Measurement of DWPF Glass Viscosity - Final Report

by

J. R. Harbour

Westinghouse Savannah River Company

Savannah River Site

Aiken, South Carolina 29808

T. B. Edwards

R. F. Schumacher

R. J. Workman

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WESTINGHOUSE SAVANNAH RIVER COMPANY
Savannah River Technology Center

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M. N. Brosee, Manager
Defense Waste Processing Facility

Attention: W. D. Kerley, 704-S

Task Initiator: R. E. Edwards, 704-25S

MEASUREMENT OF DWPF GLASS VISCOSITY – FINAL REPORT (U)

The attached report details the results of a scoping study funded by the DWPF for the measurement of melt viscosities for simulated glasses representative of Macrobatches 2 (Tank 42/51 feed). The driver for this task was the fact that Macrobatches 2 glasses had predicted viscosities very close to the upper limit of 100 poise at 1150°C.

A significant accomplishment of this work was the establishment of an in-house capability for measuring glass viscosities at 1150°C. This Harrop, high-temperature viscometer measures viscosity as a function of temperature with a very small amount of glass (~6 grams). This enables SRTC, and consequently DWPF, to obtain viscosity data within a reasonable time for relatively low cost. Several WCP glasses were measured and compared with results from previous measurements by Sharp-Shurtz. In addition, CELS (Corning) and PNNL measured viscosities of some of these glasses as part of this study. The results revealed that SRTC's measurements were ~ 10% higher than measurements by CELS and Sharp-Shurtz, but close to those of PNNL. With this knowledge, it is now possible to measure glass melt viscosities in-house and obtain useful, approximate values of melt viscosity at 1150°C.

The limited results obtained from this study on simulated Macrobatches 2 glasses (with and without uranium) reveal that uranium may increase melt viscosity in this compositional region. For uranium-bearing glasses, predicted viscosities from the measured compositions appear to be less than the measured viscosity values, whereas for glasses without uranium, the predicted viscosity tends to be less than measured. PNNL and CELS measurements support SRTC's results with these glasses (PNNL measured the uranium containing glasses while CELS measured the glasses without uranium). Further work will be required to determine whether this effect is real.

If you have any questions about the results contact J. R. Harbour at 5-8725 or T. B. Edwards at 5-5148.

E. W. Holtzscheiter
Immobilization Technology Section

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INTRODUCTION

This report details the results of a scoping study funded by the Defense Waste Processing Facility (DWPF) for the measurement of melt viscosities for simulated glasses representative of Macrobatch 2 (Tank 42/51 feed). The driver for this task was the fact that Macrobatch 2 glasses had predicted viscosities very close to the upper limit of 100 Poise [1, 2]. Therefore, one objective of this scoping study was to gain insight into the adequacy of the viscosity model in the compositional region of interest for Macrobatch 2. As part of this objective, glasses were fabricated using depleted uranium to determine whether uranium has an effect on glass viscosity at 1150°C. Uranium is not considered in the current viscosity model.

A second, major objective of this task was to determine the viability of developing a measurement technique for glass viscosity at SRTC. The benefits of establishing this measurement capability at SRTC are (1) a faster turnaround of viscosity results (2) lower cost for the data by keeping the work scope within SRTC, and (3) use of only a small amount of glass (~6 grams) for each measurement. The small sample size is important at the bench-scale experimental level since it enables SRTC to measure many more glass samples, thereby improving the quality of the results and conclusions.¹

The results of the initial viscosity measurements using the SRTC high-temperature viscometer were included in an Interim Report [3], and these values are repeated here for completeness. This Final Report focuses on (1) the quality of the data generated at SRTC and (2) on the comparison of the SRTC viscosity results with recent results from Corning (CELS) and the Pacific Northwest National Laboratory (PNNL) and with previous results from Sharp-Shurtz (SS). The CELS, PNNL, and SRTC results were determined using samples of the same batch glasses.

RESULTS

SRTC Viscometer. The setup and establishment of a Harrop, high-temperature viscometer at SRTC has been described in an internal report [4]. This unit uses approximately 6 grams of glass, which is considerably less than the amount used by CELS and PNNL. CELS required 700 grams per viscosity measurement and PNNL required 200 grams for each viscosity measurement. Two crucible/spindle sets (Set A and Set B) were used for these measurements. This allowed for one viscosity measurement per day, since it takes ~ 1 day to clean the crucible and spindle. Set A was calibrated using the NIST 717a borosilicate glass standard. This NIST glass is significantly more viscous than DWPF-type glasses with a viscosity close to 2000 Poise at 1200°C. For comparison, the normal range for DWPF glasses is from 20 to 100 Poise at 1150°C.

¹ Smaller samples are of particular advantage when working with uranium-bearing glasses.

Due to the high viscosity of the NIST 717a glass, it was decided to measure the viscosities of the HM, Purex, and Batch 1 WCP glasses. The melt viscosities for these glasses had been previously measured by SS, thereby providing an independent measure of glass viscosity for glasses in the range of interest for DWPF.

Experimental. The melt viscosity was measured according to GTOP-3-111, Rev.0. The glass density for each sample was determined since a constant volume of glass is required in the crucible for each glass sample. The mass of glass to be added to the crucible is $2.6 \text{ cc} \cdot \text{glass density in (g/cc)}$. Viscosity measurements were made at 5 temperatures starting with a temperature of $\sim 1190^\circ\text{C}$. The temperature was lowered in $\sim 50^\circ\text{C}$ intervals and, after equilibration at each temperature, another measurement was made.

Volatilization and crystallization can affect the viscosity results. For example, volatilization of a compound that reduces viscosity will lead to an increase in viscosity with time. On the other hand, crystallization in the melt has the potential to increase the measured viscosity. Starting the viscosity experiment at temperatures above the liquidus temperature minimizes the effect of crystallization on glass viscosity. The impact of volatile species can be determined by measuring the viscosity as a function of time or by choosing a thermal profile that allows for detection of hysteresis effects.

A detailed determination of the impact of volatilization and crystallization on the measured viscosity was beyond the scope of this task. Rather, a comparison of the results from PNNL, Corning, and SRTC was used to demonstrate that consistent results could be obtained. Crystallization does not significantly impact the Fulcher fit for these data since the viscosity change with temperature is relatively small in the region of 1150°C . Therefore, even if crystallization occurred, its impact on the measured viscosity at 1150°C would be small. PNNL followed a sequence of temperatures that allows for hysteresis effects on viscosity due to volatility to be observed. If the PNNL and SRTC results are close, it may be assumed that no significant volatility occurred with these glasses during the viscosity measurements.

Viscosity Measurements. The viscosities at a series of temperatures were calculated from the rpm's of the spindle, the %torque on the spindle, and a constant, K, measured from the NIST 717a glass. The K constant actually varied slightly with temperature, and for temperatures between 1050 and 1500°C it followed the form: $198.4 - (0.063454 \times T \text{ in } ^\circ\text{C})$.² Using this equation, the viscosity at a given measurement temperature was then calculated by equation (1):

$$\text{Viscosity (Poise)} \eta = [\% \text{ torque} / \text{RPM}] \cdot K \quad (1)$$

²

The development of this equation relating K to temperature is documented in notebook WSRC-NB-89-30 (E-57157) on pages 91 through 98.

All of the viscosity measurements generated by SRTC are provided in Exhibit A.1 of the Appendix. The viscosity (in Poise) of each of these glasses at 1150°C is to be estimated from a Fulcher equation fitted to these measurements. The functional form of the (three-parameter) Fulcher equation (expressed in Poise) used to fit these data is given by equation (2):

$$\ln \hat{\eta} = A + \frac{B}{(T - C)} \quad (2)$$

where $\ln \hat{\eta}$ represents the natural logarithm of the estimated viscosity (in Poise), $\hat{\eta}$, and A, B, and C represent the parameters of the model that were determined from the available measurements (expressed in Poise) at various temperatures (represented by T, in degrees Celsius). The fitted model was then used to predict the viscosity of the given glass at 1150°C.

Exhibit A.2 in the Appendix provides the results from such a Fulcher fit for each set of viscosity measurements presented in Exhibit A.1. Exhibits A.3-A.5 provide the results of the Fulcher fits to the viscosity measurements from PNNL, CELS, and SS, respectively.

Repeatability. The Batch 1 glass, with a viscosity close to 50 Poise at 1150°C (see Table 5), was chosen as the secondary standard for this work and for viscosity measurements of glasses produced during the glass studies for salt disposition. A number of measurements were made at SRTC on the Batch 1 glass as a function of time and the results are presented in Table 1 and Figure 1. These results provide a measure of the reproducibility of the technique.

Table 1. SRTC Batch 1 Viscosities at 1150°C (Poise) from Fulcher Equations

Date	Crucible/ Spindle	η_{1150} Viscosity at 1150°C (Poise)	$\ln(\eta_{1150})$
2/9/99	A	48.6	3.884
2/17/99	A	49.7	3.906
4/30/99	B	46.4	3.837
6/8/99	A	48.9	3.890
6/9/99	B	47.3	3.857
8/19/99	A	49.9	3.910
8/31/99	B	49.5	3.902

There is no indication of a statistical difference in the viscosities presented in Table 1 due to the crucible/spindle set used. The relative standard deviation of these data (expressed as a percentage) is 2.7%, a (1-sigma) measure of the repeatability of the SRTC measurement process.

Figure 1 also presents the repeatability data by providing a plot of the Fulcher fits for all of the SRTC Batch 1 measurements.

Figure 1. Graphical Comparison of SRTC Batch 1 Viscosities

Comparisons. In this section, comparisons are made between the SRTC results and those obtained by PNNL, CELS, and/or Sharp-Shurtz (SS). Figure 2 provides a plot of the SRTC values for Batch 1 along with a previous measured set of SS results for this glass.

Figure 2. Graphical Comparison of Batch 1 Viscosities (SRTC and SS)

At 1150°C, the average SRTC result is 48.6 Poise and the Sharp-Shurtz result is 44.2 Poise, a difference of 9.9% for the Batch 1 glass. When compared using a (natural) logarithm scale, the difference is only 2.5%.

