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Investigation of Waste Glass Pouring Behavior Over a Knife Edge

Topical Report
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By:
M. A. Ebadian

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U.S. Department of Energy
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P.O. Box 880
Morgantown, West Virginia 26507-0880

By
Florida International University
Hemispheric Center for Environmental Technology (HCET)
Center for Engineering & Applied Sciences
10555 West Flagler Street
EAS-2100
Miami, Florida 33174

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1.0 INTRODUCTION

This report summarizes the research carried out at the Hemispheric Center for Environmental Technology (HCET) at Florida International University (FIU) for fiscal year 1997 (FY97) under the project " Investigation of Waste Glass Pouring Behavior over a Knife Edge" in support of the Tanks Focus Area (TFA) Technology Implementation Manager (EM-50) and the Savannah River Technology Center (SRTC).

High-level radioactive waste (HLW) is generated by the reprocessing of nuclear fuel discharged from nuclear reactors. Typical HLW is the residue of chemical reprocessing of uranium fuel and targets after radiation in nuclear reactors. The total volume of HLW approaches 300,000 m^3, contained in a solution or slurry. One method of further processing this waste is vitrification, or converting or capturing these wastes in glass to transform the liquids into a durable solid that will minimize the potential for release of the radioactivity into the environment during its hazardous period. The development of vitrification technology for converting radioactive waste into a glass solid began in the early 1960s. Many improvements in areas such as the conversion process and melter design have been made since then. However, some problems encountered in the vitrification process are still waiting for a solution. One of them is "wicking." During routine operations in the defense waste processing facility (DWPF), glass pouring has not been as reliable as desired. During pouring, the glass stream flows down the wall of the pour spout until it reaches an angled cut in the wall. At this point, the stream is supposed to break cleanly away from the wall of the pour spout and fall freely into the canister. However, the glass stream is often pulled toward the wall and does not always fall into the canister, a phenomenon known as wicking. This leads to a buildup of glass on the sides of the pour spout, requiring the mechanical cleaning of this area. The effects of varying the geometry of the pour spout and several process parameters that influence the viscosity, surface tension, and flow rate of the molten glass, such as glass and pour spout temperature, should be investigated to minimize this phenomenon.

The work performed at FIU-HCET consists of three phases. Phase 1 involves the assembly, construction, and testing of a melter capable of supplying molten glass at operational flow rates over a break-off point knife edge. Phase 2 will evaluate the effects of glass and pour spout temperatures as well as glass flow rates on the glass flow behavior over the knife edge. Phase 3 will identify the effects on wicking resulting from varying the knife edge diameter and height as well as changing the back-cut angle of the knife edge. This project will take two years to complete and is expected to conclude during fiscal year 1998 (FY98). After the project is finished, the details of the duplication of the wicking problem on the pour spout will be documented in a dedicated scientific notebook. These results will be reviewed by the responsible project and program managers at FIU-HCET before being submitted to SRTC. A full description of the test parameters, data, results, and interpretation will be provided in a detailed final report to SRTC at the conclusion of this project.

2.0 PROJECT DESCRIPTION

The ultimate goal of this project is to obtain data to help minimize wicking during waste glass pouring. The project tasks include the following:

- *Design the Experimental System for Glass Melting and Pouring.* The design of the experimental system for these tests is being executed with collaboration from Westinghouse Savannah River Company (WSRC) personnel and an independent advisor with expertise in relevant fields. Design and fabrication specifications have been sent to WSRC personnel for comment and approval. This task also involves performing the necessary heat transfer calculations required for designing the experimental test rig. Heat loss, heat load, and power requirements have been calculated. The experimental system design has been also addressed by this task. The flow visualization technique that will obtain the recommended quantity of data while pouring has been considered.
- *Acquire and Assemble the Melter System.* The materials needed to construct the experimental system and for the investigation of glass pouring behavior have been provided by WRSC. The machining, fabrication, and assembly of the melter rig are being performed by HCET.
- *Test and Evaluate the Melter System and Instrumentation.* Initial tests will be performed using glycerin to evaluate the performance of the feed control system and the related instrumentation. From these results, operational techniques may be modified and prepared for use in the fully operational system.
- *Determine the Key Parameters that May Influence Wicking.* Several factors will be investigated to determine their effects on wicking. Variations in parameters such as glass temperature, pouring temperature, and glass flow rate will be studied to quantify what effects they may have on wicking. Measurements of the film thickness and width, free stream thickness, contact angle, capillary deflection, viscosity, and surface tension will be taken.
- *Determine the Effect of Pour Spout Geometry on Wicking.* Variations to the pour spout geometry will be investigated to determine their effects on wicking.
- *Develop Design and Operating Principles to Avoid Wicking.* Methods and operating parameters will be established to minimize wicking.

