INTRODUCTION TO GLAZE CALCULATION

The usual convention is to represent a glaze recipe in 100% **batch** form, with colorants, opacifiers, and conditioning agents (e.g. gums, bentonite, etc.) listed as additions to the basic 100% glaze. Please see the handout on calculating 100% format. Advantages of the 100% format:

·   glazes are more easily compared in uniform format
·   calculation of percent additions like colorants easier with 100 unit base

Glaze recipes are not given in any specific weight units. The recipe can be weighed up in any units, as long as the same unit is used throughout, and the proportions of materials will be equivalent and yield the appropriate result. Many potters use gram scales for ease and accuracy. 10,000 grams is about 2/3 of a five gallon bucket of most glazes. This is the equivalent of 22 pounds of dry glaze.

Glazes may be thought of as a colorless glass, consisting of:

·   flux (various fluxes)
·   glassformer (usually silica)
·   viscosity agent (often alumina)

The purpose of glaze calculation is to determine the total amount of each element present in a glaze, and the proportions relative to each other. With that information at hand, it is possible to calculate materials substitutions, revise melting points, and do other useful calculations. In the end, testing is the final proof, but unity molecular formula gives you a more informed method of choosing what to test.

Unity molecular formula (sometimes also called Seger or empirical formula) lists chemical oxide constituents of a glaze in a format with the oxides grouped by general function and chemical formula:

RO R_2O Flux, basic, alkaline, or monoxides group	**R_2O_3** Amphoteric, neutral, viscosity, or stabilizer group	**RO_2** Glassformer, acidic, or dioxide group
Most active flux to least active:		
PbO lead	Al_2O_3	SiO_2
Na_2O sodium	B_2O_3	ZrO_2
K_2O potassium		SnO_2
LiO lithium		TiO_2
SrO strontium		
BaO barium		
ZnO zinc		
CaO calcium		
MgO magnesium		

A unity formula uses this grouping and expresses the ratios between numbers of molecules of the oxides, not the actual number of molecules. The total of the molecule ratios in one column (for glazes this is usually the flux or RO R_2O column) is brought to "**unity**" (made to total 1) and the other two groups are expressed in relation to this. This is similar to the way numbers are manipulated to determine percentages, where the entire group of numbers is multiplied and divided by the same numbers to preserve the ratios but end up with a 100% format.

Like 100% format, the unity format allows for easy comparison, or adjustment of glazes based on the elements contained. Unity formulas are sometimes used to describe historic or foreign glazes where use of the same materials is not possible. This gives the artist the opportunity to calculate for those elemental proportions using familiar materials.

Sample unity formula

CaO   1.0 Al_2O_3 0.6 SiO_2 2.8

Limit formulas (see Rhodes p. 168) are general elemental guidelines for specific temperatures and surfaces of glaze, and may be useful to compare your glaze to a "standard" at that temperature and surface, e.g. cone 03 glossy.

To determine the unity formula of a glaze, **begin with the glaze recipe in 100% format.** This tells the ingredients and the weights of each, but the molecular ratios and elemental amounts are not apparent. See the handout on Glaze Mixing to review putting a glaze into 100% format.

Whiting	28.5
China clay	44.2
Flint	27.4
Total	100.1

Calculating from a percentage recipe to a unity formula.

1. Determine the formula and molecular weight for each ingredient by looking each up in a reference, or use the formula and weights for the elements to calculate the atomic weight.

Material	Formula	Molecular weight
Whiting	$CaCO_3$	258
China clay (kaolin)	$Al_2O_3 \bullet 2SiO_2 \bullet 2H_2O$	100
Flint	SiO_2	60

Atomic weights: see Rhodes p. 126 for discussion. Atoms of various elements weigh differing amounts. Hydrogen, the lightest element, was assigned the weight of 1, and the other elements weights stated in relationship to the weight of hydrogen. To determine the weight of a molecule, consult the chart of atomic weights of the elements (p.314 Rhodes, or the handout *Elements Common in Ceramics*), determine the number of atoms of each element, and add up the weights of its atoms. Review the handout on chemical notation. Check your work on the handout *Ceramic Materials for Glaze Calculation* Example: kaolin $Al_2O_3 \bullet 2SiO_2 \bullet 2H_2O$

2 alumina @ 26.9 ea	53.8
3 oxygen @ 16 ea	48.0
2 (1 silica 28 and two oxygen@ 16 ea)	120.0
2 (2 hydrogen @ 1 ea + 1 oxygen 16)	36.0
TOTAL	257.8

Rounded off to 258

Equivalent weights: see Rhodes p. 133. Most charts of material formulas and weights include both atomic and equivalent weights. **Equivalent weight is the weight of material which will provide one complete unit of the desired oxide.** This may be more or less than the molecular weight. With an material like flint, SiO_2, the molecular and equivalent weights are the same, as one silica molecule is provided. Materials like bone ash, $Ca_3(PO_4)_2$, M.W. 310, when fired yields 3CaO molecules per molecule of bone ash used, so the equivalent weight is 103 (one-third of the molecular weight.)

2.   Divide the weight of each ingredient in the percentage recipe by the molecular weight of one molecule of the material to determine the relative number of molecules.