For this task the melt viscosity for the HM glass was measured by CELS, SRTC, and PNNL as a function of temperature. These results are summarized in Figure 3 and Table 2 and include a previous HM viscosity measurement by SS.

Figure 3. Graphical Comparison of HM Viscosities

Table 2. HM Viscosities from the Fulcher Fits

Organization	η_{1150} Viscosity at 1150°C (Poise)	$\ln(\eta_{1150})$
CELS	111.5	4.714
PNNL	121.5	4.800
SRTC (Set A; 1/22/99)	121.8	4.802
SRTC (Set A; 1/28/99)	122.6	4.809
SRTC (Set A; 4/7/99)	121.9	4.803
SRTC (Set B; 4/28/99)	120.6	4.792
SS	114.4	4.740

The average SRTC value is 121.7 Poise: 9.1% higher than the CELS value, 0.2% higher than the PNNL value, and 6.4% higher than the Sharp-Shurtz value. In log-space, the differences are: SRTC is 1.9% higher than CELS, 0.03% higher than PNNL, and 1.3% higher than SS.

Figure 4 provides a similar plot of viscosities for the Purex glass, measured by SRTC and SS.

Figure 4. Graphical Comparison of Purex Viscosities (from Fulcher Fits)

The average SRTC value is 22.5 Poise, 12.5% higher than the SS value of 20.0 Poise for Purex. In log-space, SRTC is 0.6% higher than SS.

Uranium Glasses. The three uranium-containing glasses included in this task were sent to PNNL for viscosity measurements. This was done to provide independent verification of the SRTC results. The CELS would not accept these depleted uranium glasses for measurement of viscosity due to the radioactivity. The results are shown in Table 3 and Figures 5, 6 and 7.

**Table 3. Measured Viscosities (from the Fulcher fits)
for the Three Uranium-Containing Glasses**

Glass ID	Organization	η_{1150} Viscosity at 1150°C (Poise)	$\ln(\eta_{1150})$
1	PNNL	88.8	4.486
1	SRTC (4/12/99)	88.5	4.483
1	SRTC (5/4/99)	87.3	4.469
3	PNNL	95.8	4.562
3	SRTC (3/31/99)	98.4	4.589
3	SRTC (4/19/99)	107.4	4.677
3	SRTC (5/11/99)	101.6	4.621
5	PNNL	104.7	4.651
5	SRTC (4/15/99)	107.4	4.677
5	SRTC (4/27/99)	109.4	4.695

For Glass 1, the average SRTC viscosity at 1150°C is 87.9 Poise, 1.0% lower than the PNNL value of 88.1 Poise. For Glass 3, the average SRTC viscosity at 1150°C is 102.5 Poise, 7.0% higher than the PNNL value of 95.8 Poise. For Glass 5, the average SRTC viscosity at 1150°C is 108.4 Poise, 3.5% higher than the PNNL value of 104.7 Poise.

In log-space, the differences are: for Glass 1, SRTC is 0.2% lower than PNNL, for Glass 3, SRTC is 1.5% higher than PNNL, and for Glass 5, SRTC is 0.7% higher than PNNL.

**Figure 5. Graphical Comparison of Glass 1 Viscosities
(A Uranium-Bearing Glass)**

Figure 6. Graphical Comparison of Glass 3 Viscosities
(A Uranium-Bearing Glass)

**Figure 7. Graphical Comparison of Glass 5 Viscosities
(A Uranium-Bearing Glass)**

Other Glasses. Two other glasses (designated as Glass 2 and Glass 4) were included in this task. These glasses did not contain uranium, and they were sent to CELS for viscosity measurements. This was done to provide independent verification of the SRTC results for these glasses. The results are shown in Table 4 and Figures 8, and 9.

**Table 4. Measured Viscosities (from the Fulcher fits)
for Glass 2 and Glass 4**

Glass ID	Organization	η_{1150} Viscosity at 1150°C (Poise)	$\ln(\eta_{1150})$
2	CELS	61.2	4.114
2	SRTC (2/24/99)	65.9	4.188
2	SRTC (3/4/99)	65.3	4.179
4	CELS	92.8	4.530
4	SRTC (3/2/99)	102.3	4.628
4	SRTC (3/9/99)	102.4	4.629

For Glass 2, the average SRTC viscosity at 1150 °C is 65.6 Poise, 7.2% above the CELS value of 61.2 Poise. For Glass 4, the average SRTC viscosity at 1150°C is 102.4 Poise, 10.3% higher than the CELS value of 92.8 Poise.

In log-space, the differences are: for Glass 2, SRTC is 1.7% higher than CELS and for Glass 4, SRTC is 2.2% higher than CELS.

Figure 8. Graphical Comparison of Glass 2 Viscosities

Figure 9. Graphical Comparison of Glass 4 Viscosities

Viscosity Model Predictions. Exhibit A.5 in the Appendix provides the viscosity predictions for the glasses considered in this study determined from the DWPF model for this property, which relates viscosity at 1150°C to glass composition [5]. Viscosity predictions for the glasses are provided using target (or reference) and measured (where available) compositions. Information from Exhibit A.5 is summarized in Table 5.

Table 5: Summary of Viscosity Measurements and Predictions (in Poise) at 1150°C Based on Target and Measured Compositions of the Glasses

Glass ID	Predicted Viscosity		Measured Viscosity ²			
	Target Composition	Measured Composition	SRTC	PNNL	CELS	SS
Glass 1 (U) ¹	82.5	63.1	87.9	88.8	—	—
Glass 2	82.5	94.0	65.6	—	61.2	—
Glass 3 (U)	92.9	82.9	102.5	95.8	—	—
Glass 4	108.9	119.8	102.4	—	92.6	—
Glass 5 (U)	108.9	92.7	108.4	104.7	—	—
Batch 1	56.2	—	48.6	—	—	44.2
HM	137.2	—	121.7	121.5	111.5	114.4
Purex	24.8	—	22.5	—	—	20.0
Uranium Std	33.2	—	32.3	—	—	—

¹ U implies a uranium-bearing glass.

² Values were calculated using the Fulcher fit to the measurement data.

The results for the five glasses, denoted as Glass 1 through Glass 5, representing Macrobatch 2 (with and without uranium) are of primary interest. The PNNL and SRTC data support the idea that DWPF's current viscosity model (using measured compositions) may underpredict the viscosity for uranium-bearing glasses in this compositional region. Specifically, the viscosity model may tend to overpredict the viscosity measurements for glasses without uranium but may tend to underpredict the viscosity for glasses with uranium in this compositional region. These results indicate that uranium may play a significant role in determining melt viscosity for glass compositions similar to those of DWPF's Macrobatch 2, as suggested in the interim report [3].

Alternate Salt Studies. A large number of glasses were fabricated for the alternative salt program in FY99 [6, 7]. The two options considered were (1) small tank — involving Precipitate Aqueous Hydrolysis (PHA) and (2) Crystalline Silicotitanate (CST) pretreatment. The glasses fabricated contained PHA from 7 to 13 weight percent (wt%) or CST from 3 to 9 wt%, with both sets of glasses containing approximately 2.0 wt% oxide depleted uranium. The melt viscosities of these glasses were determined by SRTC and the results were:

- (1) The measured viscosities were generally higher than the predicted viscosities using both target and measured compositions and
- (2) The measured viscosities of the PHA glasses were closer to predicted values than was the case with CST glasses.

These results do not appear to show the influence of uranium exhibited for the sludge-only glasses (Glasses 1, 3, and 5). Further work will be required to understand the influence of uranium on glass viscosity.

CONCLUSIONS

A Harrop, high-temperature glass viscometer has been installed, calibrated using the NIST 717a borosilicate glass standard, and tested at SRTC. This viscometer uses only 6 grams of glass per viscosity measurement. The repeatability of the instrument was checked over time using Batch 1 glass. The relative standard deviation of these data (expressed as a percentage) was 2.7%.

The SRTC viscosity measurements at 1150°C (from the Fulcher fit of the data) for Batch 1, HM, and/or Purex glasses were compared with data from CELS, PNNL, and SS. The SRTC viscosity values were always higher than the CELS and SS values averaging about 9% with a range from 6 to 12 %. On the other hand the SRTC and PNNL results for the HM glass were different by only 0.2 %. Conducting these comparisons in (natural) log-space leads to even smaller differences. These results indicate that the SRTC Harrop Viscometer provides highly repeatable viscosity values at 1150°C and reasonable correspondence with CELS, PNNL, and SS data.

The 5 glasses fabricated to study the influence of uranium on viscosity were sent to PNNL (Glasses 1, 3, and 5) and to CELS (Glasses 2 and 4) for confirmation of the SRTC measurements. PNNL measured the three glasses containing uranium and the results were within 7 % of the SRTC values. CELS measured the remaining two glasses that did not contain uranium. The results revealed that the SRTC viscosity values were ~ 10% higher than those measured by CELS consistent with the Batch 1 results.

These five glasses are representative of DWPF's Macrobatches 2 (with and without uranium). The PNNL and SRTC data support the idea that DWPF's current viscosity model may underpredict the viscosity for uranium-bearing glasses in this compositional region. These results indicate that uranium may play a significant role in determining melt viscosity for glass compositions similar to those of DWPF's Macrobatches 2.

On the other hand, the results obtained with glasses produced through coupled flowsheets in an independent study for the Salt Alternatives Program do not appear to show the influence of uranium exhibited for the sludge-only glasses. Further work will be required to understand the influence of uranium on glass viscosity.

RECOMMENDATION

Initiate a task to determine the influence of uranium on melt viscosity for sludge-only glasses and, if necessary, incorporate a uranium term into the viscosity model for DWPF glasses.

PATH FORWARD

In support of this recommendation, SRTC will seek funding to initiate a task to (A) develop a procedure for measurement of glass viscosity that identifies and minimizes the impact of volatility and crystallization on measured viscosities, (B) characterize the uncertainties in the measurements through a statistically designed set of experiments, and (C) provide the basis for an in-house capability for viscosity confirmation and model revision tasks.

