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TechnoFile: Viscosity

Tina M. Gebhart
Gettysburg College

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Abstract
The article focuses on the effect the viscosity of a glaze or slip has on a piece of pottery. The article explains the term and provides tests that can be performed to determine the viscosity of a substance. It goes on to describe how one can manipulate the viscosity of a glaze or slip through the addition of water or other aids and includes step-by-step instructions for making a slip.

Keywords
viscosity, glazed pottery, ceramics

Disciplines
Art and Design | Ceramic Arts | History of Art, Architecture, and Archaeology
Viscosity

How thickly or thinly we batch our glazes and slips can determine how much ceramic material is applied to our work. Changes to viscosity can determine whether shrinking, cracking, or application drips occur, and changing the viscosity does not have to mean adjusting the water content.

Define the Terms

**Double Layer:** The two charged layers surrounding a particle in suspension. The first layer, resulting from direct electrostatic charge attraction, is on the surface of that particle. The second layer is outside that and is composed of ions attracted from the surrounding solution.

**Double Layer Compression:** If more ions or stronger charge ions are available to neutralize the attraction between the two charged layers surrounding a particle in suspension, the second layer ends closer to the particle. This allows for surface-charge repulsion in particles, but allows them to be closer together, in a network. Clay particles normally have both electrostatic attractions and repulsions, as well as gentler attractions of Van der Waals forces, which attract based on proximity of particles, like a kind of gravity. This is similar to the idea that opposites attract; the compression state harnesses both properties to make a strong network, much like a strong community.

**Peaking:** Showing meringue-like points when a slip is stretched.

**Poise:** The cling of the glaze to the bisque ware during application. Officially a unit of measure for viscosity, but is often used in our field to describe the hang time and application activity of glaze/slip (i.e. physical drips, curtaining, and flowing away from edges on application).

**Solids Loading:** The actual amount of solid material/particulate in the suspension, regardless of the viscosity. Density of the suspension; mass per volume. The mass of ceramic material in the suspension, regardless of the viscosity.

**Suspension:** Liquid with particles floating within it. Slips and glazes are suspensions.

**Solution:** Liquid with material dissolved in it.

**Super-Saturated Solution:** A solution with enough of a material dissolved that the liquid cannot contain any more of that material. It is beyond its saturation point. Additional material will not dissolve, but falls to the bottom of the solution as solids/precipitates.

**Viscosity:** Resistance to flow, or anti-flow. Low viscosity flows a lot. High viscosity flows only a little or not at all.

Finding the Flow

Glazes and slips are suspensions and behave with some amount of fluidity. This fluidity is a continuum, ranging from flowing-like-water to nearly-wedge-able. The formal term used to describe this property is viscosity.

Viscosity is the resistance to flow in a fluid or a fluid-like material. A high-viscosity fluid is thick and relatively non-flowing; a low-viscosity fluid is thin and flows with ease. We commonly use the terms thick and thin to describe these fluid states because a high-viscosity glaze typically applies a thick coating of material, and a low-viscosity glaze typically applies a thin coating. The terms high viscosity and low viscosity are more specific and clear than thick and thin, because they cannot be misunderstood as a measurement of an application layer thickness. Applied thick can mean applied while in a high viscosity state, or applied so that there is more ceramic material present, i.e. a thicker coating, and these meanings are not always interchangeable.

When applying a suspension, the application process is the how, and the actual physical layer that results is the what. Viscosity determines how the suspension moves during application—how it applies. We can also call this property poise. Solids loading, the amount of solid material in the suspension, determines the physical thickness of a resultant suspension application—what material is deposited (1).

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1 Visco-Loading Punnett Square. The solids loading of a suspension batch illustrating the potential combinations of viscosity state and solids loading levels. A standard low-water mix looks thick, applies thickly, and deposits thickly—whereas a low-viscosity mix with higher solids loading (deflocculated/dispersed) looks thin, applies thinly, but deposits thickly.
Viscosity Measurements: Ease vs. Accuracy

Measuring viscosity in ceramic suspensions can be a deceptive thing, because of the issue introduced above, that physical viscosity may not match the solids loading. The methods below are standard ways of measuring viscosity, each of which has some advantages and disadvantages. For ideal control in your suspension, any of these should be combined with specific gravity measurements to keep the solids loading consistent.