3.0 RESULTS

The following tasks were completed in FY97:

- Design the Experimental System for Glass Melting and Pouring
- Acquire and Assemble the Melter System
- Perform Initial Research Work

3.1 DESIGN THE EXPERIMENTAL SYSTEM FOR GLASS MELTING AND POURING

The experimental system design meets the following requirements:

- The melter can contain a sufficient volume of molten glass to ensure that the flow of molten glass will last longer than half an hour at a flow rate of 300 lb/h and can withstand high temperature (about 1150°C) and resist corrosion.
- The furnace can heat the glass in the melter up to 1150°C and keep the molten glass at this temperature. The pressurization system can force the glass melt to flow through the riser and pour spout. The temperature in different sections of the melter can be controlled separately.
- The experimental system has a flow rate controller to ensure that the molten glass can flow at different rates.
- The experimental system has equipment to visualize the flow behavior of the molten glass and to collect information.

According to these requirements, the conceptual design of the system is shown in Figure 1.

The whole system consists of four subsystems: the melter and pour spout; the flow control and loading system; the furnace (heater) temperature measurement and control system; and the visualization system.

3.1.1 Melter and Pour Spout

The design for the melter and pour spout is shown in Figure 2. According to the requirements for the melter and pour spout, the material Inconel 690 was selected for the components of the melter and pour spout. The properties of this material are as follows:

- Density: 8.20g/cm^3
- Specific heat: 450 J/kg • °C
- Melting range: 1343~1377°C
- Good corrosion resistance

The riser section is directly attached to the side of the melter, reducing the heat loss and simplifying the structure. The riser section and pour spout extension section are connected with the knife edge by a flange, making it easy to replace one knife edge with another of a different geometry. There are several quartz windows located on the top of the knife edge and melter feed and on the side of the extension to view the flow of the molten glass. The access port on the top of the melter is designed for measuring the temperature inside the melter.

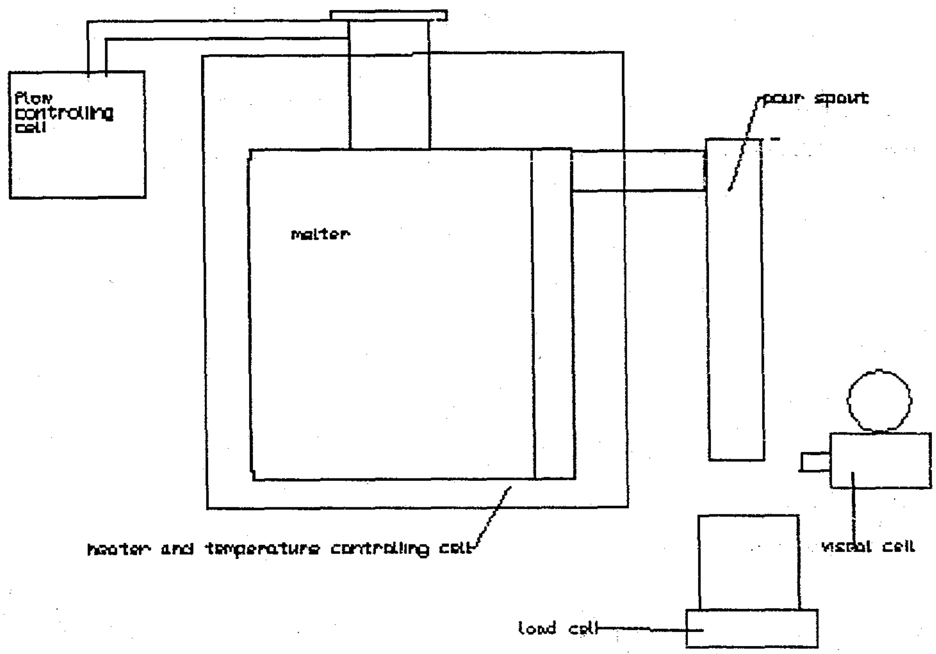


Figure 1. Conceptual design of experimental system.

