

*Conversion of Manufactured Gas Plant (MGP)  
Solid Waste to Glass Aggregate Using  
Oxy-Fueled Vitrification*

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*Prepared for:*

*The University of Wisconsin System*

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## **1.0 EXECUTIVE SUMMARY**

The overall objective of this project is to determine the feasibility of converting manufactured gas plant (MGP) waste to glass using an oxygen-fueled melter. The equipment used for demonstration purposes is located at the GlassPack Demonstration Facility, owned and operated by Minergy Corp of Milwaukee. Four samples of MGP waste from a Wisconsin location were provided by We Energies, also based in Milwaukee. The study occurred in three phases, including a series of laboratory tests, a series of crucible melts, and a demonstration melt in a commercial-scale unit.

The results of this study demonstrated full technical feasibility. Glass characteristics were good, with acceptable melting temperatures well within the limits of existing refractory. Fluxing was performed for the full-scale demonstration using ground glass, in order to improve the material handling characteristics of the MGP waste.

## **2.0 MGP BACKGROUND**

Numerous locations in the Great Lakes Basin have sediments and soils that are contaminated with wastes generated from the operation of former coal gasification and/or manufactured gas plants (MGP wastes). MGP wastes include polyaromatic hydrocarbons (PAHs), which are found in coal tar, a by-product of gasification processes, and cyanide salts, which are found in iron oxide waste produced during purification of the manufactured gas. In addition to being a problematic soil and sediment contaminant, MGP solid waste frequently causes groundwater and surface water contamination with benzene, phenanthrene, anthracene, pyrene, and benzo(a)pyrene. These contaminants pose threats to human health in the Great Lakes area to the extent that many MGP sites are listed on the Superfund National Priority List for cleanup and removal.

### **3.0 PURPOSE OF TEST**

The USEPA references a number of technologies acceptable for disposing of or treating MGP residues. In general, MGP waste is 1) stored on-site until a more suitable, permanent treatment option is developed, 2) moved to a hazardous material landfill, or 3) incinerated in a hazardous waste incinerator. However, each of these disposal or treatment options has at least one of the following significant drawbacks: high costs, low destruction capabilities, high emissions, and/or a residual waste (long-term liability) with questionable leaching characteristics that requires disposal.

During the last 5 years, Minergy Corporation of Milwaukee has developed innovative and low-cost oxygen-fueled melter systems that convert high-ash content waste materials into non-leaching, marketable glass aggregate. During 2001, the Wisconsin Department of Natural Resources and the EPA's Great Lakes National Program Office sponsored a successful Minergy demonstration on PCB-contaminated river sediments. Minergy has also successfully demonstrated and commercialized the use of its melter system on municipal sewage sludge, creating the same non-leachable glass aggregate with very high destruction efficiencies of the contaminants of concern.

Many MGP solid wastes share common characteristics of contaminated river sediment and municipal sewage sludge. Based on the success of those demonstrations, and the similarities in the feedstocks, it appears likely that an oxygen-fueled melter would be capable of processing MGP waste with high destruction efficiencies, low operating costs, low emissions, and creation of highly inert glass aggregate, which can be sold to local construction markets. Should this project be successful it would allow for the conversion of a large-quantity of highly hazardous solid waste into a usable product. This could potentially save hundreds of thousands of cubic yards of hazardous landfill space and countless amounts of transportation and disposal costs to Wisconsin companies. In addition, it rids the State and its businesses of the long-term liability of this product.

## 4.0 TEST STEPS

The study occurred in three phases, including a series of laboratory tests, a series of crucible melts, and a demonstration melt in a commercial-scale unit. The Laboratory Series was performed to determine the overall chemical and physical characteristics, and to predict melting temperatures. The Crucible Series was performed to measure the viscosity of the samples when in the molten state, this being performed at a variety of temperatures. The Demonstration melt was performed to substantiate the behavior of the molten material in a large melter process, and to determine preliminary throughput predictions for full scale operation.

## 5.0 LAB SERIES

A total of 4 samples were received for preliminary evaluation. All of the samples were received in sealed 55 gallon steel drums. A general description of the samples is shown in Table 1 below.

### 5.1 Physical Description

**Table 1. Physical Descriptions of Samples.**

<b>Sample ID</b>	<b>Location</b>	<b>Physical description</b>
ITR	Canal bottom	High tar content
TTP-1	Along shore 7 to 10 feet bgs	Clay with some tar
TTP-2	Along shore 5 to 12.5 feet bgs	Viscous liquid with MGP odor
TTP-3	Along shore 6 to 11.5 feet bgs	Clay with tar

The ITR sample was collected August 2002. All of the TTP samples were collected in December 2002.

## 5.2 Moisture Content

The samples were tested for moisture content. A summary of the moisture contents are shown in table 2. Due to the nature of the TTP-2 material, significant variations were obtained in the moisture test results. The material contained so much water, it behaved more like a liquid than a solid. Due to the varying particle size distribution in the solids fraction, settling of the larger particles tend to occur. The moisture content of a particulate samples was highly dependent on where the samples was collected from in the barrel. Due to a significant content of rock and stone the sample could not be mixed to achieve a blended sample.

**Table 2. Moisture content of Samples.**

<b>Sample ID</b>	<b>Moisture Content</b>
ITR	19.1%
TTP-1	17.6%
TTP-2	26% to 50%
TTP-3	21.6%

## 5.3 Mineral Analysis

To establish the melting properties of the material, all of the samples were prepared and analyzed for major elements. Prior to analysis the samples are dried and heated to 1600 °F. To eliminate organic compounds and mineral bound carbonates, the samples are held at this temperature for 4 hours. After heating, the samples are cooled and then ground to 400 mesh and analyzed using a method called X-ray fluorescence (or XRF). The results are reported in the common oxide form. The results of XRF analysis are summarized in Table 3.

**Table 3. XRF Mineral analysis results for MGP samples.**

<b>Mineral</b>	<b>% by weight</b>	<b>% by weight</b>	<b>% by weight</b>	<b>% by weight</b>
<b>Sample ID</b>	<b>ITR</b>	<b>TTP-1</b>	<b>TTP-2</b>	<b>TTP-3</b>
SiO <sub>2</sub>	61.6	53.3	53.3	60.7
P <sub>2</sub> O <sub>5</sub>	0.15	0.24	0.24	0.24
Fe <sub>2</sub> O <sub>3</sub>	6.74	4.81	4.81	5.27
CaO	11.8	15.4	15.4	9.4
MgO	6.0	10.5	10.5	7.86
Al <sub>2</sub> O <sub>3</sub>	10.7	11.6	11.6	12.5
TiO <sub>2</sub>	0.58	0.62	0.62	0.62
Na <sub>2</sub> O	0.57	0.64	0.64	0.71
K <sub>2</sub> O	1.83	3.55	3.55	3.52

#### **5.4 Predicted Melting Temperatures**

The mineral compositions were then further analyzed to estimate the high temperature viscosity properties of the material through a set of empirical equations. Viscosity is the measurement of the thickness with which a liquid flows. Viscosity is measured in units called “poise”. Example viscosities are water (0.01 poise), SAE 10 oil (1.0 poise), SAE 50 oil (8.0 poise), honey (approximately 50 poise). High temperature viscosities normally in a melter performing vitrification range from 10 poise to 250 poise. At viscosities above 250 poise the material is too thick to flow unassisted, and should be avoided. A common term used is T<sub>250</sub>, which is the temperature at which the liquid exhibits a viscosity of 250 poise. Calculated T<sub>250</sub>'s are shown in Table 4.

