WTP Calculation Sheet: Determining the LAW Glass Former Constituents and Amounts for G2 and AcM Models. 24590-LAW-M4C-LFP-00002, Rev. B

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

**P.O. Box 450
Richland, Washington 99352**

WTP Calculation Sheet: Determining the LAW Glass Former Constituents and Amounts for G2 and Acm Models. 24590-LAW-M4C-LFP-00002, Rev. B

R. Gimpel
Bechtel National, Inc.

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Sheet 1 of 1

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Sheet i

RIVER PROTECTION PROJECT-WASTE TREATMENT PLANT				JOB NO.: 24590			
CALC NO. 24590-LAW-M4C-LFP-00002				GROUP Process Technology			
SUBJECT Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models							
CALCULATION STATUS		☒ PRELIMINARY		☐ COMMITTED PRELIMINARY		☐ CONFIRMED	
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<p>Notes/Comments</p> <p>The purpose of this calculation is to determine the LAW glass former recipe and additives with their respective amounts. The methodology and equations contained herein are to be used in the G2 and ACM models until better information is supplied by R&T efforts.</p> <p>This revision includes calculations that determines the mass and volume of the bulk chemicals/minerals needed per batch. Plus, it contains calculations (for the G2 model) to help prevent overflow in LAW Feed Preparation Vessel.</p>							
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SHEET NO.: 1

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1 Purpose

The purpose of this calculation is to determine the LAW glass former recipe and additives with their respective amounts. The methodology and equations contained herein are to be used the G2 and ACM models until better information is supplied by R&T efforts.

Revision B contains calculations to make adjustments to input streams and glass former addition amounts to control batch volumes around the LAW Melter Feed Prep Vessel’s control volume (or set point) and prevent overflow. These calculation are presented towards the end of the document and are highlighted. The calculations presented in Revision A remain the same. Calculations to determine the amounts of minerals to be added, for the glass formers, is included for tank sizing. Extra supporting documentation and text corrections for Revision A calculations are also included.

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2 Criteria and Design Inputs

Some of the preferred recipes for LAW glasses, as developed and tested at The Vitreous State Laboratory (VSL) at The Catholic University in Washington D.C., are given in **Attachment 1**, which is attached. **Attachment 1** is an excerpted **Table 3.1** from Document No. **24590-LAW-TP- RT-01-010, LAW Glass Formulation to Support Actual Waste Testing Test Plan, Rev. 0**. These glasses meet all contract requirements and are considered the best formulations thus far. (The inputs needed in **Section 5.9** are described in that Section.)

3 Assumptions

Not Applicable

4 Methodology

With casual comparison of the glass recipes makeup it appeared that the compositions of the recipes follow trends with respect to the sulfate concentration in the glasses. The glass recipes were incorporated into a spreadsheet to determine how closely the recipes followed trends and if they could be modeled. The glass constituents concentrations did follow sulfate concentration. This was investigated by summing up all the glass recipes and finding the average glass composition. Then the difference between each individual glass recipe from the average was plotted. A copy of the plot is shown in **Attachment 3 LAW Glass Oxides vs. SO_3 – Differences from Average Glass Composition**. The plot showed trends for each of the constituents in the glass that could be modeled with reasonable accuracy with respect to sulfate concentration in the glass. Using these relationships to determine the glass recipe and glass former amounts are described as follows.

5 Calculation

5.1 Graphic Presentation of the Glass Recipe Trends

This section (Section 5.1) was written only to produce a plot, in **Attachment 3**, that shows correlation of the glass chemistry with respect to the concentration of sulfate in the glass. The equations developed in the following sections are the ones intended to be used in the models (e.g., G2 and ACM). These equations require less manipulation in the computer.

The LAW glass formulations appear to follow trends that can be modeled with respect to the sulfate concentration in the glass. Sodium happens to be main constituent in the waste, and thus, a main constituent in the glass. Sodium's concentration increases inversely proportional to the sulfate concentration. Later sections use this fact, along with the limiting waste loading characteristic of sulfur, to determine how much glass is made.

The glass formulations for all the envelopes in **Attachment 1** are incorporated into **Columns a through h** in **Attachment 2's** spreadsheet entitled **Variability in LAW Glass Recipes Determination Spreadsheet**. The spreadsheet software used was Microsoft Excel 97 on a Compaq™ Personal Computer. All the calculations are based on wt% (or 100 parts of glass). The average of these glass formulation was calculated as shown in **Column j**. Sample calculations will be done for CaO to show how the spreadsheet calculations functioned.

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Equation 1 shows the math to perform the average calculation for CaO; however, the “average function” was used in the *Excel 97* Spreadsheet to give the same results.

$$\text{CaO average concentration} = (1.994 + 1.991 + 5.065 + 5.117 + 6.409 + 6.746 + 6.746) / 7 = 4.85 \text{ wt\%} \quad \text{Equation 1}$$

(units = wt%)

Then the amount each glass recipe varied, by constituent, from the average glass composition (in **Column j**) was calculated (by the spreadsheet) by subtracting the data in **Columns b** through **h** from the average in **Column j**. Results are shown in **Columns k** through **q**.

The CaO variation calculation is shown here as an example (units are in wt%):

Equation 2

$$\begin{aligned} \text{Column k} &= 1.994 - 4.85 = -2.86 \text{ wt\%} \\ \text{Column l} &= 1.991 - 4.85 = -2.86 \text{ wt\%} \\ \text{Column m} &= 5.065 - 4.85 = 0.22 \text{ wt\%} \\ \text{Column n} &= 5.117 - 4.85 = 0.27 \text{ wt\%} \\ \text{Column o} &= 6.409 - 4.85 = 1.56 \text{ wt\%} \\ \text{Column p} &= 6.746 - 4.85 = 1.90 \text{ wt\%} \\ \text{Column q} &= 6.627 - 4.85 = 1.78 \text{ wt\%} \end{aligned}$$

Those individual constituents that appeared not to follow the trend are shown in underlined in **Columns k** through **q** of **Attachment 2**. These will be called “outliers”. The outlier in **Column k** was left unchanged. The outliers in **Columns m** through **q** were replaced by the average the adjacent values to allow a better fit. The outlier in **Column q** was set to the same value in **Column p**. The outliers were modified to visually show a better curve fit. Modifying the outliers can be justified because other VSL glass recipes can be found (I. S. Muller February 23, 2001) that approximate the adjusted values that are not presented in **Table 3.1** in **Attachment 1**.

The values (wt% of oxides in the glass) in **Columns k** through **q** were plotted with respect to the SO₃ concentration in the glass. It can be seen that the glass constituents follow a linear trend as a function of SO₃ content in the glass. The equations for determining the glass recipe and glass former amounts, using the trends shown in this section, are presented in **Section 5.3**. The outliers were not modified in the equations given in **Sections 5.3**.

5.2 Validation of use of *Microsoft Excel 97* Software for Linear Regression

Curve fitting the data, using summation and linear regression, is considered the most taxing function performed by *Microsoft Excel 97* in this Engineering Calculation. **Attachment 7** shows linear curve fitting of fictitious data using *Microsoft Excel 97* and a *Hewlett Packard 32SII* handheld calculator. Both gave the same results. The curve fitting function used called a *Trendline* function in *Microsoft Excel 97*. Equations used in the *Trendline* function is given in **Attachment 8**.

5.3 Determining Glass Recipe Based on SO₃ Concentration in the Glass

As stated above, the glass formulations for all the envelopes in **Attachment 1** are incorporated into **Columns a** through **h** in **Attachment 2**'s spreadsheet entitled *Variability in LAW Glass Recipes Determination Spreadsheet*.

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These constituents were plotted with respect to SO₃ concentration in the glass. Linear regression was performed (using *Microsoft Excel 97's Trendline* function) for each constituent in the glass and the line that best fits each constituent's data was placed on a plot shown in **Attachment 4**. Also, the **linear equation**, which is the result of linear regression, for the each line was placed on the chart. R² values as calculated by the *Microsoft Excel 97's Trendline* function are also included on the chart. For example, the **linear equation** for Na₂O is:

$$\begin{array}{lll} \text{Na}_2\text{O} = -20.321 \cdot \text{SO}_3 + 22.3690 & (\text{units wt}\%) & \text{Equation 3} \\ R^2 = 0.9405 & (\text{unitless}) & \end{array}$$

From the linear equations one can calculate a LAW glass formulation with respect to sulfate concentration in the glass. This was done in the bottom half of spreadsheet in **Attachment 2**. In the spreadsheet, the constituent is listed in **Column a**. The slope and intercept for the linear equations (taken from **Attachment 4**) are given in **Columns b** and **c**. Then using these linear equations the glass composition for SO₃ concentrations 0.10 to 1.00 wt% were calculated in **Columns e** through **n**. The glass constituents in the glass recipes summed up to nearly 100 wt%, showing good correlation. Plus, the concentration of the constituents appear to be between bounds of the acceptable glasses made at VSL (**Table 3.1, Attachment 1**) as shown in the plots in **Attachment 4**.

5.4 "Formula Displayed" Copies of Spreadsheets

"Formula displayed" copies of the spreadsheets used in the Engineering Calculation are attached behind the "standard/numerical" displayed spreadsheets. These show the formulas, numbers, and logic used in the spreadsheets.

5.5 Determining Glass Recipe Based on Sulfur Concentration in the Glass

A second spreadsheet and figure are presented in **Attachments 5** and **6**. These take the same values in the previous spreadsheet and plots (**Attachments 2**, bottom half and **Attachment 4**) and convert the constituents as oxides to elemental concentrations. Thus, the figure is called **LAW Glass Elements vs. Sulfur**. A sample oxide-to-elemental calculation follows for CaO in **Column d**:

$$\begin{aligned} \text{CaO (elemental concentration)} &= [40.08 (\text{Column c}) / 56.08 (\text{Column b})] \cdot 1.994 (\text{Attachment 3, Column b}) \\ &= 1.425 \text{ wt}\% \end{aligned}$$

One may notice that the constituents in the glass (see **Attachment 5**) do not add up to near 100 wt%. This is because oxygen has been left out. Oxygen needs to be accounted and added as a constituent in the glass. This is done by performing a mass balance for oxygen. The amount oxygen needed is that to fully oxidize the cations in the column. This was done in **Attachment 5** (second page of attachment).

5.6 Application of Glass Composition Model

The above model determines the ratios of the component in wt% (or 100 parts glass). The following adapts the model to be used in the G2 and ACM models. For example, how much glass will be made if the LAW Concentrate

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contains 120 kg SO₄ and 500 kg Na₂O equivalents? Also, what are the components amounts in the glass? The following derives the equations where these values can be determined.

Let: M_{glass} = mass of glass
 M_{Na2O} = Na₂O mass in the LAW Concentrate
 M_{SO4} = SO₄ mass in the LAW Concentrate
 M_{SO3} = SO₃ mass in the glass
 C_{Na2O} = Na₂O fraction in the glass or the wt% Na₂O/100, which is (Equation 3)/100, or
 = $(-20.321 C_{\text{SO3}} + 22.369)/100$ **Equation 4**
 C_{SO3} = SO₃ fraction in the glass or equal to the wt% SO₃(as shown in Attachment 4)/100

The amounts M_{Na2O} and M_{SO4} should be known when the process is running. However, as an the example of using the derived equations that follow, lets assign:

M_{Na2O} = 500 kg Na₂O
 M_{SO4} = 120 kg SO₄

5.6.1 Determine the amount of sulfate that will be retained in the glass

Not all of the sulfate in the LAW Concentrate will be captured by the glass. Some of the sulfate will be lost to the Offgas Treatment System at the melter(s). **Equation 5** determines the amount sulfate that goes into the glass. Also, sulfate is normally tracked in the glass or glass recipes as SO₃. Whereas, sulfate is tracked in the model as SO₄. **Equation 5** makes this adjustment for sulfate.

$$M_{\text{SO3}} = \left(1 - \frac{1}{DF_{\text{sulfate}}}\right) \left(80.06/96.06\right) M_{\text{SO4}} \quad \text{Equation 5}$$

Where: DF_{sulfate} is the decontamination factor of sulfate (or sulfur) in the melter.

For example, let $DF_{\text{sulfate}} = 5$, then 20 wt% of the sulfate is lost to the Offgas Treatment System and 80 wt% is retained in the glass. A DF of 5 for sulfate is a reasonable value at this time per VSL studies (Pegg et al. 2000)

M_{SO4} is the sulfate mass in the LAW Concentrate.

M_{SO3} is the sulfate retained in the glass.