Since this capability will benefit not only DWPF but also TFA, BNFL, and Salt Alternative programs joint funding will be sought.

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Appendix: Exhibits

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Date	1/28/99		
Glass	HM STD	cruc.&glass	293.632
Goal	6.638	crucible	287.004
Actual amt	6.628	glass	6.628

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1135	0.13	1200	1200	1188	60	43.4
1140	0.08	1200	1200	1188	60	43.4
1145	0.03	1200	1200	1188	60	43.4
1220	0.013	1150	1149	1135	30	33.6
1225	0.08	1150	1150	1134	30	33.6
1230	0.03	1150	1150	1134	30	33.6
1310	0.08	1100	1100	1081	30	53.7
1315	0.03	1100	1100	1081	30	53.7
1320	.01H	1100	1100	1081	30	53.7
1400	0.08	1050	1049	1028	12	36.3
1405	0.03	1050	1050	1028	12	36.3
1410	.01H	1050	1050	1028	12	36.3
1445	0.11	1000	999	976	6	32.7
1450	0.06	1000	999	976	6	32.6
1455	0.01	1000	1000	976	6	32.5

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1188	60	43.4	123.01665	88.982042
1134	60	33.6	126.44316	70.808172
1081	30	53.7	129.80623	232.35314
1028	12	36.3	133.16929	402.8371
976	6	32.6	136.4689	741.481

Date	1/22/99		
Glass	HM STD	cruc.&glass	293.668
Goal	6.6389	crucible	287.036
Actual amt	6.632	glass	6.632

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1025	0.12	1200	1201	1187	30	21.7
1030	0.07	1200	1200	1187	30	21.9
1035	0.02	1200	1200	1187	30	21.9
1040	.01H	1200	1200	1187	60	43.7
1045	.01H	1200	1200	1187	60	43.7
1123	0.1	1150	1149	1131	30	33.9
1128	0.05	1150	1150	1131	30	33.9
1133	.01H	1150	1150	1131	30	33.9
1205	0.12	1100	1099	1079	30	54.4
1210	0.07	1100	1100	1079	30	54.3
1215	0.02	1100	1100	1079	30	54.2
1255	0.06	1050	1049	1027	12	36.7
1300	.01H	1050	1050	1027	12	36.6
1305	.01H	1050	1050	1027	12	36.6
1240	0.1	1000	999	974	12	65.9
1345	0.05	1000	1000	974	12	65.7
1350	.01H	1000	1000	974	12	65.7

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1187	60	43.7	123.0801	89.643341
1131	30	33.9	126.63353	143.09588
1079	30	54.3	129.93313	235.17897
1027	12	36.65	133.23274	406.915
974	12	65.75	136.5958	748.43118

Appendix: Exhibits
Exhibit A.1: SRTC Viscometer Results in Date Order

WSRC-RP-99-01053
Revision 0

Date 2/2/99
Glass Purex
Goal=2.6cc=6.876gms
Actual amount 6.879
cruc.&glass 293.888
crucible 287.009
glass 6.879

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1050	0.15	1200	1200	1187	60	8.9
1055	0.1	1200	1200	1187	60	8.9
1100	0.05	1200	1200	1187	60	8.9
1135	0.15	1150	1149	1134	60	12.7
1140	0.1	1150	1149	1134	60	12.7
1145	0.05	1150	1150	1134	60	12.7
1220	0.15	1100	1099	1078	60	19.1
1225	0.1	1100	1099	1079	60	19.0
1230	0.05	1100	1100	1079	60	19.0
1235	0	1100	1100	1079	60	19.0
1305	0.15	1050	1049	1026	60	29.9
1310	0.1	1050	1049	1026	60	29.8
1315	0.05	1050	1049	1026	60	29.8
1320	0	1050	1050	1026	60	29.8
1355	0.1	1000	999	974	60	49.8
1400	0.05	1000	1000	974	60	49.7
1405	.01H	1000	1000	974	60	49.7
1410	.01H	1000	1000	974	60	49.6

Sample Temperature °C	RPM PX Glass	% Torque 2/2/99	K	Viscosity Measured Poise
1187	60	8.9	123.0801	18.256882
1134	60	12.7	126.44316	26.763803
1079	60	19	129.93313	41.145492
1026	60	29.8	133.2962	66.203777
974	60	49.7	136.5958	113.146858

Date 2/5/99
Glass Purex
Goal 2.6cc=6.876gms
Actual amount 6.879

cruc.&glass 293.945
crucible 287.066
glass 6.879

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
950	0.12	1200	1200	1187	60	8.45
955	0.07	1200	1200	1187	60	8.45
960	0.02	1200	1200	1187	60	8.45
1040	0.07	1150	1150	1134	60	12
1045	0.02	1150	1150	1132	60	12.1
1050	0.01H	1150	1150	1133	60	12.05
1122	0.12	1100	1099	1079	60	18.05
1127	0.07	1100	1099	1079	60	18
1132	0.02	1100	1100	1079	60	18
1205	0.13	1050	1049	1026	60	28.4
1210	0.08	1050	1049	1026	60	28.3
1215	0.03	1050	1049	1026	60	28.2
1250	0.14	1000	999	974	60	47.05
1255	0.09	1000	999	974	60	46.8
1300	0.04	1000	999	974	60	46.6
1305	0.01H	1000	1000	974	60	46.6

Sample Temperature °C	RPM PX Glass	% Torque 2/5/99	K	Viscosity Measured Poise
1187	60	8.45	123.0801	17.333781
1133	60	12.05	126.50662	25.406746
1079	60	18	129.93313	38.97994
1026	60	28.3	133.2962	62.871372
974	60	46.67	136.5958	106.24877

Date	2/9/99		
Glass	Batch 1	cruc.&glass	293.790
Goal 2.6cc=6.773gms		crucible	287.013
Actual amount 6.777		glass	6.777

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1025	0.15	1200	1200	1187	60	17.7
1030	0.10	1200	1200	1187	60	17.7
1035	0.05	1200	1200	1187	60	17.7
1110	0.15	1150	1149	1132	60	26.6
1115	0.10	1150	1149	1133	60	26.6
1120	0.05	1150	1150	1133	60	26.6
1200	0.10	1100	1099	1080	60	41.1
1205	0.05	1100	1100	1080	60	41.1
1210	0.00	1100	1100	1080	60	41.1
1245	0.10	1050	1049	1027	60	66.8
1252	0.02	1050	1049	1027	60	66.6
1255	0.02H	1050	1049	1027	60	66.7
1330	0.12	1000	999	975	30	57.45
1335	0.07	1000	1000	976	30	57.45
1340	0.02	1000	1000	976	30	57.45

Sample Temperature °C	RPM Batch 1	% Torque Glass	K	Viscosity Measured Poise
1187	60	17.7	123.0801	36.30863
1133	60	26.6	126.50662	56.084601
1080	60	41.1	129.86968	88.960731
1027	60	66.7	133.23274	148.1104
976	30	57.45	136.4689	261.33794

Appendix: Exhibits
Exhibit A.1: SRTC Viscometer Results in Date Order

WSRC-RP-99-01053
Revision 0

Date 2/17/99
Glass Batch 1 cruc.&glass 293.795
Goal 2.6cc=6.773gms crucible 287.021
Actual amount 6.774 glass 6.774

TIME MIN	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1045	0.16	1200	1200	1188	60	18.05
1050	0.11	1200	1200	1188	60	18.05
1055	0.06	1200	1200	1188	60	18.05
1130	0.16	1150	1149	1133	60	27.1
1135	0.11	1150	1149	1133	60	27.1
1140	0.06	1150	1150	1133	60	27.1
1215	0.16	1100	1099	1080	60	42
1220	0.11	1100	1099	1080	60	41.9
1225	0.06	1100	1100	1080	60	41.8
1305	0.22H	1050	1049	1028	60	67.7
1312	0.16	1050	1049	1028	60	67.5
1322	0.06	1050	1050	1028	60	67.5
1358	0.01	1000	999	976	30	58.5
1403	0.05	1000	1000	976	30	58.2
1408	0.01H	1000	1000	976	30	58.2

Sample Temperature °C	RPM Batch 1	Glass	% Torque	K	Viscosity Measured Poise
	1188	60	18.05	123.01665	37.007508
	1133	60	27.1	126.50662	57.138822
	1080	60	41.9	129.86968	90.692327
	1028	60	67.5	133.16929	149.81545
	976	30	58.3	136.4689	265.20455

Date	2/24/99		
Glass	# 2 (96 NoU)	cruc.&glass	293.984
Goal 2.6cc=6.907gms		crucible	287.077
Actual amount 6.907		glass	6.907

TIME MIL	TIME LEFT	SET RATE °C	FURNACE. °C	SAMPLE °C	SPEED RPM	% TORQUE
1030	0.13	1200	1200	1187.5	60	23.45
1035	0.08	1200	1200	1187.5	60	23.45
1040	0.03	1200	1200	1187.5	60	23.45
1115	0.13	1150	1149	1135	60	36.2
1120	0.08	1150	1149	1135	60	36.15
1125	0.03	1150	1150	1135	60	36.1
1205	0.08	1100	1100	1079	60	58.05
1210	0.03	1100	1100	1079	60	58.05
1250	0.08	1050	1049	1026	60	98.6
1253	0.05	1050	1050	1026	30	49.35
1258	0.01H	1050	1050	1026	30	49.35
1330	0.12	1000	999	974	30	90.1
1335	0.07	1000	999	974	12	36
1340	0.02	1000	1000	974	12	36

Sample Temperature °C	RPM Glass 2 (96 NoU)	% Torque	K	Viscosity Measured Poise
1187.5	60	23.45	123.04838	48.091407
1135	60	36.15	126.37971	76.143775
1079	60	58.05	129.93313	125.71031
1026	30	49.35	133.2962	219.27224
974	12	36	136.5958	409.78741

Date	3/2/99		
Glass	#4(high)	cruc.&glass	293.848
Goal	6.8159	crucible	287.031
Actual amt	6.817	glass	6.817
6.817			