**Table 4. Calculated T<sub>250</sub> in Degrees F**

<b>Sample ID</b>	<b>Calculated T<sub>250</sub></b>
ITR	2501
TTP-1	2291
TTP-2	2175
TTP-3	2446

### **5.5 Fluxing Curves**

As a rule of thumb, the melter operating temperature is 300 °F to 500 °F hotter than the T<sub>250</sub> to drive heat transfer and the reactions necessary to form a glass. Since the practical upper limit of the melter is 2900 °F, it is highly recommended to have the T<sub>250</sub> of 2400 °F or less. A fluxing curve was developed for all of the four of the above materials. Dolomite limestone was selected as the fluxing material. A fluxing curve, which is a plot of predicted T<sub>250</sub> at various flux additional amounts were developed. The fluxing curves are included in Section 9. Limestone was added to sample TTP-1 at a rate of 10% (by mass) to reduce the T<sub>250</sub> to 2108 °F. Limestone was also added to TTP-3 at a rate of 24% to achieve at predicted T<sub>250</sub> of 2106 °F. No adjustments were made to samples ITR and TTP-2. No flux curve was required for TTP-2 because no flux was necessary.

## **6.0 CRUCIBLE SERIES**

### **6.1 Apparatus**

A total of 5 crucible melts were conducted. The crucible melts were performed in a oxy-fuel fired furnace with 8 cubic feet of internal volume and a heat input rating of 165,000 Btu/hr of maximum heat input. The furnace has a maximum operating temperature of approximately 2800 °F. Furnace temperatures are measured continuously with two separate type R thermocouples, and intermittently with an optical pyrometer. Melting is performed in a 2000cc fused silica crucible. This type of crucible is capable of holding up to temperatures of 2800 °F. Viscosity is measured by determining the resistance to stirring with a ¼” diameter alumina oxide rod. Silicone based viscosity standards are used as the laboratory reference standard.

### **6.2 Test Procedures**

The MGP material was added to the silica crucible, and loaded into an idle (1600 F to 1800 F) furnace. After the crucible temperatures stabilized, the furnace temperature is raised. As the temperature increases the level in the crucible drops and additional material is added without removing the crucible from the furnace. Material addition and temperatures are raised, and material is added, until the material in the crucible reaches a viscosity of 10 poise. If the viscosity of 10 poise can not be achieved at a temperature of 2800 °F, the viscosity measurement phase will begin at that point.

### 6.3 High Temperature Viscosity (HTV) Measurements

In the viscosity measurement phase the firing rate of the furnace burners is reduced, and the furnace is slowly cooled at a controlled rate. The viscosity is checked at 20 °F increments. This process continues until the material inside the crucible becomes too viscous to measure. The measurement process identifies both the  $T_{125}$  and  $T_{300}$  temperatures. The “measured”  $T_{250}$  scaled by the following formula :  $T_{250} = T_{125} + 0.79*(T_{125}-T_{300})$ . A photo of the operator performing an HTV measurement is contained in Section 9. The results of the crucible melts are summarized in Table 5.

Samples TTP-1, TTP-3 and ITR were heated to 1600 °F prior to the crucible melts to eliminate organic compounds. No oxygen is used in the standard heating procedure. It was noted that all of the samples were black in appearance after the heating process, which raised a concern that a quantity of unburned fixed carbon was present in the samples. As a result of some initial observations made, it was decided to prepare two batches of TTP-2 for a crucible melt. The first batch TTP-2U (U for unprocessed) was only dried material, fed directly to the crucible. The second batch TTP-2O (for oxidized) was heated to at a temperature of 1600 °F and a flow of pure oxygen was provided to promote full oxidation of the entire batch.

**Table 5. High Temperature Viscosity Measurements**

<b>Sample ID</b>	<b>TTP-2 O</b>	<b>TTP-2U</b>	<b>TTP-1</b>	<b>TTP-3</b>	<b>ITR</b>
<b>Flux rate and type</b>	<b>None</b>	<b>None</b>	<b>10% Lime</b>	<b>24% Lime</b>	<b>None</b>
T <sub>10</sub>	2458	2573	>2803	>2770	>2820
T <sub>50</sub>	2407	2527	2727	2720	2771
T <sub>125</sub>	2329	2364	2660	2596	2714
T <sub>300</sub>	2240	2244	2549	2460	2628
Freeze point	2174	2200	2349	2259	2512
Measured T <sub>250</sub>	2259	2269	2572	2489	2646
Predicted T <sub>250</sub>	2220	2220	2108	2106	2501
Split (Measured to Predicted)	39	49	464	383	210
T <sub>10/250</sub> Range	199	304	>155	>231	>174

#### 6.4 Discussion of HTV Results

The T<sub>10</sub> temperatures were above the nominal rating of the furnace for samples TTP-1, TTP-2 ITR. In addition a very significant difference between the predicted T<sub>250</sub> and measured T<sub>250</sub> (See row labeled “split”). Both crucible melts for TTP-2 behaved more in conformance to expectations. The major difference between the two was the T<sub>10/250</sub> range, which was about 100 °F higher for the un-oxidized sample.

All of the crucibles were reheated and the molten liquid was poured off into a waster bath to form an aggregate product. A photo of the operator performing a molten glass pour-off is contained in Section 9.

All of the aggregate formed was black in cooler, and angular in shape. The iron content which ranged from 4.8% to 8.5 % is generally known and accepted at the reason for the aggregate color.

It is suspected that that the presence of unburned carbon (UBC) affected the samples to varying degrees. Additional information will need to be gathered to provide a stronger basis for a firm conclusion, although comparing the differences in performance between TTP-2 O (Oxidized) and TTP-2 U (Unprocessed) is strong supporting evidence.

One of the limitations of the crucible melt is the material under the melt line is not exposed to air or oxygen, which inhibits the removal of the UBC phase. When the MGP material is processed in a commercial scale melting furnace, better mechanisms are present to assist in the exposure of the material to the oxygen atmosphere in the furnace, allowing for combustion of UBC. It should be noted that the reaction needed may increase the time necessary to process a unit of material, and furnace sizing formulas may be different than materials that are free of UBC. This factor should be carefully studied during the pilot melting stage.

## **7.0 DEMONSTRATION MELT SERIES**

### **7.1 Apparatus**

The second phase of this study was to select, prepare and process a batch of material in the Minergy GlassPack melting furnace, located in Winneconne WI. The melter has 10 ft<sup>2</sup> of melting area, and is fired with a combination of natural gas and pure oxygen (oxygen enhanced combustion). A drawing that shows the flow sheet of the melter system is contained in Section 9.

The system consists of a melter, aggregate quench tank, aggregate recovery screw, an oxygen and natural gas supply and control system, an exhaust fan, a water cooled packed tower, and instrumentation necessary to collect all process critical data. The melter's normal rating is 3 glass tons per day. The unit can accept up to 9 mmBtu/Hr of heat input, and is intended to operate at a temperature of 2500 °F to 2800 °F. A photo of the melter is contained in Section 9.

The melter is normally fed with the waste material with a pneumatic feed system. The sludges that have been processed to date by the unit were dry and in a granular state, allowing the use of a pneumatic feed system. The agglomerating nature of the MGP waste required the construction and retrofit of a ram charger. The ram charger is attached to the front cover of the melter and uses a pneumatic cylinder to push the material into the melter. A photo of the ram charger is contained in Section 9.

## **7.2 Selection of TTP-2 for Demonstration Melt**

After several discussions with utility engineers experienced with the remedial work with MGP waste, it was determined that the sample ID TTP-2 was typical of many MGP sites and was consistent with representative much of the volume found at many sites. The material was excavated below the water table and contained a significant amount of free water. A photo of the TTP-2 material is contained in Section 9.

## **7.3 Stabilization of TTP-2**

TTP-2 in the as-received condition contained too much free moisture and was too sticky to feed directly into the melter. The sticky nature of the material would quickly foul up the ram charger used on the demonstration melter. Under normal circumstances, a thermal dryer would be selected to dry and condition the material prior to processing the material in a melter. However due to the content of volatile and semi-volatile compounds considered present in the MGP material, thermal drying was ruled out. The ram charger used on the demonstration melter is configured with a pneumatic cylinder whose motive force can accommodate non-sticky materials such as wet sludges. A higher force ram or screw feeder, as would be designed for a commercial installation, would have been less prone to sticking.