80.06/96.06 is the molar mass ratio of SO₃ to SO₄

For the example, M_{SG} is calculated as follows:

$$M_{\text{SO3}} = \left(1 - \frac{1}{5}\right) \left(80.06/96.06\right) 120\text{kg} = 80\text{kg}$$

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5.6.2 Determination of Amount of Glass Produced

The amount of glass is equal to the following relationships:

$$M_{\text{glass}} = M_{\text{SO}_3}/C_{\text{SO}_3}, \text{ and also}$$

Equation 6

$$M_{\text{glass}} = M_{\text{Na}_2\text{O}}/C_{\text{Na}_2\text{O}}$$

Equation 7

Therefore, $M_{\text{SO}_3}/C_{\text{SO}_3} = M_{\text{Na}_2\text{O}}/C_{\text{Na}_2\text{O}}$

Equation 8

We know that from **Equation 4** that $C_{\text{Na}_2\text{O}} = (-20.321C_{\text{SO}_3} + 22.369)/100$ (units mass fraction) and this relationship can be substituted into **Equation 8**.

$$\frac{M_{\text{SO}_3}}{C_{\text{SO}_3}} = \frac{M_{\text{Na}_2\text{O}}}{\frac{-20.321C_{\text{SO}_3} + 22.369}{100}} \quad (\text{units mass and mass fraction}) \quad \text{Equation 9}$$

Solving for C_{SO_3} in Equation 9 yields the following:

$$C_{\text{SO}_3} = \frac{0.22369}{\frac{M_{\text{Na}_2\text{O}}}{M_{\text{SO}_3}} + 20.321} = \frac{0.22369}{\frac{500\text{kg}}{80\text{kg}} + 20.321} = 0.008419 \text{ or } 0.8419 \text{ wt\%} \quad \text{Equation 10}$$

$$M_{\text{glass}} = M_{\text{SO}_3}/C_{\text{SO}_3} = 80 \text{ kg}/0.008419 = 9502 \text{ kg of glass made} \quad \text{Equation 11}$$

$$\text{Therefore, } C_{\text{Na}_2\text{O}} = M_{\text{Na}_2\text{O}}/M_{\text{glass}} = 500 \text{ kg}/9502 = 0.0526 \text{ or } 5.26 \text{ wt\% Na}_2\text{O in the glass} \quad \text{Equation 12}$$

5.7 Glass Former Additive Calculations

Using the linear equations (given in **Attachment 4**) the glass composition can be determined. For example, lets calculate the value for CaO. From **Attachment 2** the linear equation for CaO is:

$$\text{CaO} = 6.2767\text{SO}_3 + 2.0110 \quad (\text{units wt\%}) \quad \text{Equation 13}$$

From **Equation 10**, $\text{SO}_3 = 0.8419 \text{ wt\%}$. Therefore,

$$\text{CaO} = 6.2767*0.8419 + 2.0110 = 7.30 \text{ wt\%} \quad (\text{units wt\%}) \quad \text{Equation 14}$$

All the calculated values for the constituents in this Example are shown in **Column p** of **Attachment 2**. Some of the glass former constituents may already be in the LAW Concentrate. Therefore, to determine the correct amount of glass former additive for a constituent, the amount in the LAW Concentrate must be subtracted from the amount calculated for making the glass. The Example calculation will be continued with calculating the amount of CaO glass former additive needed.

$$M_{\text{CaO}} = M_{\text{glass}} * C_{\text{CaO}} = M_{\text{glass}} * \text{CaO}/100 = 9502 \text{ kg} * 7.30 \text{ wt\%}/100 \text{ wt\%} = 695 \text{ kg} \quad \text{Equation 15}$$

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$$A_{CaO} = M_{CaO} - CaO \text{ in the concentrate} = 695 \text{ kg} - 5 \text{ kg} = 690 \text{ kg CaO as glass former additive} \quad \text{Equation 16}$$

Also note that the glass formers are not added as pure oxides and some adjustments need to be made. For example, B_2O_3 is added as H_3BO_3 and Li_2O is added as Li_2CO_3 . The mass amounts of each is as follows:

$$A_{H_3BO_3} = 1.776 A_{B_2O_3} \quad (\text{Example, } 1908 \text{ kg}) \quad \text{Equation 17}$$

$$A_{Li_2CO_3} = 2.473 A_{Li_2O} \quad (\text{Example, } 1286 \text{ kg}) \quad \text{Equation 18}$$

Therefore, the extra mass that accompanies the glass former addition and extra gases lost to the Offgas Treatment System are as follows:

$$A_{H_2O} = A_{H_3BO_3} - A_{B_2O_3} \quad (\text{Example, } 1908 - 1075 = 388 \text{ kg}) \quad \text{Equation 19}$$

$$A_{CO_2} = A_{Li_2CO_3} - A_{Li_2O} \quad (\text{Example, } 1286 - 520 = 766 \text{ kg}) \quad \text{Equation 20}$$

5.8 Adjusting Flow to Match the Melter Feed Preparation Vessel's Control Volume (G2 Model Only)

This section applies on to the G2 model because it tracks batches and the Aspen Model does not at this time. The amounts calculated for the batch in the LAW Melter Feed Preparation Vessel are only preliminary since the batch size may be larger than the control volume (set point). Good utilization of the tank is not possible if the batch size is far off from the set point. The following calculations adjust flow into the tank and the amount of glass formers to match the tank's control volume.

Sum all the glass formers amounts presently determined (via Equations 15, 16, 18, and 17) for addition to the tank per **Equation 21**.

$$A_A = A_{CaO} + A_{SiO_2} + A_{H_3BO_3} + A_{Fe_2O_3} + A_{Li_2CO_3} + A_{ZrO_2} + A_{TiO_2} + A_{Al_2O_3} + A_{ZnO} + A_{MgO} \quad (\text{units kg}) \quad \text{Equation 21}$$

To simplify the example calculation let's assume none of the glass former constituents exist in the feed. Therefore, $A_i = M_i$. For example $A_{CaO} = M_{CaO} = 694 \text{ kg}$.

$$A_A = 695 + 4631 + 1908 + 495 + 1286 + 301 + 53 + 577 + 301 + 263 = 10,510 \text{ kg} \quad (\text{units kg})$$

Calculate the Glass Former to Evaporator Concentration fraction:

$$X_{Gf} = A_A / V_{EC} \quad \text{Equation 22}$$

where: X_{Gf} is the mass of glass formers added per unit volume of Evaporator Concentrate to the vessel, kg/L

V_{EC} is the volume of Evaporator Concentrate to the Feed Preparation Vessel, liters (for example, let $V_{EC} = 6000 \text{ L}$)

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Calculate the volume the glass formers occupy in the slurry within the tank:

$$V_{GF} = (0.4099 X_{Gf} - 0.0307) V_{EC} \text{ (units in liters)} \quad \text{Equation 23}$$

Equation 23 comes from a linear curve fit of a graphical plot of data from recent LAW pilot runs at Duratek in Columbia, MD. The data (Table 24) and linear regression performed on data in Table 24, using the same method as described in **Section 5.1**, is given in **Attachment 9**.

Continuing with the example:

$$X_{Gf} = 10,510/6000 = 1.752$$

$$V_{GF} = (0.4099 \times 1.752 - 0.0307) 6000 = 4125 \text{ L}$$

Determine the batch volume before adjustments are made:

$$V_{Batch} = V_{EC} + V_{GF} \quad \text{Equation 24}$$

Condition: If $V_{Batch} > (V_{cv} - V_H)$, proceed with the following where V_{cv} is the LAW Melter Feed Preparation Vessel's control volume (setpoint). If the condition is not met, no adjustment of the batch is necessary, proceed directly to **Section 5.9**.

Calculate the coefficient to adjust the batch to the set point.

$$k_{cv} = (V_{cv} - V_H) / V_{batch\ i} \quad \text{Equation 25}$$

where: k_{cv} is the batch adjustment coefficient
 V_H is the tank's head volume

For the example, let's say that $V_{cv} = 10,000 \text{ L}$ and $V_H = 2,000 \text{ L}$, then

$$B_{Batch} = 5670 \text{ L} + 4125 \text{ L} = 9795 \text{ L}$$

B_{Batch} of 9,795 L is $> (V_{cv} - V_H)$ which is $(10,000 \text{ L} - 2,000 \text{ L})$ or 8,000 L; therefore,

$$k_{cv} = (10,000 \text{ L} - 2,000 \text{ L}) / 9,750 \text{ L} = 0.8205$$

Adjust the amount of Evaporator Concentrates to be sent to the LAW Melter Feed Preparation Vessel per the following equation:

$$V_{EC} = k_{cv} V_{pEC} \text{ and} \quad \text{Equation 26}$$

$$M_{EC} = k_{cv} M_{pEC} \quad \text{Equation 27}$$

where: V_{pEV} and M_{pEC} are the preliminary (or previously) calculated Evaporator Concentrates volume and mass calculated.

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V_{EC} and M_{EC} are the actual Evaporator Concentrates volume and mass to be sent to the LAW Melter Feed Preparation Vessel.

For the example, $V_{EC} = 0.8205(5670 \text{ L}) = 4652 \text{ L}$.

Adjust the mass of each of the glass formers added per the following equation:

$$M_{GFi} = k_{cv} A_{pGFi}$$

Equation 28

where: A_{pGFi} is the preliminary calculated mass for glass former "i"

M_{GFi} is the actual mass of glass former "i" to add to the LAW Melter Feed Preparation Vessel.

"i" is CaO, SiO₂, H₃BO₃, Fe₂O₃, Li₂CO₃, ZrO₂, TiO₂, Al₂O₃, ZnO, and MgO

For CaO in the example, $M_{CaOi} = 0.8205(695 \text{ kg}) = 570 \text{ kg}$

5.9 Calculating Glass Former Amounts as Added Minerals

The model thus far calculated the glass formers as their oxides; however, in reality some glass formers are not added as oxides, they are added as carbonates and silicates. **Table 1** below lists the oxides, as presently tracked in G2, with the corresponding minerals in the flowsheet (Reynolds, 2002 & Johnson, 2001).

Table 1
Glass Former Molecular Weights

<u>Glass Oxide</u>	<u>Glass Oxide Molecular Weight (MW)</u>	<u>Corresponding Glass Former</u>	<u>Glass Former Molecular Weight (MW)</u>
B ₂ O ₃	69.62	H ₃ BO ₃	61.84
CaO	56.08	CaOSiO ₂	116.17
Al ₂ O ₃	101.96	Al ₂ O ₃ SiO ₂	162.05
Fe ₂ O ₃	159.96	Fe ₂ O ₃	159.69
Li ₂ O	29.88	Li ₂ CO ₃	73.89
ZrO ₂	123.22	ZrO ₂ SiO ₂	183.31
ZnO	81.37	ZnO	81.37
MgO	40.31	MgOSiO ₂	100.40
TiO ₂	79.90	TiO ₂	79.90
SiO ₂	60.09	SiO ₂	60.09

The mass of each added glass former, as the oxide in the glass, is calculated in the G2 Model.

CALCULATION SHEET

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Calculate the mass of each glass former which must be added to achieve the corresponding oxide mass in the glass using molecular weights from the table above as follows:

- $A_{H_3BO_3}$ (Previously calculated)
- $A_{CaOSiO_2} = A_{CaO} * (MW_{CaOSiO_2} / MW_{CaO})$
- $A_{Al_2O_3SiO_2} = A_{Al_2O_3} * (MW_{Al_2O_3SiO_2} / MW_{Al_2O_3})$
- $A_{Li_2CO_3}$ (Previously calculated)
- $A_{ZrO_2SiO_2} = A_{ZrO_2} * (MW_{ZrO_2SiO_2} / MW_{ZrO_2})$
- $A_{MgOSiO_2} = A_{MgO} * (MW_{MgOSiO_2} / MW_{MgO})$

The glass former mass of Fe_2O_3 ($A_{Fe_2O_3}$), ZnO (A_{ZnO}) and TiO_2 (A_{TiO_2}), which must be added to achieve the corresponding oxide mass in the glass, is the same as the mass in the glass since these components are already oxides.

The mass of SiO_2 (A_{SiO_2-GF}) which must be added as a glass former is calculated by subtracting from A_{SiO_2} the mass contributions of SiO_2 from $CaOSiO_2$, $Al_2O_3SiO_2$, ZrO_2SiO_2 , and $MgOSiO_2$.

First calculate the mass of SiO_2 associated with $CaOSiO_2$, $Al_2O_3SiO_2$, ZrO_2SiO_2 , and $MgOSiO_2$:

- $MSiO_2-CaO = A_{CaOSiO_2} * (MW_{SiO_2} / MW_{CaOSiO_2})$
- $MSiO_2-Al_2O_3 = A_{Al_2O_3SiO_2} * (MW_{SiO_2} / MW_{Al_2O_3SiO_2})$
- $MSiO_2-ZrO_2 = A_{ZrO_2SiO_2} * (MW_{SiO_2} / MW_{ZrO_2SiO_2})$
- $MSiO_2-MgO = A_{MgOSiO_2} * (MW_{SiO_2} / MW_{MgOSiO_2})$

Then subtract the contributions from M_{SiO_2} , the total mass of SiO_2 needed to obtain the mass of SiO_2 added as a glass former:

- $A_{SiO_2-GF} = A_{SiO_2} - (MSiO_2-CaO + MSiO_2-Al_2O_3 + MSiO_2-ZrO_2 + MSiO_2-MgO)$
Where: A_{SiO_2-GF} is the mass of SiO_2 added as a glass former.

Determine the bulk volume of each glass former mineral by dividing each mineral's mass by its corresponding density taken from **Table 2**. Densities come from Johnson (2001). Note that the density values may need to be converted depending on units used in the model.

