METHOD FOR PRODUCING GLASS FIBER

Quarterly Report for the Period of April 1999 to June 1999

SUBMITTED TO:

**THE UNITED STATES
DEPARTMENT OF ENERGY
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SUBMITTED BY:

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Quarterly Technical Progress Report for Method For Producing Glass Fiber

The following technical progress report summarizes the work performed over the period of April 1999 to June 1999 on the project "Method for Producing Glass Fiber." The following sections review the progress made on the individual tasks. The final section describes the work planned for the next quarter, July 1999 to September 1999.

TASK 1 ENGINEERING AND DESIGN OF MELTER

Engineering and design work has been initiated on the design of the rotating furnace. Using this information, engineering drawings of the melter were prepared, and the review of this work ongoing. Selection of a few of the melter components, such as the support of the center of the rotor is still ongoing and should be completed in the near future.

GENERAL CRITERIA

A process flow diagram (PFD) for the experimental test loop was developed. The PFD is shown in Figure 1. The PFD provides the air, gas, batch, and flue gas mass flows. Utilizing these mass flows it has been determined that the ID and FD fans at Vortec's U-PARC facility are adequate for the new test loop. Only air supply piping and flue gas ductwork will be required to tie-in the test loop to the existing equipment. Likewise, the gas supply at the U-PARC facility is adequate for the new test set-up; however, gas burners and controls will have to be purchased. A screw feeder to meet the requirements of the project will have to be purchased.

The initial primary effort of the design of the melter involved understanding the heat flow through the refractory components. The physical model previously prepared for this project, and simple heat flow models were used to predict temperatures throughout the structure. The results of this model are discussed under Task 2. The predicted temperatures for the selected areas of the furnace used in the design are listed in **Table 1**.

Table 1

Location on Melter	Temperature (°F)
Melter Roof Top	435
Melter Roof Sidewalls	400
Rotor Side-Exterior Surface	300
Rotor Bottom-Exterior Surface	400
Glass Pool in Rotor	2600
Molten Glass in Stator	2300
Glass at Bushing	2300

Figure 1. Process Flow Diagram of R

ing Fiber Furnace

				Vortec Proprietary Data			
				METHOD OF PRODUCING GLASS FIBER			
				PROCESS FLOW DIAGRAM			
				DRAWN BY J. BOTOLOMI 6/17/99 CHECKED		VORTEC ENGINE APPROVAL PROJ. MGMT. APPROVAL	
						SCALE NONE	
				CONTRACT NO. 63200			
				D-63200-102-001		A	
				DRAWING BLANKET		REV.	
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REFRACTORY

Refractory selection for the glass fiber furnace has begun. A cross-section of the furnace is presented in Figure 2. Glass contact refractories will be a 50% chrome material. It is expected that the rotor and stator will be made from pre-cast bonded shapes. Preliminary detailed drawings of the pre-cast shapes have been completed and are presented in Figure 3. North American Refractories can provide these shapes in Serv 50, a material currently in use by an E-glass manufacturer. The floor of the rotor will be backed up with low cement insulating castable refractory. Insulating firebrick, insulating board, and insulating blanket will back up the sidewall of the rotor. The rotor refractories will be installed in a steel shell. The walls of the steel shell will operate at about 300°F and the floor will operate at about 400°F.

The refractory of the stationary furnace roof will be a mullite low cement castable refractory. The refractory will be held in place with ceramic anchors. Two layers of low cement insulating castables will back up the mullite refractory. The top of the steel roof will operate at about 435°F and the sidewalls at about 400°F.

BURNERS

Natural gas fired cold air burners will be used to heat the furnace. A general rule of thumb for sizing gas burners in glass furnaces is to add the structural heat loss to the heat required to melt the batch and multiply it by a factor of five (80% of the heat goes up the stack). Several years ago Vortec designed a small glass furnace with the same capacity as the proposed glass fiber furnace using this rule of thumb. The heat input in this furnace was marginal. After doubling the heat input capacity, the furnace operated properly. For the proposed glass fibers furnace the calculated heat input has been multiplied by a factor of ten, yielding a burner system with a requirement of 2.7 million Btu/hr heat input. Three 900,000 Btu/hr burners will be used in the system. Both Pyronics and Bloom Engineering have been contacted for engineering information and pricing. The burner systems will be supplied with all gas and air controls and flame safety management.