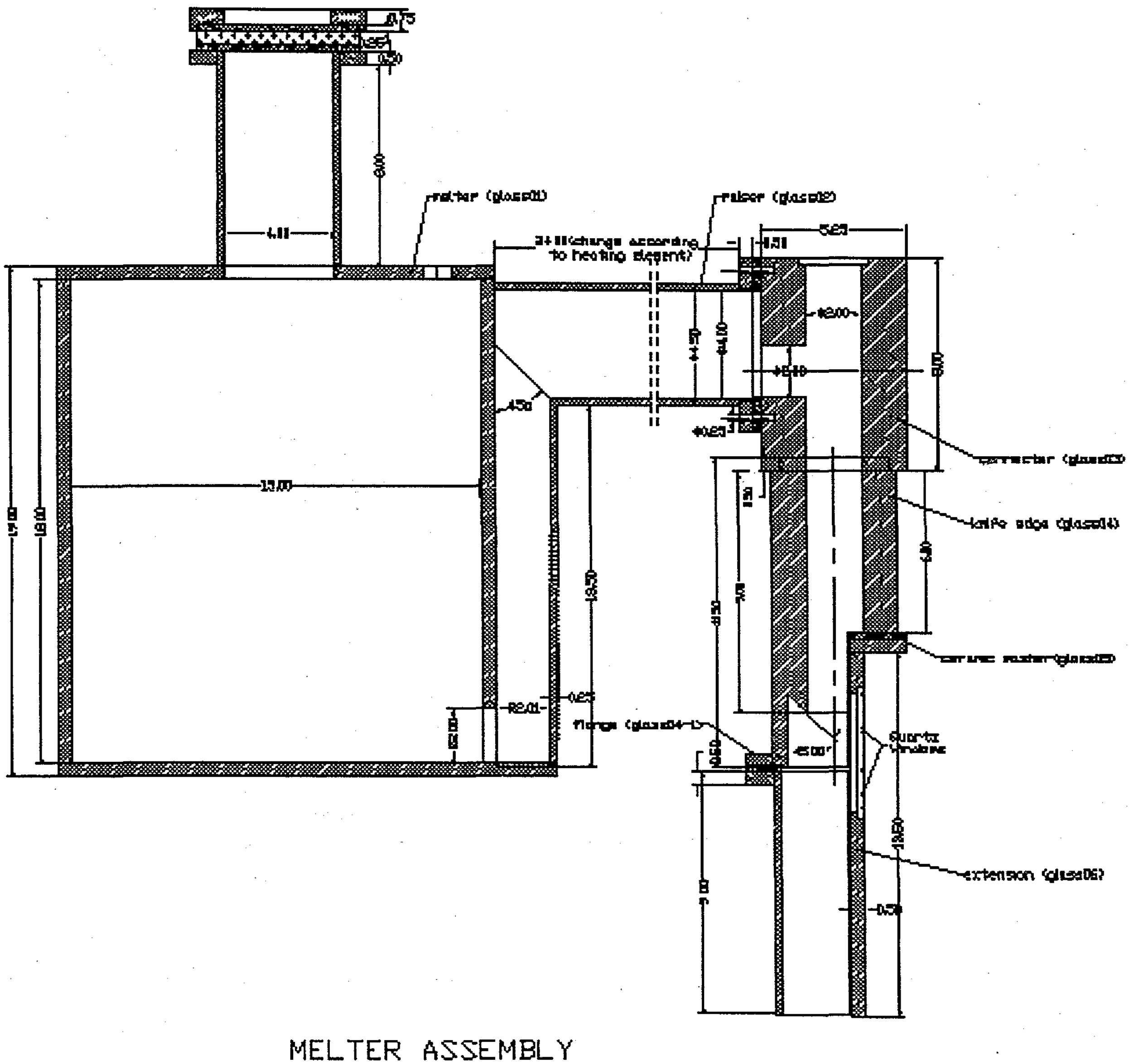


Figure 2. Melter and pour spout.

3.1.2 Furnace and Temperature Measurement and Control

3.1.2.1 Heat Balance Calculation

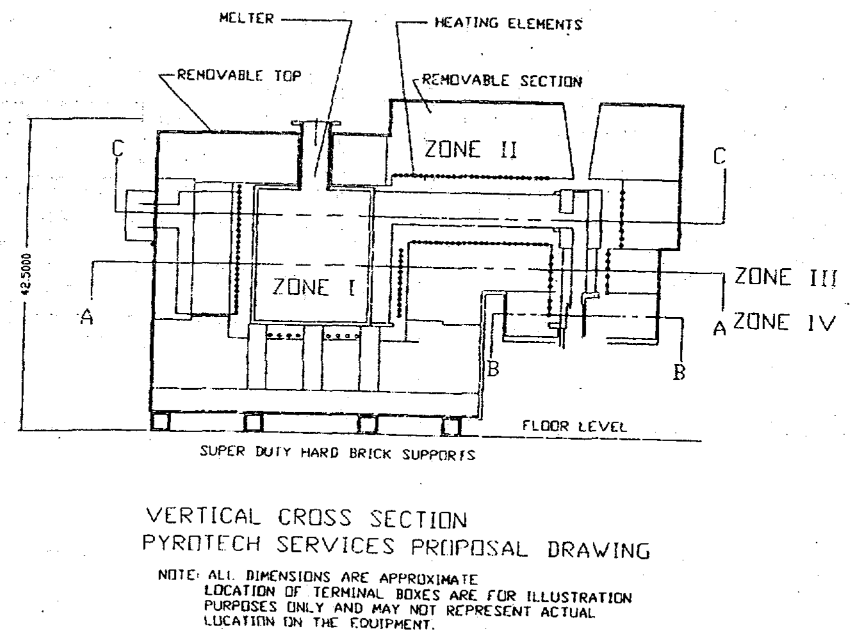
The heat balance calculations are provided in Appendix A.

According to the heat balance and the time needed to melt glass in the melter, the total power required should be: 30~40 kW.

