



GLAZE TALK

By Karen Latorre

This is the third of a series of columns focused on glazes.

Boric Oxide

There is one other oxide that has not been covered in previous columns. Boric oxide is a source of Boron (B), and its molecular formula (B_2O_3) puts it into the category of a stabilizer (R_2O_3). Despite this, this particular material has some peculiar properties and is actually a glass former, and given its low melting range (between 300C and 700C), it also acts as an additional flux in pottery glazes.

The Unity Formula

In the last column we talked about a balanced glaze and the effect you got by adding an excess of one of the glaze components.

How do you know when you have an excess of a glaze component?

The unity formula is a way to show the relative amounts of the oxides in a fired glaze. It provides us with a way to do an “apples to apples” comparison of two glazes. In addition, calculating the unity formula of a recipe allows us to make informed adjustments to achieve different results in the glaze since each of the oxides behaves in its own way and by changing one of the oxides in the unity formula, we can have greater success in achieving the results we’re looking for in our glazes. The unity formula is also known by a number of other names, such as the Seger formula, empirical formula, ratio of molecules formula, or RO formula.

The unity formula is usually displayed in three columns, corresponding to the role the oxide plays in the glaze (flux, stabilizer, or glass former). A number follows each oxide and represents the relative amount of that oxide in the glaze. Following is an example of a unity formula for a Cone 6 glaze:

GLAZE 1		
K_2O 0.07	Al_2O_3 0.34	SiO_2 3.16
Na_2O 0.14	B_2O_3 0.20	
CaO 0.51		
MgO 0.28		

Notice that when you add the amount of the fluxes together they equal 1 (or one unit). This is why this formula is called the unity formula.

As already mentioned, the numbers indicate the relative amount of each oxide in the finished glaze. This means that in the glaze structure for glaze 1 above, for every 7 molecules of potassium oxide (K_2O), you have 34 molecules of alumina (Al_2O_3) and 316 molecules of silica (SiO_2). Don’t get confused by the fractions in these formulae. A glaze

structure has millions and millions of molecules. You'll never have .14 of a molecule. The numbers are simply used to display the comparative amounts of each oxide.

This setting of the fluxes to equal 1 is also basic to the idea of being able to compare glazes, since it forms an "anchor" for the numbers.

Let's take another Cone 6 glaze unity formula for comparison:

GLAZE 2

K ₂ O	0.07	Al ₂ O ₃	0.29	SiO ₂	3.16
Na ₂ O	0.11	B ₂ O ₃	0.10		
CaO	0.52				
ZnO	0.30				

When I compare these two glaze recipes, I see that the second one has more of the lower strength fluxes (the ROs) than the first, and it has less stabilizer (Al₂O₃) than the first. From this I would expect that the second glaze would be a little less glossy (less flux to melt the same amount of silica) and it would perhaps be a little runnier (less stabilizer to hold it onto a vertical surface). Mixing up test batches of these two glazes will indicate whether the change in oxide amounts is enough to make a visible difference in the glaze.

The Silica to Alumina Ratio (Si:Al ratio)

The two numbers in a unity formula for silica and alumina form an important ratio. Take glaze 1 as an example. Silica is at 3.16 and Alumina is at 0.34. Take the silica number and divide it by the alumina number ($3.16 / 0.34 = 9.29$). This glaze has a silica to alumina ratio of 9.29 : 1. Glaze 2, by comparison has a ratio of 10.90 : 1.

Why is this important?

This ratio indicates the relative viscosity of a glaze, and will also indicate whether or not the glaze might be in balance (no excess molecules in the structure). A ratio of 10:1 tends to provide a glossy transparent glaze (one in balance). If a glaze has a ratio of 6:1, it will be very viscous and may tend to pin hole. It will also tend to be opaque and matt due to an excess of Alumina (an alumina matt). If a glaze has a ratio of 15:1, it may be very runny and run off the pot.

The silica to alumina ratio does not change with the temperature at which you fire. A ratio of around 10:1 is valid for a balanced glaze regardless whether it is fired to cone 1 or cone 10.

When a glaze has B₂O₃ in the unity formula in amounts greater than 0.05, it can no longer be compared to a glaze without boron due to boron's fluxing and glassforming properties. There is a ratio that associates Si + B to the Al in the recipe (SiB:Al ratio), and while this ratio would follow similar rules as the Si:Al ratio (higher ratio would indicate glossier and runnier glaze), there is very little documentation indicating what an appropriate ratio would be for a balanced glaze, or if this ratio would change with the temperature at which we fire.

Limit Formulas

Limit Formulas are a list of ranges for each of the oxides in a glaze. Limit formulas differ depending on the cone at which the glaze is to be fired (remember that at lower temperatures, you need more flux to get the same amount of silica to melt).

There are various books available that list limit formulas. For the purposes of discussion, I will show three ranges (earthenware, mid fire, and high fire) that I have pulled from Insight. Limit formulas should be used as guidelines for each oxide in the unity formula.