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Material	Weight in recipe	Divided by Wt/ 1 mol	Equals number of molecules
Whiting	28.5	100 M.W. units	.285 molecules whiting
China clay	44.2	258 M.W. units	.171 molecules kaolin
Flint	27.4	60 units M.W	.457 molecules flint

To do this algebraically and follow the units:

Material	Weight in recipe	Divided by Wt/ 1 mol	Equals number of molecules
Whiting	28.5 ~~units of weight~~	X I molecule whiting / 100 ~~units of mol wt whiting~~	.285 molecules whiting
China clay (kaolin)	44.2 units of weight	X 1 molecule kaolin / 258 units mol wt kaolin	.171 molecules kaolin
Flint (silica)	27.4 ~~units of weight~~	X 1 molecule flint / 60 ~~units of mol wt flint~~	.457 molecules flint

3.   Determine how much of each glaze constituent is present. Use the chart to determine the fired formula for the ingredients used.
This means you have:

Material	# of mol	What is in one mol	Which yields:
whiting	.285	CaO	.285 (CaO)
kaolin	.171	$Al_2O_3 \bullet 2SiO_2$	.171 ($Al_2O_3 \bullet 2 SiO_2$) = .171 $Al_2O_3 \bullet$ .342 SiO_2
flint	.457	SiO_2	

Arrange this in the unity format chart:

RO, R_2O (flux)	R_2O_3 (viscosity)	RO_2 (glassformer)
.285 CaO	.171 Al_2O_3	.342= .171 x 2 SiO_2 . .457 SiO_2 .799 SiO_2 total

This shows the molecular ratios in the glaze. Now you must put this into **unity format, which will make the flux column equal 1.**

4.   **Add the total of the fluxes in the RO column**. Divide each number of molecules by the total of the flux column. In this case there is only one flux, CaO. As a check, the numbers in the flux column should add up to 1.

Divide each of the numbers by .285 (total of the flux column).
.285 CaO ÷ .285 = 1 CaO
.171 Al_2O_3 ÷ .285 = .6 Al_2O_3
.799 SiO_2 ÷ .285 = 2.803 SiO_2 The unity format for this glaze is:

RO, R_2O	R_2O_3	RO_2
1.0 CaO	.6 Al_2O_3	2.803 SiO_2 .

To solve from the unity formula to a recipe. The purpose of this calculation is to determine what raw materials in what amounts will yield the ratio of the unity formula.

RO, R_2O	R_2O_3	RO_2
1.0 CaO	.6 Al_2O_3	2.803 SiO_2 .

A **unity formula** represents the ratio of molecules of the ceramic oxides present in the glaze.
A **batch recipe** gives the raw materials needed and their quantities as weights.
A **percentage recipe** indicates the raw materials and weights expressed as a total of 100.

The unity formula above indicates 1 molecule calcium oxide to .6 molecules alumina to 2.08 molecules silica in this glaze.

1.   Choose raw materials which will provide the oxides required. In this example, whiting would provide CaO, kaolin would provide alumina and silica.
2.   Multiply the molecular weight of the material by the amount required.
        1.0 CaO molecules needed x   <u>100 units M.W. CaO</u> = 100 units of wt. whiting
                                                          1 molecule CaO

        .6 Al_2O_3 molecules needed x   <u>258 units M.W. kaolin</u> = 154.8 unit of wt. kaolin

The fired formula for kaolin is Al_2O_3 •2 SiO_2. Solve for the smallest amount first. If you used .6 molecules of kaolin, it would provide the .6 molecules of Al_2O_3 needed and .6 x 2 SiO_2 or 1.2 molecules of silica. The unity formula calls for 2.803 SiO_2 minus the 1.2 already contributed by the kaolin, the formula still needs 1.603 silica.
        1.603 SiO_2 molecules needed x   <u>60 units M.W. SiO_2,</u>=   96.18 units of wt. flint
                                                          1 molecule SiO_2
3.   Put into 100% format:
        100.0   whiting x100 ÷ 350.98 = 28.49

154.8	kaolin	"	44.10
96.18	flint	"	27.40
350.98	total	"	99.69

References:

Ceramic Industry magazine for ceramic manufacturing, annual January issue is a materials handbook for ceramic chemicals and materials. $25.00 for just the Jan. issue from Ceramic Industry, 5900 Harper Rd., Suite 109, Solon, OH 44139-1835. (216) 498-9214

Greene, David, *A Handbook of Pottery Glazes*. Watson-Guptill, NY, 1979. ISBN 0-8230-2181-5. Discussion of glazes from a molecular viewpoint.

Lawrence, W.G. *Ceramic Science for the Potter*. Chilton Book Co, Philadelphia, 1972. ISBN 0-8019-5728-1. Out of print. Well worth having if you can find it.

McKee, Charles, Ceramics Handbook; a Guide to Glaze Calculation, Materials, and Processes. Star Publishing, Belmont, CA, 1984. ISBN 0-89863-072-X.

Rhodes, Daniel, *Clay and Glazes for the Potter* Chilton Book Co., Radnor, PA. 1973. ISBN 0-8019-5633-1. Standard text. Great reference, esp. for high fire.

Online references:

DigitalFire. Tony Hansen's site for his Insight glaze calculation program and much more technical information on clay and glaze issues. http://digitalfire.com/index.html

Glazy. Online glaze discussion community, glaze recipe archive with images, and materials info.

HyperGlaze. Excellent glaze calculation and indexing software for the MAC by Richard Burkett. $60.00. We have a copy of this on the CIRCA server, available in the CIRCA lab server with 900 + glazes in the database. http://hyperglaze.com/