciner is available for use, or off to one side in an idling mode when an in-can melter experiment is in progress. Service connections to the melter are made through flexible systems to enable the melter to be maintained in an operating condition while it is in its idle position. No provision has been made for connecting the melter to the offgas system while it is in its idle position, although very little, if any, offgas is generated in this mode.

As is shown in Figure 2, the ceramic melter is divided into two sections, the melting tank and the discharge section. Both sections are built within a single containment vessel, each with a lid that is sealed to the flanged lip

of the containment vessel. The first part of the melter description focuses on the design, performance, and modification of the melter tank. The second part describes the discharge section, and the last part describes the containment vessel, supporting mechanical, electrical and instrument systems, and data acquisition systems.

2.0 MELTER TANK

2.1 SIZE

The electric glass melter is shown in detail in Figures 3 and 4. Figure 3 is a cutaway drawing of the melter as viewed from the southeast corner of the discharge section and looking toward the northwest corner of the melter tank. Figure 4 is a section view of the melter along its east-west centerline, with the melter tank west wall on the left of the drawing, the melter tank east wall, throat, and riser in the center of the drawing, and the discharge section on the right side of the drawing.

The melter tank is 71 cm wide and 117 cm long; however, the electrodes are 5 cm thick and entirely cover each end of the melter tank, thus reducing the effective tank length to 107 cm and the surface area of the tank to 0.76 m^2 . With the melter in a horizontal position and the discharge trough free of obstructions, the glass in the melter tank is 32 cm deep, giving the tank a volume of 240 L. When the melter is receiving feed materials and is discharging glass in its horizontal position, the glass level may be 2 to 5 cm higher, depending on the resistance to flow in the discharge throat, the riser and the discharge trough.

2.2 REFRACTORIES

Because of its high corrosion resistance, the fused-cast chrome alumina refractory, Monofrax K-3[®] is used wherever contact with the molten glass is expected. This includes the tank lining, the throat, the riser and the discharge trough. Void-free "DCI" K-3 blocks, 10 cm x 15 cm x 46 cm, are used for the 10-cm-thick tank lining and throat. Similar blocks with machined semi-circular grooves are used for the riser and for the discharge trough. All these blocks were laid up without mortar and with block-to-block joints staggered as much as possible between courses to minimize glass leakage. A chrome oxide patching mixture was "battered" over some of the more obvious block-to-block misfits.

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FIGURE 3. Electric Glass Melter

While the K-3 refractory has excellent resistance to the corrosive waste glass compositions, its high thermal conductivity results in a relatively low temperature gradient across the initial glass barrier. Zirmul® 8-cm x 31-cm x 46-cm paving blocks--a zirconia-stabilized mullite--are used as backup refractory for any glass that may penetrate the K-3 through the block-to-block joints in the floor and sides of the melter; they also provide an additional thermal barrier. A 15-cm layer of Zirmul is provided under the K-3 floor blocks, and an 8-cm layer is provided behind the K-3 walls. An additional course of Zirmul blocks extends above the K-3 melter walls to the tank lid.

Alfrax 66,® a high-alumina castable refractory, was poured into the 8-cm space between the outer melter tank walls and the 1-cm-thick, crushable, expansion Joint Board® that lines the 1/2-cm-thick Inconel-601® containment box. The Alfrax and Joint Board layers provide the bulk of the thermal insulation for the melter tank, and the Joint Board provided a means for absorbing the refractory expansion as the melter was initially brought up to its operating temperature.

A 2-mm-thick mica sheet was installed between the Inconel containment vessel and the Joint Board to provide a measure of electrical insulation between the glass and the containment vessel in the event of an intrusion of the glass into the refractory tank lining.

The undersides of the 1-cm-thick, Inconel-601 lids covering the melter sections were insulated with an 18-cm-thick layer of Fiberfrax® LDS moldable refractory, held in place with Inconel-690 wire hangers welded to the underside of the lid and imbedded in the molded refractory. The lids were bolted to the flanged Inconel containment vessel and were gasketed with two coils of 2.5-cm² braided Fiberfrax rope.

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FIGURE 4. Melter Tank East-West Cross Section

The thermal properties of the refractories used in the melter are listed in Table 2.

2.2.1 Fabrication Sequence

As mentioned previously, the melter tank was laid up without the use of mortar, starting with an empty, prefabricated Inconel-601 containment vessel. The 2-mm-thick mica sheet and the 1-cm-thick sheet of Fiberfrax Dura Board were first laid on the containment vessel floor. This was followed by the first 8-cm-thick course of Zirmul paving blocks positioned as closely together as possible. A diagonal, 2-cm² groove was cut in the top surface of this first layer of Zirmul blocks in such a manner that it would pass directly under the northwest corner of the melting tank and directly under the underflow discharge throat from the melter. An Inconel-601 thermowell was laid in the groove and gently curved so that it exited the containment vessel in the southeast corner.

A second 8-cm course of Zirmul paving blocks was added, with the inter-block joints arranged to lay above the centerlines of the blocks below. The third closely packed course was a 10-cm-thick layer of K-3 that formed the floor of the melter and the foundation for the melter walls and discharge section. In positioning each of these three courses, care was taken to leave a 30-cm x 15-cm hole for the later insertion of the bottom discharge freeze valve from below the containment vessel.

TABLE 2. Refractory Thermal Properties

<u>Material</u>	<u>W/M⁰C</u>	<u>Range, ⁰C</u>
K-3	2.9	1000 to 1300
Zirmul	1.9	700 to 1000
Alfrax 66	1.4	1000
Alfrax 57	0.7	1000
LDS Moldable	0.3	1200
Joint Board	0.1	300
Dura Board	0.2	1000
Braided Fiberfrax Rope	---	---

The inner lining of the melting cavity was formed by three courses of 10-cm x 15-cm x 46-cm K-3 blocks positioned horizontally, and on edge, so that the finished wall was 10 cm thick and 46 cm tall. A 10-cm gap in the bottom K-3 wall course on the centerline of the discharge side of the tank (east side) provided the underflow discharge throat for the melter. A single course of 8-cm x 30-cm x 46-cm Zirmul paving blocks on edge on the top of the K-3 tank liner extended the tank walls to 76 cm above the melter floor. On the east wall the Zirmul was flush with the inner K-3 tank surface; however, on the other three sides the Zirmul was flush with the back side of the K-3 wall, leaving a 2-cm ledge on the top of the K-3 wall. This ledge served as a reference point during subsequent melter experiments. A backup layer of 8-cm Zirmul blocks was positioned behind the west melter wall from the Zirmul sub-floor to the top of the containment vessel.

Next, the 2-mm mica sheeting and the 1-cm crushable Joint Board were positioned next to the containment vessel walls and the 8-cm space between the Joint Board and the tank walls was filled with Alfrax castable refractory. Alfrax-66 was used from the bottom of the containment vessel to a position level within the top of the K-3 tank liner, and from this point to the top of the containment vessel, Alfrax-57 was used. Two Inconel-601 thermowells, positioned tightly up against the Zirmul back-up refractory of the west wall, were cast into the Alfrax as it was poured. Both thermowells extended down to the Zirmul subflooring. One thermowell was positioned on the centerline of the west wall, and the other was positioned directly in line with the inner surface of the north K-3 wall.