Table 2
Bulk Density of Minerals used for Glass Formers

<u>Glass Former/ Mineral</u>	<u>Common Name</u>	<u>Bulk Density, kg/m³</u>
H_3BO_3	Boric acid	910
$CaOSiO_2$	Wollastonite, calcium silicate	730
$Al_2O_3SiO_2$	Kyanite, aluminum silicate	1050
Fe_2O_3	Ferric oxide	2150
Li_2CO_3	Lithium carbonate	920
ZrO_2SiO_2	Zircon sand, zirconium silicate	1650
ZnO	Zinc oxide	660
$MgOSiO_2$	Olivine, magnesium Silicate	1550
TiO_2	Rutile, Titanium dioxide	650
SiO_2	Sand, silica, silicon dioxide	920

CALCULATION SHEET

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SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

6 Conclusions

The LAW glass formulations, developed by VSL, follow a trend that can be plotted and glass constituents and their concentrations can be calculated. This was incorporated into the model presented in this paper. This model then can be used to calculate glass former amounts needed in the G2 and ACM models.

7 References

I. S. Muller and I. L. Pegg, Vitreous State Laboratory (VSL) Report Document No. 24590-LAW-TP- RT-01-010, *LAW Glass Formulation to Support Actual Waste Testing Test Plan, Rev. 0*, Vitreous State Laboratory, The Catholic University of America, Washington D.C.

I. S. Muller, Andrew C. Buechele and I. L. Pegg, February 23, 2001, Vitreous State Laboratory (VSL) report Document No. VSL-01R3560-2, *Glass Formulation and Testing with RPP-WTP LAW Simulants*, Vitreous State Laboratory, The Catholic University of America, Washington D.C.

Pegg, I. L. et al., 2000. *Interim Report: Summary of Preliminary Results on Enhanced Sulfate Incorporation During Vitrification of LAW Feeds*. VSL-00R3630-1. Vitreous State Laboratory, Catholic University of America, Washington, D.C.

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Johnson, P., 2001, *LAW Blended Glass Former Average Densities*, CALC-W375LV-PR00055, Rev. 1. Bechtel National, Inc., Richland, Washington.

Reynolds, J. R., 2002, *Calculation of Oxide Density of Some Glass Former Batches for LAW*, 24590-LAW-M4C-LFP-00003, Rev. B, Bechtel National, Inc., Richland, Washington.

8 Attachments

The attachments addressed in this document follow.

CALCULATION SHEET

PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.:24590-LAW-M4C-LFP-00002

SHEET REV: B

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SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Attachment 1

Excerpt from:

I. S. Muller and I. L. Pegg, Vitreous State Laboratory (VSL) report Document No. 24590-LAW-TP-RT-01-010, *LAW Glass Formulation to Support Actual Waste Testing Test Plan, Rev. 0*, Vitreous State Laboratory, The Catholic University of America, Washington D.C.

(One page)

CALCULATION SHEET

PROJECT: RPP-WTP

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SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Table 3.1
Glass Compositions Selected in Part B1.

GLASS	LAWA44	LAWA88	LAWA102	LAWB45	LAWB53	LAWC21	LAWC22
Tank ID (based on case 3S6E)	AN-105 SY-101 AN-103	AP-101 AW-101	AN-104 AW-104	AZ-102	AZ-101	AN-102	AN-107
Typical waste Loading	26%	26%	18%	9%	6%	14%	16%
Al ₂ O ₃	6.201	6.080	6.054	6.129	6.099	6.125	6.080
B ₂ O ₃	8.902	9.698	9.995	12.340	10.026	10.088	10.068
BaO	0.000	0.000	0.001	0.000	0.000	0.000	0.000
CaO	1.994	1.991	5.065	6.627	6.746	6.409	5.117
Cl	0.652	0.329	0.333	0.006	0.005	0.124	0.090
Cr ₂ O ₃	0.020	0.009	0.018	0.073	0.113	0.020	0.021
Cs ₂ O	0.001	0.001	0.001	0.002	0.000	0.000	0.001
F	0.010	0.000	0.025	0.081	0.063	0.060	0.162
Fe ₂ O ₃	6.981	5.531	5.407	5.256	5.341	6.477	5.431
K ₂ O	0.501	2.583	0.260	0.262	0.227	0.151	0.095
Li ₂ O	0.000	0.000	2.499	4.616	5.856	2.733	2.505
MgO	1.994	1.475	1.494	2.971	2.998	1.509	1.513
MnO ₂	0.000	0.000	0.000	0.000	0.000	0.004	0.037
MoO ₃	0.000	0.000	0.000	0.000	0.005	0.000	0.000
Na ₂ O	20.000	20.000	14.478	6.500	5.000	11.871	14.400
NiO	0.000	0.000	0.000	0.000	0.000	0.000	0.030
PbO	0.001	0.000	0.000	0.000	0.000	0.000	0.021
P ₂ O ₅	0.034	0.070	0.133	0.030	0.013	0.118	0.174
SiO ₂	44.553	43.991	46.569	47.859	48.924	46.727	46.667
SO ₃	0.095	0.214	0.441	0.844	0.807	0.424	0.341
SrO	0.0000	0.0000	0.000	0.000	0.000	0.000	0.000
TiO ₂	1.994	1.991	1.143	0.000	1.405	1.121	1.143
UO ₂	0.000	0.000	0.000	0.000	0.000	0.000	0.004
ZnO	2.965	2.950	3.062	3.153	3.186	3.018	3.069
ZrO ₂	2.992	2.987	3.022	3.153	3.186	3.021	3.027
SUM	100.000	100.000	100.000	100.000	100.000	100.000	100.000

CALCULATION SHEET

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SHEET REV: B
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BY: Rod Gimpel
DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Attachment 2 Variability in LAW Glass Recipes Determination Spreadsheet -- Elements as Oxides

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q
	GLASS	LAW A44	LAW A88	LAW A102	LAW C22	LAW C21	LAW B53	LAW B45	LAW AZ-102	Average Glass Formula	LAW A44	LAW A88	LAW A102	LAW C22	LAW C21	LAW B53	LAW B45
Tank ID	AN-105	AN-101	AN-101	AN-104	AN-107	AN-102	AZ-101	AZ-102	AZ-102		AN-105	AP-101	AN-104	AN-107	AN-102	AZ-101	AZ-102
(based on SY-101 case AN-103 3S6E)																	
Typical Waste Loading	26%	26%	26%	18%	16%	14%	6%	9%	16.43%	9.57%	9.57%	9.57%	1.57%	-0.43%	-2.43%	-10.43%	-7.43%
SO3	0.095	0.214	0.441	0.441	0.341	0.424	0.807	0.844	SO3	0.45	-0.36	-0.24	-0.01	-0.02	-0.03	0.35	0.39
Al2O3	6.201	6.08	6.054	6.054	6.08	6.125	6.099	6.129	Al2O3	6.11	0.09	-0.03	-0.06	-0.03	0.02	-0.01	0.02
B2O3	8.902	9.698	9.995	9.995	10.068	10.088	10.026	12.34	B2O3	10.16	-1.26	-0.46	-0.16	-0.09	-0.07	-0.13	-0.13
CaO	1.994	1.991	5.065	5.065	5.117	6.409	6.746	6.627	CaO	4.85	-2.86	-2.86	0.22	0.27	1.56	1.90	1.78
Fe2O3	6.981	5.531	5.407	5.407	5.431	6.477	5.341	5.256	Fe2O3	5.77	1.21	-0.24	-0.37	-0.34	-0.43	-0.43	-0.52
Li2O	0	0	2.499	2.499	2.505	2.733	5.856	4.616	Li2O	2.60	-2.60	-2.60	-0.10	-0.10	0.13	3.25	2.01
MgO	1.994	1.475	1.494	1.494	1.513	1.509	2.998	2.971	MgO	1.99	0.00	-0.52	-0.50	-0.48	-0.48	1.00	0.98
Na2O	20	20	14.478	14.478	14.4	11.871	5	6.5	Na2O	13.18	6.82	6.82	1.30	1.22	-1.31	-8.18	-6.68
SiO2	44.553	43.991	46.569	46.569	46.667	46.727	48.924	47.859	SiO2	46.47	-1.92	-2.48	0.10	0.20	0.26	2.45	1.39
TiO2	1.994	1.991	1.143	1.143	1.143	1.121	1.405	0	TiO2	1.26	0.74	0.73	-0.11	-0.11	-0.14	-0.70	-1.26
ZnO	2.965	2.95	3.062	3.062	3.069	3.018	3.186	3.153	ZnO	3.06	-0.09	-0.11	0.00	0.01	-0.04	0.13	0.10
ZrO2	2.992	2.987	3.022	3.022	3.027	3.021	3.186	3.153	ZrO2	3.06	-0.06	-0.07	-0.03	-0.03	-0.03	0.13	0.10
Totals	98.671	96.908	99.229	99.229	99.361	99.523	99.574	99.448	Totals	98.96	-0.28	-2.05	0.27	0.49	-0.57	-0.23	-1.82

	Slope a	Intercept b	SO3 =	Glass Compositions per the Linear Equations at Left																	Example	
	"na - x-axis"			0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	0.8419	0.8419							
SO3	-0.0909	6.1417		6.13	6.12	6.11	6.11	6.10	6.09	6.08	6.07	6.06	6.05	6.07	6.07							
Al2O3	2.8932	8.8510		9.14	9.43	9.72	10.01	10.30	10.59	10.88	11.17	11.45	11.74	11.29	11.29							
B2O3	6.2767	2.0110		2.64	3.27	3.89	4.52	5.15	5.78	6.40	7.03	7.66	8.29	7.30	7.30							
CaO	-1.4830	6.4456		6.30	6.15	6.00	5.85	5.70	5.56	5.41	5.26	5.11	4.96	5.20	5.20							
Fe2O3	7.3397	-0.7183		0.02	0.75	1.48	2.22	2.95	3.69	4.42	5.15	5.89	6.62	5.46	5.46							
Li2O	1.9610	1.1065		1.30	1.50	1.69	1.89	2.09	2.28	2.48	2.68	2.87	3.07	2.76	2.76							
MgO	-20.3210	22.3690		20.34	18.30	16.27	14.24	12.21	10.18	8.14	6.11	4.08	2.05	5.26	5.26							
Na2O	5.5762	43.9480		44.51	45.06	45.62	46.18	46.74	47.29	47.85	48.41	48.97	49.52	48.64	48.70							
SiO2	-1.8035	2.0724		1.89	1.71	1.53	1.35	1.17	0.99	0.81	0.63	0.45	0.27	0.55	0.55							
TiO2	0.2684	2.9340		2.96	2.99	3.01	3.04	3.07	3.10	3.12	3.15	3.18	3.20	3.16	3.16							
ZnO	0.2684	2.9340		2.96	2.99	3.01	3.04	3.07	3.10	3.12	3.15	3.18	3.20	3.16	3.16							
ZrO2																						
Others			Sum =	98.28	98.47	98.66	98.85	99.04	99.23	99.41	99.60	99.79	99.98	99.68	100.00							

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SHEET REV: B

SHEET NO.: 15

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DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Attachment 2 (Continued)**Variability in LAW Glass Recipes Determination Spreadsheet -- Elements as Oxides
Formula Displayed Spreadsheet Format****Spreadsheet's Sheet Name: GF as Oxides**
(Four pages)

CALCULATION SHEET

PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.: 24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 16

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	A	B	C	D
1				
2	a	b	c	d
3	GLASS	Mol. Wt.	Mol. Wt.	LAWA44
	Tank ID (based on case 3S6E)	as Oxide	as Element	AN-105 SY-101 AN-103
4				
	Typical Waste Loading			
5				0.26
6	S	80.06	32.06	=\$C\$6/\$B\$6*GF as Oxide DiflB7
7	Al	101.96	26.982	=2*\$C\$7/\$B\$7*GF as Oxide DiflB8
8	B	69.62	10.81	=2*\$C\$8/\$B\$8*GF as Oxide DiflB9
9	Ca	56.08	40.078	=\$C\$9/\$B\$9*GF as Oxide DiflB10
10	Fe	159.69	55.847	=2*\$C\$10/\$B\$10*GF as Oxide DiflB11
11	Li	29.88	6.941	=2*\$C\$11/\$B\$11*GF as Oxide DiflB12
12	Mg	40.31	24.305	=\$C\$12/\$B\$12*GF as Oxide DiflB13
13	Na	61.98	22.99	=2*\$C\$13/\$B\$13*GF as Oxide DiflB14
14	Si	60.08	28.086	=\$C\$14/\$B\$14*GF as Oxide DiflB15
15	Ti	79.9	47.9	=\$C\$15/\$B\$15*GF as Oxide DiflB16
16	Zn	81.37	65.37	=\$C\$16/\$B\$16*GF as Oxide DiflB17
17	Zr	123.22	91.22	=\$C\$17/\$B\$17*GF as Oxide DiflB18
18	Cation Totals			=SUM(D6:D17)
19	O. oxygen balance			=D54
20	Totals			=D18+D19
21				
22		Slope a	Intercept b	
23	S	"na -- x-axis"		SO3 =
24	Al	-0.506	3.2428	
25	B	2.2437	2.7486	
26	Ca	11.202	1.4372	
27	Fe	-2.5903	4.05083	
28	Li	8.5153	-0.3337	
29	Mg	2.9526	0.6672	
30	Na	-37.646	16.595	
31	Si	6.509	20.545	
32	Ti	-2.7	1.2424	
33	Zn	0.5949	2.3486	
34	Zr	0.4961	2.1721	
35	O. oxygen balance			
36	Minors			
37	Totals			