The decision was made to stabilize the feedstock using a granulated material. Since no fluxing material was required to modify the mineral chemistry, the following criteria was used for the selection of the stabilizer:

- 1) The material must be free of organic compounds to prevent further consumption of excess oxygen in the melter
- 2) The material must be dry and free flowing
- 3) The material must be fine (finer than 400 mesh) to make a good absorbent of free water

- 4) The material mineral chemistry must not have a significant effect the high temperature viscosity properties of the base MGP material
- 5) The material must be commercially available, and of relatively low cost

Minergy selected the use of ground glass aggregate as the stabilizer. Ground glass aggregate is readily available from one of Minergy's customers. Their facility makes its product "Badger Pozz" or "BP" by grinding glass aggregate from the Minergy-Neenah Plant to a fineness of 45 microns. This degree of fineness was determined to provide sufficient stabilization to allow the feeding through the pneumatic ram charger at the front of the demonstration melter. Table 6 is a mineral analysis of the BP material.

**Table 6. XRF Mineral analysis results for BP material**

<b>Mineral Oxide</b>	<b>% by weight</b>
SiO <sub>2</sub>	35.8
P <sub>2</sub> O <sub>5</sub>	0.4
Fe <sub>2</sub> O <sub>3</sub>	1.3
CaO	37.2
MgO	1.5
Al <sub>2</sub> O <sub>3</sub>	18.7
TiO <sub>2</sub>	4.9
Na <sub>2</sub> O	0.1
K <sub>2</sub> O	0.1

The BP material meets the stabilizing criteria listed above. In addition, it has already been melted which completes many of the mineral reactions that directly influence the size and energy consumption of a full scale melter. For these reasons, the BP material was used to stabilize the TTP-2 sample.

## 7.4 Preparation of TTP-2

Prior to blending the BP material with the MGP waste, all debris, rocks, stones and roots were hand picked out the sample. A trial batch of material was made with a 1:1 ratio of BP to MGP. A visual inspection indicated that the material was too sticky for processing and it was decided to increase the BP content. A second trial batch was prepared with a 2:1 ratio of BP to MGP. The material was no longer sticky. The material was tested in the pneumatic ram charger. The ram charger was prone to stalling, indicating that the cohesive strength of the material was still beyond the capability of the pneumatic ram charger. A third batch was prepared with a 3:1 ratio of BP to MGP. This material could be pushed through the ram charger. A summary of the mixing ratio's and material properties shown below an table 7. A total of 428 lbs. of BP was blended with 142 lbs. of MGP waste from barrel TTP-2 to create 570 pounds of material to be process in the pilot scale melter.

**Table 7. Material properties at different blending ratios for BP : MGP**

Blending ratio (by mass)	Moisture content	Description
1:1	22.0%	Very sticky
2:1	14.6%	Not sticky, not suitable for pneumatic ram charger
3:1	11.0%	Suitable for pneumatic ram charger

## 7.5 Demonstration Melter Trial Results

Minergy processed the MGP material its oxy-fired pilot melter located in Winneconne, WI. The test was conducted on March 25, 2003. Prior to feeding the material the support systems were started using standard operating procedure, and the melter is warmed up to operating temperature over a period of 4 to 5 hours. The material was first transferred to a 25 pound bucket then the ram charger was manually feed with material using 1 to 3 pound scoops. A 25 pound increment was logged each time a 25 pound bucket was finished. Chart 1 (see Section 9) shows a trend of feed rate over time to the melter. The test duration lasted for about two hours, and the average feed rate of 276 pounds per hour. The feed rate chart appears like a square wave pattern due to the large 25 pound increment of material feed combined with the short 10-minute rolling average used.

The process conditions established for this initial test were conservatively established based on past operating practice when processing a new material for the first time. The natural gas and oxygen consumption rates observed here should not be used to establish consumption rates for a commercial scale test.

Prior to feeding the mixture to the process, the natural gas flow rate was established at a rate of 4500 SCFH (Standard Cubic Feet per Hour). The heating valve for natural gas was assumed to be 1005 Btu/standard cubic foot. The total heat input to the melter can be calculated at this data. The average flow during the 120 minute test duration was 4461 SCFH with a minimum reading of 3986 SCFH and a maximum of 4515 SCFH. The average oxygen flow was 5207 SCFH of oxygen. The oxygen flow was established to maintain a melter outlet oxygen concentration of 10% oxygen by volume plus or minus 3%. The outlet oxygen concentration during the test average 10.4% during the 2 hour duration while feeding the mixture. The readings ranged from 9.7% to 12.1% during the test. The synthetic air flow rate of 380 to 414 cubic feet per minute was observed during the test. The average synthetic air flow was 396 CFM. All 3 injection nozzles were set at 0.25 inch open and a synthetic air supply pressure of 2.4 IWC (inches water column), and supply oxygen concentration of 20.9% was maintained. A non-contact pyrometer

provided continuous temperature measurements inside the melter. A default emissivity of 0.95 was assumed in the calculations of the measurement device. The average melter temperature was 2508 °F. The maximum recorded temperature was 2585 °F and the minimum temperature was 2257 °F. Chart 2 (see Section 9) shows a plot of temperature over time. The operating temperatures gradually increased over the first 40 minutes of the test and remained at steady state conditions for the remaining 80 minutes of the test.

## **7.6 Glass Aggregate Qualities**

The melter started to yield product after 30 minutes of testing. The aggregate was a dark amber color. Qualitative analysis by Minergy indicated that the glass was of gradation and hardness as the other glass aggregates made in its vitrification systems. A photo of the aggregate is contained in Section 9.

Analysis of the initial MGP mixture and the final glass aggregate using gas chromatography coupled with a mass selective detector (GC-MS) revealed that the process had successfully destroyed the PAHs present in the initial material. A detailed list of analytes and concentration are found in Table 8. Additionally, there was no sign of secondary products requiring additional mitigation. This group of compounds was chosen for analysis due to their prevalence in the starting material and the ability of most of these compounds to be carcinogenic, teratogenic, and/or mutagenic. They are among the most problematic and long-lived compounds in the starting MGP material. Analysis performed was EPA Method 8270C. All analysis was performed by an EPA certified laboratory.

As can be seen in Table 8, the glass aggregate product did not exhibit any levels of any PAH's above their limits of quantitation. For calculation purposes, if one-half the quantitation limit is assumed, the resultant destruction efficiency is >99.9% for each analyte.

**Table 8. Polyaromatic Hydrocarbon (PAH) Analysis<sup>a</sup> of Beginning MGP Mixture and Final Glass Aggregate Product.**

Compound	Beginning MGP Mixture	Glass Product
	Concentration (µg/kg)	Concentration (µg/kg)
Acenaphthalene	90,000	<11 <sup>b</sup>
Acenaphthylene	65,500	<19
Anthracene	130,000	<11
Benzo(s)anthracene	88,000	<6.2
Benzo(b)fluoranthrene	28,000	<6.7
Benzo(k)fluoranthrene	31,000	<9.3
Benzo(g,h,i)perylene	17,000	<12
Benzo(a)pyrene	43,000	<6.2
Chrysene	88,000	<7.1
Dibenzo(a,h)anthracene	5,000	<7.6
Fluoranthrene	140,000	<8.2
Fluorene	110,000	<6.2
Indeno(1,2,3-cd)pyrene	16,000	<11
1-Methylnaphthalene	120,000	<7.2
2-Methylnaphthalene	76,000	<7.7
Naphthalene	77,000	<7.7
Phenanthrene	380,000	<6.2
Pyrene	160,000	<13

<sup>a</sup>Method was EPA SW846-8270C by GC-MS.

<sup>b</sup>"<" means less than the Level of Quantitation (LOQ) indicated.