2.2.2 Modifications

The examination of the melter refractories (Dierks et al. 1980) following the November 1979 shutdown revealed severe corrosion in the discharge throat area, some corrosion in the horizontal joints of the tank liner, and considerable penetration of the glass through the block-to-block joints of the refractory courses. To correct these problems, several refractory design changes were implemented during the rebuilding of the melter unit. To minimize corrosion around the discharge throat, the throat and riser are being fabricated

from a single monolithic K-3 block 30 x 46 x 56 cm in size. All of the tank liner refractories will be positioned vertically instead of horizontally to minimize corrosion of the horizontal joints. To eliminate the penetration of the glass through the tank liner and the tank floor, the refractories will be cemented with appropriate refractory cements. In addition, the lower course of Zirmul refractories in the melter tank floor will be replaced with a monolithic layer of Zircon® Ramming Mix.

2.3 FREEZE VALVE

The melter tank is provided with a freeze-type bottom discharge valve. This valve was intended to enable the melter tank to be partially drained to flush molten metal accumulations from the tank, to speed up the process of changing the composition of the glass in the tank, or to enable the tank to be completely drained in preparation for modification or repair operations. As mentioned earlier, in positioning each of the floor and subfloor refractory courses, care was taken to leave a 30-cm x 15-cm hole in the floor for the later insertion of the bottom discharge freeze valve from below the containment vessel. For this purpose, a 30-cm x 15-cm rectangular nozzle was welded to the bottom of the containment vessel, penetrating the floor cooling jacket. The freeze valve is equidistant from the two electrodes, but 16 cm closer to the west wall than to the discharge throat. The long axis of the freeze valve assembly is parallel to the long axis of the melter tank.

2.3.1 Original Unit

The original freeze valve assembly is shown in Figure 5. This freeze valve was fabricated from two pieces of the 5-cm-thick Inconel-690 plate: one 30-cm x 15-cm piece formed the top of the valve, and a second 13-cm x 25-cm piece, welded to the under-side of the top plate in a "T" shape, formed the body of the valve. The centerlines of both pieces were coincident, and a 1.6-cm-dia hole, bored along the intersection of the two vertical centerline planes (through the top plate and the body), formed the glass passage through

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FIGURE 5. Original Bottom Drain Freeze Valve

the valve. On either side of the glass passage, 4.5-cm-dia plenum chambers were bored in the valve body block, which were then connected to one another with 20 equally spaced 5-mm-dia horizontal holes on either side of the vertical glass passage. Cooling air, supplied to the inlet air plenum, passed through these 40 passages to the discharge plenum and then to the exhaust air

pipng system. Two 1500-watt resistance heaters, positioned one on either side of the valve body, provide the heat required to thaw the glass that is normally frozen in the glass passage.

As is shown in Figure 5, a double-flanged rectangular box of Inconel-601 plate encloses the freeze valve and the heaters. This enables the entire assembly to be electrically insulated from, and secured to, the containment vessel flanged opening; and to be electrically insulated from, and secured to, a lower flanged section suitable for connection to a receiving canister. As noted in Figure 5, when the freeze valve assembly is positioned in the containment vessel, the top of the valve assembly is recessed 2 cm below the floor of the melter and has a uniform 5-mm clearance from the adjacent refractories. During the initial melter assembly, after the freeze valve was secured to the containment vessel flange, the space between the freeze valve box and the adjacent floor refractories was filled with dry granular Alfrax-66 refractory material. During the operation of the melter, glass penetration of this Alfrax-66 filler material was limited to about 3 to 10 mm. After the melter was shut down, drained and cooled, it was relatively simple to crush the vitrified material and then vacuum out the granular refractory filling. This enabled the freeze valve assembly to be removed for inspection and repair.

2.3.2 Operation

During normal operation of the melter, $0.74 \text{ std m}^3/\text{min}$ of cooling air at 0.28 kg/cm^2 was passed through the freeze valve cooling passages, extracting about 1 kW of heat from the Inconel valve body block, reducing its temperature to about 350°C and freezing any glass that might have flowed down the glass passage. During normal operation of the melter, direct visual observation of the freeze valve revealed a sharp temperature difference between the top Inconel slab, which was red hot, and the cooled valve body, which was black--suggesting very little heat flow from the top slab to the valve body and that perhaps very little weld penetration had been achieved when the two pieces were assembled.

When the melter was shut down for a modification in October 1978, the glass inventory in the tank was successfully drained to a receiving canister

through this freeze valve device. The cooling air to the freeze valve body was first shut off and then the power to heating elements was slowly increased, slowly increasing valve body temperature. When the valve body temperature reached 900°C, the material in the glass passage (a mixture of glass and sludge crystals) began to slowly issue from the discharge tip. As the percentage of sludge in the discharging glass decreased, the glass effluent rate increased until a maximum rate of 133 kg/h was reached. By turning off the power to the freeze valve heaters, and slowly increasing the air flow to the freeze valve cooler, the flow of glass was slowed. At an air flow of 0.3 std m³/min, the glass flow was substantially decreased. At an air flow of 0.4 std m³/min, the glass in the discharge tube was completely frozen and the flow had stopped. Again, by turning the cooling air off and reapplying power to the valve body heaters, glass flow from the glass passage resumed, and was allowed to continue until all of the molten glass had drained from the melter.

Some leakage of glass from the freeze valve assembly was noted after the tank had been drained completely, and later inspection revealed that the valve body had not been chamfered where it was welded to the top plate, and that the weld penetration and filler material was extremely thin in the weld area. With the valve body cooling extending to within 1 cm of the body-to-top plate weldment, the thermal gradient across the weldment was excessive, and the weldment probably cracked during the cycling of the freeze valve cooling air while the freeze valve performance was being tested.

2.3.3 Modifications

The original freeze valve was modified slightly (Figure 6) to correct some problem areas and to make the valve responsive to different needs. The design specifications were: a) that the valve remain frozen during normal melter operations, b) that the valve could be thawed electrically, c) that the valve be capable of passing relatively large pieces of slag, and d) that the valve be reusable. The valve was not expected to be able to stop the flow of glass from the tank once it had started until virtually all of the glass had drained from the tank.

FIGURE 6. Modified Bottom Drain Freeze Valve

The glass passage was increased from a 1.6-cm dia to 3.8-cm dia to increase the discharge rate and to accommodate larger slag pieces. The valve body was machined from Inconel-690 bar stock and was slip-fitted into a hole bored through the original Inconel-690 top plate. To improve the heat transfer from the top plate to the valve body, and to smooth out the temperature

transition from the glass-heated top of the valve body to its air-cooled tip, two massive full-penetration welds attached the valve body to the top plate. In addition, only the lower 13 cm of the glass passage was cooled with the cooling air entering the spiral baffled cooling jacket at the nozzle tip, and flowing counter-current to the heat flow to exit at the top of the cooling jacket. One thermowell, butt-welded to the cooling jacket at the nozzle tip, monitored the approximate temperature of the discharge nozzle tip. A second thermowell, welded to the side of the freeze valve enclosure box, monitored the glass incursion into the Alfrax packing between the enclosure box and the surrounding floor refractories.