ROTOR DESIGN

Two schemes have been investigated for driving the rotor: a gear and pinion arrangement, and a roller chain drive. Of the two schemes the roller chain drive is the least expensive and more flexible with regard to variable drive speed once the system has been built. Also the roller chain drive can be made with standard components from suppliers such as McMaster-Carr and Grainger while the gear and pinion are custom made components. Components for the roller chain drive have been selected and will be incorporated in the layout drawings.

The rotor portion of the furnace will be supported with steel rollers and wedge style leveling mounts. These are standard components that can be obtained from McMaster-Carr and Grainger.

Figure 2. Preliminary Drawing of Cross-

Section of Rotating Furnace

DOC METHOD OF PRODUCING GLASS FIBER ROTATING FURNACE STATIONARY CIRCULAR FOREHEARTH				DRAWN BY V.C. SKOOG 6/1/99 CHECKED VORTEC ENGINE APPRVL PROJ MGMT APPRVL SCALE 1"=1'-0"
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CIRCULAR FOREHEARTH

TOP VIEW

SECTION A-A

BOT. VIEW

Figure 3. Preliminary Drawing

DETAIL-1
SCALE 3" = 1'-0"

DETAIL-2
SCALE 3" = 1'-0"

BOT. VIEW

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BATCH FEED SYSTEM

Glass batch ingredients will be fed through the furnace roof sidewall by a screw feeder. Preliminary discussions with screw feeder manufacturers have been initiated and will continue through July. There are concerns that the fine particles in the batch will become entrained in the turbulence within the combustion zone and may be carried out through the stack. An investigation into batch wetting systems to minimize this problem will be made during the third quarter.

TEMPERATURE CONTROL OF STATOR

Based on the physical rotor stator model prepared, it is expected that glass temperature in the stator can be controlled by raising or lowering the stator position within the rotor. Two schemes for accomplishing this action have been investigated. The first scheme used acme threaded rods to support the stator. A system of handwheels and roller chains would be used to control the position of the stator. This scheme was complex and interfered with access to the platinum bushings. A second concept using hydraulic cylinders and a hand pump was investigated. This arrangement is compact and allows for easy access to the bushing area, this concept is currently shown on the drawings in this report.

SUPPORT STEEL

A structural steel support frame to raise the melter to allow for access to the bottom of the melter for fiber drawing is required. An existing structural steel test cell at Vortec's U-PARC facility will be modified to accept the new test loop. Steel members have been sized and layout drawings will show the new steel. Information on the glass fiber winder is needed to set the elevation of the furnace. A preliminary drawing of the steel with the furnace in place is shown in Figure 4.

TASK 2 MODELING OF THE MELTER

The heat transfer between the rotating pool and the stator/forhearth was initially thought to be insufficient. The stator and rotor are separated by an air gap. To calculate the heat flux across this gap, an emissivity value and a shape factor for this area were needed. The physical model was constructed to measure these values on the basis that the heat transfer software selected, Algor, would have difficulties with modeling the free surfaces, specifically those of the rotor and stator. If insufficient heat flow occurs between these two components, then the temperature of the stator may drop below that required to produce suitable fibers.

Figure 4. Preliminary Drawing of S

Support Steel with Furnace in Place

DOE METHOD OF PRODUCING GLASS FIBER EQUIPMENT ARRANGEMENT ROTATING FURNACE		DRAWN BY Y.G. SKOOG CHECKED VORTEC ENGINEERING APPROVAL PROJ MGMT APPROVAL SCALE 1"=1'-0"
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Refractory pieces, to simulate the rotor and stator components of the melter, were shaped by Global Ceramic Services and the model assembled as shown in Figure 5. The rotor and stator portions of the model were machined from dense chrome refractory to the expected shapes of the rotor and stator interface. Dense chrome refractory is the same material that will be selected for these components in the pilot scale melter. Holes were drilled in the refractory to allow thermocouples to be inserted into the blocks to measure the temperature below the hot-face (P1 in Figure 5), on the rotor face between the rotor and stator (P2), and near the gap surface of the stator (P3). Additionally, the temperature of the furnace and the outside of the stator block were measured. To input heat into the model, the rotor block was positioned in front of a high temperature furnace. This simulates the refractory being heated by the molten glass at the bottom of the glass pool. The rotor and stator pieces were placed in a box constructed of 2 inch thick fiber board refractory to prevent heat from escaping through the edges of the system. The joints between the model components were made tight to prevent convection heat losses.