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	L	M	N	O	P	Q	R
1	Termination Spreadsheet -- Elements as Oxides						
2							
3							
4	LAWA88	LAWA102	LAWB45	LAWB53	LAWC21	LAWC22	
	AN-101 AW-101	AN-104 AW-104	AZ-102	AZ-101	AN-102	AN-107	Average Glass Formula
5							
6	=C6-\$J6	=D6-\$J6	=H6-\$J6	=G6-\$J6	=F6-\$J6	=E6-\$J6	0.164285714285714
7	=C7-\$J7	=D7-\$J7	=H7-\$J7	=G7-\$J7	=F7-\$J7	=E7-\$J7	0.452285714285714
8	=C8-\$J8	=D8-\$J8	=H8-\$J8	=G8-\$J8	=F8-\$J8	=E8-\$J8	6.10971428571429
9	=C9-\$J9	=D9-\$J9	=H9-\$J9	=G9-\$J9	=F9-\$J9	=E9-\$J9	10.1595714285714
10	=C10-\$J10	=D10-\$J10	=H10-\$J10	=G10-\$J10	=F10-\$J10	=E10-\$J10	4.84985714285714
11	=C11-\$J11	=D11-\$J11	=H11-\$J11	=G11-\$J11	=F11-\$J11	=E11-\$J11	5.77485714285714
12	=C12-\$J12	=D12-\$J12	=H12-\$J12	=G12-\$J12	=F12-\$J12	=E12-\$J12	2.60128571428571
13	=C13-\$J13	=D13-\$J13	=H13-\$J13	=G13-\$J13	=F13-\$J13	=E13-\$J13	1.99342857142857
14	=C14-\$J14	=D14-\$J14	=H14-\$J14	=G14-\$J14	=F14-\$J14	=E14-\$J14	13.1784285714286
15	=C15-\$J15	=D15-\$J15	=H15-\$J15	=G15-\$J15	=F15-\$J15	=E15-\$J15	46.47
16	=C16-\$J16	=D16-\$J16	=H16-\$J16	=G16-\$J16	=F16-\$J16	=E16-\$J16	1.25671428571429
17	=C17-\$J17	=D17-\$J17	=H17-\$J17	=G17-\$J17	=F17-\$J17	=E17-\$J17	3.05757142857143
18	=C18-\$J18	=D18-\$J18	=H18-\$J18	=G18-\$J18	=F18-\$J18	=E18-\$J18	3.05542857142857
19	=SUM(L8:L18)	=SUM(M8:M18)	=SUM(N8:N18)	=SUM(O8:O18)	=SUM(P8:P18)	=SUM(Q8:Q18)	99.9554285714286
20							
21							
22							
23	=L23*\$B\$24+\$C\$24	=M23*\$B\$24+\$C\$24	=N23*\$B\$24+\$C\$24	=O23*\$B\$24+\$C\$24	=P23*\$B\$24+\$C\$24	=Q23*\$B\$24+\$C\$24	=R23*\$B\$24+\$C\$24
24	=L23*\$B\$25+\$C\$25	=M23*\$B\$25+\$C\$25	=N23*\$B\$25+\$C\$25	=O23*\$B\$25+\$C\$25	=P23*\$B\$25+\$C\$25	=Q23*\$B\$25+\$C\$25	=R23*\$B\$25+\$C\$25
25	=L23*\$B\$26+\$C\$26	=M23*\$B\$26+\$C\$26	=N23*\$B\$26+\$C\$26	=O23*\$B\$26+\$C\$26	=P23*\$B\$26+\$C\$26	=Q23*\$B\$26+\$C\$26	=R23*\$B\$26+\$C\$26
26	=L23*\$B\$27+\$C\$27	=M23*\$B\$27+\$C\$27	=N23*\$B\$27+\$C\$27	=O23*\$B\$27+\$C\$27	=P23*\$B\$27+\$C\$27	=Q23*\$B\$27+\$C\$27	=R23*\$B\$27+\$C\$27
27	=L23*\$B\$28+\$C\$28	=M23*\$B\$28+\$C\$28	=N23*\$B\$28+\$C\$28	=O23*\$B\$28+\$C\$28	=P23*\$B\$28+\$C\$28	=Q23*\$B\$28+\$C\$28	=R23*\$B\$28+\$C\$28
28	=L23*\$B\$29+\$C\$29	=M23*\$B\$29+\$C\$29	=N23*\$B\$29+\$C\$29	=O23*\$B\$29+\$C\$29	=P23*\$B\$29+\$C\$29	=Q23*\$B\$29+\$C\$29	=R23*\$B\$29+\$C\$29
29	=L23*\$B\$30+\$C\$30	=M23*\$B\$30+\$C\$30	=N23*\$B\$30+\$C\$30	=O23*\$B\$30+\$C\$30	=P23*\$B\$30+\$C\$30	=Q23*\$B\$30+\$C\$30	=R23*\$B\$30+\$C\$30
30	=L23*\$B\$31+\$C\$31	=M23*\$B\$31+\$C\$31	=N23*\$B\$31+\$C\$31	=O23*\$B\$31+\$C\$31	=P23*\$B\$31+\$C\$31	=Q23*\$B\$31+\$C\$31	=R23*\$B\$31+\$C\$31
31	=L23*\$B\$32+\$C\$32	=M23*\$B\$32+\$C\$32	=N23*\$B\$32+\$C\$32	=O23*\$B\$32+\$C\$32	=P23*\$B\$32+\$C\$32	=Q23*\$B\$32+\$C\$32	=R23*\$B\$32+\$C\$32
32	=L23*\$B\$33+\$C\$33	=M23*\$B\$33+\$C\$33	=N23*\$B\$33+\$C\$33	=O23*\$B\$33+\$C\$33	=P23*\$B\$33+\$C\$33	=Q23*\$B\$33+\$C\$33	=R23*\$B\$33+\$C\$33
33	=L23*\$B\$34+\$C\$34	=M23*\$B\$34+\$C\$34	=N23*\$B\$34+\$C\$34	=O23*\$B\$34+\$C\$34	=P23*\$B\$34+\$C\$34	=Q23*\$B\$34+\$C\$34	=R23*\$B\$34+\$C\$34
34	=L23*\$B\$35+\$C\$35	=M23*\$B\$35+\$C\$35	=N23*\$B\$35+\$C\$35	=O23*\$B\$35+\$C\$35	=P23*\$B\$35+\$C\$35	=Q23*\$B\$35+\$C\$35	=R23*\$B\$35+\$C\$35
35							
36	=SUM(L23:L34)	=SUM(M23:M34)	=SUM(N23:N34)	=SUM(O23:O34)	=SUM(P23:P34)	=SUM(Q23:Q34)	=SUM(R23:R34)

CALCULATION SHEET

PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.: 24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 20

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Attachment 3

Law Glass Oxide vs. SO_3 – Differences from Average Glass Composition Plot

(One Page)

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

CALCULATION SHEETPROJECT: RPP-WTPJOB NO.: 24590CALC NO.: 24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 22

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Attachment 4**Law Glass Oxides vs. SO_3 Plot**

(11 pages)

Page 1	Combined Plot
Page 2	SiO_2 Plot
Page 3	Na_2O Plot
Page 4	B_2O_3 Plot
Page 5	CaO Plot
Page 6	Al_2O_3 Plot
Page 7	Fe_2O_3 Plot
Page 8	Li_2O Plot
Page 9	ZrO_2 & ZnO Plot
Page 10	MgO Plot
Page 11	TiO_2 Plot

CALCULATION SHEET

ORP-56511, Rev. B

PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.: 24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 23

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

CALCULATION SHEETPROJECT: RPP-WTPJOB NO.: 24590CALC NO.: 24590-LAW-M4C-LFP-00002SHEET REV: BSHEET NO.: 26

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

CALCULATION SHEET

BY: Rod Gimpe

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

CALCULATION SHEET

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DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

CALCULATION SHEET

PROJECT: RPP-WTP
 JOB NO.: 24590
 CALC NO.: 24590-LAW-M4C-LFP-00002
 SHEET REV: B
 SHEET NO.: 35

BY: Rod Gimpel
 DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Attachment 5 (Continued)

Variability in LAW Glass Recipes Determination Spreadsheet – Element Concentrations

Oxygen Balance		a	b	c	d	e	f	j	g	h	i	k	l	m	n	o	p	q	r	s
S	0.057	0.128	0.264	0.204	0.506	0.484	0.284	0.060	0.120	0.180	0.240	0.299	0.359	0.419	0.479	0.539				
Al	2.919	2.862	2.850	2.862	2.885	2.871	2.883	2.866	2.848	2.830	2.812	2.794	2.776	2.758	2.740	2.704				
B	6.138	6.686	6.891	6.941	8.508	6.912	6.955	6.302	6.501	6.700	6.899	7.099	7.298	7.497	7.696	8.095				
Ca	0.569	0.568	1.445	1.460	1.891	1.925	1.829	0.753	0.932	1.111	1.289	1.468	1.647	1.826	2.005	2.363				
Fe	2.098	1.662	1.625	1.632	1.580	1.605	1.947	1.696	1.652	1.607	1.563	1.518	1.474	1.429	1.384	1.295				
Li	0.000	0.000	1.338	1.341	2.471	3.135	1.463	0.008	0.400	0.793	1.186	1.578	1.971	2.363	2.756	3.541				
Mg	0.792	0.586	0.593	0.601	1.180	1.190	0.599	0.517	0.595	0.673	0.750	0.828	0.906	0.984	1.062	1.217				
Na	5.163	5.163	3.737	3.717	1.678	1.291	3.064	5.251	4.727	4.203	3.679	3.155	2.631	2.107	1.583	0.535				
Si	23.726	23.426	24.799	24.851	25.486	26.053	24.883	23.700	23.997	24.293	24.590	24.887	25.183	25.480	25.776	26.370				
Ti	0.799	0.797	0.458	0.458	0.000	0.563	0.449	0.758	0.686	0.614	0.541	0.469	0.397	0.325	0.253	0.108				
Zn	0.583	0.580	0.602	0.603	0.620	0.626	0.593	0.581	0.586	0.592	0.598	0.604	0.610	0.616	0.621	0.633				
Zr	0.777	0.776	0.785	0.786	0.819	0.827	0.785	0.769	0.776	0.783	0.790	0.797	0.804	0.811	0.819	0.832				
Total O, oxygen	43.619	43.235	45.388	45.458	47.624	47.484	45.705	43.260	43.819	44.378	44.937	45.496	46.055	46.614	47.173	48.292				

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Attachment 5 (Continued)

Variability in LAW Glass Recipes Determination Spreadsheet -- Elemental Concentrations Formula Displayed Spreadsheet Format

**Spreadsheet's Sheet Name: GF as Elements
(13 Pages)**

CALCULATION SHEET

 ORP-56511 Rev. B
 PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.: 24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 37

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

A		B	C	D
	a	b	c	d
1				
2	GLASS			LAWA44
3	Tank ID (based on case 3S6E)			AN-105 SY-101 AN-103
4				
5	Typical Waste Loading			0.26
6	S	80.06	32.06	=C\$6/\$B\$6*GF as Oxide DiflB7
7	Al	101.96	26.982	=2*C\$7/\$B\$7*GF as Oxide DiflB8
8	B	69.62	10.81	=2*C\$8/\$B\$8*GF as Oxide DiflB9
9	Ca	56.08	40.078	=C\$9/\$B\$9*GF as Oxide DiflB10
10	Fe	159.69	55.847	=2*C\$10/\$B\$10*GF as Oxide DiflB11
11	Li	29.88	6.941	=2*C\$11/\$B\$11*GF as Oxide DiflB12
12	Mg	40.31	24.305	=C\$12/\$B\$12*GF as Oxide DiflB13
13	Na	61.98	22.99	=2*C\$13/\$B\$13*GF as Oxide DiflB14
14	Si	60.08	28.086	=C\$14/\$B\$14*GF as Oxide DiflB15
15	Ti	79.9	47.9	=C\$15/\$B\$15*GF as Oxide DiflB16
16	Zn	81.37	65.37	=C\$16/\$B\$16*GF as Oxide DiflB17
17	Zr	123.22	91.22	=C\$17/\$B\$17*GF as Oxide DiflB18
18	Cation Totals			=SUM(D6:D17)
19	O, oxygen balance			=D54
20	Totals			=D18+D19
21				
22		Slope a	Intercept b	SO3 =
23	S	"na -- x-axis"		
24	Al	-0.506	3.2428	
25	B	2.2437	2.7486	
26	Ca	11.202	1.4372	
27	Fe	-2.5903	4.05083	
28	Li	8.5153	-0.3337	
29	Mg	2.9526	0.6672	
30	Na	-37.646	16.595	
31	Si	6.509	20.545	
32	Ti	-2.7	1.2424	
33	Zn	0.5949	2.3486	
34	Zr	0.4961	2.1721	
35	O, oxygen balance			
36	Minors			Totals
37				
38				
39				
40				