## 8.0 CONCLUSIONS AND RECOMMENDATIONS

### 8.1 Conclusions

- 1) Vitrification of the TTP-2 material in a oxygen enhanced melter is technically feasible.
- 2) The mineral analysis for all of the MGP materials were not outside of Minergy engineering range of experience. The high temperature viscosity properties were higher than expected, and the suspected cause is unburned carbon in the sample.

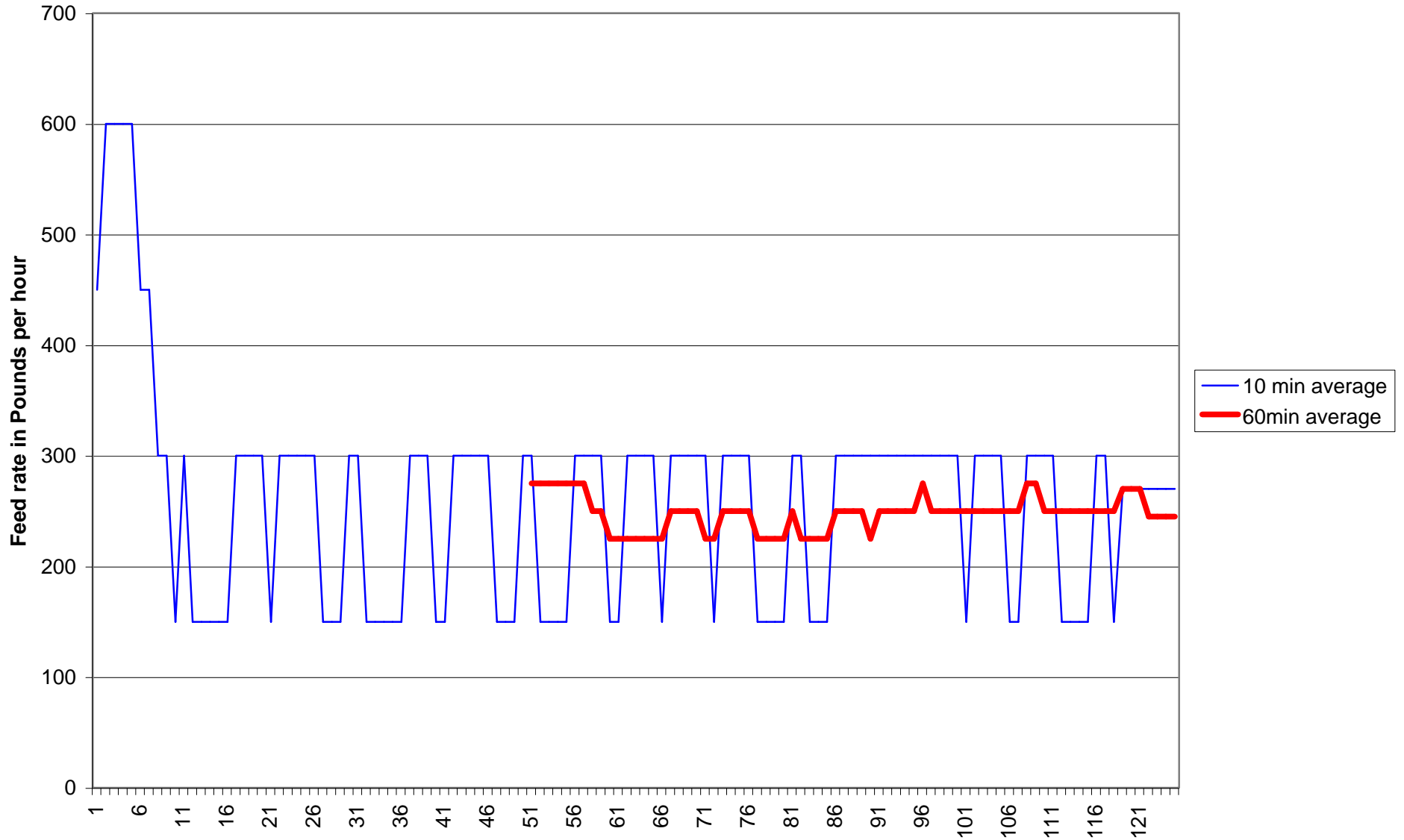
- 3) The use of the “Badger Pozz” material as an stabilizer to control the cohesiveness of the MGP material was successful although the use rate was high. The use rate was influenced by the very high standing moisture content found on the top of barrel TTP-2, and the lower force available from the pneumatic ram charger used on the pilot unit.
- 4) The TTP-2 material will present several challenges to the preparation process design. Issues such as varying moisture content, and the separation and treatment of rock, stone and debris will need to be addressed as part of an overall system flow sheet.

## **8.2 Recommendations**

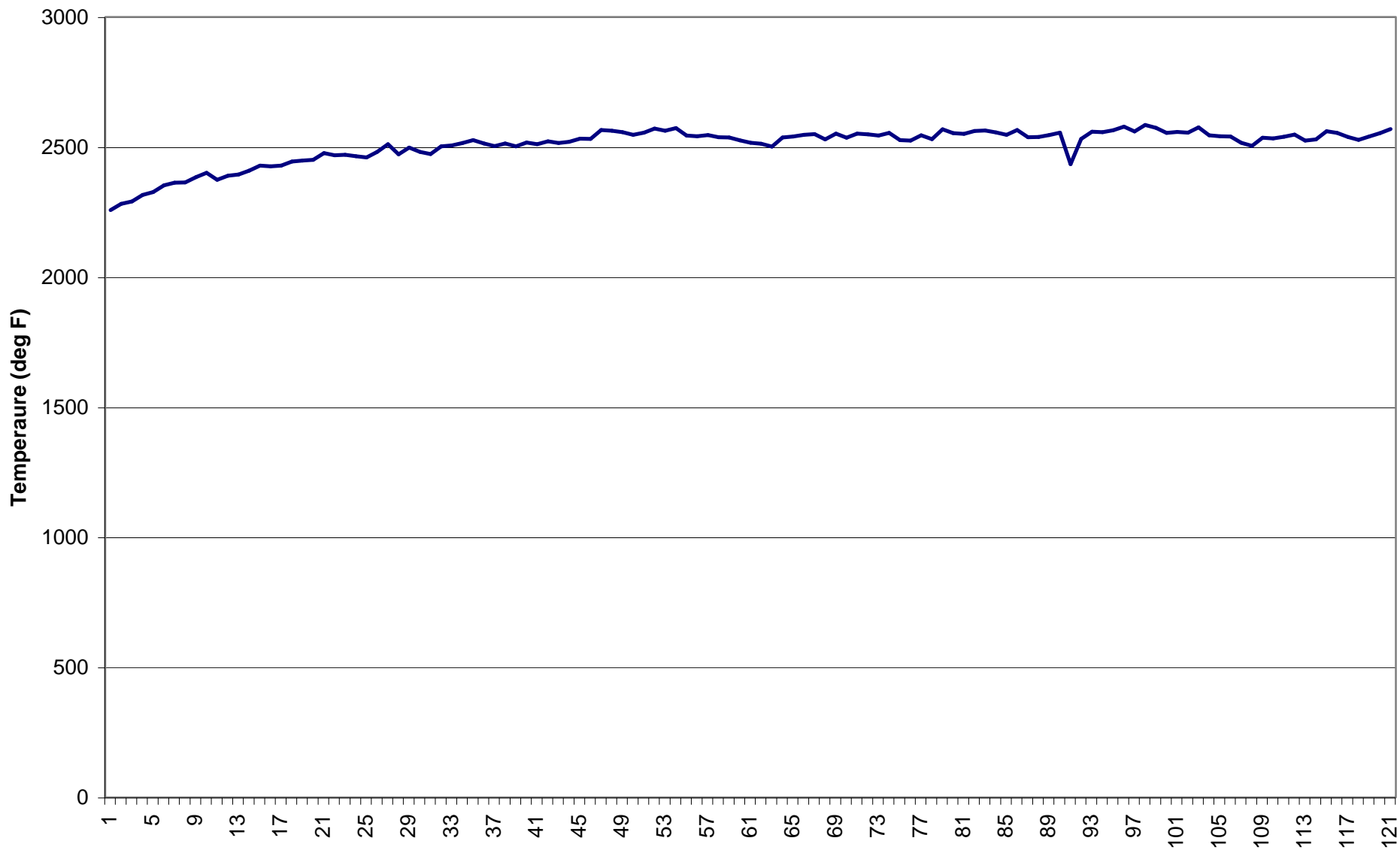
- 1) Additional testing of the TTP-2 material is recommended to obtain more data to verify the environmental emissions assumptions. This data will be required to complete an environmental feasibility review.
- 2) A second round of testing should also include process optimization to achieve the lowest use of consumables (primary natural gas and oxygen), and to validate the existing performance computer models. Unit sizing parameters are also confirmed during this stage of testing to allow the scaling of the process.
- 3) Review the technical and economic feasibility if grinding the aggregate from the discharge of the melter to create the additive on site. This will avoid product mark-up and shipping expenses incurred when using a purchased recycle material like “Badger Pozz”.