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1042	0.11	1200	1200	1187	60	36.05
1047	0.06	1200	1200	1187	60	36
1052	0.01	1200	1200	1187	60	35.95
1126	0.12	1150	1149	1136	60	55.9
1131	0.07	1150	1150	1136	60	55.8
1136	0.02	1150	1150	1136	60	55.8
1211	0.12	1100	1099	1081	30	45.6
1216	0.07	1100	1099	1081	30	45.55
1221	0.02	1100	1100	1081	30	45.5
1256	0.12	1050	1049	1028	12	31.5
1301	0.07	1050	1050	1028	12	31.4
1306	0.02	1050	1050	1028	12	31.3
1341	0.12	1000	999	976	12	58
1346	0.07	1000	999	976	12	57.7
1351	0.02	1000	1000	976	12	57.6

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1187	60	36	123.0801	73.848061
1136	60	55.8	126.31626	117.47412
1081	30	45.55	129.80623	197.08912
1028	12	31.4	133.16929	348.45964
976	12	57.7	136.4689	656.18794

Appendix: Exhibits
Exhibit A.1: SRTC Viscometer Results in Date Order

WSRC-RP-99-01053
Revision 0

Date	3/4/99		
Glass	#2 (96 NoU)	cruc.&glass	293.938
Goal 2.6cc=6.907gms		crucible	287.028
Actual amt	6.91	glass	6.91

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1035	0.06	1200	1200	1186	60	23.75
1040	.01H	1200	1200	1186	60	23.75
1045	.01H	1200	1200	1186	60	23.75
1123	0.09	1150	1150	1131	60	36.4
1128	0.04	1150	1150	1131	60	36.4
1133	.01H	1150	1150	1131	60	36.4
1205	0.12	1100	1099	1078	60	58.6
1210	0.07	1100	1099	1078	60	58.5
1215	0.02	1100	1100	1078	60	58.4
1252	0.1	1050	1049	1025	30	49.85
1257	0.05	1050	1050	1025	30	49.75
1302	0	1050	1050	1025	30	49.65
1340	0.07	1000	999	974	30	90.45
1345	0.02	1000	1000	974	12	36.3
1350	0.01H	1000	1000	974	12	36.3

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1186	60	23.75	123.14356	48.744324
1131	60	36.4	126.63353	76.824339
1078	60	58.5	129.99659	126.74667
1025	30	49.75	133.35965	221.15475
974	12	36.3	136.5958	413.20231

Date	3/9/99		
Glass	#4(high)	cruc.&glass	293.887
Goal	6.8159	crucible	287.067
Actual amt	6.82	glass	6.82

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1010	0.1	1200	1200	1188	60	36.35
1015	0.05	1200	1200	1188	60	36.35
1020	0	1200	1200	1188	60	36.35
1055	0.1	1150	1150	1132	60	56.25
1100	0.05	1150	1150	1133	60	56.2
1105	0	1150	1150	1133	60	56.2
1140	0.1	1100	1099	1080	30	45.95
1145	0.05	1100	1100	1080	30	45.95
1150	0	1100	1100	1080	30	45.95
1310	0.1	1000	999	974	12	57.8
1315	0.05	1000	1000	975	12	57.8
1320	0	1000	1000	975	12	57.8

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1188	60	36.35	123.01665	74.527586
1133	60	56.2	126.50662	118.49453
1080	30	45.95	129.86968	198.91706
975	12	57.8	136.53235	657.63082

Date 3/31/99
Glass #3 (97-Like)
Goal 6.856
Actual amt 6.86

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1136	0.14	1200	1200	1187	60	34.75
1140	0.1	1200	1200	1187	60	34.75
1145	0.05	1200	1200	1187	60	34.75
1220	0.15	1150	1149	1136	60	53.8
1225	0.1	1150	1149	1137	60	53.5
1230	0.05	1150	1150	1137	60	53.5
1305	0.15	1100	1099	1080	30	43.45
1310	0.1	1100	1099	1080.5	30	43.2
1315	0.05	1100	1100	1080.5	30	43.2
1350	0.15	1050	1049	1026	12	29.5
1355	0.1	1050	1049	1026	12	29.4
1400	0.05	1050	1049	1026	12	29.3
1435	0.15	1000	999	973	12	54.1
1440	0.1	1000	999	974	12	53.5
1445	0.05	1000	1000	974	12	53.3

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1187	60	34.75	123.0801	71.283892
1137	60	53.5	126.2528	112.57542
1080.5	30	43.2	129.83795	186.96665
1026	12	29.4	133.2962	326.57568
974	12	53.4	136.5958	607.85133

Date	4/7/99		
Glass	HM	cruc.&glass	293.638
Goal	6.638	crucible	287
Actual amt	6.638	glass	6.638

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1035	0.12	1200	1200	1191	60	42.15
1040	0.07	1200	1200	1191	60	42.15
1045	0.02	1200	1200	1191	60	42.15
1120	0.12	1150	1149	1136	30	32.8
1125	0.07	1150	1149	1136	30	32.75
1130	0.02	1150	1150	1136	30	32.75
1205	0.12	1100	1099	1083	30	52.4
1210	0.07	1100	1100	1084	30	52.25
1215	0.02	1100	1100	1084	30	52.15
1250	0.12	1050	1049	1031	12	35.4
1255	0.07	1050	1049	1031	12	35.2
1300	0.02	1050	1050	1031	12	35.2
1335	0.12	1000	999	978	6	31.8
1340	0.07	1000	999	978	6	31.7
1345	0.02	1000	1000	978	6	31.6

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1191	60	42.15	122.82629	86.285466
1136	30	32.75	126.31626	137.89525
1084	30	52.2	129.61586	225.5316
1031	12	35.2	132.97893	390.07152
978	6	31.7	136.34199	720.34017

Date 4/12/99
Glass #1
Goal 6.905
Actual amt 6.92

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
12:08	0.15	1200	1200	1188	60	31.2
12:13	0.10	1200	1200	1188	60	31.2
12:18	0.05	1200	1200	1188	60	31.2
12:52	0.15	1150	1149	1133.5	60	48.65
12:57	0.10	1150	1149	1134	60	48.45
13:02	0.05	1150	1149	1134	60	48.35
13:37	0.15	1100	1099	1080	30	39.45
13:42	0.10	1100	1099	1081	30	39.35
13:47	0.05	1100	1100	1081	30	39.25
14:27	0.10	1050	1050	1028	30	67
14:32	0.05	1050	1050	1028	30	66.9
14:37	0.00	1050	1050	1028	30	66.8
15:15	0.07	1000	999	975	12	49
15:20	0.02	1000	1000	975	12	48.9

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1188	60	31.2	123.01665	63.968657
1134	60	48.4	126.44316	101.99749
1081	30	39.3	129.80623	170.04616
1028	30	66.9	133.16929	296.96751
975	12	48.95	136.53235	556.93821

Date 4/15/99
Glass #5
Goal 6.852
Actual amt 6.852

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1027	0.15	1200	1200	1188	60	37.75
1032	0.1	1200	1200	1188	60	37.8
1037	0.05	1200	1200	1188	60	37.8
1114	0.12	1150	1149	1135.5	60	58.8
1119	0.07	1150	1150	1135.5	60	58.7
1124	0.02	1150	1150	1135.5	60	58.6
1157	0.15	1100	1099	1079.5	30	47.75
1202	0.1	1100	1099	1080	30	47.6
1207	0.05	1100	1100	1080	30	47.4
1242	0.15	1050	1049	1026.5	12	32.8
1247	0.1	1050	1049	1027	12	32.75
1252	0.05	1050	1049	1027	12	32.65
1327	0.15	1000	999	974	12	60
1332	0.1	1000	999	975.5	12	59.3
1337	0.05	1000	999	975	12	59.1

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1188	60	37.8	123.01665	77.500488
1135.5	60	58.7	126.34798	123.61044
1080	30	47.5	129.86968	205.62699
1027	12	32.7	133.23274	363.05922
975	12	59.4	136.53235	675.83513

Date 4/19/99
Glass #3 (97-Like)
Goal 6.856
Actual amt 6.858

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1155	0.15	1200	1200	1189.5	60	37.35
1200	0.1	1200	1200	1190	60	37.35
1205	0.05	1200	1200	1190	60	37.35
1240	0.15	1150	1149	1136.5	60	58.25
1245	0.1	1150	1149	1137	60	58
1250	0.05	1150	1150	1137	60	57.9
1325	0.15	1100	1099	1078.5	30	47.3
1330	0.1	1100	1099	1080.5	30	47
1335	0.05	1100	1099	1079.5	30	47
1405	0.15	1050	1049	1028	12	32.4
1410	0.1	1050	1049	1028	12	32.3
1415	0.05	1050	1049	1028	12	32.2
1450	0.15	1000	999	974.5	12	59.35
1455	0.1	1000	999	975	12	58.75
1500	0.05	1000	1000	975.5	12	58.45

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1190	60	37.35	122.88974	76.498863
1137	60	57.95	126.2528	121.93916
1080	30	47	129.86968	203.4625
1028	12	32.3	133.16929	358.44733
975	12	58.75	136.53235	668.43963

Date 4/27/99
Glass #5
Goal 6.852
Actual amt 6.850

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1107	0.08	1200	1200	1190.5	60	37.95
1112	0.03	1200	1200	1190.5	60	37.95
1117	.02H	1200	1200	1190.5	60	37.95
1150	0.15	1150	1149	1136.5	60	59.15
1155	0.1	1150	1149	1137	60	58.85
1200	0.05	1150	1150	1135.5	60	58.8
1240	0.1	1100	1099	1081.5	30	47.75
1245	0.05	1100	1099	1081.5	30	47.75
1250	0	1100	1100	1081.5	30	47.75
1320	0.15	1050	1049	1028	12	33
1325	0.1	1050	1050	1028	12	32.8
1330	0.05	1050	1050	1028	12	32.7
1405	0.15	1000	999	975	12	59.95
1410	0.1	1000	999	975.5	12	59.6
1415	0.05	1000	1000	976	12	59.3