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	E	F	G
1			
2			
3	LAWA88	LAWA102	LAWC22
	AP-101 AW-101	AN-104 AW-104	AN-107
4			
5	0.26	0.18	0.16
6	=C\$6/\$B\$6*GF as Oxide DifI'C7	=C\$6/\$B\$6*GF as Oxide DifI'D7	=C\$6/\$B\$6*GF as Oxide DifI'H7
7	=2*\$C\$7/\$B\$7*GF as Oxide DifI'C8	=2*\$C\$7/\$B\$7*GF as Oxide DifI'D8	=2*\$C\$7/\$B\$7*GF as Oxide DifI'H8
8	=2*\$C\$8/\$B\$8*GF as Oxide DifI'C9	=2*\$C\$8/\$B\$8*GF as Oxide DifI'D9	=2*\$C\$8/\$B\$8*GF as Oxide DifI'H9
9	=C\$9/\$B\$9*GF as Oxide DifI'C10	=C\$9/\$B\$9*GF as Oxide DifI'D10	=C\$9/\$B\$9*GF as Oxide DifI'H10
10	=2*\$C\$10/\$B\$10*GF as Oxide DifI'C11	=2*\$C\$10/\$B\$10*GF as Oxide DifI'D11	=2*\$C\$10/\$B\$10*GF as Oxide DifI'H11
11	=2*\$C\$11/\$B\$11*GF as Oxide DifI'C12	=2*\$C\$11/\$B\$11*GF as Oxide DifI'D12	=2*\$C\$11/\$B\$11*GF as Oxide DifI'H12
12	=C\$12/\$B\$12*GF as Oxide DifI'C13	=C\$12/\$B\$12*GF as Oxide DifI'D13	=C\$12/\$B\$12*GF as Oxide DifI'H13
13	=2*\$C\$13/\$B\$13*GF as Oxide DifI'C14	=2*\$C\$13/\$B\$13*GF as Oxide DifI'D14	=2*\$C\$13/\$B\$13*GF as Oxide DifI'H14
14	=C\$14/\$B\$14*GF as Oxide DifI'C15	=C\$14/\$B\$14*GF as Oxide DifI'D15	=C\$14/\$B\$14*GF as Oxide DifI'H15
15	=C\$15/\$B\$15*GF as Oxide DifI'C16	=C\$15/\$B\$15*GF as Oxide DifI'D16	=C\$15/\$B\$15*GF as Oxide DifI'H16
16	=C\$16/\$B\$16*GF as Oxide DifI'C17	=C\$16/\$B\$16*GF as Oxide DifI'D17	=C\$16/\$B\$16*GF as Oxide DifI'H17
17	=C\$17/\$B\$17*GF as Oxide DifI'C18	=C\$17/\$B\$17*GF as Oxide DifI'D18	=C\$17/\$B\$17*GF as Oxide DifI'H18
18	=SUM(E6:E17)	=SUM(F6:F17)	=SUM(G6:G17)
19	=E54	=F54	=G54
20	=E18+E19	=F18+F19	=G18+G19
21			
22			
23	0.04	0.08	0.12
24	=B24*E\$23+C24	=B24*F\$23+C24	=B24*G\$23+C24
25	=B25*E\$23+C25	=B25*F\$23+C25	=B25*G\$23+C25
26	=B26*E\$23+C26	=B26*F\$23+C26	=B26*G\$23+C26
27	=B27*E\$23+C27	=B27*F\$23+C27	=B27*G\$23+C27
28	=B28*E\$23+C28	=B28*F\$23+C28	=B28*G\$23+C28
29	=B29*E\$23+C29	=B29*F\$23+C29	=B29*G\$23+C29
30	=B30*E\$23+C30	=B30*F\$23+C30	=B30*G\$23+C30
31	=B31*E\$23+C31	=B31*F\$23+C31	=B31*G\$23+C31
32	=B32*E\$23+C32	=B32*F\$23+C32	=B32*G\$23+C32
33	=B33*E\$23+C33	=B33*F\$23+C33	=B33*G\$23+C33
34	=B34*E\$23+C34	=B34*F\$23+C34	=B34*G\$23+C34
35	=K54	=L54	=U54
36			
37	=SUM(E23:E35)	=SUM(F23:F35)	=SUM(G23:G35)
38			
39			
40			

Glass Compositions at the Following Sulfate Concentrations

CALCULATION SHEET

 ORP-56511 Rev. B
 PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.: 24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 39

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

H				I	J	Variability in LAW Glass R	
g				h	i	k	k
1	LAWB45			LAWB53		LAWC21	
2	AZ-102			AZ-101		AN-102	
3							
4							
5	0.09			0.06		0.14	
6	=C\$6/\$B\$6**GF as Oxide DifI'E7			=C\$6/\$B\$6**GF as Oxide DifI'E7		=C\$6/\$B\$6**GF as Oxide DifI'E7	S
7	=2*C\$7/\$B\$7**GF as Oxide DifI'E8			=2*C\$7/\$B\$7**GF as Oxide DifI'E8		=2*C\$7/\$B\$7**GF as Oxide DifI'E8	Al
8	=2*C\$8/\$B\$8**GF as Oxide DifI'E9			=2*C\$8/\$B\$8**GF as Oxide DifI'E9		=2*C\$8/\$B\$8**GF as Oxide DifI'E9	B
9	=2*C\$9/\$B\$9**GF as Oxide DifI'E10			=2*C\$9/\$B\$9**GF as Oxide DifI'E10		=2*C\$9/\$B\$9**GF as Oxide DifI'E10	Ca
10	=2*C\$10/\$B\$10**GF as Oxide DifI'E11			=2*C\$10/\$B\$10**GF as Oxide DifI'E11		=2*C\$10/\$B\$10**GF as Oxide DifI'E11	Fe
11	=2*C\$11/\$B\$11**GF as Oxide DifI'E12			=2*C\$11/\$B\$11**GF as Oxide DifI'E12		=2*C\$11/\$B\$11**GF as Oxide DifI'E12	Li
12	=2*C\$12/\$B\$12**GF as Oxide DifI'E13			=2*C\$12/\$B\$12**GF as Oxide DifI'E13		=2*C\$12/\$B\$12**GF as Oxide DifI'E13	Mg
13	=2*C\$13/\$B\$13**GF as Oxide DifI'E14			=2*C\$13/\$B\$13**GF as Oxide DifI'E14		=2*C\$13/\$B\$13**GF as Oxide DifI'E14	Na
14	=2*C\$14/\$B\$14**GF as Oxide DifI'E15			=2*C\$14/\$B\$14**GF as Oxide DifI'E15		=2*C\$14/\$B\$14**GF as Oxide DifI'E15	Si
15	=2*C\$15/\$B\$15**GF as Oxide DifI'E16			=2*C\$15/\$B\$15**GF as Oxide DifI'E16		=2*C\$15/\$B\$15**GF as Oxide DifI'E16	Ti
16	=2*C\$16/\$B\$16**GF as Oxide DifI'E17			=2*C\$16/\$B\$16**GF as Oxide DifI'E17		=2*C\$16/\$B\$16**GF as Oxide DifI'E17	Zn
17	=2*C\$17/\$B\$17**GF as Oxide DifI'E18			=2*C\$17/\$B\$17**GF as Oxide DifI'E18		=2*C\$17/\$B\$17**GF as Oxide DifI'E18	Zr
18	=SUM(H6:H17)			=SUM(I6:I17)		=SUM(J7:J17)	Totals
19	=H54			=I54		=J54	
20	=H18+H19			=I18+I19		=J18+J19	
21							
22							
23	0.16			0.2		0.24	0.28
24	=B\$24*H\$23+C\$24			=B\$24*H\$23+C\$24		=B\$24*H\$23+C\$24	=B\$24*H\$23+C\$24
25	=B\$25*H\$23+C\$25			=B\$25*H\$23+C\$25		=B\$25*H\$23+C\$25	=B\$25*H\$23+C\$25
26	=B\$26*H\$23+C\$26			=B\$26*H\$23+C\$26		=B\$26*H\$23+C\$26	=B\$26*H\$23+C\$26
27	=B\$27*H\$23+C\$27			=B\$27*H\$23+C\$27		=B\$27*H\$23+C\$27	=B\$27*H\$23+C\$27
28	=B\$28*H\$23+C\$28			=B\$28*H\$23+C\$28		=B\$28*H\$23+C\$28	=B\$28*H\$23+C\$28
29	=B\$29*H\$23+C\$29			=B\$29*H\$23+C\$29		=B\$29*H\$23+C\$29	=B\$29*H\$23+C\$29
30	=B\$30*H\$23+C\$30			=B\$30*H\$23+C\$30		=B\$30*H\$23+C\$30	=B\$30*H\$23+C\$30
31	=B\$31*H\$23+C\$31			=B\$31*H\$23+C\$31		=B\$31*H\$23+C\$31	=B\$31*H\$23+C\$31
32	=B\$32*H\$23+C\$32			=B\$32*H\$23+C\$32		=B\$32*H\$23+C\$32	=B\$32*H\$23+C\$32
33	=B\$33*H\$23+C\$33			=B\$33*H\$23+C\$33		=B\$33*H\$23+C\$33	=B\$33*H\$23+C\$33
34	=B\$34*H\$23+C\$34			=B\$34*H\$23+C\$34		=B\$34*H\$23+C\$34	=B\$34*H\$23+C\$34
35	=V54			=W54		=X54	=Y54
36							
37	=SUM(H23:H35)			=SUM(I23:I35)		=SUM(J23:J35)	=SUM(K23:K35)
38							
39							
40							

CALCULATION SHEET

 ORP-56511, Rev. B
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JOB NO.: 24590

CALC NO.:24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 40

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	L	M	N	O	P	Q	R	S
1	ecipes Determination Spreadsheet -- Elements as Elemental							
2	I							
3	Average Glass Formula							
4								
5	=AVERAGE(D5:J5)							
6	=AVERAGE(D6:J6)							
7	=AVERAGE(D7:J7)							
8	=AVERAGE(D8:J8)							
9	=AVERAGE(D9:J9)							
10	=AVERAGE(D10:J10)							
11	=AVERAGE(D11:J11)							
12	=AVERAGE(D12:J12)							
13	=AVERAGE(D13:J13)							
14	=AVERAGE(D14:J14)							
15	=AVERAGE(D15:J15)							
16	=AVERAGE(D16:J16)							
17	=AVERAGE(D17:J17)							
18	=SUM(L6:L17)							
19								
20								
21								
22								
23	0.32							
24	=B24*L23+\$C24							
25	=B25*L23+\$C25							
26	=B26*L23+\$C26							
27	=B27*L23+\$C27							
28	=B28*L23+\$C28							
29	=B29*L23+\$C29							
30	=B30*L23+\$C30							
31	=B31*L23+\$C31							
32	=B32*L23+\$C32							
33	=B33*L23+\$C33							
34	=B34*L23+\$C34							
35	=Z54							
36								
37	=SUM(L23:L35)							
38								
39								
40								

CALCULATION SHEET

 ORP-56511, Rev. B
 PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.: 24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 41

BY: Rod Gimpei

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

T	U	V	W
1			
2			
3	LAWA44 AN-105 SY-101 AN-103	LAWA88 AP-101 AW-101	LAWA102 AN-104 AW-104
4	Average Glass Formula		
5	0.164285714285714	0.0957142857142857	0.0157142857142857
6	0.452285714285714	=C\$6/\$B\$6*GF as Oxide Dif'I'7	=C\$6/\$B\$6*GF as Oxide Dif'I'7
7	6.10971428571429	=2*C\$7/\$B\$7*GF as Oxide Dif'I'8	=2*C\$7/\$B\$7*GF as Oxide Dif'I'8
8	10.1595714285714	=2*C\$8/\$B\$8*GF as Oxide Dif'I'9	=2*C\$8/\$B\$8*GF as Oxide Dif'I'9
9	4.84985714285714	=C\$9/\$B\$9*GF as Oxide Dif'I'10	=C\$9/\$B\$9*GF as Oxide Dif'I'10
10	5.77485714285714	=2*C\$10/\$B\$10*GF as Oxide Dif'I'11	=2*C\$10/\$B\$10*GF as Oxide Dif'I'11
11	2.60128571428571	=2*C\$11/\$B\$11*GF as Oxide Dif'I'12	=2*C\$11/\$B\$11*GF as Oxide Dif'I'12
12	1.99342857142857	=C\$12/\$B\$12*GF as Oxide Dif'I'13	=C\$12/\$B\$12*GF as Oxide Dif'I'13
13	13.1784285714286	=2*C\$13/\$B\$13*GF as Oxide Dif'I'14	=2*C\$13/\$B\$13*GF as Oxide Dif'I'14
14	46.47	=C\$14/\$B\$14*GF as Oxide Dif'I'15	=C\$14/\$B\$14*GF as Oxide Dif'I'15
15	1.25671428571429	=C\$15/\$B\$15*GF as Oxide Dif'I'16	=C\$15/\$B\$15*GF as Oxide Dif'I'16
16	3.05757142857143	=C\$16/\$B\$16*GF as Oxide Dif'I'17	=C\$16/\$B\$16*GF as Oxide Dif'I'17
17	3.05542857142857	=C\$17/\$B\$17*GF as Oxide Dif'I'18	=C\$17/\$B\$17*GF as Oxide Dif'I'18
18	99.9554285714286	=SUM(U6:U17)	=SUM(W6:W17)
19			
20			
21			
22			
23	0.4	0.44	
24	=B24*U23+C24	=B24*V23+C24	
25	=B25*U23+C25	=B25*V23+C25	
26	=B26*U23+C26	=B26*V23+C26	
27	=B27*U23+C27	=B27*V23+C27	
28	=B28*U23+C28	=B28*V23+C28	
29	=B29*U23+C29	=B29*V23+C29	
30	=B30*U23+C30	=B30*V23+C30	
31	=B31*U23+C31	=B31*V23+C31	
32	=B32*U23+C32	=B32*V23+C32	
33	=B33*U23+C33	=B33*V23+C33	
34	=B34*U23+C34	=B34*V23+C34	
35	=AA54	=AB54	
36			
37	=SUM(U23:U35)	=SUM(V23:V35)	
38			
39			
40			