Oxides	Earthenware Cone 08 – 05	Mid Fire Cone 3 – 7	High Fire Cone 8 – 10
KNO*	0.25 – 0.5	0.1 – 0.5	0.1 – 0.5
Li ₂ O		0 – 0.2	0 – 0.2
BaO	0 – 0.2	0 – 0.3	0 – 0.3
CaO	0.15 - 0.5	0.1 – 0.7	0.35 – 0.8
PbO**	0 – 0.6		
ZnO	0 – 0.15	0 – 0.25	0 – 0.3
MgO	0 – 0.15	0 – 0.3	0 – 0.4
SrO		0 – 0.4	0 – 0.7
B ₂ O ₃	0.6 – 1.3	0 – 0.4	0 – 0.3
Al ₂ O ₃	0.1 – 0.25	0.2 – 0.35	0.3 – 0.55
SiO ₂	1.5 – 2.5	2.5 – 3.5	3 – 5

* KNO is a short form to indicate the combination of both K₂O and Na₂O (potassium oxide and sodium oxide). To determine the KNO amount, add the K₂O and Na₂O amounts together.

** As indicated in the previous column, lead is only available in a frit, and is a banned substance in many studios. Lead is also a government regulated substance and pottery made with lead containing glazes must be tested to ensure that the glaze is stable, releasing (leaching) no more than a given concentration of lead. Further details can be found in Ron Roy & John Hesselberth's book "Mastering Cone 6 Glazes", ISBN: 0-9730063-0-7. The PbO limits have been taken from Daniel Rhodes "Clay and Glazes for the Potter", ISBN: 0-87341-863-8.

One can compose glazes with oxide amounts sitting within these ranges and still not have a good functional glaze. By ensuring that the oxides in your unity formula are within these ranges, that you have a mixture or more than two flux oxides, that you have enough silica (well within the limit formula range), and that your Silica:Alumina ratio is close to 10:1, you have a good chance of producing a stable, functional glaze. Going outside of these ranges produces the excess required for textural non-functional glazes, and some of the effects discussed in the previous newsletters' glaze talk.

Let's take a look at one more glaze recipe:

GLAZE 3 (Cone 6)

K ₂ O	0.01	Al ₂ O ₃	0.49	SiO ₂	3.20
Na ₂ O	0.09	B ₂ O ₃	0.23		
CaO	0.86				
MgO	0.04			Si:Al	6.53

When comparing this formula to the limit formulas, we see that the KNO and MgO oxides are within range. The CaO is much higher than the high end of the range, therefore there is an excess of calcium oxide in this glaze. In addition, the silica is within range, but the alumina is above the range, thereby suggesting that there is excess alumina in this recipe as well. The Si:Al ratio is rather low indicating a very viscous glaze. Given the above information, at cone 6, this glaze would be expected to be matt and opaque, and would be considered a part of the calcium/alumina matt glaze family. The boron in this recipe may be sufficient to add to the melt and glass former enough to make it a stable, functional glaze. Mixing a sample of this glaze, firing it to temperature and having the glaze tested for leaching would confirm whether or not the glaze is stable and functional.

R₂O₃ Formula

There is one more unity formula, the R₂O₃ formula. This formula does not refer to glazes. It is used to compare and adjust clay bodies. In the R₂O₃ formula, the fluxes are not brought to unity (or 1), instead, the alumina (the R₂O₃) is set to equal a value of 1.

Calculating a Unity Formula from a Raw Material Recipe

There are a couple of texts that are good at explaining how to hand calculate a unity formula from a raw material recipe. These are:

Clay and Glazes for the Potter, by Daniel Rhodes, ISBN: 0-87341-863-8

Glazes for the Craft Potter, by Harry Frazer, ISBN: 0-7136-5141-5

There are also software programs available that will do this calculation for you (in each of these programs, you enter the raw material, and number of grams of the material in the recipe, and the program does the conversion to the final oxides in the glaze, in unity format). These are:

Insight (<http://www.digitalfire.com>) – for Windows and Mac

HyperGlaze (<http://members.aol.com/hyperglaze>) - for Mac

Matrix (<http://www.matrix2000.co.nz/Page2.htm>) – for Windows

GlazeChem (<http://www.glazechem.com/>) – for Windows

The Glaze Workbook (<http://www.dhpot.demon.co.uk/software.htm>) – for Windows & Mac

Glaze Calculator (<http://www.glazecalc.com/>) – for Windows and Amiga

Glaze Simulator (<http://www.glazeexchange.com/topFrame.php3>) – for Windows

There are mailing addresses available to order each of these software programs. Should you be interested, please call me, send me an email, or leave me a note in the newsletter folder at the guild.

The next two columns will cover the properties of each of the oxides in a glaze, and the raw materials that we use and what oxides each of them provides.