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1190.5	60	37.95	122.85801	77.707693
1136.3	60	58.93	126.29722	124.04492
1081.5	30	47.75	129.7745	206.55774
1028	12	32.83	133.16929	364.32898
975.5	12	59.62	136.50062	678.1806

Date 4/28/99
Glass HM
Goal 6.638
Actual amt 6.641

NEW CRUCIBLE AND SPINDLE
cruc.&glass 291.516
crucible 284.875
glass 6.641

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1205	0.05H	1200	1200	1193	60	41.25
1210	0.05H	1200	1200	1193	60	41.25
1215	0.04	1200	1200	1193	60	41.35
1250	0.14	1150	1149	1139	60	63.8
1255	0.09	1150	1149	1138.5	60	63.65
1300	0.04	1150	1150	1138.5	60	63.65
1340	0.09	1100	1099	1083.5	30	51.1
1345	0.04	1100	1100	1083.5	30	51.05
1350	0.01H	1100	1100	1083.5	30	51
1424	0.1	1050	1049	1030.5	30	85.95
1429	0.05	1050	1050	1030.5	30	85.7
1434	0	1050	1050	1030.5	30	85.7
1505	0.15	1000	999	977	12	62.3
1510	0.1	1000	999	977.5	12	61.8
1515	0.05	1000	1000	977.5	12	61.6

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1193	60	41.3	122.69938	84.458072
1138.5	60	63.65	126.15762	133.83221
1083.5	30	51.05	129.64759	220.61698
1030.5	30	85.78	133.01065	380.32179
977.5	12	61.7	136.37372	701.18818

Date	4/30/99	Crucible B and Spindle B
Glass	Batch 1	cruc.&glass 291.683
Goal	6.773	crucible 284.905
Actual amt	6.778	glass 6.778

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1033	0.15	1200	1200	1194.5	60	16.2
1038	0.1	1200	1200	1194	60	16.2
1043	0.05	1200	1200	1194	60	16.2
1118	0.15	1150	1149	1137	60	24.2
1123	0.1	1150	1150	1138	60	24
1128	0.05	1150	1150	1141	60	24
1203	0.15	1100	1099	1085.5	60	37.3
1208	0.1	1100	1100	1086	60	37.2
1213	0.05	1100	1100	1086	60	37.2
1248	0.15	1050	1049	1031.5	60	60.55
1253	0.1	1050	1049	1032	60	60.2
1258	0.05	1050	1050	1032	60	60.1
1333	0.15	1000	999	978.5	30	52.1
1338	0.1	1000	999	979	30	51.8
1343	0.05	1000	1000	979	30	51.6

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1194	60	16.2	122.63592	33.111699
1139	60	24	126.12589	50.450358
1086	60	37.2	129.48896	80.283153
1032	60	60.15	132.91547	133.24776
979	30	51.7	136.27853	234.85334

Date 5/4/99
Glass #1
Goal 6.905
Actual amt 6.904

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
940	0.15	1200	1200	1196	60	29.2
945	0.1	1200	1200	1195.5	60	29.25
950	0.05	1200	1200	1195.5	60	29.3
1025	0.15	1150	1149	1139.5	60	45.35
1030	0.1	1150	1150	1139.5	60	45.2
1035	0.05	1150	1150	1139.5	60	45.05
1110	0.15	1100	1099	1087	30	36.7
1115	0.1	1100	1099	1088	30	36.45
1120	0.05	1100	1099	1088	30	36.35
1155	0.15	1050	1049	1034	30	62.15
1200	0.1	1050	1049	1035	30	61.65
1205	0.05	1050	1050	1035	30	61.35
1240	0.15	1000	999	981.5	12	44.95
1245	0.1	1000	999	982.5	12	44.55
1250	0.05	1000	1000	982.5	12	44.45

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1195.5	60	29.25	122.54074	59.738612
1139.5	60	45.2	126.09417	94.990939
1088	30	36.4	129.36205	156.95928
1035	30	61.5	132.72511	272.08648
982.5	12	44.5	136.05645	504.54265

Date	5/7/99	Crucible B and Spindle B
Glass	Purex	cruc.&glass 291.749
Goal	6.876	crucible 284.872
Actual amt	6.877	glass 6.877

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1025	0.1	1200	1200	1196.5	60	7.55
1030	0.05	1200	1200	1196.5	60	7.55
1035	0	1200	1200	1196.5	60	7.55
1110	0.1	1150	1150	1141.5	60	10.85
1115	0.05	1150	1150	1141.5	60	10.85
1120	0	1150	1150	1141.5	60	10.85
1155	0.1	1100	1099	1088	60	16.2
1200	0.05	1100	1100	1088	60	16.2
1205	0	1100	1100	1088	60	16.2
1240	0.1	1050	1049	1035	60	25.25
1245	0.05	1050	1049	1035	60	25.2
1250	0	1050	1050	1035	60	25.15
1325	0.1	1000	999	982.5	60	41.85
1330	0.05	1000	999	982.5	60	41.6
1335	0	1000	1000	982.5	60	41.55

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1196.5	60	7.55	122.47729	15.411726
1141.5	60	10.85	125.96726	22.779079
1088	60	16.2	129.36205	34.927753
1035	60	25.2	132.72511	55.744546
982.5	60	41.65	136.05645	94.445849

Date 5/11/99
Glass #3 (97-Like)
Goal 6.856
Actual amt 6.858

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1045	0.15	1200	1200	1196.5	60	34.1
1050	0.1	1200	1200	1196.5	60	34.1
1055	0.05	1200	1200	1196.5	60	34.1
1135	0.1	1150	1149	1140.5	60	52.35
1140	0.05	1150	1150	1140.5	60	52.05
1145	0	1150	1150	1140.5	60	52.05
1220	0.1	1100	1099	1088	30	41.95
1225	0.05	1100	1100	1087.5	30	41.85
1230	0	1100	1100	1088	30	41.75
1305	0.1	1050	1049	1034.5	30	70.75
1310	0.05	1050	1049	1034	30	70.65
1315	0	1050	1050	1034	30	70.65
1350	0.1	1000	999	981	12	51.3
1355	0.05	1000	1000	981.5	12	51.05
1400	0	1000	1000	981.5	12	50.95

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1196.5	60	34.1	122.47729	69.607926
1140.5	60	52.15	126.03071	109.54169
1088	30	41.85	129.36205	180.46006
1034	30	70.65	132.78856	312.71707
981.5	12	51	136.1199	578.50957

Date	6/8/99	Crucible & Spindle A
Glass	Batch 1	cruc.&glass 293.800
Goal 2.6cc=6.773gms		crucible 287.020
Actual amount 6.780		glass 6.780

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1209	0.10	1200	1200	1199.5	60	16.5
1214	0.05	1200	1200	1199.5	60	16.5
1219	0.00	1200	1200	1199.5	60	16.5
1254	0.10	1150	1149	1143.5	60	24.55
1259	0.05	1150	1150	1143.5	60	24.55
1304	0.00	1150	1150	1143.5	60	24.55
1339	0.10	1100	1099	1089.5	60	37.8
1344	0.05	1100	1100	1089.5	60	37.75
1349	0.00	1100	1100	1089.5	60	37.75
1424	0.10	1050	1049	1037	60	61.1
1429	0.05	1050	1049	1037	60	61
1434	0.00	1050	1050	1037	60	60.9
1509	0.10	1000	999	983.5	30	52.35
1415	0.05	1000	1000	984	30	52.2
1519	0.00	1000	1000	984	30	52.2

Sample Temperature °C	RPM Batch 1	% Torque Glass	K	Viscosity Measured Poise
1199.5	60	16.5	122.28693	33.628905
1143.5	60	24.55	125.84035	51.489677
1089.5	60	37.75	129.26687	81.330404
1037	60	61	132.5982	134.80817
984	30	52.2	135.96126	236.5726

Date	6/9/99	Crucible & Spindle B	
Glass	Batch 1	cruc.&glass	291.672
Goal 2.6cc=6.773gms		crucible	284.900
Actual amount 6.772		glass	6.772

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
925	0.10	1200	1200	1197.5	60	16.3
930	0.05	1200	1200	1198	60	16.3
935	0.00	1200	1200	1198.5	60	16.3
1010	0.10	1150	1149	1141.5	60	23.85
1015	0.05	1150	1150	1142	60	23.85
1020	0.00	1150	1150	1142	60	23.85
1055	0.10	1100	1099	1088.5	60	36.45
1100	0.05	1100	1100	1089	60	36.45
1105	0.00	1100	1100	1089	60	36.45
1140	0.10	1050	1049	1035.5	60	59.05
1145	0.05	1050	1050	1035.5	60	59.05
1150	0.00	1050	1050	1035.5	60	59.05
1225	0.10	1000	999	982.5	30	50.7
1230	0.05	1000	999	982.5	30	50.65
1235	0.00	1000	1000	982.5	30	50.6

Sample Temperature °C	RPM Batch 1	Glass	% Torque	K	Viscosity Measured Poise
1198	60		16.3	122.38211	33.247139
1142	60		23.85	125.93553	50.059374
1089	60		36.45	129.29859	78.548896
1035.5	60		59.05	132.69338	130.5924
982.5	30		50.65	136.05645	229.70863

Date 8/19/99
Glass Batch 1
Goal 2.6cc=6.773gms
Actual amount 6.791

Crucible & Spindle A
cruc.&glass 293.784
crucible 286.993
glass 6.791

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1030	0.12	1200	1200	1199	60	16.85
1035	0.07	1200	1200	1199	60	16.85
1040	0.02	1200	1200	1199	60	16.85
1115	0.12	1150	1149	1143	60	25.05
1120	0.07	1150	1150	1143.5	60	25
1125	0.02	1150	1150	1144	60	25
1200	0.12	1100	1099	1090	60	38.55
1205	0.07	1100	1100	1090	60	38.55
1210	0.02	1100	1100	1090	60	38.55
1245	0.12	1050	1049	1037	60	61.9
1250	0.07	1050	1049	1037	60	61.9
1255	0.02	1050	1050	1037	60	61.9
1330	0.12	1000	999	984	30	53.2
1335	0.07	1000	1000	984	30	52.9
1340	0.02	1000	1000	984	30	52.8