## 9.0 PHOTOS, CHARTS, AND FLOWSHEET

**Chart 1**  
**MGP Feed rate for 3/25, 2003 pilot trial**

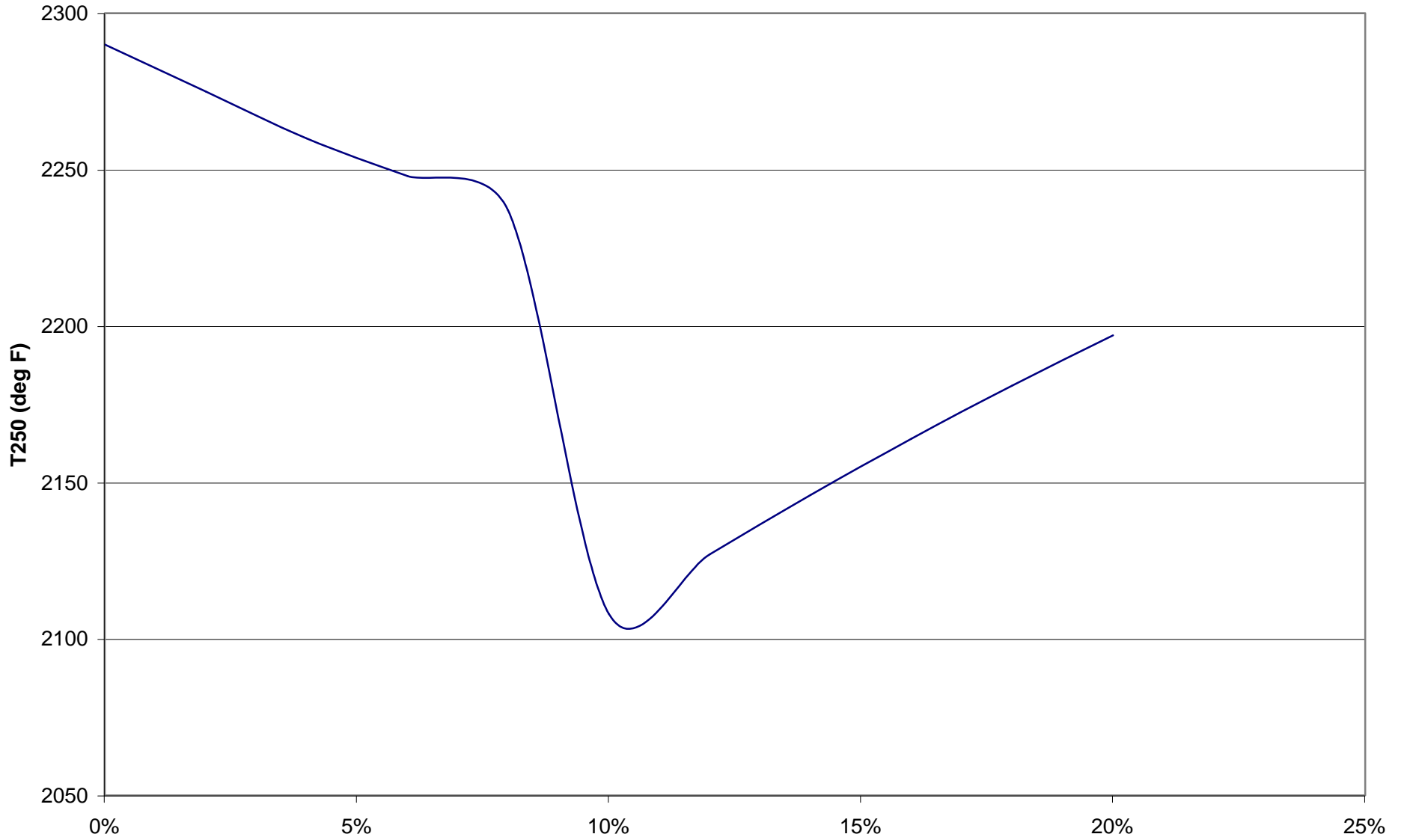


**Chart 2**  
**Melter temperature vs time**

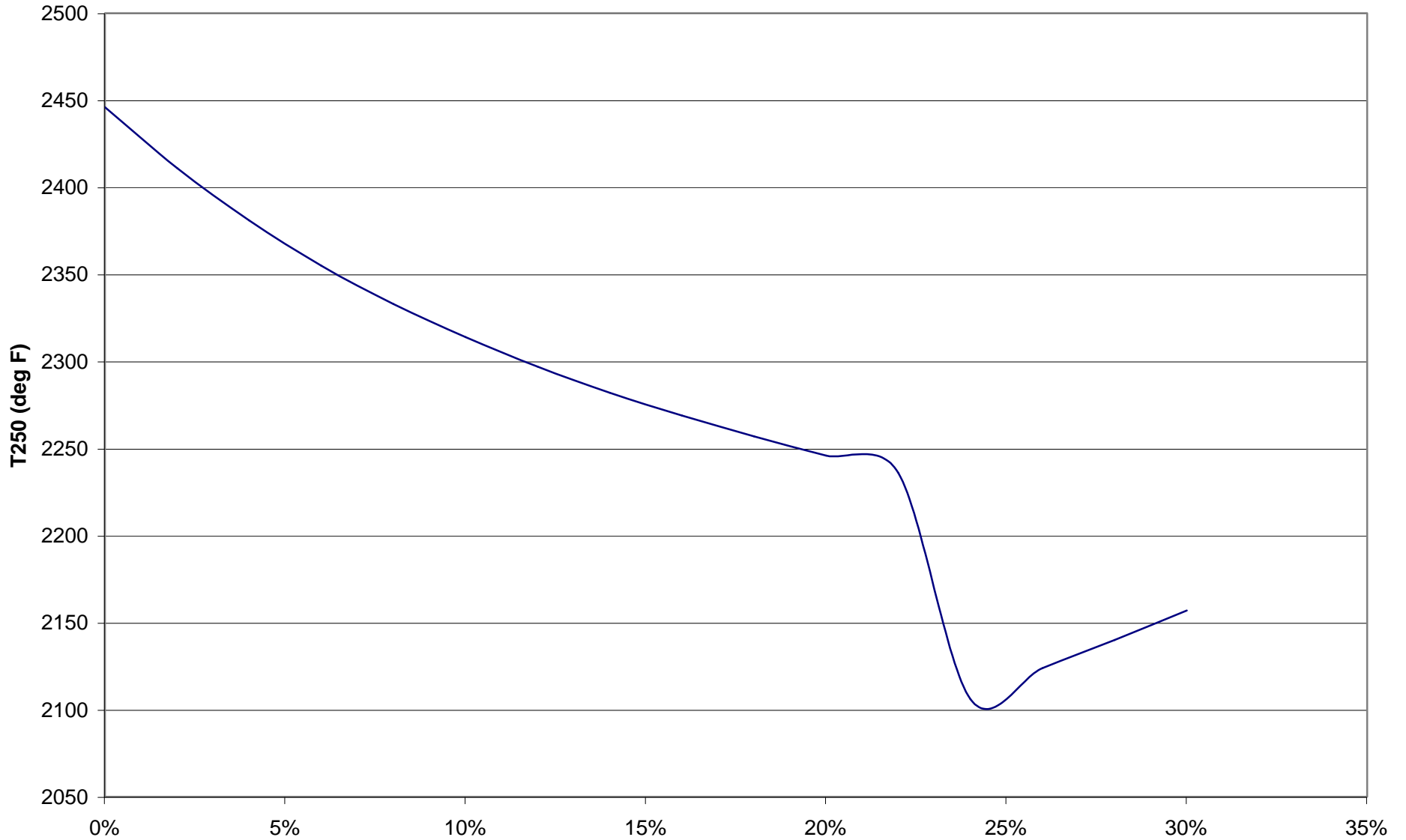


Time (10:10 am = 0)