2.4 ELECTRODES

2.4.1 Original Design

The original electrodes installed in the melter are shown in Figure 7. They consisted of a slab of Inconel-690 that was 5 cm thick, 69 cm wide and 61 cm tall. A rectangular duct 5 cm thick, 14 cm wide, and 50 cm tall, fabricated from 6-mm-thick Inconel-690 plates, was welded to the top of each electrode on the electrode centerline. The electrodes weighed about 177 kg each and rested on the floor of the melter, pushed as tightly against the melter tank end walls as possible. With the melter tank lid in place, the ducts on the top of the electrode slabs extended through rectangular openings in the lid and the insulation under the lid. The lid opening is fitted with a packing gland that utilizes 2-cm² Fiberfrax rope to effect a vacuum-tight and an electrically insulating seal between the electrode duct and the melter lid. The power connections to the electrodes are made on the electrode ducts that protrude above the melter lid.

Serpentine cooling air passages were machined into the back side of each of the electrodes. These passages were covered with 6-mm-thick Inconel-690 plate welded in place, forming a 1.3-cm² passage 366 cm long in the back side of each electrode. The two ends of these passages terminate at the top of the electrodes inside the electrode duct, and Inconel tubing welded to these terminations enables cooling-air inlet and outlet connections to be made at the top end of the electrode duct above the melter tank lid.

FIGURE 7. Original Slab-Type Electrode (Back Side View)

Each of the electrodes has a 6-mm-dia hole drilled on the centerline of the electrode 1.6 cm back from the front face of the electrode and extending to within 1 cm of the bottom of the electrode. These holes are extended to the top of the electrode ducts with Inconel tubing and are used as thermowells. The north electrode had a bundle of seven 2-mm-dia type "K" thermocouples permanently positioned in its thermowell, with one sensor set on the bottom of the well and the others staggered above it, 8 cm apart. The south electrode has a single 3-mm-dia type "K" thermocouple that can be positioned, and held, at any level desired.

Each of the electrodes has two other sets of 1.3-cm-dia holes drilled down from the top of the electrodes. One hole in each electrode goes to within 1 cm of the bottom and is intercepted by a similar-sized hole drilled in from the front, or molten-glass side, of the electrode. The other hole in each electrode is drilled and intercepted in the same manner, except that on one electrode the second hole is positioned 25 cm above the first hole, and in the other electrode the second hole is positioned 20 cm above its lower hole. These two sets of holes were intended to be used to indicate pneumatically the depth and density of the molten glass in the melter tank.

The Conax® insulating tubing connectors shown in Figure 8 that were installed on the cooling-air and instrument-air lines to the electrodes are used to electrically insulate the electrodes from ground through these air lines. The thermowells are not insulated, and care must be taken to avoid contacting the thermocouple sheaths with the piping and lid structure surrounding the top of the electrode duct.

2.4.2 Modifications

As mentioned earlier, the original electrodes installed in the melter, shown in Figure 7, were used through experiment CFCM-5. During the period between CFCM-5 and CFCM-6, when the melter was shut down for inspection and modification, the electrodes were modified by the addition of feet as shown in

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FIGURE 8. Conax Electrical Connector

Figure 9. With these feet in place, the distance between the electrodes for the bottom 5 cm is reduced from 107 cm to 76 cm, and approximately 30% of the total power dissipated in the normal 30-cm-deep pool of glass in the melter is concentrated in the bottom 5 cm of glass. This modification should improve the thermal mixing of the tank and the homogeneity of the glass product.

The examination of the melter refractories and the modified electrodes (Dierks et al. 1980) following the November 1979 shutdown suggested that sludge accumulations on the electrode feet were adversely distorting the current flux

FIGURE 9. Modified Slab Electrodes (Front Side View)

distribution from the electrodes. To correct this problem, an Inconel-690 fillet will be added on top of the electrode feet to prevent the accumulation of sludge. In addition, the electrodes will be slightly narrower than before to keep the current flux away from the tank wall, and the front edges of the electrodes will be rounded to minimize the tendency of the current flow to discharge from the formerly sharp corners of the electrodes.

2.5 LIDS

2.5.1 Original Design

An Inconel-601 flange, 10 cm wide and 2.5 cm thick, extends completely around the top edge of the containment vessel, and another Inconel-601 plate, 20 cm wide and 2.5 cm thick welded flush with the two side flanges, connects the two sides together and outlines the melter tank and discharge sections. Each of these two sections is covered with a lid of 1-cm Inconel-601 plate, which is bolted to the containment vessel flange with 5/8-12 carbon-steel bolts, studs and nuts. Two loops of 2-cm² braided Fiberfrax® rope, placed inside of the flange bolt line, effectively seals the lids to the containment vessel, minimizing air in-leakage into the melter system.

Each of the lids was fitted with an 18-cm-thick layer of LDS® moldable ceramic refractory on the underneath side of the lid. The refractory was held in place with Inconel-690 "V"-shaped hangers welded to the underside of the lid that became imbedded in the refractory as it was molded to shape. The refractory was molded to the lid to fit snugly into the cavities formed by the refractories built up in the melter tank and discharge sections when the lids are positioned and bolted in place.

The melting cavity lid and insulation layer are penetrated by several openings that will be described in detail in later sections (i.e., two rectangular openings for the electrode power ducts, three oval openings for the view-port nozzles, 13 holes for the startup silicon carbide heaters, four vapor

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space thermocouple holes, three vapor space instrument and sample holes, two glass sample access ports, and a calcine feed inlet port). An Inconel-601 box with an airtight flanged lid was built on the top of the lid to cover the startup heaters, and to enclose the electrical connections to these heaters and their mechanical support system.

The discharge section lid and its insulation layer are penetrated by four holes for the discharge section silicon carbide heaters (to be described later), three holes for the discharge section thermocouple access ports, and one hole for a riser access port. An airtight box, very similar in design and function to the box containing the melter startup heaters, was built to contain the discharge sections silicon carbide heaters.

2.5.2 Feed Inlet Nozzle

As mentioned earlier, the calcine and frit drops from the calciner cone through a flexible connecting pipe and into the glass melting tank. The original feed inlet nozzle to the melter was a section of 10-cm, schedule-40 Inconel-690 pipe that penetrated the melter lid and extended about 1 cm below the under-lid insulation. A 3-mm-thick, Inconel-601 collar was welded around the lower end of the 10-cm pipe to assist in supporting the insulation layer. The feed nozzle was welded to the lid and was fitted with a 10-cm, 150-lb 304L stainless steel flange, 2 cm above the lid. A 50-cm-long, nominal 10-cm-dia, flanged section of corrugated, 0.6-mm-thick 321 stainless steel flexible pipe connected the feed inlet nozzle to the flanged calciner cone outlet. The flexible pipe enabled the melter to be tipped forward or backward to realize a small degree of control over the glass discharge from the melter during its operation.