The Finger Test
This is a simple, non-numerical test performed by dipping one’s finger into the well-mixed suspension. The finger is removed and the ceramist judges the remaining coating of suspension by eye. Judgment is based discerning the forms of the cuticle, fingernail, and skin folds through the ceramic material layer while it is still wet. Seeing the skin surface/color through the layer (visual sheerness) generally indicates very low viscosity; seeing no discernible form details, where the finger looks like a corn dog, is very high viscosity. Nuances of seeing some form details, with no sheerness, are the typical indicators of “just right” viscosity.

Pros: This test is quick, and tools are readily available. Cons: The measurements of low and high viscosity are relative to the particular suspension. Familiarity and practice with that particular suspension are needed to establish accurate judgment. This is not quantitative, and not easily transferable from person to person.

Drip Cup (Ford Cup or Zahn Cup)
These are cups of a standard volume that have a hole of standard size (there are multiple standard sizes) in the base, allowing a suspension to flow out. Drip cups have a ladle handle making them easy to dip and withdraw from the suspension bucket. A given volume of the suspension flows out of the hole, that flow time is recorded, and that time indicates the viscosity of that material.

Pros: This testing method is accurate for viscosity proper, and is consistent across different materials, slips, and glazes. Viscosity results can be well quantified, and data/accuracy is transferable between people and studios. Cons: Can be more physically awkward due to multiple tools (cup, timer) and simultaneous handling. Standard drip cups cannot be used with very high-viscosity suspensions.

Hydrometer
This is a glass bobber that floats at a certain depth depending on the viscosity of the suspension. Normally a hydrometer is used to measure the density (specific gravity) of a solution. When used to measure a suspension, a hydrometer is more effectively measuring viscosity (as will be apparent if used in a pre-Darvaned and post-Darvaned suspension). This tool must still be paired with the long-hand specific gravity measurements below for full control. Hydrometers are made with different measurement ranges for different applications.

Pros: This testing method is fast, simple to use, and is quantifiable. Relative accuracy can be transferred between people/studios. Cons: Finding a hydrometer of the desired range in the desired length (so that it fits into your bucket) can be a slight challenge.

Specific Gravity
Specific gravity is a measurement to pair with the above viscosity measurements. Given that potential viscosity shifts may or may not indicate more or less water, we must check the amount of solids loading by measuring the specific gravity. A given volume of the suspension is weighed against the same volume of water, and the relationship between these two weights indicates how much particulate is present in the suspension. Traditionally, the volume used for testing specific gravity is 100mL, and this allows for comparison in a universal measurement system. (Ideal terra sigillatas have a specific gravity of 1.1-1.2 whereas standard glazes and traditional slips may be in the range of 1.4-2.0.) Water is 1.0 in this system, and is the standard of measure.

If a suspension has a different specific gravity than usual, even if it has the same viscosity measurements in a Zahn cup or with a hydrometer, it will not deposit the same, even if it seems to apply the same, because it has a different solids loading.

Viscosity Manipulations: Best of Both Worlds

The simple addition of water is the most direct method of adjusting viscosity and is the primary difference between plastic clay and slip. Sometimes a water addition brings with it undesirable changes, such as increased shrinkage on drying, problems with cracking, a shift in the poise of the material, or creating a gradient in the suspension application layer where the application is actually thinner on edges and ridges than it is elsewhere.

We may want that suspension to apply with a low-viscosity nature, such as flowing off of high points, or a high-viscosity nature, where it clings well over edges. We may, at the same time, want the resultant suspension layer to be thin or thick because the look of that fired material is different in those different states. What if we need a glaze to cling while applying, yet we need the look of the physically thin glaze? Or vice versa? Knowing how to increase or reduce viscosity will give you the best of both worlds during the glazing process.

Additions of deflocculant will reduce the viscosity of a suspension, and can allow it to act like it has more water without having more water. That suspension will then apply with a thin application nature, yet cling to the artwork in a thicker deposit (1). This can be a helpful characteristic to have in a slip used for attachments or for slip trailing, where shrinkage from high water levels can cause cracking or loss of the three-dimensional effect.