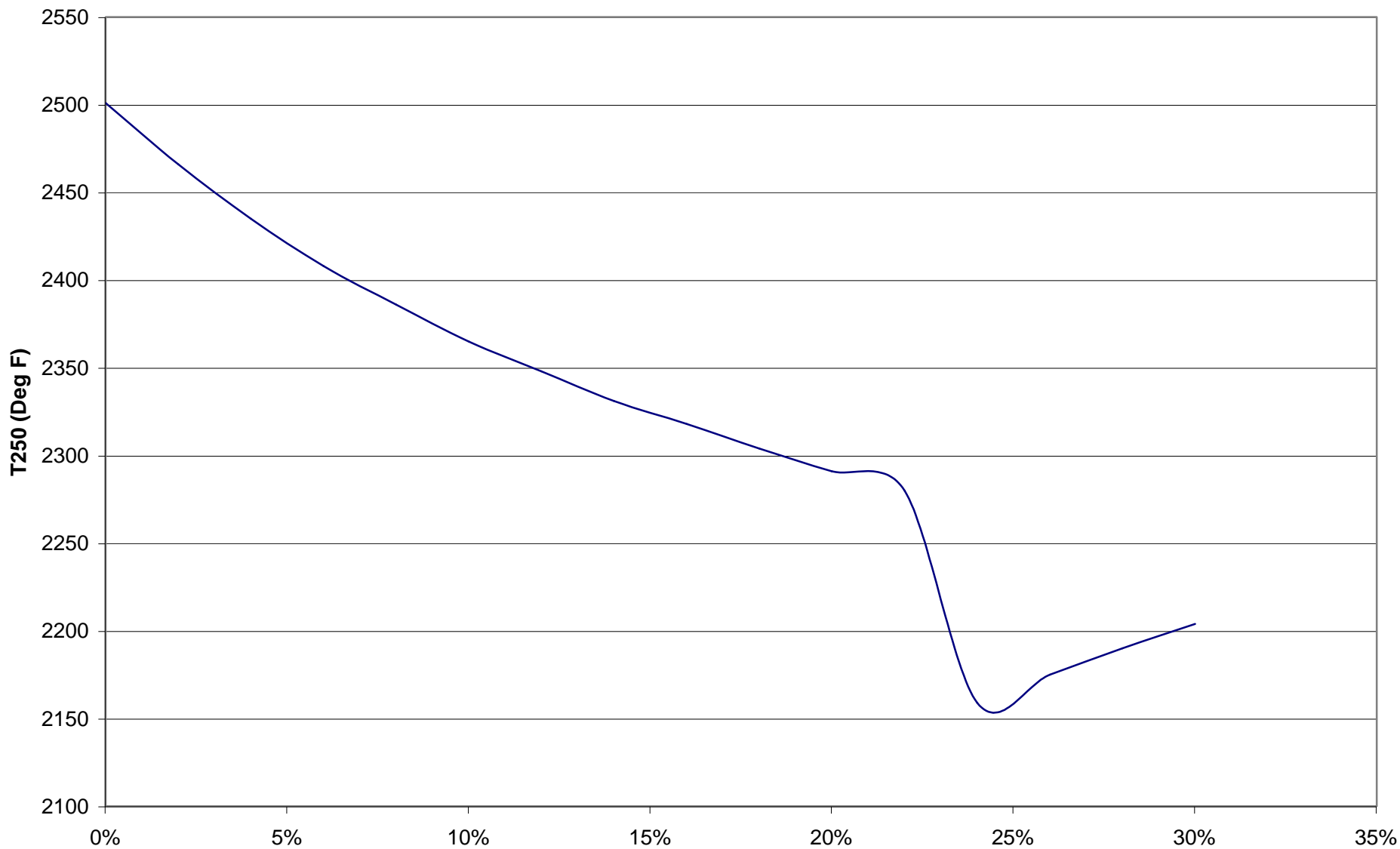
**Chart 3**  
**Predicted T250 temp vs fluxing rate for TTP-1**