During the initial operation of the melter, it was found that during idling periods or periods of intermittent operation the temperature of the lower portion of the feed inlet nozzle would rise to 800⁰ to 900⁰C and the nozzle flange temperature would reach about 400⁰ to 500⁰C. Then, if the feedrates to the melter were low, frit would stick to the lower portion of the inlet nozzle, where it would melt and cause more frit to stick, eventually blocking the feed

inlet nozzle completely. The build-up and eventual blocking of the feed line was clearly indicated by a differential pressure indicator that monitored the pressures in the melter and in the calciner cone.

The feed inlet pipe and nozzle not only serve to introduce the frit and calcine into the melter, but serve to route the melter offgas (from the melting of the glass and from air in-leakage) up into the calciner and through the offgas filters. It was noted during the initial operation of the melter that under certain circumstances the melter offgas rate was sufficient to cause some refluxing of calcine in the cone as it tried to enter the 10-cm melter inlet pipe. In addition, it was noted that when the glass level rose in the melter and lifted the feed pile up to the feed inlet nozzle, feed was blocked from entering the melter even though there was considerable freeboard remaining above the glass level.

2.5.3 Melter Lid Modifications

As a result of the observations made during the initial operation of the melter, modifications to the feed inlet system were made during the September 1978 shutdown period. These modifications included: a) changing the calciner cone discharge from a 10-cm flange to a 15-cm flange, b) changing the flexible pipe from a nominal 10-cm to a nominal 15-cm corrugated 321 stainless steel flexible pipe, and c) changing the inlet nozzle from a 10-cm straight pipe to a 15-cm conically shaped pipe that tapered at 45° from a 15-cm dia to a 36-cm dia. In addition, the conical nozzle projected 5 cm above the top of the lid and a water-cooled collar was welded to this section. Thus, the increased size of the flexible pipe and the connecting flanges provided ample volume for the unimpeded, counter-current flow of the feed materials and offgases, and the water-cooled, divergent inlet nozzle minimized the tendency for the frit to stick to the inlet nozzle surfaces and block the flow of feed into the melter. In addition, the conical shape of the inlet nozzle enabled the glass level to rise to the underside of the lid insulation without danger of the feed pile blocking off the feed inlet nozzle.

The examination of the melter lid (Dierks et al. 1980) following the November 1980 shutdown revealed extensive corrosion damage to the

water-cooled, conical inlet nozzle, to the LDS moldable refractory on the underside of the lid, and to the exposed portions of the lid itself. To minimize the feed nozzle damage, the 15-cm conical nozzle will be replaced with a ceramic-lined 20-cm cylindrical nozzle with an air- or steam-cooled sleeve that will convey the calcine and frit into the melter tank. The LDS moldable refractory will be replaced with a multiple-layer design, graduating in three steps from a low-density ceramic felt on the cold face to a high-density castable refractory on the hot face. In addition, the penetrations through the lid will be minimized (the 13 silicon carbide start-up heaters will be replaced with a plasma torch or a fuel combustion burner operating through the feed inlet nozzle) to avoid compromising the performance of the under-lid insulation.

2.5.4 Viewports

Five viewports are included in the design of the melter to enable visual data to be accumulated on the operation of the melter (three viewports are in the melter section and two are in the discharge section).

The three ports viewing the melter surface consist of short sections of 10-cm, schedule-40 304L stainless steel pipe welded to the melter section lid. The axis of the melter viewports are inclines at 45° to the surface of the lid. Each viewport nozzle is fitted with a 10-cm, 150-lb stainless steel flange and a pneumatically operated 10-cm knife valve. A 15-cm^2 piece of 6-mm flat polished quartz glass, gasketed on both sides with 15-cm-O.D. x 13-cm-I.D. Fiberfrax felt paper gaskets and lightly bolted to the outer surface of the knife valve with a 10-cm slip-on flange, provided a window that was easily removable and could be cleaned with a dry cloth. The knife valves not only simplified the removal of the glass for cleaning but, by opening the knife valves only when it was necessary to view the melter interior, the condensation of volatiles from the molten glass onto the viewport glasses was minimized and the frequency of cleaning the windows was reduced. The viewports were oriented on the lid such that the north viewport viewed the east wall from almost to centerline to the northeast corner, and the north electrode from its east edge to a point a little past its centerline toward the west

wall. The viewport was angled slightly toward the centerline of the east wall. The center viewport was positioned 15 cm to the north of the melter tank centerline and looked directly at the east wall, parallel to the tank centerline. The south viewport was angled to look directly at the centerline of the north electrode from the southwest corner of the melter tank (its view included the west wall to about the west wall centerline) and the glass surface to about the centerline of the tank. A conical-shaped piece of refractory was removed from under the melter lid with the axis of the conical-shaped piece coincident with the axis of the viewports. These openings provided as wide an angle of view of the melter as possible without compromising the performance of the lid insulation too greatly.

3.0 DISCHARGE SECTION

3.1 THROAT, RISER, AND DISCHARGE TROUGH

As discussed in the previous section, 10-cm x 15-cm x 46-cm K-3 refractory blocks were stacked in three courses to form the primary glass containment tank walls 10 cm thick and 46 cm high. Figure 4 shows a cross section of the tank, throat, riser and discharge trough. A 10-cm-wide gap was left in the bottom K-3 course on the vertical centerline of the east tank wall to serve as an underflow discharge throat for the glass leaving the melting cavity. A 10-cm x 15-cm x 36-cm K-3 block with a 36-cm-long, 4-cm-radius, semi-circular groove machined on the 10-cm x 36-cm face was positioned on the back side of the K-3 tank wall with the groove oriented vertically on the centerline of the discharge throat. The semi-circular passage thus formed served as a riser from the discharge throat up the back side of the melter tank K-3 wall. At the top end of the riser block, a second 4-cm-radius, semi-circular groove was machined in the 10-cm x 15-cm face to intersect with the riser passage.

A second K-3 block, 10 cm x 15 cm x 46 cm, with a 4-cm-radius, semi-circular groove machined on the 10-cm x 15-cm x 46-cm face, was positioned horizontally (butted against the riser block) with its groove aligned with the top side groove of the riser block. The horizontal grooved K-3 block is referred to as the discharge trough. The end of the discharge trough (opposite from the end butted against the riser block) is referred to as the discharge face and has a 2-cm-radius, semi-circular groove machined on its vertical centerline. An Inconel-690 discharge lip, with a 2-cm-radius, semi-circular groove, is positioned under the discharge face with its 2-cm-radius groove aligned with the groove on the discharge face. Thus, as glass is accumulated in the melter tank, fluid head forces molten glass through the discharge throat at the bottom of the melter tank wall, up through the semi-circular riser passage and into the semi-circular groove in the discharge trough. With the melter in its horizontal position, molten glass flows down the discharge trough, down the discharge face, and falls freely from the discharge lip into a receiving canister. The bottom of the discharge lip is tapered, which allows the glass to drop cleanly from the lip without having a tendency to curl back under the discharge face.