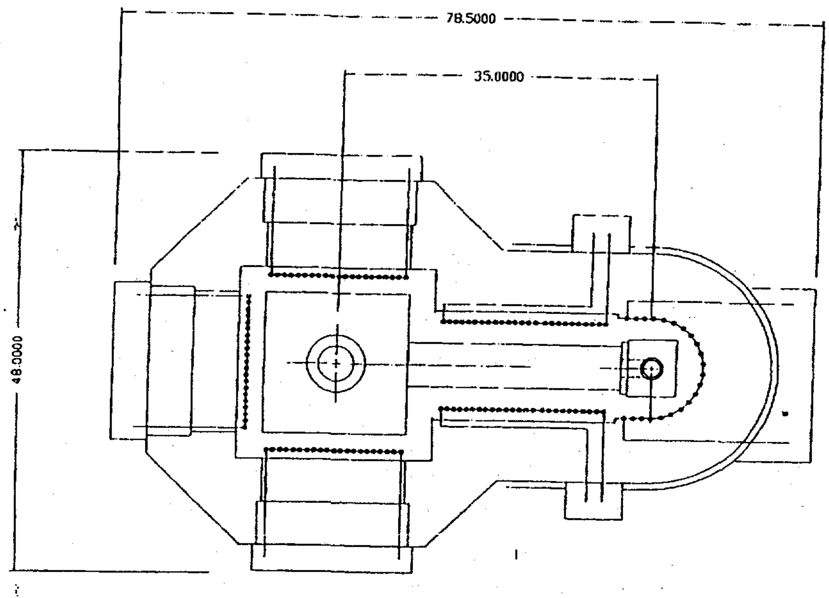
3.1.2.2 Furnace and Temperature Control

For the furnace design, approximately 30 furnace manufacturers were contacted, and eight companies were asked to provide detailed melter drawings. After sending out the drawings and detailed descriptions of the melter to these companies, two companies—ElectroGlass Furnace Inc. and Allegheny Industrial Systems Inc.—submitted conceptual designs and quotations. HCET ordered the furnace from Allegheny Industrial Systems Inc. The details of the furnace are shown in Figure 3.

The heating system is divided into four zones, each of which can be controlled separately. Zone 1 is designed to heat the Inconel bath, which is approximately 20 in. × 20 in. × 20 in. The chamber will be heated from the four sides and from the bottom. The bottom will be equipped with hard refractory piers to support the Inconel bath. The supports will be located between the bottom heating elements. Total heat input into Zone 1 will be 36 kW. Zone 2 will be the horizontal transition piece. This section will be heated with three elements, each approximately 24 in. × 6 in. located in a triangular configuration around the Inconel transition pipe. The insulation/heating element package will be fabricated to be easily removed for access to the pipe. Total heat input into Zone 2 will be 12 kW. Zones 3 and 4 will be constructed similar to Zone 2, except they will be located in the vertical plane. Zone 4 will be equipped with a view port for visual access to the Inconel sight glass located on the piping unit. Both Zones 3 and 4 will have a 12 kW heat input.



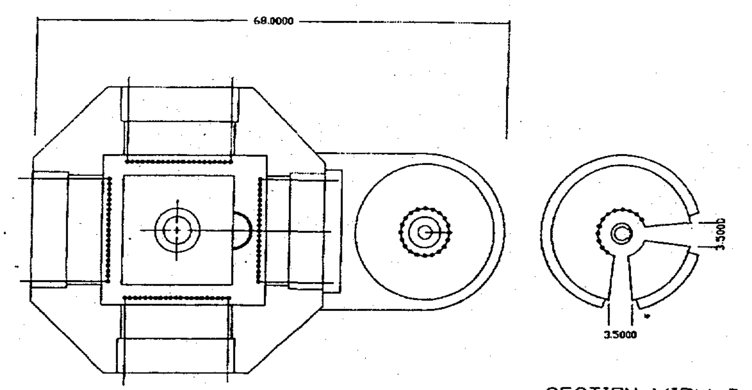
(a)



HORIZONTAL CROSS SECTION C-C

(b)

Figure 3. Furnace Design.



SECTION VIEW B-B

HORIZONTAL CROSS SECTION A-A

PYROTECH SERVICES PROPOSAL DRAWING
REVISION SHOWING DOUBLE VIEW PORTS NOVEMBER 17,1997

(c)

Figure 3. Furnace Design (Continued).

3.1.3 The Molten Glass Flow Rate Control

After the glass in the melter reaches the desired temperature, nitrogen gas will be introduced into the melter, pushing the molten glass flow out the pour sport. According to the calculation (Appendix B), the quantity of the gas needed is approximately constant to keep a constant flow rate of the molten glass (Figure 4), and the flow rate of the molten glass can be changed by controlling the flow rate of the nitrogen. The system to control the nitrogen flow rate consists of a nitrogen flow meter and controller. The flow rate of the molten glass is monitored with the load cell. Different flow rates can be obtained by adjusting the flow meter according to the load cell reading.