Sample Temperature °C	RPM Batch 1	% Torque Glass	K	Viscosity Measured Poise
1199	60	16.85	122.31865	34.351155
1143.5	60	25	125.84035	52.43348
1090	60	38.55	129.23514	83.033577
1037	60	61.9	132.5982	136.79715
984	30	52.95	135.96126	239.97163

Date 8/31/99
Glass Batch 1
Goal 2.6cc=6.773gms
Actual amount 6.774

Crucible & Spindle B
cruc.&glass 291.650
crucible 284.876
glass 6.774

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1100	0.10	1200	1200	1200	60	16.55
1105	0.05	1200	1200	1200	60	16.55
1110	0.00	1200	1200	1200	60	16.55
1145	0.10	1150	1149	1147.5	60	24.35
1150	0.05	1150	1150	1148	60	24.3
1155	0.00	1150	1150	1148	60	24.3
1230	0.10	1100	1099	1092	60	37.35
1235	0.05	1100	1100	1092	60	37.35
1240	0.00	1100	1100	1092	60	37.35
1315	0.10	1050	1049	1040	60	59.2
1320	0.05	1050	1050	1040	60	59.4
1325	0.00	1050	1050	1040	60	59.6
1400	0.10	1000	999	986	30	51.4
1405	0.05	1000	1000	986	30	51.4
1410	0.00	1000	1000	986	30	51.4

Sample Temperature °C	RPM Batch 1	% Torque Glass	K	Viscosity Measured Poise
1200	60	16.55	122.2552	33.722059
1148	60	24.3	125.55481	50.849697
1092	60	37.35	129.10823	80.369874
1040	60	59.4	132.40784	131.08376
986	30	51.4	135.83436	232.72953

Date 10/8/99
Glass Uranium Standard
Goal
Actual amt 7.1097

TIME MIL	TIME LEFT	SET RATE °C	FURNACE °C	SAMPLE °C	SPEED RPM	% TORQUE
1100	0.1	1200	1200	1199.5	60	10.95
1105	0.05	1200	1200	1199.5	60	11.05
1110	0	1200	1200	1199.5	60	10.9
1145	0.1	1150	1149	1145	60	15.9
1150	0.05	1150	1150	1145	60	15.95
1155	0	1150	1150	1145	60	15.95
1230	0.1	1100	1099	1091	60	24.35
1235	0.05	1100	1100	1091	60	24.35
1240	0	1100	1100	1091	60	24.35
1315	0.1	1050	1049	1038.5	60	39.3
1320	0.05	1050	1050	1038.5	60	39.4
1325	0	1050	1050	1038.5	60	39.5
1400	0.1	1000	999	984.5	30	34.4
1405	0.05	1000	1000	984.5	30	34.4
1410	0	1000	1000	984.5	30	34.4

Sample Temperature °C	RPM	% Torque	K	Viscosity Measured Poise
1199.5	60	10.95	122.28693	22.317364
1145	60	15.95	125.74517	33.427258
1091	60	24.35	129.17169	52.422176
1038.5	60	39.4	132.50302	87.010317
984.5	30	34.4	135.92954	155.86587

HM
1/22/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.62340847	0.63004215
B	10258.573027	1274.44165
C	61.650376873	62.5434012

Graph of Fulcher Fit

HM

Temp (Deg C)	Measured Visc. (Poise)	In Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1187	89.64334	4.49249	4.495839	89.34
1131	143.0959	4.969874	4.963515	144.01
1079	235.179	5.460217	5.460347	235.15
1027	406.915	6.003387	6.008604	404.80
974	748.7312	6.620716	6.61838	750.48
1150	?	4.802398	?	121.8

HM
1/28/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.582908606	0.35512756
B	10167.71155	715.479671
C	67.374106932	35.2822506

Graph of Fulcher Fit

HM 1

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1188	88.98204	4.490335	4.488435	89.15
1134	141.6163	4.949685	4.953122	141.13
1081	232.3531	5.448121	5.448258	232.32
1028	402.8371	6.001557	5.998532	404.06
976	741.481	6.607298	6.60865	740.48
1150	?	4.808804	?	122.58

Purex
2/2/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-3.605459573	0.30455242
B	6349.3945382	523.880195
C	212.03562655	35.2584469

Graph of Fulcher Fit

Purex

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1187	18.2569	2.906978	2.904543	18.30
1134	26.738	3.281352	3.286086	26.61
1079	41.1455	3.718249	3.717115	41.19
1026	66.2038	4.195121	4.192738	66.36
974	113.1469	4.727469	4.728687	113.01
1150	?	3.163875	?	23.66

Purex
2/5/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-3.898484758	0.13987201
B	6788.1400585	249.207654
C	181.45202066	16.2567964

Graph of Fulcher Fit

Purex

Temp (Deg C)	Measured Visc. (Poise)	In Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1187	17.3338	2.852203	2.852658	17.33
1133	25.4067	3.235302	3.235013	25.41
1079	38.9799	3.664498	3.663046	39.04
1026	62.8714	4.139117	4.141091	62.75
974	106.2488	4.666473	4.665784	106.32
1150	?	3.110089	?	22.42

Batch 1
2/9/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.494750139	0.61567372
B	8724.7982887	1188.84714
C	108.53429464	65.4570676

Graph of Fulcher Fit

Batch 1

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1187	36.30863	3.59526	3.592055	36.43
1133	56.0846	4.021687	4.026861	55.80
1080	88.96073	4.486317	4.488195	88.79
1027	148.1104	5.004568	4.997958	149.09
976	261.3379	5.563052	5.565814	260.62
1150	?	3.882672	?	48.55

Batch 1
2/17/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.368131388	0.24007985
B	8555.4053557	460.183922
C	115.94617024	25.6476823

Batch 1

Temp (Deg C)	Measured Visc. (Poise)	In Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1188	37.00751	3.612256	3.611121	37.05
1133	57.13882	4.043818	4.045484	57.04
1080	90.69233	4.506275	4.507473	90.58
1028	149.8155	5.012242	5.009404	150.24
976	265.2045	5.579392	5.580501	264.91
1150	?	3.905524	?	49.68

Glass 2
2/24/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.189857342	1.03450359
B	8245.3057008	1876.67085
C	165.8200733	102.631977

Graph of Fulcher Fit

Glass 2

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1187.5	48.09141	3.880484	3.873104	48.45
1135	76.14377	4.31765	4.332623	75.01
1079	125.7103	4.839366	4.83398	126.39
1026	219.2722	5.395702	5.390314	220.46
974	409.7874	6.012457	6.015639	408.49
1150	?	4.187986	?	65.89

Glass 4
3/2/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-5.021262968	1.00618082
B	10407.799087	2018.70962
C	71.368094278	96.8389453

Graph of Fulcher Fit

Glass 4

Temp (Deg C)	Measured Visc. (Poise)	In Visc (Fulcher, Poise)	Measured InVisc. (Poise)	Predicted Visc. (poise)
1187	73.84806	4.307799	4.30201	74.28
1136	117.4741	4.754697	4.766218	116.13
1081	197.0891	5.287246	5.283656	197.80
1028	348.4596	5.858365	5.853522	350.15
976	656.1879	6.483747	6.486447	654.42
1150	?	4.627811	?	102.29

Glass 2

3/4/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-3.425115457	0.24581215
B	6856.6345785	404.535923
C	248.27043953	24.1101762

Graph of Fulcher Fit

Glass 2

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1186	48.74432	3.886838	3.886589	48.76
1131	76.82434	4.342422	4.341522	76.89
1078	126.7467	4.838583	4.84219	126.29
1025	221.1547	5.402455	5.398863	221.95
974	413.2023	6.022804	6.023937	412.73
1150	?	4.178755	?	65.28

Glass 4
3/9/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.084227367	0.68012829
B	8668.993743	1244.73887
C	155.1141533	65.2453892

Graph of Fulcher Fit

Glass 4

Temp (Deg C)	Measured Visc. (Poise)	In Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1188	74.52759	4.308756	4.311169	74.35
1133	118.4945	4.780809	4.774867	119.20
1080	198.9171	5.288814	5.292888	198.11
975	657.6308	6.489188	6.488644	657.99
1150	?	4.629329	?	102.45

Glass 3
3/31/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-5.203487644	2.01681083
B	11025.282625	4234.6444
C	24.135611033	200.696009

Graph of Fulcher Fit

Glass 3

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1187	71.28389	4.277655	4.26667	72.07
1137	112.5754	4.703634	4.723623	110.35
1080.5	186.9667	5.233519	5.23093	187.45
1026	326.5757	5.801278	5.788662	330.72
974	607.8513	6.40373	6.40993	604.09
1150	?	4.589239	?	98.42
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HM
4/7/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-5.043143248	0.17175151
B	11083.92262	361.695094
C	24.344662735	17.1110281

Graph of Fulcher Fit

HM

Temp (Deg C)	Measured Visc. (Poise)	In Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1191	86.28547	4.457454	4.457661	86.27
1136	137.8952	4.927503	4.926494	138.03
1084	225.5316	5.416789	5.41846	225.15
1031	390.0715	5.9675	5.96633	390.53
978	720.3402	6.579423	6.579724	720.12
1150	?	4.803497	?	121.94

Glass 1
4/12/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-5.251703083	0.25159913
B	10720.570572	516.056657
C	48.707616219	24.5749404

Graph of Fulcher Fit

Glass 1

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1188	63.96866	4.158147	4.158393	63.95
1134	101.9975	4.626345	4.624948	102.14
1081	170.0462	5.133504	5.13607	169.61
1028	296.9675	5.695559	5.693623	297.54
975	556.9382	6.321933	6.322454	556.65
1150	?	4.482833	?	88.49

Glass 5
4/15/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.513995046	0.95575278
B	9651.1515193	1862.32804
C	99.882043264	93.5353944

Graph of Fulcher Fit

Glass 1

Temp (Deg C)	Measured Visc. (Poise)	In Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1188	77.50049	4.355587	4.350284	77.91
1135.5	123.6104	4.805225	4.817135	122.15
1080	205.627	5.332934	5.326064	207.04
1027	363.0592	5.895847	5.894566	363.52
975	675.8351	6.514406	6.515949	674.79
1150	?	4.676545	?	107.40
	..			