3.2 DISCHARGE SECTION HEATERS

Auxiliary heat is supplied to the discharge trough and to the discharge face to maintain the refractories at about the melter glass temperature to minimize thermal strains in the refractories, and to maintain desired glass properties as the glass is discharged to the receiving canister. Six silicon carbide resistance-heating elements penetrate the discharge section lid and insulation, and extend down into a 30-cm-wide x 61-cm-long x 36-cm-tall cavity over the discharge trough. An airtight box on the discharge section lid covers the upper end of the heater elements and prevents air from leaking into the melter because of the normal negative pressure maintained within the melter containment box. The six elements are wired in parallel and each element is rated at 3.3 kW at 104 VAC (19.8 kW max). The maximum recommended operating temperature for these heating elements is 1250⁰C.

Two other similar silicon carbide heating elements are positioned in a similar manner in front of the discharge face. These heaters are slightly larger than the discharge trough heaters (5.25 kW each with a 162V max operating voltage), and extend down below the lip of the discharge trough. These two heaters are used to keep the Inconel discharge lip hot to minimize the tendency of the glass to curl back under the discharge trough as it pours, and to discourage "stringing" as the discharge from the melter is terminated.

3.3 DISCHARGE TUBES

The riser block and the back end of the discharge trough are backed up with additional K-3 blocks, and the front end of the discharge trough is backed up with Zirmul blocks. Zirmul blocks are used above the discharge trough and around the discharge face to form the trough and discharge cavities. A 43-cm-long, 24-cm-O.D. Inconel cylinder (outer discharge tube) is welded to a 20-cm, 150-lb Inconel flange that had been bored to 24 cm and had been welded into the containment box floor, axially in line with the drop point from the discharge lip. A standard pressed insulation fire brick fills the void from the Inconel containment box floor up to the top of the outer discharge tube, which forms

the floor of the discharge face cavity. A light-weight insulating brick fills the voids around the Zirmul walls of the discharge trough and discharge face cavities up to the 1-cm-thick Inconel 601 lid covering the discharge section. A second flanged Inconel tube (inner discharge tube), 22-cm O.D., is inserted into the outer tube and bolted to the outer discharge tube flange from the underside of the melter. In the event that the glass discharge to the receiving canister should become blocked and glass should fill up into the discharge tube, the major portion could easily be removed after it had been allowed to freeze, by disconnecting the flanged connection from below and removing the inner tube and glass from the outer fixed discharge tube.

3.4 FLEXIBLE CANISTER CONNECTING SECTION

A 50-cm-long flanged section of flexible 20-cm stainless steel pipe is used to effect a sealed, flexible connection between the melter and the receiving canister. One end of the flanged pipe is connected directly to the discharge tube flange assembly discussed above and the other end is connected to a 20-cm pneumatic-operated knife valve. When the receiving canister is not in place, the knife valve is closed to stop the flow of air into the melter due to its normal negative operating pressure. The closed knife valve also prevents accidental discharges of glass from the melter system. When the receiving canister is not in place, the flexible pipe and knife valve are retracted upwards to provide clearance for canister movement. With the receiving canister in place, the knife valve is lowered into position on the canister inlet flange, secured with quick-disconnect clamping devices, and then opened.

3.5 INNER REFRACTORY COOLERS

These slab-type coolers (8 cm thick, 38 cm wide and 51 cm tall) are located in the midst of the refractories in the discharge end of the containment box. These coolers extend from the water-cooled containment box wall about 23 cm from the back side of the K-3 tank wall, toward the discharge trough, and rest on top of the bottom layer of Zirmul paving blocks on the containment box floor. This puts the top of the coolers right at the level of

the discharge trough. The purpose of these coolers is to cool the east wall of the melting cavity and the riser blocks to inhibit glass leakage from the melter tank, the discharge throat, the riser and the discharge trough. Because of the possibility of leaking water into the refractories, the inner refractory coolers are limited to air-cooling. The heat loss to these coolers runs about 1.8 kW each.

4.0 SUPPORT SYSTEMS

4.1 CONTAINMENT VESSEL

4.1.1 Size

The melter tank and discharge section refractories discussed in the previous section were assembled inside a prefabricated Inconel box. The box is uniformly rectangular in shape with inside dimensions 2.03 m long, 1.55 m wide and 1.12 m deep. The intent of this box is to contain any glass leak that may penetrate the refractories, and the intent of using Inconel for the box is to guarantee the integrity of the box regardless of the temperature or corrosive glass conditions that might be encountered. The containment box below the flanged lids is formed from 5-mm-thick Inconel-601 plate, solidly welded together, except for the discharge tube and the freeze valve flange which have been previously described, and a view port positioned to view the discharge trough and to enable glass samples to be obtained from the discharge lip.

4.1.2 Cooling Jackets

Cooling jackets are built into the containment box to control the cold-side temperature of the refractories, to prevent molten glass from completely penetrating the refractory walls to the containment box, and to assist in cooling the Inconel electrodes. The cooling jackets are located on three sides and on about one-half of the bottom of the containment box. The unjacketed fourth side and the unjacketed bottom are at the discharge end of the melter where refractory temperatures are not severe. The floor jacket completely covers the bottom of the containment box under the melter tank and is split into two separate sections, running the length of the melter tank. The smaller section is positioned under the melter tank wall containing the discharge throat and riser block, and is intended to afford some control over the throat and riser temperatures. The larger section, about twice the size of the smaller section, is adjacent to the smaller cooler and is positioned under the floor of the melting tank and the wall opposite the discharge throat. While these cooling jackets are designed for either water- or air-cooling, to date--in order to

keep the floor glass temperatures above the liquidus temperature--only cooling air has been circulated through the floor jackets, and even then only enough to enable the jacket effluent temperature sensors to monitor changes in the floor temperature. The heat loss to these jackets runs about 0.4 kW to the smaller jacket, and 0.6 kW to the larger jacket. The side wall coolers extend up 79 cm from the bottom of the containment box, which puts the top of the coolers about 23 cm above the normal glass level in the tank, and about 8 cm below the top of the Inconel electrodes. These jackets are also designed for air- or water-cooling and, to date, have been operated with cooling water at a flow of about 5 l/min. The heat loss to these jackets runs about 12 kW to the larger side jackets and about 6 kW to the smaller end jacket.

4.1.3 Melter Cradle

The melter unit is mounted in a cradle assembly, which in turn is mounted on a trolley device (Figure 3). The six-wheeled trolley enables the melter to be moved back and forth, as needed, between its operate position and its idle position. The 15-cm-dia, "V"-grooved trolley wheels on one side of the trolley ride on a "V"-rail to keep the melter on its horizontal "I"-beam supports. The wheels on the opposite side ride on a flat rail to allow for the side movement that accompanies temperature changes of the melter unit.

The underslung melter cradle supports the melter slightly below the trolley rails in order to pick up some additional clearance between the calciner cone and the melter lid. The cradle is pivoted at approximately the centerline of the melting cavity (Figures 3 and 4) with two massive self-aligning journal bearings. Two electrically operated 1800-kg jack screws, positioned at the discharge end of the melter, attach the free end of the cradle to the trolley frame. With the melter full of glass and the cooling jackets full of water, the melter weighs approximately 10,000 kg. Seven-thousand seven-hundred kilograms are supported by the journal pivot bearings and 2,300 kg are supported by the jack screws. The jack screws enable the melter to be tipped $\pm 5^\circ$ from horizontal, but due to structural interferences with the flexible inlet pipe, the movement of the melter is limited to $\sim 3^\circ$ forward and $\sim 2^\circ$ backward. An electronic sensor monitors the attitude of the melter and records this value on one of the multi-point strip chart recorders.