**Chart 4**  
**Predicted T250 temp vs fluxing rate for TTP-3**



**Chart 5**  
**Predicted T250 temp vs fluxing rate for ITR**

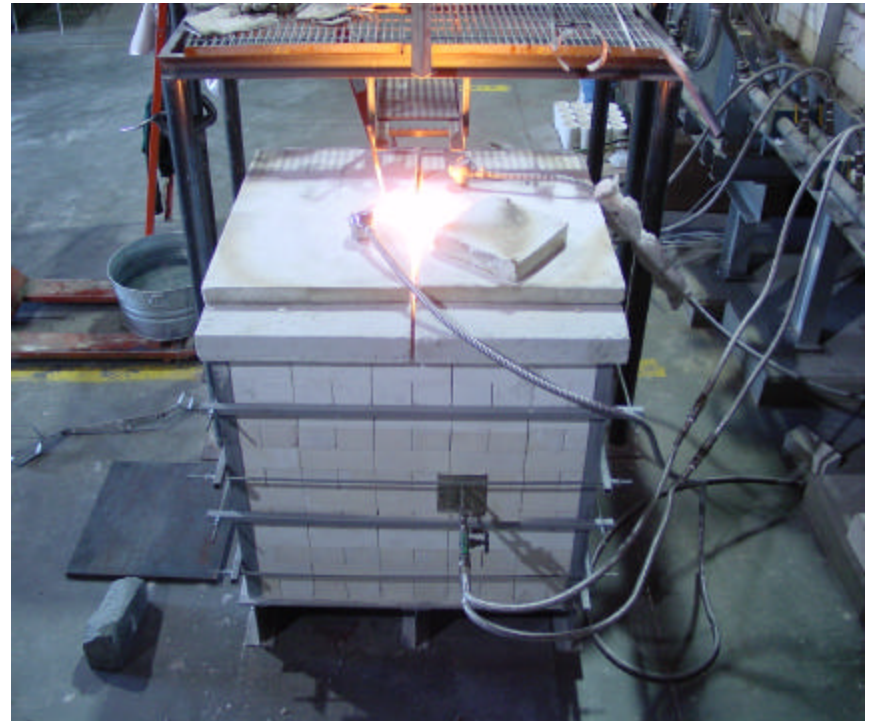


# Photos of Crucible and Demonstration Melts

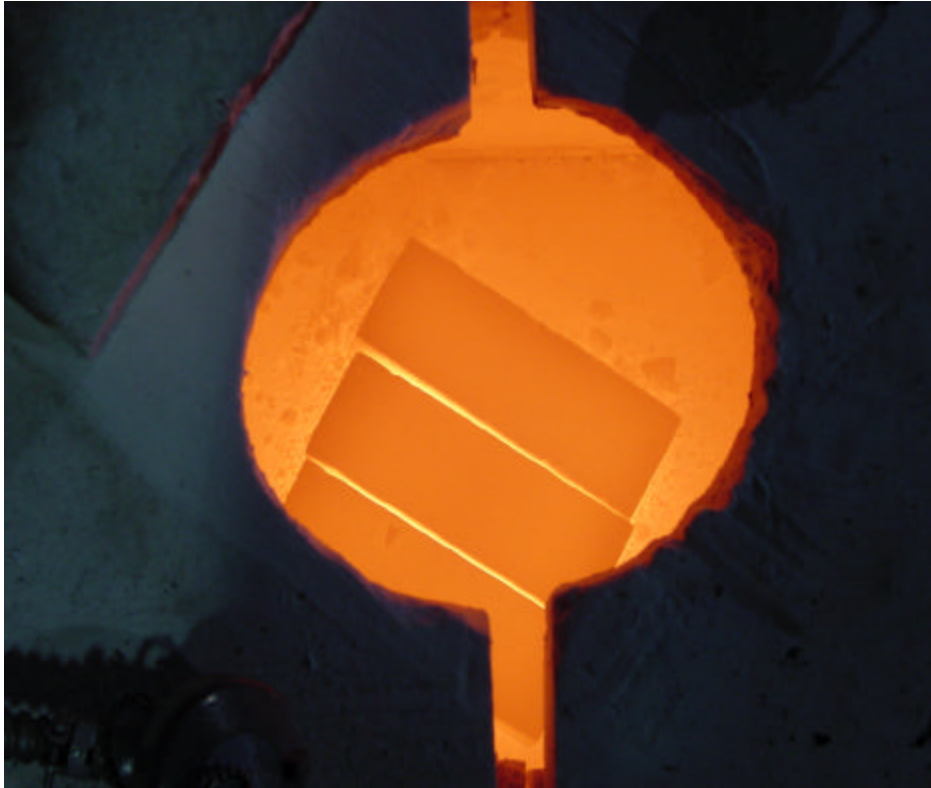


**Sample TTP-2**

**Crucible  
Furnace in  
Operation**



# Photos of Crucible and Demonstration Melts

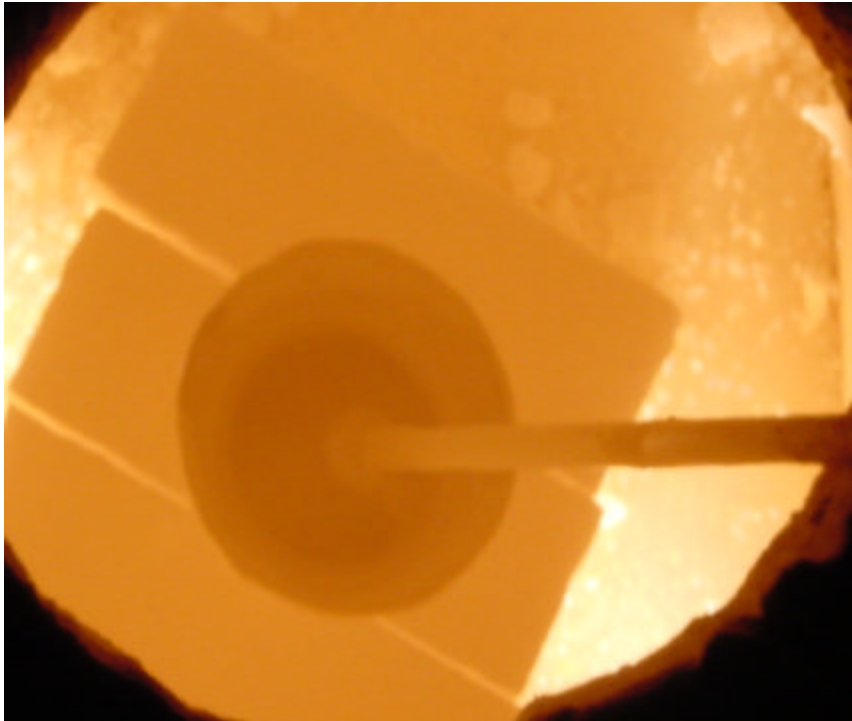


**View Looking Down into  
Furnace Prior to Placement  
of Crucible**

**High Temperature  
Viscosity  
Measurement in  
Crucible Furnace**

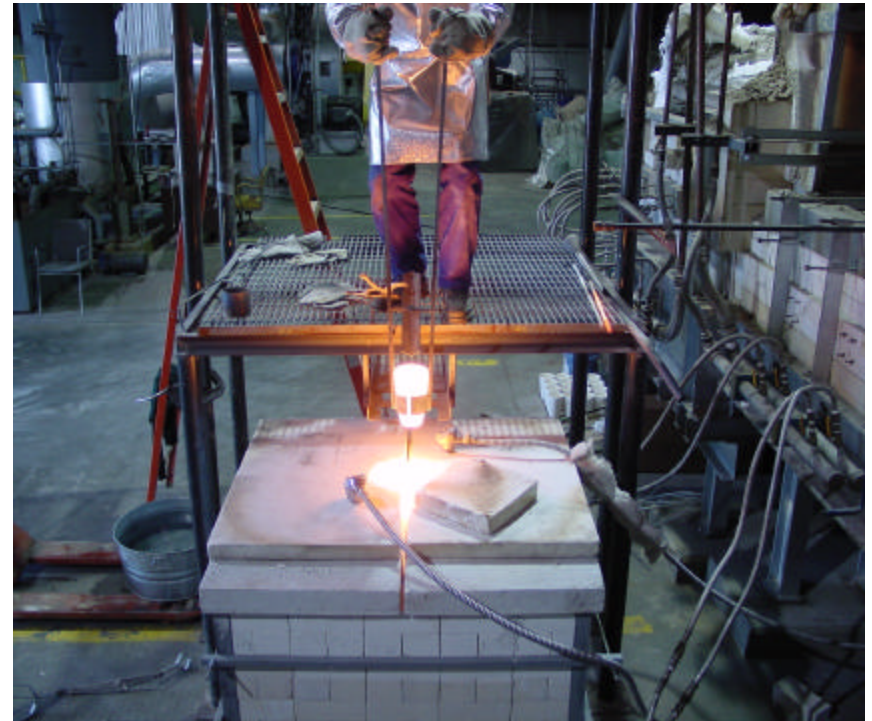


# Photos of Crucible and Demonstration Melts



**Inside Crucible  
Furnace with Stir  
Rod for High  
Temperature  
Viscosity  
Measurements**

**Removing  
Crucible from  
Furnace**

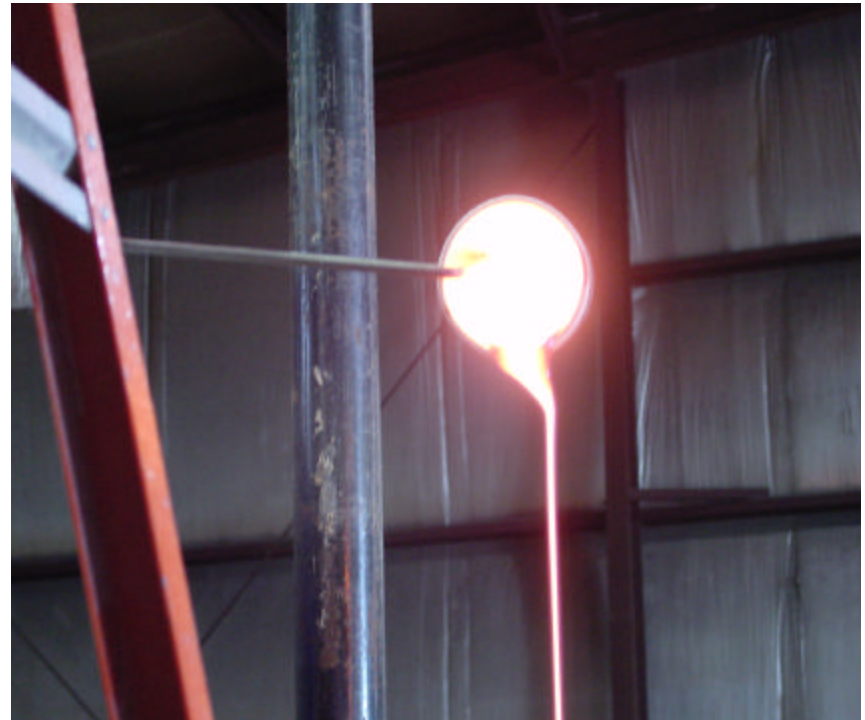


# Photos of Crucible and Demonstration Melts



**Pour-off of Molten Glass from Crucible**

**Front View of Pour-off from Crucible**



# Photos of Crucible and Demonstration Melts



**Water Quenching  
Molten Glass from  