Figure 5. Schematic of Rotor Stator Model.

Data were collected as a function of spacing between the refractory and temperature set point in the furnace. The gap between the rotor and stator was adjusted with spacers to 1 and 2 inches. The rotor hot face temperature was adjusted by furnace set point. The temperature of the furnace ranged from 500°C (970°F) and 1500°C (2730°F). The temperature of the refractory was measured at the various points as a function of time. When the temperature rate of change became negligible, the system was assumed to have reached steady state and the temperatures recorded. Typically 2 to 3 hours were required for the system to reach steady state. The results of the experiment are presented in Figure 6.

Figure 6. Temperature Results from Physical Model

In the radiation heat flux equation the emissivity value and the shape factor are multiplied together. Although we cannot determine the value of each item, we were able to calculate the product of the two values. From the physical model, this product was determined to be 0.74. The details of this calculation are given in Appendix A. As a check of this experimentally determined value, a value was determined from the product of the textbook data for the emissivity of silica brick at 2500°F, 0.84, and the shape factor for two parallel plates one-inch apart, approximately 0.8, as 0.67. From the small difference between the experimental and the text book value, it was concluded that our experimental value should be good for predicting the steady state temperature profile of the glass furnace.

Utilizing a thermal conductivity for soda lime glass as a function of temperature from The Handbook of Glass Manufacture, a refractory manufacturer's conductance data for the selected refractories in the furnace and the experimental data for radiation, a steady state heat transfer analysis of the glass furnace was performed. The calculation predicts that with a glass surface temperature of 2600°F inside the glass furnace the glass temperature at the platinum bushing will be about 2300°F.

Knowing that the predicted temperatures within the furnace would be adequate was a major first step. If the predicted temperatures were too low, supplemental heating of the stator would have been required for the success of the glass fiber furnace.

The Algor modeling to determine the heat flow through the remaining sections of the melter will be performed if required.

TASK 3 EVALUATE MELTER DESIGN

The initial melter design was reviewed on a preliminary basis with a group of Vortec engineers. Several changes in the preliminary design were identified and incorporated in the presented drawings.

TASK 4 PREPARE ENGINEERING DRAWINGS OF PILOT SCALE MELTER

Three preliminary engineering drawings have been completed for the pilot scale melter. Copies of these drawings are included in Figures 2 thru 4.

TASK 5 COST ANALYSIS

An initial list of the individual components required for the construction of the demonstration melter has been compiled to determine the materials costs. Additionally vendors have been contacted to obtain price quotes of the individual components.

TASK 6

The third quarterly technical and financial quarterly reports have been completed and submitted. Monthly reports will be prepared to up date the Department of Energy Technical Project Officers of contract progress.

WORK PLANNED FOR JULY 1999-SEPTEMBER 1999

During this period, the engineering on the remainder of the melter will be completed to finish Task 1. Areas that need additional investigation include the platinum bushings and their ceramic keepers, the platinum drain tube assembly inside the rotor, and the winding mechanism for the glass fibers. For Task 2, additional modeling will be performed on an as need basis to determine heat flow through various system components. For Task 3, a meeting is planned with Mr. Drummond in July for the evaluation of the engineering work performed by Vortec. After this meeting, his input will be incorporated into the design of the system. Work will continue on the engineering drawings being prepared for Task 4 with the majority of this work being completed during this quarter. Additional vendors will be contacted to obtain further costing information for Task 5.

APPENDIX A

DOE GLASS FIBER FURNACE

RADIATION HEAT TRANSFER EXPERIMENT

OBJECTIVE - RUN A LABORATORY TEST TO CONFIRM THAT AN ADEQUATE HEAT FLUX WILL OCCUR BETWEEN THE ROTOR AND STATOR OF THE GLASS FIBER FURNACE TO MAINTAIN THE PROPER GLASS TEMPERATURE IN THE STATOR.