4.2 ELECTRICAL SUPPLY AND CONTROL SYSTEMS

4.2.1 Electrode Power Control

The power required to vitrify the calcine and glass-former chemicals and to maintain the melter at its operating temperature is supplied by passing an electric current through the molten glass, between two massive Inconel top-entering electrodes. Approximately 40 kW are required to maintain the melter in an idle mode, and power requirements of 90 kW have been experienced during some of the melter experiments.

As is seen in the schematic electrical diagram of Figure 10, 480-V, single-phase, 60-hertz power is supplied to a 500-amp, proportional, phase-angle-controlled, SCR power controller; a 0-to-5 VDC control signal from an external process controller (or an internal manual potentiometer) regulates the SCR output voltage from 0 to 480 V. The SCR output voltage is reduced by a multi-tapped, 250-kVA power transformer. Reduction ratios of 1.52, 2.04, 2.77, 3.64 and 4.71 are available. During startup, or after unscheduled power outages, the 2.04:1 ratio is used for the 235-V maximum output necessary to achieve the initial conduction through the cold charge. During normal operation, the 3.64:1 ratio is used to reduce the primary current flow through the SCR required for the 1000- to 1200-amp electrode currents realized during some of the experiments. The Research Incorporated, Model 651 SCR power controller used in this application employs a digital integrating circuit that continually calculates the exact time for the previous crossover and determines the precise time when each diode should be turned on in order to exactly balance the positive and negative conduction periods of the SCR. This apparently has resulted in no detectable DC corrosion of the electrodes. The power transformer is not center-grounded and, with the exception of leakage melter currents to ground, is completely floating from ground. The melter containment vessel and the frameworks of all major electrical equipment pieces are bussed together with ground cables that terminate at the power distribution panel building-ground connection.

The SCR power controller is regulated either manually from a 10-turn, digital potentiometer mounted on the door of the SCR containment box, or

FIGURE 10. Electrode Power Control

automatically from the 0-to-5 VDC output of a remotely located, three-mode process controller. The process controller has the option of using the melter glass temperature or the melter electrode temperature as feedback in the control of the voltage output from the SCR. The electrode temperatures are cooler than the glass temperatures by 100° to 150°C, but tend to be more stable than the glass temperatures. Other feedback options available to the SCR power output controller are: electrode voltage, electrode current, electrode power dissipation (EI), and melter tank electrical resistance (E/I), which is related to the bulk glass temperature. The north electrode contains an internal thermowell fitted with seven 2-mm-dia, type-"K" thermocouples staggered such that they monitor the temperature of the electrode at every 8 cm, starting with the first thermocouples 1 cm from the melter floor. These thermocouples generally show a maximum temperature between 15 and 25 cm up from the tank floor. The south electrode contains a single 3-mm-dia thermocouple that is positioned at the hottest level indicated by the thermocouple bundle in the north electrode, and it is this single, south electrode thermocouple that is used as the feedback indication if the electrode temperature feedback option is chosen for electrode power control.

4.2.2 Startup Heater Power Control

Since the initial melter charge (cullet or a mixture of calcine and frit) has a high resistance to electrical flow at room temperature, radiant electrical heaters are temporarily inserted into the melter tank vapor space through the melter lid to effect the initial melting of the startup charge. For this purpose, 13 bayonet-type silicon carbide resistance heaters are used. These heaters have a recommended power loading of 11 watts/cm² of radiating surface, up to an operating temperature of 1250°C, which translates to maximum operating values of 104 V, 31.5 amps and 3.3 kW/element. The elements are electrically connected in parallel and release a maximum of 43 kW to the melter cavity. The melting cavity near the startup heaters is monitored by two 3-mm type-"K" thermocouples, one of which is used as feedback in a heater power control system.

The temperature of the melting cavity during startup is regulated by controlling the AC voltage applied to the 13 silicon carbide heaters in the melting cavity vapor space. As is seen in the schematic electrical diagram of Figure 11, 480-V, single-phase, 60-hertz power is supplied to a 100-amp, proportional, phase-angle-controlled, SCR power controller. A 0-to-5 VDC control signal from an external process controller regulates the SCR output voltage from 0 to 480 V. The SCR output voltage is reduced by a power transformer to 0 to 120 V, and is applied directly to the bus bars for the 13 startup heaters. One of the vapor space thermocouples is used as a temperature feedback for this process controller.

The startup heater power controller has the option of either "manual" or "automatic" operation, and in the automatic mode has the option of local setpoint control or remote setpoint control. For the remote setpoint control option, the process controller has been connected to a Model 5300 Data-Trak[®] controller programmer. The programmer is fitted with a program card that will increase the process controller setpoint uniformly from 100°C to 1000°C over a 70-h period for a maximum temperature rate increase of 13°C/h. The programmer has a "hold" capability that will stop the increase of the controller setpoint and allow the startup heaters to "soak" the melter at a particular temperature as long as desired. When the temperature of the startup charge has reached 800°C to 1000°C, power is applied to the melter electrodes and, as soon as conduction is achieved and maintained, the power to the startup heaters is secured and the temporary startup heaters are removed from the tank vapor space.

To minimize thermal strain during shutdown, the startup heaters were reinstalled and a program card that decreased the melter vapor space temperature from 1000°C to 20°C over a 4-d period was used. Unfortunately, several heater units were lost as salts volatilized from the glass and condensed on the relatively cooler upper sections of the heaters and shorted the two halves of the particular type of silicon carbide heaters being used together, which caused arcing, high local thermal gradients in the heaters, and eventual cracking.

[®]Registered trademark of Research Incorporated, Minneapolis, Minnesota.

FIGURE 11. Startup Heater Power Control

4.2.3 Discharge Trough Heater Power Control System

Glass flows out of the melter through a submerged throat in one side wall of the melter, upward through a refractory riser block, and into one end of the horizontal refractory discharge trough. After flowing the length of the discharge trough, the glass spills over the end face of the trough and into the receiving canister. To maintain the glass in the trough at a temperature suitable for pouring, the discharge trough is radiantly heated with six

bayonet-type silicon carbide resistance heaters positioned in a cavity in the refractory directly above the discharge trough. These heaters have a recommended power loading of 11 watts/cm² of radiating surface up to an operating temperature of 1250°C, which translates to maximum operating values of 104 V, 31.5 amps and 3.3 kW/element. The six elements are electrically connected in parallel and released a maximum of 20 kW to the discharge trough cavity.