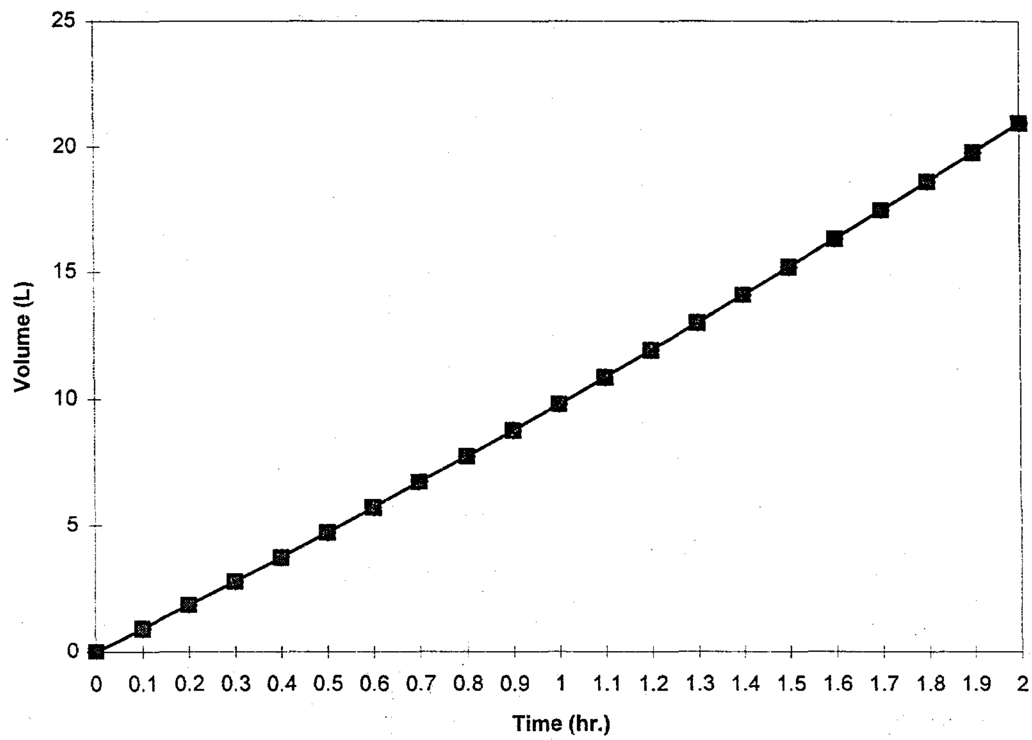


Figure 4. The volume of gas feed as a function of time.

3.2 ACQUIRE EQUIPMENT AND INSTRUMENTS

The equipment and instruments needed to set up the experimental system are listed in Appendix C.

The glass melter chamber has been welded with the exception of the feeding port. Other components of the melter are being machined. The pressurizing feed and flow control system, visualizing system, and load cell have been checked out.

3.3. INITIAL RESEARCH WORK

3.3.1 Melting and Solidification Performance of the Waste Glass

To estimate the working temperature of the melter and the melting point of the waste glass, the melting performance of the waste glass (about 3 pounds) has been tested using an induction melter. Figure 5 shows the melting state of the waste glass at different temperatures. The fluent state for Savannah River Site (SRS) waste glass occurs at approximately 1000°C. Below this temperature, the glass is too viscous, and if the temperature of the glass increases, foaming and smoking occur.

Temperature profiles of the glass melt during heating and solidification have been investigated using small amounts of SRS waste glass simulant melted in a conduction furnace. The results of these tests are shown in Figures 6 and 7. In the early stages of heating, the difference between the outside and center of the glass become larger as time increases, but in the later stages, the difference become smaller as time increases.

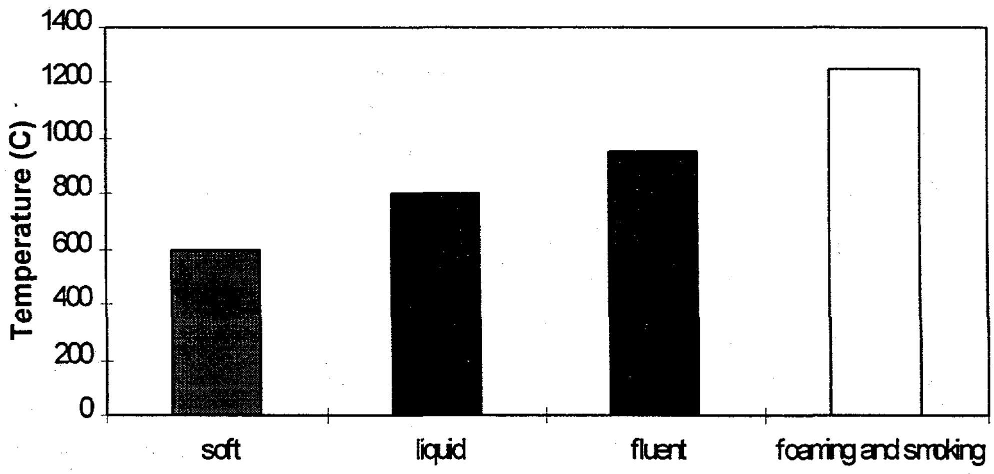


Figure 5. SRS waste glass melting performance.