Crucible Melt**

**Final Glass  
Aggregate from  
Crucible Melt**



# Photos of Crucible and Demonstration Melts

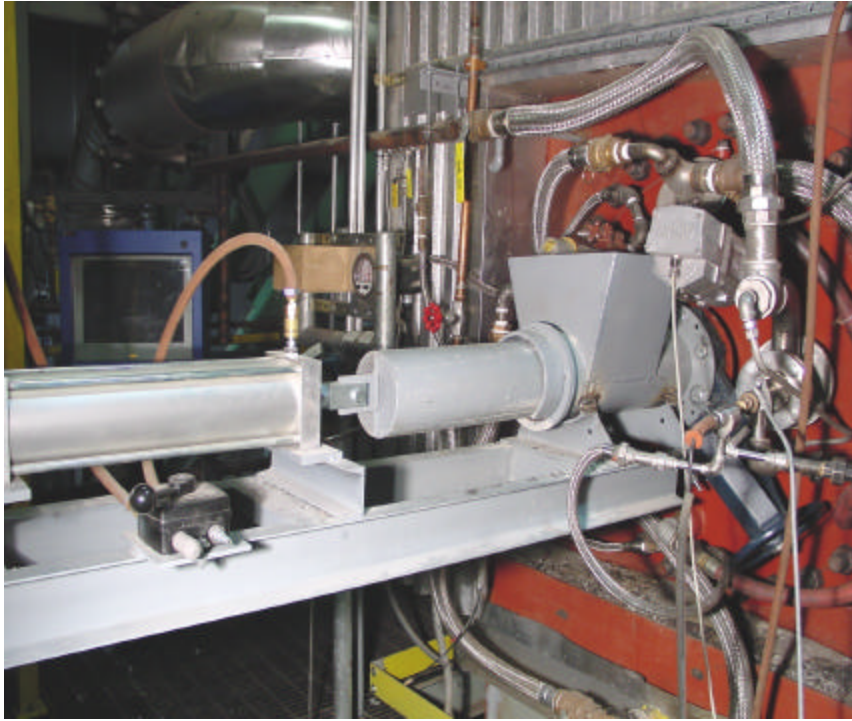


**Demonstration  
Melter**

**Exhaust Gas Treatment on  
Demonstration Melter**



# Photos of Crucible and Demonstration Melts



**Ram Charge Feeder  
into Demonstration  
Melter**

**Molten Glass in  
Demonstration Melter**



# Photos of Crucible and Demonstration Melts

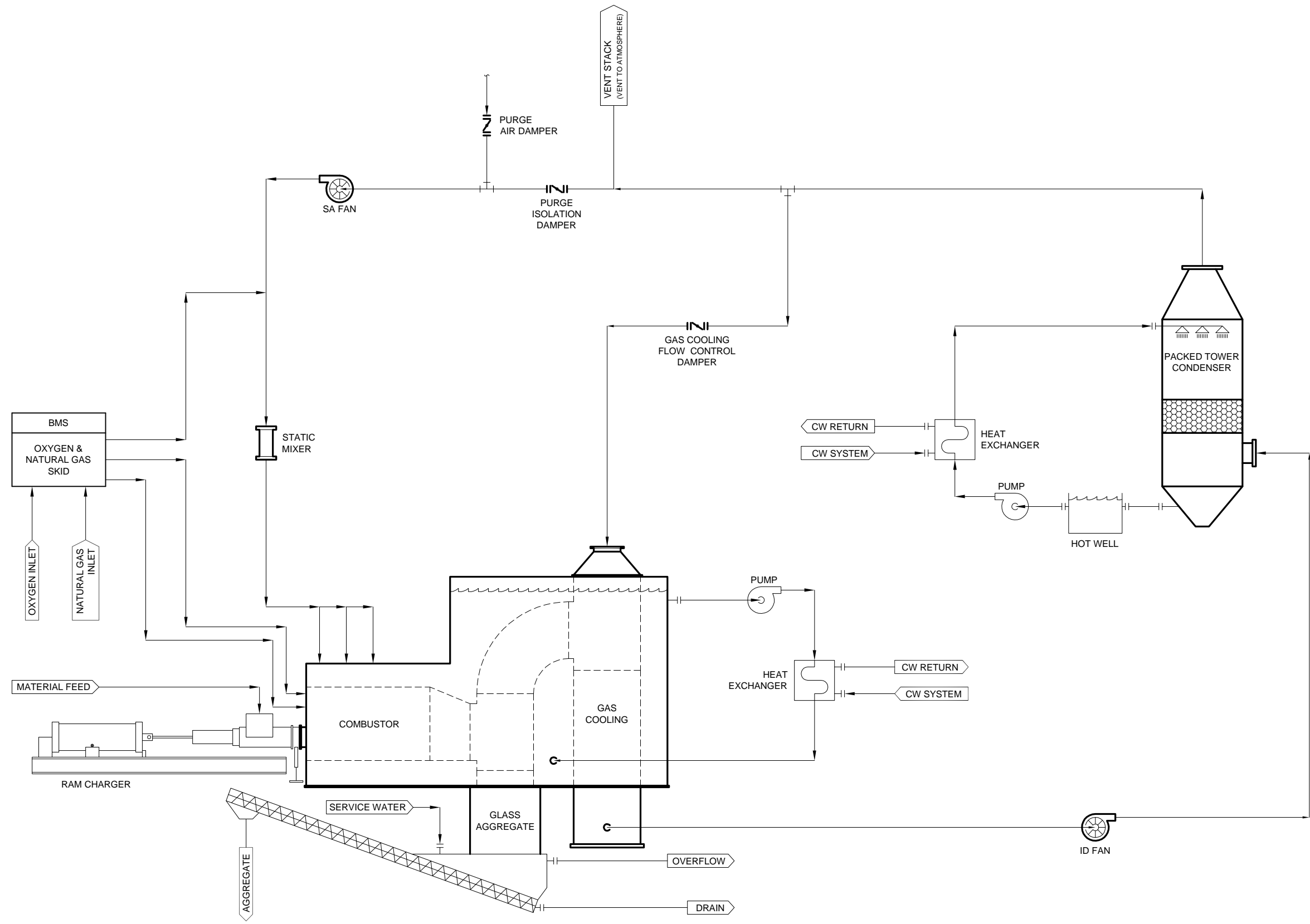


**Quench Tank &  
Aggregate Conveyor  
on Demonstration  
Melter**

**Aggregate in Barrel  
from Demonstration  
Melt**



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**LEGEND:**  
 CW = COOLING WATER

CONFIDENTIAL	Rev. No.	Description	Date	Drawn	Chkd
AS BUILT					

**MINERGY**  
 A WISCONSIN ENERGY CORPORATION  
 in association with  
**GLASSPACK LLC**

GLASSPACK, LLC  
 GP12 MELTER - PILOT PLANT  
 WINNECONNE, WI 54986  
 PROCESS FLOW DIAGRAM  
 GLASSPACK PROCESS

Date	MAY 2003
Drawing No.	012-1002-FD01
Sheet	02 OF 02
Rev.	-