The temperature of the discharge trough cavity is regulated by controlling the A.C. voltage applied to the six silicon carbide heaters in the discharge trough vapor space. As is seen in the schematic electrical diagram of Figure 12, 480-V, single-phase, 60-hertz power is supplied to a 100-amp, proportional, phase-angle-controlled, SCR power controller, and a 0-to-5 VDC control signal from an external process controller regulates the SCR output voltage from 0 to 480 V. The SCR output voltage is reduced by a power transformer to 0 to 120 V and is applied directly to the six parallel-connected heater elements. One of the two thermocouple assemblies that are monitoring the discharge cavity temperature is used as a temperature feedback to the process controller. A 10-turn, 10K potentiometer, set at about 78%, is used as a voltage divider in the process controller output signal to reduce the 0-to-5 VDC output signal to 0 to 4.33 VDC. This limits the SCR output to a maximum of 104 VAC, which is the maximum operating voltage recommended for the discharge cavity silicon carbide heaters.

4.2.4 Discharge Face Heater Power Control System

When the glass is discharged from the melter, it flows along the horizontal discharge trough, spills over the end, down the end refractory face of the trough, down and off the tip of an Inconel-690 discharge lip, to free-fall into a receiving canister. The discharge face and lip are radiantly heated with two bayonet-type silicon carbide resistance heaters to maintain the discharge face and lip at a temperature where "stringing" of the glass will be minimized when the melter is tilted back to terminate a pouring operation. The two heaters are in front of, and to either side of the discharge face and lip. These two heaters have a recommended power limitation of 11 watts/cm² of radiating surface but, being longer than the discharge trough heaters, they have maximum

FIGURE 12. Discharge Trough Heater Power Control

operating values of 162 V, 32.5 amps, and 5.25 kW/element. These elements are also electrically connected in parallel and release a maximum of 10.5 kW to the discharge face space.

The temperature of the discharge face space is regulated by controlling the A.C. voltage applied to the two silicon carbide heaters in the discharge face space. As is seen in the schematic electrical diagram of Figure 13, 480-V, single-phase, 60-hertz power is supplied to a 100-amp, proportional, phase-angle-controlled, SCR power controller, and a 0-to-5 VDC control signal from an external process controller regulates the SCR output voltage from 0 to

FIGURE 13. Discharge Face Heater Power Control

480 V. The SCR output voltage is reduced by a power transformer to 0 to 240 V, and is applied directly to the two parallel-connected heater elements. A single thermocouple monitoring the discharge face space temperature is used as a temperature feedback to the process controller. A 10-turn, 10K potentiometer set at about 68% is used as a voltage divider in the process controller output signal to reduce the 0-to-5 VDC output signal to 0 to 3.38 VDC. This will limit the SCR output to a maximum of 162 VAC, which is the maximum operating voltage recommended for the discharge face silicon carbide heaters.

4.2.5 Freeze Valve Heater Power Control System

During normal melter operation cooling air is applied to the tip of the freeze-type, melter bottom drain. This cooling air maintains the temperature of the valve tip at about 350°C, freezing any glass that has drained into the valve. To melt the frozen glass in the valve, and thus to enable the glass to drain from the tank, the cooling air is shut off to the valve tip and power is applied to two 1.5-kW flat-plate resistance heaters, positioned on one either side of the freeze valve body. As is seen in the schematic electrical diagram of the freeze valve power control system (Figure 14), 480-V, single-phase, 60-hertz power is supplied to a 100-amp, proportional, phase-angle-controlled, SCR power controller. A 0-to-5 VDC control signal from an external process controller regulates the SCR output voltage from 0 to 480 V. The SCR output voltage is reduced by a power transformer to 0 to 240 V, and is applied to the two 1.5-kW heaters wired in parallel. A thermocouple in contact with the freeze valve tip provides feed-back information to the process controller regulating the valve temperature.

FIGURE 14. Freeze Valve Heater Power Control

4.3 FRIT ADDITION SYSTEM

The frit is added to the melter as a premelted solid that has been crushed and sized to a -20 +80 mesh range. The frit is continuously metered by weight with a belt-type weigh-feeder into an airlock device and by gravity through the airlock and connecting piping into the conical section of the calciner. From there the frit drops with the calcine through a flexible 17-cm-dia connecting pipe into the glass-melting tank.

4.3.1 Solids Feeder

The solids feeder is a standard Merrick Model 950-C Gravimerik® Solids Feeder that is controlled with a Model DSC-1 Digital Feed Controller. The crushed frit, sieved to the nominal -20 +80 mesh range, is a dry, free-flowing, nonflooding solid that is ideally suited to the Gravimerik Solids Feeder. These characteristics allow the frit to flow smoothly out of an internal hopper-distributor to deposit a uniform layer of frit in the center of the weigh belt regardless of belt speed. Actual measured delivery rates within $\pm 0.5\%$ of the setpoint values have been consistently maintained with this system. As the frit mesh size is decreased, the free-flowing quality of the material decreases, and bridging in the internal hopper-distributor compromises the accuracy of the solids feeder.

4.3.2 Frit

Although the frit is originally packaged with a size range of -20 +80 mesh, the material that discharges from the solids feeder contains a significant fraction of material ranging from -80 mesh to -325 mesh, which probably results from the shipping and materials-handling techniques used in getting the frit to the solids feeder hopper. As the frit drops from the end of the solids feeder conveyor weigh belt, it encounters a free-fall of about 25 cm before entering the airlock system. During this free-fall there is some separation of the fines from the coarser frit material, which are then picked up in the air currents generated by the free-falling frit and generally

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distributed within the solids-feeder housing. While the solids-feeder bearings and load cell are compatible with a dusty environment, the built-in weigh belt cleaning device and the built-in belt pulley scrapers are unable to keep the inside surface of the weigh belt free of powdered frit accumulations. Periodic manual cleaning of these surfaces is required to maintain the precision performance of the solids feeder.

4.3.3 Air Lock

Since the solids feeder is not an airtight system, an airlock system is required in the frit transport line from the solids feeder discharge to the calciner cone. A standard GEMCO® airlock valve, consisting of two GEMCO type "T," 10-cm flanged, spherical valves, separated with a 14-in intervening chamber, is used for this purpose. Each spherical valve is driven by an air cylinder operator and requires only a quarter turn to go from fully open to a dust-tight seal. The air operators are electrically controlled and are sequenced to operate the valves intermittently. Position sensing switches inhibit the opening of either valve unless the other valve is fully closed, thereby reducing the air in-leakage into the calciner-melter system. The performance of this airlock has been acceptable to date; although it has failed twice, neither failure can be attributed to a weakness of the unit, but rather to a weakness in the overall system. In the first failure, the drive shaft for the lower spherical valve galled and seized in its journal bearing because the stellite-protected drive shaft had been improperly installed. In the second failure, the same drive shaft sheared, leaving the spherical valve in its fully open position. This, however, was caused by a blockage of the frit transport line in the calciner cone, and as the frit packed in the airlock, the torque required to rotate the lower valve increased until the drive shaft sheared.

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4.4 DATA RECORDING AND INSTRUMENT SENSORS

4.4.1 Automatic Data Recording

Type-"K" thermocouples were used to monitor temperatures throughout the melter facility. Table 3 and Figure 15 show the location of the thermocouples and of the multipoint recorders on which these indications were recorded.