Small additions of a flocculant (like Epsom salts) can increase the viscosity of a suspension, allowing for more cling during application without much affecting the overall thickness of the layer applied. This allows artwork to be evenly coated with a generally thin layer—less material applied, but less flowing during the application process. This can be a helpful change when using persnickety glazes that normally show even the slightest difference in application layer thickness, such as drips and thickness gradients.

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Adding Darvan (typically Darvan 811 for slips, Darvan 7 for glazes) affects the surface charge on clay particles, causing them to repel each other. This repulsion, much like magnets aimed toward one another, increases fluidity of the particles because of reduced friction, therefore reducing the viscosity of the suspension. As John Gill says, "Darvan makes water wetter." Casting slips rely on this effect of increased flow and decreased water, which allows more casting cycles before the plaster molds become water saturated. (2a and 2b).

**Viscosity Curve: Casting and Stick-Up Slip**

Casting slips typically reside around point A on the viscosity curve (3). At point B, larger material particles (silica, feldspar, frit) will often settle out. An addition of a saturated Epsom Salt solution will move the material back to point A, and the slip becomes an excellent attachment/trailing/meringue slip. In this slip, we have higher solids loading (more particles per volume) as well as high flow (as compared to the solids loading in a standard slip) with high cling (compressed double layer, with dispersion and flocculation).

2a, 2b: Diagrams of clay particle charges and Darvan. (a) Mechanics of Darvan's attachment to clay platelets. (b) Negative surfaces repel/flow. 3 Relationship of deflocculant additions to viscosity and tracking of the Super Slip experiment (described below).

**Super Slip: The “Carty” Approach**

The following Super Slip works as an attachment slip, is perfect for slip trailing, and also as a meringue slip. The slip has nearly the same solids loading, and nearly the same shrinkage as the clay body in the plastic (wedge-able) form, unlike slip batched to the same viscosity with water only.

The exact recipe for this slip modification will be different for each clay body, and the procedure (below) is written to accommodate those differences. This slip batching process will work for a commercial clay body, where you do not know the ingredients and cannot batch the body from scratch, as well as for a homemade clay body. For commercial clay, use dry trimmings and crush them (I use a mortar and pestle). For homemade clay, batch from dry powdered ingredients, or use crushed trimmings. You can also use a slip recipe from dry ingredients for this experiment.

As you proceed, keep track of 1) the amount of water added, 2) the number of drops of Darvan added, and 3) the number of drops of super-saturated Epsom salt solution added. Afterward you can create a standard recipe for subsequent batching.
1. To 200 grams (or more, just keep good records) of dry clay body, add just enough water to make the material an extremely thick paste (nearly wedge-able but still sticky). Mix to an even consistency (4a).
2. Add Darvan 811 drop by drop (I use a syringe, but I used to use a chopstick). Continuing to mix the slip thoroughly (I use a hand-held immersion mixer). As you continue to add Darvan, first the viscosity of the clay will decrease as the clay becomes slip and it will develop slight peaking tendencies as it continues to decrease in viscosity (4b), nearing point A on the viscosity curve. Then it will stop peaking and become excessively fluid (4c). At this point, increased deflocculant will make no additional visual difference. The batch is now at the bottom of the viscosity curve in (2), at approximately point B.

3. Batch a separate container of super-saturated Epsom salt solution by mixing about 50–70 g of Epsom salt with 100 g of room-temperature water, adding salt until some settles on the bottom (as precipitate) and will not dissolve. Mix thoroughly. Allow to settle.
4. While continuing to mix the slip thoroughly, add the Epsom salt solution, drop by drop, until the magnified peaking tendencies of the slip result and the slip is of a middle (near point A) viscosity (4d).
5. Adjust water content to suit method of use, remembering to record additions in the batch recipe or to measure specific gravity for consistency. Determine how many drops of Darvan you need when scaling up to a larger batch. If the number becomes too high, convert to something other than drops (tablespoons, grams, etc.).