Glass 3
4/19/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.275829886	1.16787639
B	9234.5665897	2234.14731
C	118.44944286	115.103158

Graph of Fulcher Fit

Glass 3

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1190	76.49886	4.342118	4.337276	76.87
1137	121.9392	4.79055	4.803522	120.37
1080	203.4625	5.327999	5.315482	206.03
1028	358.4473	5.87706	5.881782	356.76
975	668.4396	6.505281	6.504946	668.66
1150	?	4.676292	?	107.37

Glass 5
4/27/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.47062997	0.38089472
B	9636.0868103	744.068783
C	98.661509029	37.5229028

Graph of Fulcher Fit

Glass 5

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1190.5	77.70769	4.354931	4.352954	77.86
1136.3	124.0449	4.815925	4.820644	123.46
1081.5	206.5577	5.333714	5.33058	207.21
1028	364.329	5.898129	5.898057	364.36
975.5	678.1806	6.51895	6.519414	677.87
1150	?	4.694912	?	109.39
	..			

HM (Crucible and Spindle Set B) 4/28/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.320142575	0.41438758
B	9711.6078471	823.40395
C	84.219234228	41.9154646

Graph of Fulcher Fit

HM

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1193	84.45807	4.438674	4.436255	84.66
1138.5	133.8322	4.891453	4.896587	133.15
1083.5	220.617	5.398455	5.396428	221.06
1030.5	380.3218	5.942782	5.941018	380.99
977.5	701.1882	6.5517	6.552776	700.43
1150	?	4.792058	?	120.55
	--			

Batch 1 (Crucible and Spindle Set B)
4/30/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.874851565	0.5159502
B	9491.1788828	1051.02319
C	60.500972194	56.1382161

Graph of Fulcher Fit

Batch 1

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1194	33.1117	3.498494	3.499887	33.07
1139	50.45036	3.925508	3.92099	50.68
1086	80.28315	4.380329	4.38556	79.86
1032	133.2478	4.894771	4.89221	133.59
979	234.8533	5.458506	5.458961	234.75
1150	?	3.836656	?	46.37

Glass 1
5/4/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.699833614	0.76175876
B	9562.1367256	1483.96856
C	107.18914576	75.2170732

Graph of Fulcher Fit

Glass 1

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1195.5	59.73861	4.086385	4.089979	59.52
1139.5	94.99094	4.563013	4.553782	95.87
1088	156.9593	5.049382	5.055986	155.93
1035	272.0865	5.606294	5.60612	272.13
982.5	504.5407	6.224442	6.223648	504.94
1150	?	4.469746	?	87.33

Purex
5/7/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.372307534	0.15629799
B	7485.1219273	293.275854
C	143.34920218	18.2825477

Graph of Fulcher Fit

Purex

Temp (Deg C)	Measured Visc. (Poise)	In Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1196.5	15.41173	2.735053	2.735129	15.41
1141.5	22.77908	3.126682	3.125843	22.80
1088	34.92775	3.551384	3.553282	34.86
1035	55.74455	4.022371	4.02078	55.83
982.5	94.44585	4.547569	4.548027	94.40
1150	?	3.063361	?	21.40

Glass 3
5/11/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-3.949730409	0.61395649
B	8562.9111795	1141.73437
C	150.96686754	61.6522803

Graph of Fulcher Fit

Glass 3

Temp (Deg C)	Measured Visc. (Poise)	In Visc (Fulcher, Poise)	Measured In Visc. (Poise)	Predicted Visc. (poise)
1196.5	69.60793	4.240265	4.242878	69.43
1140.5	109.5417	4.703756	4.696305	110.36
1088	180.4601	5.188592	5.195509	179.22
1034	312.7171	5.747427	5.745299	313.38
981.5	578.5096	6.360408	6.360455	578.48
1150	?	4.621468	?	101.64

Batch 1
6/8/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.163417666	0.26297363
B	8160.6533445	498.124624
C	136.65295042	28.7540657

Graph of Fulcher Fit

Batch 1

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1199.5	33.6289	3.514689	3.515386	33.61
1143.5	51.48968	3.941739	3.941381	51.51
1089.5	81.3304	4.401077	4.39852	81.54
1037	134.8082	4.90048	4.903853	134.35
984	236.5726	5.46741	5.466255	236.85
1150	?	3.88975	?	48.90

Batch 1 (Crucible and Spindle Set B)

6/9/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-3.478220023	0.37284869
B	6922.5011794	652.766354
C	206.14511702	41.019357

Graph of Fulcher Fit

Batch 1

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1198	33.24714	3.501129	3.503969	33.15
1142	50.05937	3.918761	3.91321	50.34
1089	78.5489	4.362821	4.363721	78.48
1035.5	130.5924	4.86863	4.872081	130.14
982.5	229.7086	5.438451	5.436812	230.09
1150	?	3.856065	?	47.28

Batch 1
8/19/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.546871487	0.20916011
B	8960.434251	415.591051
C	90.405311289	22.929557

Graph of Fulcher Fit

Batch 1

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1199	34.35115	3.535825	3.536636	34.32
1143.5	52.43348	3.961798	3.959545	52.55
1090	83.03358	4.417196	4.419245	82.86
1037	136.7972	4.919096	4.918499	136.88
984	239.9716	5.480532	5.480521	239.97
1150	?	3.909602	?	49.88

Batch 1 (Crucible and Spindle Set B) 8/31/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.429398801	0.82998878
B	8734.1932506	1633.32405
C	101.72050786	91.5526932

Graph of Fulcher Fit

Batch 1

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1200	33.72206	3.523216	3.518152	33.89
1148	50.84697	3.91846	3.928821	50.32
1092	80.36987	4.390529	4.386639	80.68
1040	131.0838	4.879334	4.875837	131.54
986	232.7295	5.447787	5.449877	232.24
1150	?	3.902533	?	49.53

Uranium Standard Glass

10/8/99

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-3.565831384	0.24348389
B	6350.8231927	406.90651
C	247.41179886	26.5893295

Graph of Fulcher Fit

Uranium Standard Glass

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1199.5	22.31736418	3.104583	3.105365	22.30
1145	33.42725769	3.509599	3.509372	33.43
1091	52.4221759	3.962514	3.95933	52.59
1038.5	87.01031712	4.462127	4.466027	86.67
984.5	155.8658691	5.050265	5.048996	156.06
1150	?	3.470404	?	32.15
	..			

PNNL HM

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-2.193010134	0.32322725
B	5907.120649	556.112826
C	305.22809368	40.17480

Graph of Fulcher Fit

HM Measured by PNNL

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1235	65.13	4.160291	4.176385	64.09
1187	89.54	4.506138	4.494685	90.57
1137	136.34	4.908841	4.915152	135.48
1186	90.46	4.513744	4.504908	91.26
1235	64.48	4.160291	4.166355	64.09
1284	46.52	3.842227	3.839882	46.63
1333	34.75	3.554491	3.54818	34.97
1236	63.93	4.153465	4.157789	63.65
1088	209.51	5.353404	5.344771	211.33
1039	351.47	5.85734	5.862124	349.79
1150	?	4.799553	?	121.46

PNNL Glass 1

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-6.454877277	1.43078068
B	13955.979894	3567.35447
C	-125.5193544	158.757186

Graph of Fulcher Fit

Glass 1 Measured by PNNL

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1186	67.98	4.186201	4.219214	65.77
1138	98.01	4.590446	4.58507	98.54
1088	156.05	5.045541	5.050176	155.33
1137	98.38	4.599195	4.588838	99.40
1187	66.42	4.178093	4.195998	65.24
1235	44.58	3.802955	3.797285	44.83
1283	31.21	3.453386	3.440739	31.61
1187	64.76	4.178093	4.170688	65.24
1039	243.78	5.529449	5.496266	252.01
990	434.83	6.055869	6.074955	426.61
1150	?	4.486532	?	88.81

PNNL Glass 3

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.806614893	0.76767238
B	10310.952765	1640.15538
C	49.452807306	84.5435612

Graph of Fulcher Fit

Glass 3 Measured by PNNL

Temp (Deg C)	Measured Visc. (Poise)	In Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1184	73.32	4.281551	4.294833	72.35
1136	107.22	4.683035	4.674883	108.10
1087	170.23	5.131201	5.13715	169.22
1135	107.59	4.691777	4.678328	109.05
1184	72.96	4.281551	4.289911	72.35
1233	50.2	3.905292	3.916015	49.66
1281	34.75	3.565742	3.54818	35.37
1184	73.05	4.281551	4.291144	72.35
1037	273.81	5.634357	5.612434	279.88
989	483.45	6.16777	6.180948	477.12
1150	?	4.562318	?	95.81

PNNL Glass 5

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-4.194028723	0.46612412
B	9166.6082047	935.617028
C	113.63583061	50.9315169

Graph of Fulcher Fit

Glass 5 Measured by PNNL

Temp (Deg C)	Measured Visc. (Poise)	In Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1184	80.23	4.36998	4.384898	79.04
1136	117.17	4.77206	4.763626	118.16
1087	185.34	5.223421	5.222192	185.57
1135	117.91	4.780839	4.769922	119.20
1184	79.5	4.36998	4.375757	79.04
1233	54.35	3.995092	3.995445	54.33
1282	38.14	3.651649	3.641264	38.54
1184	79.96	4.36998	4.381527	79.04
1038	303.13	5.722635	5.714162	305.71
989	536.24	6.277737	6.284582	532.58
1150	?	4.65094	?	104.68

CELS HM

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-2.483958723	0.11834895
B	6343.3354217	133.842921
C	268.78934915	5.59577481

