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 Na_2O sodium K_2O potassium LiO lithium SrO strontium BaO barium ZnO zinc CaO calcium MgO magnesium	 Al_2O_3 B_2O_3	 SiO_2 ZrO_2 SnO_2 TiO_2

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 atomic 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	$CaCO_3$	100
China clay (kaolin)	Al_2O_3•$2SiO_2$•$2H_2O$	258
Flint	SiO_2	60

Atomic weights: see Rhodes p. 126 for discussion. Atoms weigh differing amounts. Hydrogen, the lightest element, was assigned the weight of 1, and the other elements expressed in relationship to the weight of hydrogen. To determine the weight of a molecule, consult the chart of atomic weights (p.314 Rhodes), add up the weights of its atoms. Review the handout on chemical notation.

Example: kaolin Al_2O_3•$2SiO_2$•$2H_2O$

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	
		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 atomic weight. With an material like flint, SiO_2,, the atomic 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.

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

Whiting 28.5 units whiting x $\frac{\text{1 molecule}}{\text{100 M.W. units}}$ = .285 molecules whitng

China clay 44.2 units kaolin x $\frac{\text{1 molecule kaolin}}{\text{258 M.W. units}}$ = .171 molecules kaolin

Flint 27.4 units flint x $\frac{\text{1 molecule flint}}{\text{60 units M.W.}}$ = .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:
whiting .285 CaO
kaolin .171 $Al_2O_3 \bullet 2SiO_2$
flint .457 SiO_2

Arrange this in the unity format chart:

RO, R_2O	R_2O_3	RO_2
.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 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 $\frac{\text{100 units M.W. CaO}}{\text{1 molecule CaO}}$ = 100 units of wt. whiting

.6 Al_2O_3 molecules needed x 258 units M.W. kaolin = 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 $\frac{\text{60 units M.W. } SiO_2}{\text{1 molecule } SiO_2}$,= 96.18 units of wt. flint

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:

<u>Ceramic Industry</u> 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

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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:

CeramicsWeb, a major resource for much information about Ceramics, glazes, glaze calculation by Richard Burkett (author of HyperGlaze) at San Diego State University. See Class Information for articles on clays and glazes, glaze chem, et al. GlazBase resource for public database of glazes, and much more.
http://art.sdsu.edu/ceramicsweb/

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

GlazChem. Good PC Shareware program for glaze indexing and calculation by Bob Wilt. Download and try. Pay $30.00 if you decide to keep it. I have over 1000 glazes in the program and will share them with registered users.
http://www.dinoclay.com/software/index.html

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://members.aol.com/hyperglaze/