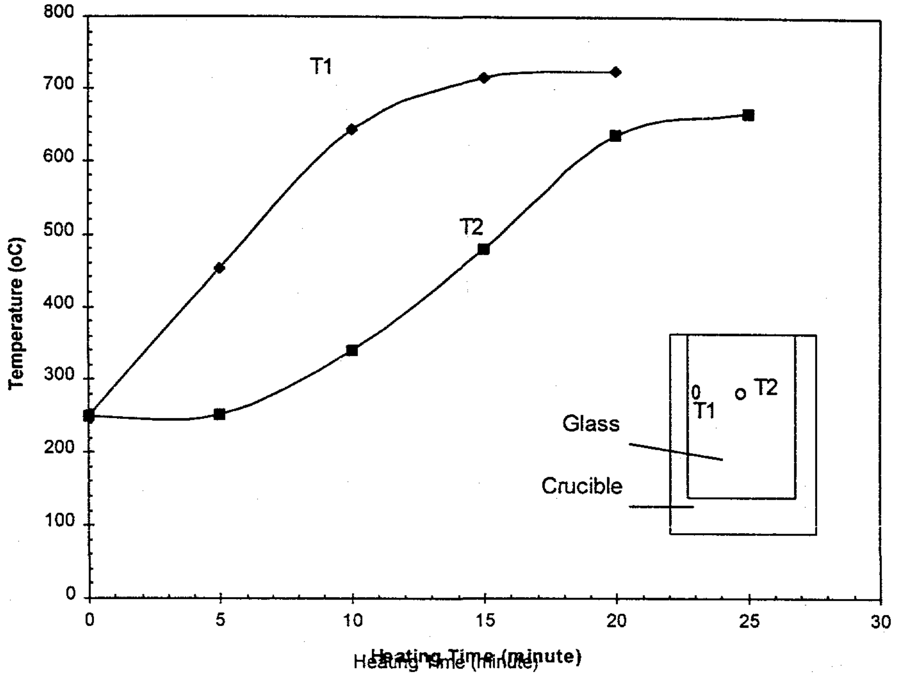


Figure 6. Temperature distribution in glass during heating (Glass is heated in graphite crucible in induction furnace).

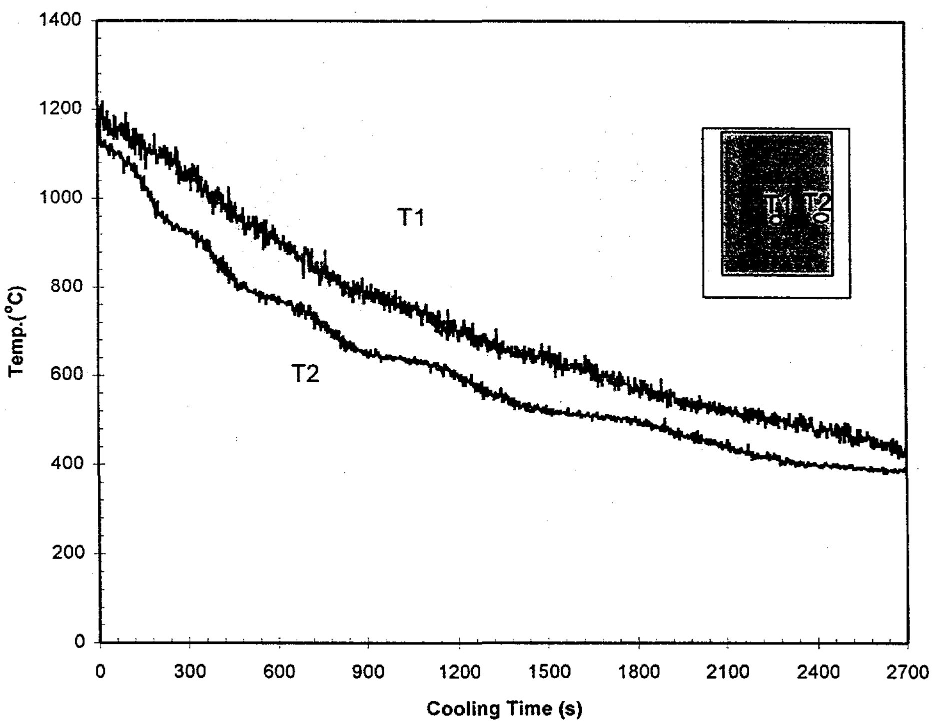


Figure 7. Solidification history of SRS glass (Melting in graphite crucible).

4.0 ACTIVITIES PLANNED FOR FY98

- *Continue to Acquire and Assemble the Melter System.*
- *Test and Evaluate the Melter System and Instrumentation.* Initial tests using glycerin will be performed to evaluate the performance of the feed control system and the related instrumentation. From these results, operational techniques may be modified and prepared for use in the fully operational system.
- *Determine the Key Parameters that May Influence Wicking.* Several factors will be investigated to determine their effects on wicking. Variations in parameters such as glass temperature, pouring temperature, and glass flow rate will be studied to quantify what effects they may have on wicking. Measurements of the film thickness and width, free stream thickness, contact angle, capillary deflection, viscosity, and surface tension will be taken.
- *Determine the Effect of Pour Spout Geometry on Wicking.* Variations to the pour spout geometry will be investigated to determine their effects on wicking.
- *Develop Design and Operating Principles to Avoid Wicking.* Methods and operating parameters will be established to minimize wicking.