CALCULATION SHEET

 ORP-56511, Rev. B
 PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.: 24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 42

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	X	Y	Z
1			
2			
3	LAWC22 AN-107	LAWC21 AN-102	LAWB53 AZ-101
4			
5	-0.00428571428571428	-0.0242857142857143	-0.104285714285714
6	=C\$6/\$B\$6**GF as Oxide Dif'I V7	=C\$6/\$B\$6**GF as Oxide Dif'I W7	=C\$6/\$B\$6**GF as Oxide Dif'I X7
7	=2*C\$7/\$B\$7**GF as Oxide Dif'I V8	=2*C\$7/\$B\$7**GF as Oxide Dif'I W8	=2*C\$7/\$B\$7**GF as Oxide Dif'I X8
8	=2*C\$8/\$B\$8**GF as Oxide Dif'I V9	=2*C\$8/\$B\$8**GF as Oxide Dif'I W9	=2*C\$8/\$B\$8**GF as Oxide Dif'I X9
9	=C\$9/\$B\$9**GF as Oxide Dif'I V10	=C\$9/\$B\$9**GF as Oxide Dif'I W10	=C\$9/\$B\$9**GF as Oxide Dif'I X10
10	=2*C\$10/\$B\$10**GF as Oxide Dif'I V11	=2*C\$10/\$B\$10**GF as Oxide Dif'I W11	=2*C\$10/\$B\$10**GF as Oxide Dif'I X11
11	=2*C\$11/\$B\$11**GF as Oxide Dif'I V12	=2*C\$11/\$B\$11**GF as Oxide Dif'I W12	=2*C\$11/\$B\$11**GF as Oxide Dif'I X12
12	=C\$12/\$B\$12**GF as Oxide Dif'I V13	=C\$12/\$B\$12**GF as Oxide Dif'I W13	=C\$12/\$B\$12**GF as Oxide Dif'I X13
13	=2*C\$13/\$B\$13**GF as Oxide Dif'I V14	=2*C\$13/\$B\$13**GF as Oxide Dif'I W14	=2*C\$13/\$B\$13**GF as Oxide Dif'I X14
14	=C\$14/\$B\$14**GF as Oxide Dif'I V15	=C\$14/\$B\$14**GF as Oxide Dif'I W15	=C\$14/\$B\$14**GF as Oxide Dif'I X15
15	=C\$15/\$B\$15**GF as Oxide Dif'I V16	=C\$15/\$B\$15**GF as Oxide Dif'I W16	=C\$15/\$B\$15**GF as Oxide Dif'I X16
16	=C\$16/\$B\$16**GF as Oxide Dif'I V17	=C\$16/\$B\$16**GF as Oxide Dif'I W17	=C\$16/\$B\$16**GF as Oxide Dif'I X17
17	=C\$17/\$B\$17**GF as Oxide Dif'I V18	=C\$17/\$B\$17**GF as Oxide Dif'I W18	=C\$17/\$B\$17**GF as Oxide Dif'I X18
18	=SUM(X6:X17)	=SUM(Y6:Y17)	=SUM(Z6:Z17)
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
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31			
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34			
35			
36			
37			
38			
39			
40			

CALCULATION SHEET

ORP-56511, Rev. B
PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.:24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 43

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	AA
1	
2	s
3	LAWB45
	AZ-102
4	
5	-0.0742857142857143
6	=C\$6/B\$6*GF as Oxide DifY7
7	=2*C\$7/B\$7*GF as Oxide DifY8
8	=2*C\$8/B\$8*GF as Oxide DifY9
9	=C\$9/B\$9*GF as Oxide DifY10
10	=2*C\$10/B\$10*GF as Oxide DifY11
11	=2*C\$11/B\$11*GF as Oxide DifY12
12	=C\$12/B\$12*GF as Oxide DifY13
13	=2*C\$13/B\$13*GF as Oxide DifY14
14	=C\$14/B\$14*GF as Oxide DifY15
15	=C\$15/B\$15*GF as Oxide DifY16
16	=C\$16/B\$16*GF as Oxide DifY17
17	=C\$17/B\$17*GF as Oxide DifY18
18	=SUM(AA6:AA17)
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	
31	
32	
33	
34	
35	
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37	
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CALCULATION SHEET

 ORP-56511, Rev. B
 PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.: 24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 44

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	A	B	C	D	E
41	Oxygen Balance (color corresponds to above table)				
42	S			$=\$B6-\$C6)/\$C6*D6$	$=\$B6-\$C6)/\$C6*E6$
43	Al			$=\$B7-2*\$C7)/2*\$C7*D7$	$=\$B7-2*\$C7)/2*\$C7*E7$
44	B			$=\$B8-2*\$C8)/2*\$C8*D8$	$=\$B8-2*\$C8)/2*\$C8*E8$
45	Ca			$=\$B9-\$C9)/\$C9*D9$	$=\$B9-\$C9)/\$C9*E9$
46	Fe			$=\$B10-2*\$C10)/2*\$C10*D10$	$=\$B10-2*\$C10)/2*\$C10*E10$
47	Li			$=\$B11-2*\$C11)/2*\$C11*D11$	$=\$B11-2*\$C11)/2*\$C11*E11$
48	Mg			$=\$B12-\$C12)/\$C12*D12$	$=\$B12-\$C12)/\$C12*E12$
49	Na			$=\$B13-2*\$C13)/2*\$C13*D13$	$=\$B13-2*\$C13)/2*\$C13*E13$
50	Si			$=\$B14-\$C14)/\$C14*D14$	$=\$B14-\$C14)/\$C14*E14$
51	Ti			$=\$B15-\$C15)/\$C15*D15$	$=\$B15-\$C15)/\$C15*E15$
52	Zn			$=\$B16-\$C16)/\$C16*D16$	$=\$B16-\$C16)/\$C16*E16$
53	Zr			$=\$B17-\$C17)/\$C17*D17$	$=\$B17-\$C17)/\$C17*E17$
54	Total O, oxygen			$=SUM(D42:D53)$	$=SUM(E42:E53)$
55					

CALCULATION SHEET

 ORP-56511, Rev. B
 PROJECT: RPP-WTP

JOB NO.: 24590

BY: Rod Gimpel

CALC NO.: 24590-LAW-M4C-LFP-00002

DATE: 05/30/02

SHEET REV: B

SHEET NO.: 45

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	F	G	H
41			
42	=(\$B6:\$C6)/\$C6*F6	=(\$B6:\$C6)/\$C6*G6	=(\$B6:\$C6)/\$C6*H6
43	=(\$B7-\$C7)/2*\$C7*F7	=(\$B7-\$C7)/2*\$C7*G7	=(\$B7-\$C7)/2*\$C7*H7
44	=(\$B8-\$C8)/2*\$C8*F8	=(\$B8-\$C8)/2*\$C8*G8	=(\$B8-\$C8)/2*\$C8*H8
45	=(\$B9-\$C9)/\$C9*F9	=(\$B9-\$C9)/\$C9*G9	=(\$B9-\$C9)/\$C9*H9
46	=(\$B10-\$C10)/2*\$C10*F10	=(\$B10-\$C10)/2*\$C10*G10	=(\$B10-\$C10)/2*\$C10*H10
47	=(\$B11-\$C11)/2*\$C11*F11	=(\$B11-\$C11)/2*\$C11*G11	=(\$B11-\$C11)/2*\$C11*H11
48	=(\$B12-\$C12)/\$C12*F12	=(\$B12-\$C12)/\$C12*G12	=(\$B12-\$C12)/\$C12*H12
49	=(\$B13-\$C13)/2*\$C13*F13	=(\$B13-\$C13)/2*\$C13*G13	=(\$B13-\$C13)/2*\$C13*H13
50	=(\$B14-\$C14)/\$C14*F14	=(\$B14-\$C14)/\$C14*G14	=(\$B14-\$C14)/\$C14*H14
51	=(\$B15-\$C15)/\$C15*F15	=(\$B15-\$C15)/\$C15*G15	=(\$B15-\$C15)/\$C15*H15
52	=(\$B16-\$C16)/\$C16*F16	=(\$B16-\$C16)/\$C16*G16	=(\$B16-\$C16)/\$C16*H16
53	=(\$B17-\$C17)/\$C17*F17	=(\$B17-\$C17)/\$C17*G17	=(\$B17-\$C17)/\$C17*H17
54	=SUM(F42:F53)	=SUM(G42:G53)	=SUM(H42:H53)
55			

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	I	J	K	L	M
41					
42	=(\$B6-\$C6)/\$C6*J6	=(\$B6-\$C6)/\$C6*J6	=(\$B6-\$C6)/\$C6*E23	=(\$B6-\$C6)/\$C6*F23	
43	=(\$B7-2*\$C7)/2/\$C7*J7	=(\$B7-2*\$C7)/2/\$C7*J7	=(\$B7-2*\$C7)/2/\$C7*E24	=(\$B7-2*\$C7)/2/\$C7*F24	
44	=(\$B8-2*\$C8)/2/\$C8*J8	=(\$B8-2*\$C8)/2/\$C8*J8	=(\$B8-2*\$C8)/2/\$C8*E25	=(\$B8-2*\$C8)/2/\$C8*F25	
45	=(\$B9-\$C9)/\$C9*J9	=(\$B9-\$C9)/\$C9*J9	=(\$B9-\$C9)/\$C9*E26	=(\$B9-\$C9)/\$C9*F26	
46	=(\$B10-2*\$C10)/2/\$C10*J10	=(\$B10-2*\$C10)/2/\$C10*J10	=(\$B10-2*\$C10)/2/\$C10*E27	=(\$B10-2*\$C10)/2/\$C10*F27	
47	=(\$B11-2*\$C11)/2/\$C11*J11	=(\$B11-2*\$C11)/2/\$C11*J11	=(\$B11-2*\$C11)/2/\$C11*E28	=(\$B11-2*\$C11)/2/\$C11*F28	
48	=(\$B12-\$C12)/\$C12*J12	=(\$B12-\$C12)/\$C12*J12	=(\$B12-\$C12)/\$C12*E29	=(\$B12-\$C12)/\$C12*F29	
49	=(\$B13-2*\$C13)/2/\$C13*J13	=(\$B13-2*\$C13)/2/\$C13*J13	=(\$B13-2*\$C13)/2/\$C13*E30	=(\$B13-2*\$C13)/2/\$C13*F30	
50	=(\$B14-\$C14)/\$C14*J14	=(\$B14-\$C14)/\$C14*J14	=(\$B14-\$C14)/\$C14*E31	=(\$B14-\$C14)/\$C14*F31	
51	=(\$B15-\$C15)/\$C15*J15	=(\$B15-\$C15)/\$C15*J15	=(\$B15-\$C15)/\$C15*E32	=(\$B15-\$C15)/\$C15*F32	
52	=(\$B16-\$C16)/\$C16*J16	=(\$B16-\$C16)/\$C16*J16	=(\$B16-\$C16)/\$C16*E33	=(\$B16-\$C16)/\$C16*F33	
53	=(\$B17-\$C17)/\$C17*J17	=(\$B17-\$C17)/\$C17*J17	=(\$B17-\$C17)/\$C17*E34	=(\$B17-\$C17)/\$C17*F34	
54	=SUM(I42:I53)	=SUM(J42:J53)	=SUM(K42:K53)	=SUM(L42:L53)	
55					

CALCULATION SHEET

 ORP-56511, Rev. B
 PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.: 24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 47

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	N	O	P	Q	R	S	T	U
41								
42								$=\$B6:\$C6)/\$C6*G23$
43								$=\$B7:2*\$C7)/2*\$C7*G24$
44								$=\$B8:2*\$C8)/2*\$C8*G25$
45								$=\$B9:\$C9)/\$C9*G26$
46								$=\$B10:2*\$C10)/2*\$C10*G27$
47								$=\$B11:2*\$C11)/2*\$C11*G28$
48								$=\$B12:\$C12)/\$C12*G29$
49								$=\$B13:2*\$C13)/2*\$C13*G30$
50								$=\$B14:\$C14)/\$C14*G31$
51								$=\$B15:\$C15)/\$C15*G32$
52								$=\$B16:\$C16)/\$C16*G33$
53								$=\$B17:\$C17)/\$C17*G34$
54								$=SUM(U42:U53)$
55								