Graph of Fulcher Fit

HM Measured by CELS

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1136.1	123.2	4.82984	4.813809	125.19
1115.2	146.6	5.010436	4.987708	149.97
1075	216.2	5.384128	5.376204	217.92
1029.3	349.9	5.856931	5.857647	349.65
984.8	601.2	6.375317	6.398928	587.17
940.3	1096	6.962407	6.999422	1056.17
899.3	1993	7.576673	7.597396	1952.12
859.3	3863	8.25816	8.259199	3858.99
809.9	10310	9.238848	9.24087	10289.18
762.2	31360	10.37214	10.35329	31956.75
713.6	125900	11.7768	11.74324	130195.9
669	622900	13.36603	13.34214	637961.2
643.2	1975000	14.45823	14.49608	1901643
1150	?	4.714474	?	111.55

CELS Glass 2

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-2.753492044	0.05972876
B	5804.0133568	62.611818
C	304.83858554	2.63956508

Graph of Fulcher Fit

Glass 2 Measured by CELS

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1131.5	71.7	4.267536	4.272491	71.35
1115	80.79	4.410529	4.391853	82.31
1071.5	122.8	4.817012	4.810557	123.60
1028.4	196	5.26796	5.278115	194.02
982.7	331	5.80875	5.802118	333.20
935.7	646.5	6.446648	6.471573	630.59
893.2	1244	7.111216	7.126087	1225.64
851.1	2590	7.871482	7.859413	2621.45
809.5	6336	8.747315	8.754003	6293.76
766.2	18060	9.826696	9.801455	18521.66
723.2	67880	11.11971	11.1255	67488.48
679.8	335000	12.72547	12.72189	336202.7
640.5	2070000	14.53778	14.54306	2059104
1150	?	4.113851	?	61.18

CELS Glass 4

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-2.662146769	0.11906161
B	6132.528355	128.209885
C	297.45020649	5.28653656

Graph of Fulcher Fit

Glass 4 Measured by CELS

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1137.7	103.7	4.636312	4.641502	103.16
1115.6	122.8	4.833459	4.810557	125.64
1074.4	182.1	5.230935	5.204556	186.97
1030.1	296.3	5.708194	5.691372	301.33
985.2	531.6	6.254655	6.275891	520.43
943	975.9	6.837552	6.88336	932.20
898.8	1955	7.535792	7.578145	1873.93
858.3	3906	8.272204	8.270269	3913.56
823.2	8076	9.002201	8.996652	8120.94
781	21910	10.02016	9.994698	22475.10
737.2	78140	11.28335	11.26626	79486.92
690.2	411600	12.95219	12.92781	421760.2
647.6	2893000	14.85187	14.8778	2818928
1150	?	4.531015	?	92.85

Sharp-Schurtz (SS) HM

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-2.801823619	0.36173537
B	6904.78796	575.945501
C	234.43663463	32.7818745

Graph of Fulcher Fit

HM Measured by SS

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1192.53	81.33	4.404977	4.398515	81.86
1136.36	128.57	4.853802	4.856474	128.23
1079.07	218.56	5.37307	5.387061	215.52
1021.47	389.61	5.97136	5.965146	392.04
960.08	816.11	6.713578	6.704549	823.51
901.78	1900.55	7.544856	7.549899	1890.99
1150	?	4.739749	?	114.41

Sharp-Schurtz (SS) Batch 1

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-3.032985109	0.28107546
B	6242.3592243	459.435771
C	235.02116276	29.5718562

Graph of Fulcher Fit

Batch 1 Measured by SS

Temp (Deg C)	Measured Visc. (Poise)	In Visc (Fulcher, Poise)	Measured ln Visc. (Poise)	Predicted Visc. (poise)
1264.72	20.85	3.02933	3.037354	20.68
1207.85	29.4	3.383724	3.380995	29.48
1153.8	42.85	3.761206	3.757706	43.00
1094.46	67.25	4.230312	4.208417	68.74
1050.26	103.01	4.624107	4.634826	101.91
999.91	171.95	5.128147	5.147204	168.70
945.56	312.32	5.752403	5.744028	314.95
892.53	638.85	6.46097	6.45967	639.68
1150	?	3.789423	?	44.23

Sharp-Schurtz (SS)

Purex

JMP® Nonlinear Regression

Parameter	Estimate	ApproxStdErr
A	-3.158433857	0.02522208
B	5390.4148385	35.2858111
C	274.39604438	2.24902056

Graph of Fulcher Fit

Purex Measured by SS

Temp (Deg C)	Measured Visc. (Poise)	ln Visc (Fulcher, Poise)	Measured lnVisc. (Poise)	Predicted Visc. (poise)
1155.32	19.33	2.960613	2.961658	19.31
1097.62	29.61	3.389499	3.388112	29.65
1051.16	43.85	3.781145	3.780775	43.87
998.24	72.85	4.288496	4.288403	72.86
946.17	129.97	4.865716	4.867304	129.76
893	258.42	5.555404	5.554586	258.63
838	605.34	6.405755	6.40579	605.32
1150	?	2.997791	?	20.04

Target & Measured Compositions and Predicted & Average Measured Viscosities at 1150 °C

SRTC																Predicted				
Glass ID	Target Compositions as Weight Fractions															Visc.	SRTC	CELS	PNNL	SS
	Al2O3	B2O3	CaO	Cr2O3	CuO	Fe2O3	K2O	Li2O	MgO	MnO	Na2O	NiO	SiO2	TiO2	U3O8	Poise				
Glass 1	0.0623	0.0850	0.0148	0.0010	0.0003	0.1291	0.0000	0.0342	0.0219	0.0159	0.1097	0.0022	0.5040	0.0010	0.0160	82.51	87.9		88.8	
Glass 2	0.0623	0.0850	0.0230	0.0013	0.0009	0.1291	0.0000	0.0342	0.0280	0.0185	0.1097	0.0020	0.5040	0.0020	0.0000	82.51	65.6	61.2		
Glass 3	0.0605	0.0865	0.0139	0.0009	0.0003	0.1115	0.0000	0.0355	0.0209	0.0143	0.1096	0.0020	0.5177	0.0020	0.0160	92.884	102.5		95.8	
Glass 4	0.0664	0.0853	0.0178	0.0010	0.0003	0.1115	0.0000	0.0333	0.0275	0.0188	0.1095	0.0020	0.5257	0.0010	0.0000	108.895	102.4	92.6		
Glass 5	0.0664	0.0853	0.0140	0.0010	0.0003	0.1115	0.0000	0.0333	0.0200	0.0150	0.1095	0.0020	0.5257	0.0010	0.0150	108.895	108.4		104.7	
Batch 1	0.0488	0.0777	0.0122	0.0011	0.0040	0.1284	0.0327	0.0443	0.0142	0.0173	0.0900	0.0075	0.5022	0.0067	0.0000	56.167	48.6			44.2
HM	0.0715	0.0703	0.0101	0.0009	0.0025	0.0778	0.0221	0.0462	0.0149	0.0176	0.0856	0.0041	0.5579	0.0056	0.0000	137.244	121.7	111.5	121.5	114.4
Purex	0.0299	0.1033	0.0109	0.0015	0.0042	0.1325	0.0341	0.0322	0.0141	0.0169	0.1262	0.0119	0.4654	0.0068	0.0000	24.832	22.5			20
Uranium Std	0.0410	0.0921	0.0130	0.0030	0.0000	0.1320	0.0300	0.0306	0.0121	0.0289	0.1180	0.0112	0.4535	0.0105	0.0241	33.2	32.2			

SRTC																Predicted				
Glass ID	Measured Compositions as Weight Fractions															Visc.	SRTC	CELS	PNNL	SS
	Al2O3	B2O3	CaO	Cr2O3	CuO	Fe2O3	K2O	Li2O	MgO	MnO	Na2O	NiO	SiO2	TiO2	U3O8	Poise				
Glass 1	0.0683	0.0892	0.0174	0.0008	0.0003	0.1320	0.0000	0.0343	0.0207	0.0160	0.1190	0.0022	0.4820	0.0014	0.0131	63.14	87.9		88.8	
Glass 2	0.0648	0.0864	0.0232	0.0012	0.0009	0.1160	0.0000	0.0290	0.0241	0.0158	0.1060	0.0019	0.4790	0.0022	0.0000	94.003	65.6	61.2		
Glass 3	0.0651	0.0880	0.0158	0.0007	0.0004	0.1030	0.0000	0.0373	0.0195	0.0139	0.1140	0.0019	0.5050	0.0022	0.0146	82.875	102.5		95.8	
Glass 4	0.0685	0.0896	0.0195	0.0010	0.0003	0.0988	0.0000	0.0275	0.0242	0.0153	0.1130	0.0020	0.5120	0.0133	0.0000	119.752	102.4	92.6		
Glass 5	0.0665	0.0867	0.0144	0.0008	0.0003	0.1010	0.0000	0.0343	0.0177	0.0143	0.1120	0.0019	0.5000	0.0012	0.0143	92.654	108.4		104.7	

D.WPF Distribution

M. N. Brosee, 704-S
R. E. Edwards, 704-25S
H. H. Elder, 704-S
D. C. Iverson, 704-30S
W. D. Kerley, 704-S
J. E. Occhipinti, 704-27S
J. F. Ortaldo, 704-S
J. W. Ray, 704-35S

SRTC Distribution

D. F. Bickford, 773-43A
K. G. Brown, 704-1T
A. D. Cozzi, 773-43A
D. A. Crowley, 773-43A
T. B. Edwards, 773-42A
C. R. Goetzman, 773-A
J. R. Harbour, 773-43A
E. W. Holtzscheiter, 773-A
C. M. Jantzen, 773-A
J. C. Marra, 773-43A
S. L. Marra, 704-T
L. M. Papouchado, 773-A
D. K. Peeler, 773-43A
R. F. Schumacher, 773-43A
M. E. Smith, 773-43A
R. H. Spires, 773-A
R. C. Tuckfield, 773-42A
J. R. Workman, 773-A