TEST SET-UP - TWO CHROME ALUMINA REFRACTORY PIECES WERE PURCHASED. THE PIECES WERE MACHINED TO THE PROFILE SHOWN ON ATTACHED SKETCH #1. THE PROFILES SHOWN WOULD APPROXIMATE THE CROSS-SECTIONS SHOWN IN THE WENDE DRUMMOND CONCEPTUAL SKETCHES.

THE TWO REFRACTORY PIECES WERE MOUNTED WITHIN A FOUR SIDE CHAMBER MADE OUT OF INSULATION BOARD. THE REFRACTORY WAS THEN DRILLED TO ACCEPT THERMOCOUPLES TO MONITOR THE REFRACTORY TEMPERATURES. THE CHAMBER WAS THEN ATTACHED TO AN ELECTRIC LABORATORY FURNACE. A SKETCH ILLUSTRATING A CROSS-SECTION OF THE TEST SET-UP AND THE TEMPERATURES TO BE MONITORED ARE ON PAGE 2.

THE FURNACE WAS TURNED ON AND THE TEMPERATURES WERE RECORDED. THE EXPERIMENT WAS RUN TWICE, ONCE WITH A 1" AIR GAP AND A SECOND TIME WITH A 2" AIR GAP.

A CURVE SHOWING THE TEMPERATURES MEASURED VS. THE FURNACE SET POINT IS PRESENTED ON PAGE 3.

DOE GLASS FIBER FURNACE

RADIATION HEAT TRANSFER EXPERIMENT

DOE GLASS FIBER FURNACE

RADIATION HEAT TRANSFER EXPERIMENT

ANALYSIS

FOR RADIATION BETWEEN TWO SURFACES

$$q_r = (E_{b1} - E_{b2}) F_{1-2} A \quad (1)$$

F_{1-2} = UNKNOWN SHAPE FACTOR BETWEEN PIECES 1 AND 2

A = AREA OF RADIANT SURFACES (BOTH PIECES HAVE EQUAL AREA)

$$E_{b1} = \epsilon b_1 \sigma T_1^4 \quad (2)$$

$$E_{b2} = \epsilon b_2 \sigma T_2^4 \quad (3)$$

WHERE:

$\epsilon b_1 = \epsilon b_2$ = EMISSIVITY OF REFRACTORY (UNKNOWN)

$$\sigma = 0.1714 \times 10^{-8} \text{ BTU/hr} \cdot \text{ft}^2 \cdot ^\circ\text{R}$$

T = SURFACE TEMPERATURE IN $^\circ\text{R}$

SUBSTITUTING EQUATIONS (2) & (3) IN EQUATION (1) YIELDS:

$$q_r = (\epsilon \sigma T_1^4 - \epsilon \sigma T_2^4) F_{1-2} A$$

$$q_r = \epsilon \sigma F_{1-2} A (T_1^4 - T_2^4)$$

$$\epsilon F_{1-2} = \frac{q_r}{\sigma A (T_1^4 - T_2^4)} \quad (4)$$

WE ALSO HAVE CONDUCTION BETWEEN PIECES 1 AND 2

$$q_c = \frac{kA}{L} \Delta T$$

k = THERMAL CONDUCTIVITY OF THE AIR GAP

A = AREA :

ΔT = TEMPERATURE DIFFERENCE ACROSS GAP

L = THICKNESS OF AIR GAP

DOE GLASS FIBER FURNACE

RADIATION HEAT TRANSFER EXPERIMENT

FOR OUR TEST SET-UP

$$q_1 = q_r + q_c = q_2$$

q_1 = HEAT FLUX IN REFRACTORY PIECE 1

$q_r + q_c$ = COMBINED RADIATION AND CONDUCTIVE
HEAT FLUX IN AIR GAP

q_2 = HEAT FLUX IN REFRACTORY PIECE 2

REFRACTORY PIECE 1

$$q_1 = \frac{kA}{L} \Delta T = kA (T_{P1} - T_{P2})$$

WHERE:

$$k = 20 \text{ BTU-in/}^{\circ}\text{F-ft}^2 \text{ (HANDBOOK VALUE)}$$

$$T_{P1} = 2300^{\circ}\text{F}$$

$$T_{P2} = 1575^{\circ}\text{F}$$

$$L = 1.5''$$

$$A = 1 \text{ FT}^2$$

$$q_1 = \frac{20(1)}{1.5} (2300 - 1575) = 9667 \text{ BTU/HR}$$

DOE GLASS FIBER FURNACE

RADIATION HEAT TRANSFER EXPERIMENT

REFRACTORY PIECE 2

$$q_2 = \frac{kA}{L} (T_{p3} - T_{\text{outside}})$$

WHERE:

$$k = 2.0 \text{ BTU-in/hr-ft}^2\text{-}^\circ\text{F}$$

$$T_{p3} = 1250^\circ\text{F}$$

$$T_{\text{outside}} = 750^\circ\text{F}$$

$$L = \frac{15}{16}''$$

$$A = 1 \text{ ft}^2$$

$$q_2 = \frac{2.0(1)}{\frac{15}{16}} (1250 - 750) = 10,667 \text{ BTU/hr}$$

q_1 & q_2 ARE WITHIN 10% OF EACH OTHER - GOOD

FOR EVALUATING THE AIR GAP WILL USE AVERAGE

$$q_{\text{ave}} = \frac{9667 + 10667}{2} = 10167 \text{ BTU/hr}$$

TO EVALUATE THE AIR GAP WE NEED TO CALCULATE T_3

$$q_2 = \frac{kA}{L} (T_3 - T_{p3})$$

$$T_3 = \frac{q_2 L}{kA} + T_{p3}$$

$$T_3 = \frac{10,667(\frac{1}{16})}{2.0(1)} + 1250$$

$$T_3 = 1283^\circ\text{F}$$

SHR 6 OF 8

DOE GLASS FIBER FURNACE

RADIATION HEAT TRANSFER EXPERIMENT

AIR GAP EVALUATION

AS INDICATED BEFORE

$$q_1 = q_2 = q_c + q_r = 10,167 \text{ BTU/HR. (CALCULATED FROM DATA)}$$

CONDUCTION ACROSS AIR GAP

$$q_c = \frac{kA}{L} (T_2 - T_3)$$

$$k = .48 \text{ BTU} \cdot \text{in} / \text{HR} \cdot \text{FT}^2 \cdot ^\circ\text{F} \text{ (HANDBOOK VALUE)}$$

$$L = 1''$$

$$T_2 = 1575^\circ\text{F}$$

$$T_3 = 1283^\circ\text{F}$$

$$q_c = \frac{(.48)(1)}{(1)} (1575 - 1283) = 140 \text{ BTU/HR}$$

$$q_c + q_r = 10,167 = 140 + q_r$$

$$\therefore q_r = 10,027 \text{ BTU/HR}$$

DOE GLASS FIBER FURNACE

RADIATION HEAT TRANSFER EXPERIMENT

RADIATION HEAT FLUX ACROSS AIR GAP

FROM EQUATION (4);

$$\epsilon F_{1-2} = \frac{g_r}{\sigma A (T_1^4 - T_2^4)} \quad (4)$$

where:

$$g_r = 10,027 \text{ BTU/HR}$$

$$\sigma = 0.1714 \times 10^{-8}$$

$$T_1 = 1575^\circ\text{F} \approx 2035^\circ\text{R}$$

$$T_2 = 1293^\circ\text{F} \text{ or } 1743^\circ\text{R}$$

$$\epsilon F_{1-2} = \frac{10,027}{(0.1714 \times 10^{-8})(2035^4 - 1743^4)} = 0.74$$

HANDBOOK VALUES FOR:

$$\epsilon_{\text{SILICA BRICK @ } 2500^\circ\text{F}} = 0.84$$

SHAPE FACTOR FOR TWO FLAT PARALLEL PLATES = 0.8

$$\text{HANDBOOK VALUE FOR } \epsilon F_{1-2} = 0.84 \times 0.8 = 0.67$$

CONCLUSION - THE CALCULATED PRODUCT OF EMISSIVITY (ϵ) TIMES A SHAPE FACTOR (F_{1-2}) OF 0.74 COMPARES FAVORABLY WITH A HANDBOOK VALUE OF 0.67. SINCE THE EXPERIMENTAL PROFILE IS CLOSER TO OUR DESIGN THAN TWO FLAT PLATES, WE WILL USE 0.74 IN FUTURE ANALYSIS.

$$\text{FOR FUTURE ANALYSIS } g_r = 0.74 \sigma A (T_1^4 - T_2^4).$$