5.0 CONCLUSION

The following preliminary activities for this project have been completed:

- The design of the experimental system for this project was executed and finalized with collaboration from WSRC personnel and an independent advisor with expertise in relevant fields. Heat loss, heat load, and power requirements have been calculated.
- The materials needed for the construction of the experimental system and for the investigation of glass pouring behavior have been provided by WRSC. The machining, fabrication, and assembly of the melter rig are being performed by HCET; most of this work has been finished. The visualization system and flow rate control system have been designed, checked out, and are ready for use.
- Some initial research on the melting and solidification of the waste glass was performed.

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APPENDIX A

HEAT BALANCE CALCULATION

HEAT BALANCE CALCULATION

THE HEAT NEEDED FOR MELTING GLASS IN THE MELTER

The volume of glass in the melter (V)

$$\mathbf{V} = 15 \times 15 \times 18 = 4050 \text{ in}^3 = 66368 \text{ cm}^3$$

The weight $W_g = V_g \times \rho = 66368 \times 2.4 = 159$ kg $= 350$ lb

The heat needed for heating the glass from 25°C to 1150 °C (J_g)

$$\mathbf{J_g} = W_g \times Cp_g \times (T_2 - T_1)$$
$$= 159 \times 1046.7 \times (1150 - 25)$$
$$= 1.87 \times 10^8 \text{ J}$$

The heat needed for heating melter from 25°C to 1200 °C (J_m)

$$\mathbf{W_m} = (18 \times 16 \times 0.5 \times 4 + 16 \times 16 \times 0.5 \times 2) \times 0.296$$
$$= 243 \text{ lb} = 117 \text{ kg}$$

$$\mathbf{J_m} = W_m \times Cp_m \times (T_2 - T_1)$$
$$= 117 \times 450 \times (1200 - 25)$$
$$= 0.617 \times 10^8 \text{ J}$$

Total heat needed

$$\mathbf{J} = J_g + J_m$$
$$= 1.87 \times 10^8 + 0.617 \times 10^8$$
$$= 2.487 \times 10^8 \text{ J}$$

Heat Loss

If the structural and insulation components of the walls are 8 in. thick, then the outside dimensions of the furnace are approximately 48 in. × 36 in. × 36 in. An average value for the thermal conductivity of the wall is approximately 0.5 BUT/ft^2·hr·F.inch. Using a correction factor of 1.29 for the top and 0.63 for the bottom, the total heat loss is approximately,

$$Q_L = 1.83 \text{ kW}$$

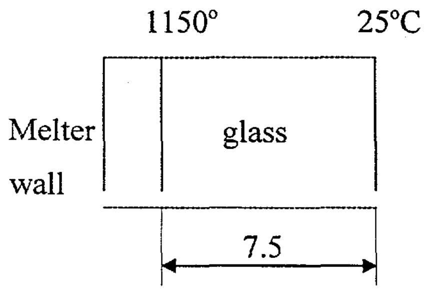
The Time Needed to Melt the Glass in the Melter at Given Power

$$t = \frac{J}{(P - Q_L)3600}(hr)$$

P (kW)	10	20	30	40
t (hr)	8.1	3.7	2.4	1.9

(Here the heat storage in heater and insulator are not considered in the calculation.)

The Heat Transfer from Melter to Glass



$$Q = \frac{T_1 - T_2}{\frac{b}{\lambda S}} \quad (W)$$

T_1, T_2 ---temperature of melter wall and glass inside (°C)

b--- distance from surface to center of glass (m)

S --- surface area vertical to the heat transfer direction (m^2)

λ --- heat transfer coefficient (w/(m·°C))

Heat transfer from the side wall of melter to glass

$$Q_s = \frac{1150 - 25}{\frac{0.1905}{(0.5 \sim 1) \times 0.7845}} = 2316 \sim 4633(W)$$

Heat transfer from the top and bottom of melter to glass

$$Q_{tb} = \frac{1150-25}{\dfrac{0.2159}{(0.5\sim 1)\times 0.3303}} = 861 \sim 1722(w)$$

Total heat transfer from the melter to glass

Q = Qs + Qtb = 3177~6355(w)

Here, heat transfer is considered only in conduction. In a real case, during heating, the glass near the side of melter will be molten and convection will occur, which accelerates heat transfer from melter to glass. So more heat than the calculation can be transferred from melter to glass.

APPENDIX B

THE CALCULATION FOR FLOW RATE CONTROL

THE CALCULATION FOR FLOW RATE CONTROL

Depending on the dimensions of the melter, the highest pressure in the melter should be calculated as the following equation:

$$p = Hr + Atm \quad (1)$$

where p is the highest pressure; H, the vertical distance between the top surface and bottom level in the melter; r, the density of the glass; and Atm, the atmosphere.