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	V	W	X	Y
41				
42	=(\$B6-\$C6)/\$C6*H23	=(\$B6-\$C6)/\$C6*I23	=(\$B6-\$C6)/\$C6*I23	=(\$B6-\$C6)/\$C6*K23
43	=(\$B7-2*\$C7)/2/\$C7*H24	=(\$B7-2*\$C7)/2/\$C7*I24	=(\$B7-2*\$C7)/2/\$C7*I24	=(\$B7-2*\$C7)/2/\$C7*K24
44	=(\$B8-2*\$C8)/2/\$C8*H25	=(\$B8-2*\$C8)/2/\$C8*I25	=(\$B8-2*\$C8)/2/\$C8*I25	=(\$B8-2*\$C8)/2/\$C8*K25
45	=(\$B9-\$C9)/\$C9*H26	=(\$B9-\$C9)/\$C9*I26	=(\$B9-\$C9)/\$C9*I26	=(\$B9-\$C9)/\$C9*K26
46	=(\$B10-2*\$C10)/2/\$C10*H27	=(\$B10-2*\$C10)/2/\$C10*I27	=(\$B10-2*\$C10)/2/\$C10*I27	=(\$B10-2*\$C10)/2/\$C10*K27
47	=(\$B11-2*\$C11)/2/\$C11*H28	=(\$B11-2*\$C11)/2/\$C11*I28	=(\$B11-2*\$C11)/2/\$C11*I28	=(\$B11-2*\$C11)/2/\$C11*K28
48	=(\$B12-\$C12)/\$C12*H29	=(\$B12-\$C12)/\$C12*I29	=(\$B12-\$C12)/\$C12*I29	=(\$B12-\$C12)/\$C12*K29
49	=(\$B13-2*\$C13)/2/\$C13*H30	=(\$B13-2*\$C13)/2/\$C13*I30	=(\$B13-2*\$C13)/2/\$C13*I30	=(\$B13-2*\$C13)/2/\$C13*K30
50	=(\$B14-\$C14)/\$C14*H31	=(\$B14-\$C14)/\$C14*I31	=(\$B14-\$C14)/\$C14*I31	=(\$B14-\$C14)/\$C14*K31
51	=(\$B15-\$C15)/\$C15*H32	=(\$B15-\$C15)/\$C15*I32	=(\$B15-\$C15)/\$C15*I32	=(\$B15-\$C15)/\$C15*K32
52	=(\$B16-\$C16)/\$C16*H33	=(\$B16-\$C16)/\$C16*I33	=(\$B16-\$C16)/\$C16*I33	=(\$B16-\$C16)/\$C16*K33
53	=(\$B17-\$C17)/\$C17*H34	=(\$B17-\$C17)/\$C17*I34	=(\$B17-\$C17)/\$C17*I34	=(\$B17-\$C17)/\$C17*K34
54	=SUM(V42:V53)	=SUM(W42:W53)	=SUM(X42:X53)	=SUM(Y42:Y53)
55				

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	Z	AA	AB
41			
42	=(B6-\$C6)/\$C6*L23	=(B6-\$C6)/\$C6*U23	=(B6-\$C6)/\$C6*V23
43	=(B7-2*\$C7)/2/\$C7*L24	=(B7-2*\$C7)/2/\$C7*U24	=(B7-2*\$C7)/2/\$C7*V24
44	=(B8-2*\$C8)/2/\$C8*L25	=(B8-2*\$C8)/2/\$C8*U25	=(B8-2*\$C8)/2/\$C8*V25
45	=(B9-\$C9)/\$C9*L26	=(B9-\$C9)/\$C9*U26	=(B9-\$C9)/\$C9*V26
46	=(B10-2*\$C10)/2/\$C10*L27	=(B10-2*\$C10)/2/\$C10*U27	=(B10-2*\$C10)/2/\$C10*V27
47	=(B11-2*\$C11)/2/\$C11*L28	=(B11-2*\$C11)/2/\$C11*U28	=(B11-2*\$C11)/2/\$C11*V28
48	=(B12-\$C12)/\$C12*L29	=(B12-\$C12)/\$C12*U29	=(B12-\$C12)/\$C12*V29
49	=(B13-2*\$C13)/2/\$C13*L30	=(B13-2*\$C13)/2/\$C13*U30	=(B13-2*\$C13)/2/\$C13*V30
50	=(B14-\$C14)/\$C14*L31	=(B14-\$C14)/\$C14*U31	=(B14-\$C14)/\$C14*V31
51	=(B15-\$C15)/\$C15*L32	=(B15-\$C15)/\$C15*U32	=(B15-\$C15)/\$C15*V32
52	=(B16-\$C16)/\$C16*L33	=(B16-\$C16)/\$C16*U33	=(B16-\$C16)/\$C16*V33
53	=(B17-\$C17)/\$C17*L34	=(B17-\$C17)/\$C17*U34	=(B17-\$C17)/\$C17*V34
54	=SUM(Z42:Z53)	=SUM(AA42:AA53)	=SUM(AB42:AB53)
55			

CALCULATION SHEETPROJECT: RPP-WTPJOB NO.: 24590

CALC NO.:24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 50

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Attachment 5 (Continued)**Variability in LAW Glass Recipes Determination Spreadsheet -- Elemental
Concentrations****Formula Displayed Spreadsheet Format****Spreadsheet's Sheet Name: GF as Oxide Dif.
(3 Pages)**

CALCULATION SHEET

 ORP-56511, Rev. B
 PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.: 24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 51

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	A	B	C	D	E	F	G	H
1								
2								
3								
4	GLASS Tank ID (based on case 3S6E)	LAWA44 AN-105 SY-101 AN- 103	LAWA88 AP-101 AW-101	LAWA102 AN-104 AW-104	LAWB45 AZ-102	LAWB53 AZ-101	LAWC21 AN-102	LAWC22 AN-107
5	Typical Waste Loading							
6		0.26	0.26	0.18	0.09	0.06	0.14	0.18
7	SO ₃	0.095	0.214	0.441	0.844	0.807	0.424	0.341
8	Al ₂ O ₃	6.201	6.08	6.054	6.129	6.059	6.125	6.08
9	B ₂ O ₃	8.902	9.698	9.995	12.34	10.026	10.088	10.068
10	CaO	1.994	1.991	5.065	6.627	6.746	6.409	5.117
11	Fe ₂ O ₃	6.981	5.531	5.407	5.256	5.341	6.477	5.431
12	Li ₂ O	0	0	2.499	4.616	5.856	2.733	2.505
13	MgO	1.994	1.475	1.494	2.971	2.998	1.509	1.513
14	Na ₂ O	20	20	14.478	6.5	5	11.871	14.4
15	SiO ₂	44.553	43.991	46.569	47.859	48.924	46.727	46.667
16	TiO ₂	1.994	1.991	1.143	0	1.405	1.121	1.143
17	ZnO	2.965	2.95	3.062	3.153	3.186	3.018	3.069
18	ZrO ₂	2.992	2.987	3.022	3.153	3.186	3.021	3.027
19	Totals	=SUM(B7:B18)	=SUM(C7:C18)	=SUM(D7:D18)	=SUM(E7:E18)	=SUM(F7:F18)	=SUM(G7:G18)	=SUM(H7:H18)

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Determination Spreadsheet -- Elements as Oxides									
	I	J	S	T	U	V	W	X	
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

	Y
1	
2	
3	q
4	LAWB45
	AZ-102
5	
6	-0.0742857142857143
7	0.391714285714286
8	0.0192857142857143
9	-0.13
10	1.77714285714286
11	-0.518857142857143
12	2.01471428571429
13	0.977571428571429
14	-6.67842857142857
15	1.38900000000001
16	-1.25671428571429
17	0.0954285714285716
18	0.0975714285714284
19	=SUM(Y7:Y18)

CALCULATION SHEET

PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.: 24590-LAW-M4C-LFP-00002

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SHEET NO.: 54

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Attachment 6

Law Glass Elements vs. Sulfur Plot

(One Page)

CALCULATION SHEET

 ORP-56511, Rev. B
 PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.: 24590-LAW-M4C-LFP-00002

SHEET REV: B

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CALCULATION SHEET

PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.:24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 56

BY: Rod Gimpel

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SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Attachment 7

Validation of Use of Microsoft Excel 97 Software

(One Page)

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Input Data			
	x	y1	y2
	1	2	1.5
	2	2	1.5
	4	8	6
	5	8	6
	9	18	13.5
	10	18	13.5
Sum	31	56	42

Calibration with Hewlett Packard 32SII Calculator

Calculated values for:
Excel 97 HP 32S11

y1		
Slope, m	1.9551	1.9551
Intercept, b	-0.7681	-0.7681
y2		
Slope, m	1.4663	1.4663
Intercept, b	-0.5761	-0.5761

Print from Excel 97

CALCULATION SHEET

PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.:24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 58

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Attachment 7 (Continued)

Validation of Use of Microsoft Excel 97 Software Corresponding "Formula Displayed" Spreadsheet Format

(One Page)

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

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Attachment 8

Equations Microsoft Excel 97 Uses for Calculating Trendlines

(Six Pages)

CALCULATION SHEET

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Equations for calculating trendlines

Linear

Calculates the least squares fit for a line represented by the following equation:

$$y = mx + b$$

where m is the slope and b is the intercept.

Polynomial

Calculates the least squares fit through points by using the following equation:

$$y = b + c_1x + c_2x^2 + c_3x^3 + \dots + c_6x^6$$

where b and $c_1 \dots c_6$ are constants.

Logarithmic

Calculates the least squares fit through points by using the following equation:

$$y = c \ln x + b$$

where c and b are constants, and $\ln$ is the natural logarithm function.

Exponential

Calculates the least squares fit through points by using the following equation:

$$y = ce^{bx}$$

where c and b are constants, and e is the base of the natural logarithm.

Power

Calculates the least squares fit through points by using the following equation:

$$y = cx^b$$

where c and b are constants.

R-squared Value

$$R^2 = 1 - \frac{SSE}{SST}$$

where

$$SSE = \sum (Y_i - \hat{Y}_i)^2$$

and

$$SST = \left(\sum Y_i^2 \right) - \frac{\left(\sum Y_i \right)^2}{n}$$

Note The R-squared value you can display with a trendline is not an adjusted R-squared value. For logarithmic, power, and exponential trendlines, Microsoft Excel uses a transformed regression model.

Moving Average

$$F_t = \frac{A_t + A_{t-1} + \dots + A_{t-n+1}}{n}$$

Note The number of points in a moving average trendline equals the total number of points in the series less the number you specify for the period.

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LINEST

See Also

Calculates the statistics for a line by using the "least squares" method to calculate a straight line that best fits your data, and returns an array that describes the line. Because this function returns an array of values, it must be entered as an array formula. For more information about array formulas, click [here](#).

The equation for the line is:

$$y = mx + b \text{ or } y = m_1x_1 + m_2x_2 + \dots + b \text{ (if there are multiple ranges of x-values)}$$

where the dependent y-value is a function of the independent x-values. The m-values are coefficients corresponding to each x-value, and b is a constant value. Note that y, x, and m can be vectors. The array that LINEST returns is {mn,mn-1,...,m1,b}. LINEST can also return additional regression statistics.

Syntax

LINEST(known_y's,known_x's,const,stats)

Known_y's is the set of y-values you already know in the relationship $y = mx + b$.

- If the array known_y's is in a single column, then each column of known_x's is interpreted as a separate variable.
- If the array known_y's is in a single row, then each row of known_x's is interpreted as a separate variable.

Known_x's is an optional set of x-values that you may already know in the relationship $y = mx + b$.

- The array known_x's can include one or more sets of variables. If only one variable is used, known_y's and known_x's can be ranges of any shape, as long as they have equal dimensions. If more than one variable is used, known_y's must be a vector (that is, a range with a height of one row or a width of one column).
- If known_x's is omitted, it is assumed to be the array {1,2,3,...} that is the same size as known_y's.

Const is a logical value specifying whether to force the constant b to equal 0.

- If const is TRUE or omitted, b is calculated normally.
- If const is FALSE, b is set equal to 0 and the m-values are adjusted to fit $y = mx$.

Stats is a logical value specifying whether to return additional regression statistics.

- If stats is TRUE, LINEST returns the additional regression statistics, so the returned array is {mn,mn-1,...,m1,b;sen,sen-1,...,se1,seb;r2,sey;F,df;ssreg,ssresid}.
- If stats is FALSE or omitted, LINEST returns only the m-coefficients and the constant b.

The additional regression statistics are as follows.

Statistic	Description
se1,se2,...,sen	The standard error values for the coefficients $m_1, m_2, \dots, m_n$.
Seb	The standard error value for the constant b (seb = #N/A when const is FALSE).
r2	The coefficient of determination. Compares estimated and actual y-values, and ranges in value from 0 to 1. If it is 1, there is a perfect correlation in the sample — there is no difference between the estimated y-value and the actual y-value. At the other extreme, if the coefficient of determination is 0, the regression equation is not helpful in predicting a y-value. For information about how r2 is calculated, see "Remarks"

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later in this topic.

sey

The standard error for the y estimate.