During the September 1978 shutdown some new thermocouples were added, and there was some rearrangement of recorder assignments made. Table 4 and Figures 16 show the location and recorder assignment changes.

4.4.2 Manual Data Recording

Some parameter monitoring systems (i.e., water flow, air flow, air pressure, etc.) were not installed with electronic recording capabilities, and rely on manual observation and transcription of these sensors. Table 5 is a typical data sheet for this purpose.

TABLE 3. Original CFCM Thermocouple List

<u>T/C</u>	<u>Location</u>	<u>Recorder</u>	<u>Point</u>
1	Cooling Water Header	1	0
2	N Cooling Jacket Outlet	1	1
3	W Cooling Jacket Outlet	1	2
4	S Cooling Jacket Outlet	1	3
5	Cooling Air Header	2	0
6	N Electrode Cooling Air Outlet	2	18
7	S Electrode Cooling air Outlet	2	22
8	N IRC Air Outlet	2	2
9	S IRC Air Outlet	2	6
10			
11			
12	West Wall Corner - Bottom	1	4
13	West Wall Corner - Middle	1	5
14	West Wall Corner - Top	1	6
15	West Wall Center - Bottom	1	7
16	West Wall Center - Middle	1	8
17	West Wall Center - Top	1	9
18	N IRC - Bottom	2	3
19	N IRC - Middle	2	4
20	N IRC - Top	2	5
21	S IRC - Bottom	2	7
22	S IRC - Middle	2	8
23	S IRC - Top	2	9
24	Discharge Trough Sub-Floor - Inner	2	10
25	Discharge Trough Sub-Floor - Middle	2	11
26	Discharge Trough Sub-Floor - Outer	2	12

TABLE 3. (contd)

<u>T/C</u>	<u>Location</u>	<u>Recorder</u>	<u>Point</u>
27	N Electrode - Bottom	2	19
28	N Electrode - Middle	2	20
29	N Electrode - Top	2	21
30	S Electrode - Bottom (control)	2	23
31	S Electrode - Middle	2	24
32	S Electrode - Top	2	25
33	Discharge Trough - 1	2	13
34	Discharge Trough - 2 (control)	2	14
35	Discharge Trough - 3	2	15
36	Discharge Trough - 4	2	16
37	Discharge Face (control)	2	17
38	Auxiliary Tank Heaters N	1	22
39	Auxiliary Tank Heaters S (control)	1	23
40	Freeze Valve Nozzle - Top (control)	1	15
41	Freeze Valve Nozzle - Middle	1	16
42	Freeze Valve Shell - Top	1	17
43			
44	Tank Sub-Floor - Tank Corner	1	12
45	Tank Sub-Floor - Tank Center	1	13
46	Tank Sub-Floor - Discharge Throat	1	14
47	West Floor Cooler Exhaust	1	10
48	East Floor Cooler Exhaust	1	11
49	Freeze Valve Exhaust	1	19
50	Discharge Tube	1	18
51	Melter Tank - West Wall	1	20
52	Melter Tank - West Wall	1	21

FIGURE 15. Original Thermocouple Locations

TABLE 4. Modified CFCM Thermocouple List

<u>T/C</u>	<u>Location</u>	<u>Recorder</u>	<u>Point</u>
1	Cooling Water Header	1	0
2	N Cooling Jacket Outlet	1	1
3	W Cooling Jacket Outlet	1	2
4	S Cooling Jacket Outlet	1	3
5	Cooling Air Header	2	0
6	N Electrode Cooling Air Outlet	2	15
7	S Electrode Cooling Air Outlet	2	16
8	N IRC Air Outlet	2	2
9	S IRC Air Outlet	2	6
10	HX1 Air Outlet	2	13
11	HX1 Air Inlet	2	1
12	West Wall Corner - Bottom	1	4
13	West Wall Corner - Middle	1	5
14	West Wall Corner - Top	1	6
15	West Wall Center - Bottom	1	7
16	West Wall Center - Middle	1	8
17	West Wall Center - Top	1	9
18	N IRC - Bottom	2	3
19	N IRC - Middle	2	4
20	N IRC - Top	2	5
21	S IRC - Bottom	2	7
22	S IRC - Middle	2	8
23	S IRC - Top	2	9
24	Discharge Trough Sub-Floor	2	10
25	Discharge Trough Cooler	1	18
26	Feed Nozzle Cooler	1	19
27			
28			
29			
30	S Electrode - Bottom (control)	2	17
31			
32			
33			

TABLE 4. (contd)

<u>T/C</u>	<u>Location</u>	<u>Recorder</u>	<u>Point</u>
34	Discharge Trough - 1 (control)	2	11
35	Discharge Trough - 2	2	12
36			
37	Discharge Face (control)	2	14
38	Auxiliary Tank Heaters N	1	21
39	Auxiliary Tank Heaters S (control)	1	22
40	Freeze Valve Nozzle - Top (control)	1	15
41			
42	Freeze Valve Shell - Top	1	17
43			
44	Tank Sub-Floor - Tank Corner	1	12
45	Tank Sub-Floor - Tank Center	1	13
46	Tank Sub-Floor - Discharge	1	14
47	West Floor Cooler Exhaust	1	10
48	East Floor Cooler Exhaust	1	11
49	Freeze Valve Exhaust	1	18
50	Discharge Tube	1	16
51	Melter Tank - West Wall	1	19
52	Melter Tank - West Wall	1	20
53	Glass Probe, 0-in. level	1	23
54	Glass Probe, 3-in. level	1	24
55	Glass Probe, 6-in. level	1	25
56	Glass Probe, 9-in. level	1	26
57	Glass Probe, 12-in. level	1	27
58	Glass Probe, 15-in. level	1	28
59	Glass Probe, 18-in. level	1	29
60	N Electrode Probe, 0-in. level	2	23
61	N Electrode Probe, 3-in. level	2	24
62	N Electrode Probe, 6-in. level	2	25
63	N Electrode Probe, 9-in. level	2	26
64	N Electrode Probe, 12-in. level	2	27
65	N Electrode Probe, 15-in. level	2	28
66	N Electrode Probe, 18-in. level	2	29

FIGURE 16. Modified Thermocouple Locations

TABLE 5. Status Log #4--Miscellaneous Data

By _____
 Date _____
 Time _____

	<u>Unit</u>
Frit Feedrate	kg/h
Frit Accumulation	kg
Calciner Feedrate	ℓ/h
System Vacuum	in. H ₂ O
Canister Weight	kg
Electrode Power	kW/h
Electrode Power	kW
Water Flow - %	%
South Wall	
North Wall	
West Wall	
Freeze Valve Collar	
Discharge Lip	
Inlet Nozzle	
Heat Exchanger	
Air Flow - %	%
West Floor	
East Floor	
Freeze Valve	
South IRC	
N Electrode	
S Electrode	
North IRC	
Air Pressure - psig	psig
West Floor	
East Floor	
Freeze Valve	
South IRC	
N Electrode	
S Electrode	
North IRC	
Header	
Heater Purge - scfh	scfh
Glass Level - in.	in.

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H. H. Van Tuyl
Technical Information (5)
Publishing Coordination ChT(2)