According to the requirements of the project, the range of the flow rate should be from 50 lb/h to 300 lb/h. The basic equation is as follows:

$$M = r * A * h \quad (2)$$

the melter; and h, vertical distance.

$$\frac{dM}{dt} = r * A * \frac{dh}{dt} = \omega(lbs / hr.) \quad (3)$$

$$\frac{dh}{dt} = \frac{\omega}{r * A} \quad (4)$$

$$p = r * h$$

$$\frac{dp}{dt} = r * \frac{dh}{dt} = \frac{\omega}{A} \quad (5)$$

$$p = \frac{\omega}{A} * t + c_1 \text{ (C1: Atm)} \quad (6)$$

$$V = h * A$$

$$\frac{dV}{dt} = A * \frac{dh}{dt} = \frac{\omega}{r} \quad (7)$$

$$V = \frac{\omega}{r} * t + C2 \quad \text{(C2=0)} \tag{8}$$

$$n = \frac{PV}{RT} = \frac{P'V'}{R'T'} \tag{9}$$

where: T = Temperature in the melter, 1150 + 273 (K)

T' = Room temperature, 25 + 273 (K)':

P' = Inlet pressure, 3psiG

V' = Volume of the gas.

$$V' = \frac{PVT'}{P'T} = \frac{(\frac{\omega}{A} t + atm) * \frac{\omega}{r} t * T'}{P'T} \tag{10}$$

IF: $\omega = 300 lbs / hr., A = 0.176 m^2, r = 0.94 lbs / in^3.$

$$V' = 0.701 t^2 + 9.075 t \quad \text{(L)}$$

Table 1.
Volume of Gas Feed as a Function of Time

t (hr)	**V** (=0.701t²+9.075t) (L)
0	0
0.1	0.91451
0.2	1.84304
0.3	2.78559
0.4	3.74216
0.5	4.71275
0.6	5.69736
0.7	6.69599
0.8	7.70864
0.9	8.73531
1	9.776
1.1	10.83071
1.2	11.89944

Table 1.
Volume of Gas Feed as a Function of Time (Continued)

t (hr)	**V** (=0.701t²+9.075t) (L)
1.3	12.98219
1.4	14.07896
1.5	15.18975
1.6	16.31456
1.7	17.45339
1.8	18.60624
1.9	19.77311
2	20.954

APPENDIX C

EQUIPMENT AND INSTRUMENTS

Table 2.
Equipment and instruments

	Parts name	Company	Catalog No	Unit Price	Quant.	Total	Status
1	Multiplexer (color)	Micro Optics of Florida	MPC-MP	1488	2	2976	received
2	Color Camera	……	MM7	1248	4	4992	…..
3	Zoom lens	……	MZ18-108	379.	4	1516	…
4	BNC cable	..	BNC-4	17.28	5	86.4	….
5	Sony color monitor	……	PYM14N17	571	1	571	….
6	Digital Video Caliper	…..	DMZR	1920	1	1920	…..
7	Heater and Insulator	ElectroGlass etc.					ordered
8	Load Cell						received
9	Chipmunk Jaw Crusher (capacity: 800lbs/hr)	BICO	241-36	3750	1	3750	received
10	Quartz Window	American Precision Glass Corp.	2.5"Dia. × 1/2" 6.0"Dia. × 1/2" 2.5" × 5.0" × 1/2"	35 188 155.5	2 2 2	70 376 311	ordered
11	High Temp. Bolt & Nut	United Titanium. Inc.	½"-13 × 1 ¾" bolt ×2 ½" bolt ½"-13 Nut ½" washer ¾" NPT nut	11.97 13.05 5.03 1.49 93.0	12 12 2	143.64 155.6 120.72 35.76 186.0	received
12	Exceptional Digital Thermometer	OMEGA	HH-23	219	1	219	received
13	9V Nicad Battery Charger for HH-23	…..	HH22-AC	50	1	50	….
14	Multiprobe Switchbox	…..	HH20SW-K	109	1	109	….
15	Rugged Carrying Case Type Kit	…	TK-2-K	299	1	299	….
16	Thermowell	….	¾"-260H-U16½"316	138	2	276	….

Table 2.
Equipment and instruments (Continued)

	Parts name	Company	Catalog No	Unit Price	Quant.	Total	Status
17	…..	…..	$\frac{3}{4}$"-260HL-U16$\frac{1}{2}$"316	138	2	276	….
18	Thermocouple	…..	NB2-CAIN-14G-24-TBSL	69.5	2	139	…..
19	…..	….	NB2-CAIN-14G-21-TBSL	69.5	2	139	…..
20	…..	…..	NB2-CAIN-14G-12-TBSL	62	4	248	…..
21	Nipple Extension	……	Type3-6	8	2	16	……
22	Thermocouple Head	…..	NB2-4	28	2	56	……
23	Thermocouple Element	……	XC-20-K-18	17	2	34	……
24	…..	……	XC-20-K-24	19	2	38	……
25	Flowmeter	Instrument Specialties Inc.	840-i-2-ov1-e—v1—s1	1145	1	1145	received
26	Cable	………	840-CZE	35	1	35	……….
27	Digital Display	………	901u-ps-bm-11-00	925	1	925	……….
28	high temperature material for gaskets	Industrial Gasket & Shim Co., Inc. American Ring & Tool Co.					received