F

The F statistic, or the F-observed value. Use the F statistic to determine whether the observed relationship between the dependent and independent variables occurs by chance.

df

The degrees of freedom. Use the degrees of freedom to help you find F-critical values in a statistical table. Compare the values you find in the table to the F statistic returned by LINEST to determine a confidence level for the model.

ssreg

The regression sum of squares.

ssresid

The residual sum of squares.

The following illustration shows the order in which the additional regression statistics are returned.

	A	B	C	D	E	F
1	m_n	m_{n-1}	...	m_2	m_1	b
2	se_n	se_{n-1}	...	se_2	se_1	se_b
3	r^2	se_y				
4	F	df				
5	ssreg	ssresid				

Remarks

- You can describe any straight line with the slope and the y-intercept:

Slope (m):

To find the slope of a line, often written as m, take two points on the line, (x1,y1) and (x2,y2); the slope is equal to (y2 - y1)/(x2 - x1).

Y-intercept (b):

The y-intercept of a line, often written as b, is the value of y at the point where the line crosses the y-axis.

The equation of a straight line is $y = mx + b$. Once you know the values of m and b, you can calculate any point on the line by plugging the y- or x-value into that equation. You can also use the TREND function. For more information, see TREND.

- When you have only one independent x-variable, you can obtain the slope and y-intercept values directly by using the following formulas:

Slope:

INDEX(LINEST(known_y's,known_x's),1)

Y-intercept:

INDEX(LINEST(known_y's,known_x's),2)

- The accuracy of the line calculated by LINEST depends on the degree of scatter in your data. The more linear the data, the more accurate the LINEST model. LINEST uses the method of least squares for determining the best fit for the data. When you have only one independent x-variable, the calculations for m and b are based on the following formulas:

$$m = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2}$$

$$b = \frac{(\sum y)(\sum x^2) - (\sum x)(\sum xy)}{n(\sum x^2) - (\sum x)^2}$$

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- The line- and curve-fitting functions LINEST and LOGEST can calculate the best straight line or exponential curve that fits your data. However, you have to decide which of the two results best fits your data. You can calculate TREND(known_y's,known_x's) for a straight line, or GROWTH(known_y's, known_x's) for an exponential curve. These functions, without the new_x's argument, return an array of y-values predicted along that line or curve at your actual data points. You can then compare the predicted values with the actual values. You may want to chart them both for a visual comparison.
- In regression analysis, Microsoft Excel calculates for each point the squared difference between the y-value estimated for that point and its actual y-value. The sum of these squared differences is called the residual sum of squares. Microsoft Excel then calculates the sum of the squared differences between the actual y-values and the average of the y-values, which is called the total sum of squares (regression sum of squares + residual sum of squares). The smaller the residual sum of squares is, compared with the total sum of squares, the larger the value of the coefficient of determination, r^2 , which is an indicator of how well the equation resulting from the regression analysis explains the relationship among the variables.
- Formulas that return arrays must be entered as array formulas. For more information about entering array formulas, click [here](#).
- When entering an array constant such as known_x's as an argument, use commas to separate values in the same row and semicolons to separate rows. Separator characters may be different depending on your country settings.
- Note that the y-values predicted by the regression equation may not be valid if they are outside the range of the y-values you used to determine the equation.

Example 1 Slope and Y-Intercept

LINEST({1,9,5,7},{0,4,2,3}) equals {2,1}, the slope = 2 and y-intercept = 1

Example 2 Simple Linear Regression

Suppose a small business has sales of \$3,100, \$4,500, \$4,400, \$5,400, \$7,500, and \$8,100 during the first six months of the fiscal year. Assuming that the values are entered in the range B2:B7, respectively, you can use the following simple linear regression model to estimate sales for the ninth month.

SUM(LINEST(B2:B7)*{9,1}) equals SUM({1000,2000}*{9,1}) equals \$11,000

In general, SUM({m,b}*{x,1}) equals $mx + b$, the estimated y-value for a given x-value. You can also use the TREND function.

Example 3 Multiple Linear Regression

Suppose a commercial developer is considering purchasing a group of small office buildings in an established business district.

The developer can use multiple linear regression analysis to estimate the value of an office building in a given area based on the following variables.

Variable	Refers to the
y	Assessed value of the office building
x1	Floor space in square feet
x2	Number of offices
x3	Number of entrances
x4	Age of the office building in years

This example assumes that a straight-line relationship exists between each independent variable (x1, x2, x3, and x4) and the dependent variable (y), the value of office buildings in the area.

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The developer randomly chooses a sample of 11 office buildings from a possible 1,500 office buildings and obtains the following data.

	A	B	C	D	E
	x1	x2	x3	x4	y
1	Floor Space	Offices	Entrances	Age	Value
2	2,310	2	2	20	\$142,000
3	2,333	2	2	12	\$144,000
4	2,356	3	1.5	33	\$151,000
5	2,379	3	2	43	\$150,000
6	2,402	2	3	53	\$139,000
7	2,425	4	2	23	\$169,000
8	2,448	2	1.5	99	\$126,000
9	2,471	2	2	34	\$142,900
10	2,494	3	3	23	\$163,000
11	2,517	4	4	55	\$169,000
12	2,540	2	3	22	\$149,000

"Half an entrance" means an entrance for deliveries only. When entered as an array, the following formula:

`LINEST(E2:E12,A2:D12,TRUE,TRUE)`

returns the following output.

	A	B	C	D	E
14	-234.23716	2553.21066	12529.7682	27.6413874	52317.8305
15	13.2680115	530.669152	400.066838	5.42937404	12237.3616
16	0.99674799	970.578463	#N/A	#N/A	#N/A
17	459.753674	6	#N/A	#N/A	#N/A
18	1732393319	5652135.32	#N/A	#N/A	#N/A

The multiple regression equation, $y = m_1 \cdot x_1 + m_2 \cdot x_2 + m_3 \cdot x_3 + m_4 \cdot x_4 + b$, can now be obtained using the values from row 14:

$$y = 27.64 \cdot x_1 + 12,530 \cdot x_2 + 2,553 \cdot x_3 + 234.24 \cdot x_4 + 52,318$$

The developer can now estimate the assessed value of an office building in the same area that has 2,500 square feet, three offices, and two entrances and is 25 years old, by using the following equation:

$$y = 27.64 \cdot 2500 + 12530 \cdot 3 + 2553 \cdot 2 - 234.24 \cdot 25 + 52318 = \$158,261$$

You can also use the TREND function to calculate this value. For more information, see TREND.

Example 4 Using The F And R2 Statistics

In the previous example, the coefficient of determination, or r^2 , is 0.99675 (see cell A16 in the output for LINEST), which would indicate a strong relationship between the independent variables and the sale price. You can use the F statistic to determine whether these results, with such a high r^2 value, occurred by chance.

Assume for the moment that in fact there is no relationship among the variables, but that you have drawn a rare sample of 11 office buildings that causes the statistical analysis to demonstrate a strong relationship. The term "Alpha" is used for the probability of erroneously concluding that there is a relationship.

There is a relationship among the variables if the F-observed statistic is greater than the F-critical value. The F-critical value can be obtained by referring to a table of F-critical values in many statistics textbooks. To read the table, assume a single-tailed test, use an Alpha value of 0.05, and for the degrees of freedom (abbreviated in most tables as v_1 and v_2), use $v_1 = k = 4$ and $v_2 = n - (k + 1) = 11 - (4 + 1) = 6$, where k is the number of variables in the regression analysis and n is the number of data points. The F-critical value is 4.53.

The F-observed value is 459.753674 (cell A17), which is substantially greater than the F-critical value

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of 4.53. Therefore, the regression equation is useful in predicting the assessed value of office buildings in this area.

Example 5 Calculating The T-Statistics

Another hypothesis test will determine whether each slope coefficient is useful in estimating the assessed value of an office building in example 3. For example, to test the age coefficient for statistical significance, divide -234.24 (age slope coefficient) by 13.268 (the estimated standard error of age coefficients in cell A15). The following is the t-observed value:

$$t = m_4 \div se_4 = -234.24 \div 13.268 = -17.7$$

If you consult a table in a statistics manual, you will find that t-critical, single tail, with 6 degrees of freedom and Alpha = 0.05 is 1.94. Because the absolute value of t, 17.7, is greater than 1.94, age is an important variable when estimating the assessed value of an office building. Each of the other independent variables can be tested for statistical significance in a similar manner. The following are the t-observed values for each of the independent variables.

Variable	t-observed value
Floor space	5.1
Number of offices	31.3
Number of entrances	4.8
Age	17.7

These values all have an absolute value greater than 1.94; therefore, all the variables used in the regression equation are useful in predicting the assessed value of office buildings in this area.

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Attachment 9**Linear Curve Fit of LAW Pilot Runs**

Page 1 Excerpt Table 24, *Recipe for the Envelope B Feeds Tested*, from Final Report, VSL-01 R3520-1, *LAW Simulants and Melter Feeds*, The Catholic University of America, Vitreous State Laboratory. This table used to calculate volume increase in feed due to glass former addition.

Page 2 Liner Curve Fit of data presented in Table 24.

CALCULATION SHEET

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JOB NO.: 24590

CALC NO.: 24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 68

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SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

The Catholic University of America
Vitreous State Laboratory

LAW Simulants and Melter Feeds
Final Report, VSL-01R3520-1, Rev. 0

Table 24. Recipes for the Envelope B Feeds Tested (All Based on 1 liter of Simulant).

Additives Source	Feed LAWB30 for AZ101/102 Low Sulfate 7 Molar FLAWB7	Feed LAWB30 for AZ101/102 Low Sulfate 5 Molar FLAWB5	Feed LAWB30 for AZ101/102 Low Sulfate 3 Molar FLAWB3	Feed LAWB41 for AZ101/102 High Sulfate 4 Molar	Feed LAWB45 for AZ101/102 High Sulfate 3.5 Molar
Additives in Glass (wt%)	90.49%	90.49%	90.49%	91.40%	89.68%
Kyanite (Al ₂ SiO ₅) 325 Mesh	402.05	287.19	172.31	157.58	171.07
H ₃ BO ₃	510.22	364.53	218.72	350.69	380.72
Wollastonite NYAD 325 Mesh	454.86	324.93	194.96	232.93	252.87
Fe ₂ O ₃	209.50	149.64	89.79	71.69	77.83
Li ₂ CO ₃ (Chemetall Foote Co. Tech. gr.)	279.60	199.70	119.82	179.05	194.38
Olivine (Mg ₂ SiO ₄) 325 Mesh (#180)	177.80	126.99	76.20	96.02	104.24
SiO ₂ (Sil-co-Sil 75)	676.84	482.75	289.65	497.91	540.54
TiO ₂ (Rutile Airfloated)	0	0	0	0	0
ZnO	114.20	81.58	48.95	48.93	53.12
Zircon ZrSiO ₄ (Flour) Mesh 325	128.80	91.97	55.18	72.75	78.98
Addition of Sucrose as Reductant	0	0	0		
+Na ₂ SO ₄ (from recycled off-gas) g	0	0	0	0	0
Simulant Weight for 1 liter	1326	1238	1131	1200	1160
Sum of Additives (g) / <i>as Oxides (g)</i>	2954	2109 / 1831	1266 / 1096	1708 / 1447	1854 / 1572
Sum of Complete Batch (g)	4280	3347	2397	2908	3014
Final Volume (l)	2.52	1.819	1.479	1.681	1.742
Density (g/ml)	1.70 *	1.84	1.62	1.73	1.73
Expected Glass Produced (g); i.e., Glass Yield (g/l of simulant)	2745	1961	1177	1569	1669
Weight % Water in Slurry Feed	20%	27%	38%	38%	35%
Weight % Additives in Slurry	69%	63%	53%	59%	62%
Glass Yield (g/kg of Feed)	641	586	491	540	554
Glass Yield (g/l of Feed)	1089 *	1078	796	934	958
Total Solids (g/l of Feed)	1359 *	1343	1004	1073	1125
Additives (g/l of Feed)	1172 *	1159	856	1016	1064

* active foaming observed in this sample

Not applicable, see*

Volume increase = Final Volume - 1 liter Initial Volume, L-T-30

C. 772

C. 661

C. 479

C. 819

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GF Additives, kg/L	Volume Increase, L/L	
	as Compounds	as Oxides
1.266	0.479	
1.708	0.681	
1.854	0.742	
2.109	0.819	
1.098		0.479
1.447		0.681
1.572		0.742
1.831		0.819

CALCULATION SHEET

PROJECT: RPP-WTP

JOB NO.: 24590

CALC NO.:24590-LAW-M4C-LFP-00002

SHEET REV: B

SHEET NO.: 70

BY: Rod Gimpel

DATE: 05/30/02

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models

Attachment 9 (Continued)

Linear Curve Fit of LAW Pilot Runs

(One Page)

CALCULATION SHEET

BY: Rod Gimpel
DATE: 05/30/02

PROJECT: RPP-WTP
JOB NO.: 24590
CALC NO.: 24590-LAW-M4C-LFP-00002
SHEET REV: B
SHEET NO.: 71

SUBJECT: Determining the LAW Glass Former Constituents and Amounts for G2 and ACM Models