TECHNO FILE

casting rheology
by Jonathan Kaplan

Clay exhibits remarkable properties that, with the help of some basic chemistry, allow it to be fully dispersed in water to become a casting slip. With an understanding of some basic concepts of rheology, we can increase our skill set and formulate smarter casting slips.

Define the Terms

**Casting Slip:** A suspension of plastic and non-plastic ingredients, chemicals, and water, with a high concentration of solids and a low water content.

**Deflocculants (deflocculation):** Materials that increase a liquid clay’s fluidity by affecting the charge on the clay particle and preventing flocculation.

**Dipole:** A molecule in which a concentration of positive electric charge is separated from a concentration of negative charge.

**Flocculation:** The opposite of deflocculation, it is the process of making a thin and liquid clay slurry into a gel in order to improve suspension. Flocculated slips have a high water content, thus a higher shrinkage.

**Meniscus:** The curved upper surface of a liquid in a cylinder.

**Rheology:** The study of how fluids flow, in this case the array of characteristics that ceramic slurries exhibit (viscosity, thixotropy, etc.) over an entire range of applied shear conditions.

**Slip:** A slurry made of clay and other clay body ingredients suspended in water.

**Slurry:** Suspension of solids in a liquid.

**Specific Gravity:** The weight of a volume of liquid divided by the weight of the same volume of water. Sometimes referred to as specific density.

**Thixotropy:** The property of a slurry’s viscosity to decrease when subjected to shear, followed by a gradual increase in the viscosity when the shear is stopped.

**Viscosity:** Resistance to flow of any fluid, caused by internal friction. High viscosity fluids are thick (think cold honey), low viscosity fluids are thin (think water).

**Fluid Flow**

Rheology is a broad term that covers the flow of fluids. Newtonian fluids are simple fluids that have constant viscosity regardless of shear. The viscosity of non-Newtonian fluids changes depending on the shear rate. Mayonnaise and ketchup are good examples of non-Newtonian fluids: shaking or mixing them up will change the viscosity. Water is a Newtonian fluid and a casting slip is a non-Newtonian fluid.

The relationship between clay and the water suspending it is the foundation of slip casting. The water molecule plays a very important role in a clay-water system. The structure of water exhibits a dipole—there are positive and negative charges on opposite sides of the molecule. Further, water molecules are attracted to each other. The positive charge of one side of the molecule is attracted to the negatively charged side of another water molecule (unlike charges attract, like charges repel). This is called dipole-dipole attraction.

When a clay particle is suspended in water a “water-hull” forms around the clay particle, wherein the minute clay particle is totally surrounded by water molecules. The size of clay particles suspended in water is quite small, but there is a large concentration of solids.

The water molecules attracted by the surface of the clay particles form a very ordered structure. This means that the arrangement, or fit, of the ions and molecules is tight and closely packed. The arrangement of the water structure with the principal clay mineral, kaolinite, is critical in a clay-water system.

When clay settles out into the bottom of the container, this is a clear demonstration of the attraction of oppositely charge particles. These clumps of materials are called flocs. However, in casting, combining a high concentration of solids with low water content and an added deflocculant results in a fully dispersed volume of material where the clay particles are repelling each other. Deflocculants allow the dispersion in water of both plastic and non-plastic materials.

What we wish to accomplish in casting slips is to deflocculate the mixture, preventing the clay particles from forming flocs. This is accomplished with the addition of materials that contain sodium ions (+Na). With the additions of soda-based materials such as sodium silicate or Darvan products, often referred to as electrolytes, the result will be a stable clay system.

A While the science is more complex, it is convenient to visualize a deflocculated slip as being like a deck of cards, densely stacked, and a flocculated slip as like a jumble of cards, resulting in much lower stacking density of the particles. The shrinkage in a flocculated system is greater as there is more water in the space between each clay particle. Diagram adapted from W.G. Lawrence & R.R. West, Ceramic Science for the Potter, figure 5-4, page, 79.
For deflocculation, sodium silicate in conjunction with soda ash is common. However, like other deflocculants they have a very tight range of effective concentration with little or no room for error. Sodium silicate deflocculation is also very hard on plaster mold life. Other sodium-based products, Darvan 7 and Darvan 811 (generally considered a more superior product for slip casting) are sodium poly-electrolyes, are much more forgiving, and do not adversely affect mold life. They help obtain higher solid content slips, improved viscosity stability, fewer soda or hard spots in the castings, are easier to reclaim without constant adjustments with more deflocculant, and have little tendency to thicken on standing.6

Water content will vary depending on the materials used. In general, to mix a 10 pound batch of casting slip, the amount of water will be between 28–45% of the dry weight. A good starting point for using Darvan products for deflocculation would be 0.35%. These amounts will need to be fine tuned for each particular casting slip.

Measuring Specific Gravity
Since a casting slip needs a very specific ratio of solids to water to work properly, measuring specific gravity is important. Specific gravity can be measured with a hydrometer, but a hydrometer can be inaccurate. A more precise method is to weigh a known volume of casting slip and divide that number by the weight of the same volume of water. While any container can be used to measure specific gravity, it is important to use the same container for weighing the water and the casting slip. Water always has a specific gravity of 1.00. In both cases, the weight of the container must be considered, as well as the presence or absence of a meniscus. For example, if the

To design a casting slip from raw materials, the general ratio, derived from traditional bodies and the greenware industry, is 50 parts of plastic materials (clays) and 50 parts non-plastic materials (silica, feldspar, fillers, etc). In contrast, a body designed for wheel throwing or handbuilding might have a ratio of 70–95 parts plastic materials to 5–30 parts non-plastic materials—these are ratios that have been tested and proven to work, although there are many other possibilities.

Plastics
Casting bodies can be built around most, but not all, clays. First, it is important to have a variety of materials including kaolins, ball clays, fire clays, and even red clays if desired. There are both ball clays and kaolins that are specifically designed for casting such as Opticast (formerly Velvacast) Kaolin from Imerys and Old Hickory FC340 (Fast Cast 340 ball clay). Second, it is also important to pay attention to the particle sizes of the component clays so that the rate of water migration through the clay wall and into the plaster mold can be optimized. For example, a cone 04 terra-cotta casting body containing Cedar Heights Red Art and a ball clay for plasticity, which both have extremely fine particle sizes, will cast very slowly. The addition of a coarse-grained kaolin such as Opticast will appreciably speed up the casting rate without affecting the desired terra-cotta color. Using FC340 will also help as ball clays are the glue that holds everything together in a casting slip by promoting gelling.

Non-Plastics
For the 50 parts non-plastic side of the formula, feldspars, talc, pyrophyllite, and flint are necessary. The amounts and selection of these materials are based on the desired maturing temperature of the clay body.
weight of 1 pint of casting slip is 795 grams, and 1 pint of water is 454 grams the specific gravity of the slip is 1.75 (1.75 times heavier than the same volume of water). While every casting slip has its own unique specific gravity, a good rule of thumb is 1.75–1.76.

**Measuring Viscosity**

Viscosity is best measured with a viscometer. A standard one used in slip casting is a #2 Zahn Cup (C). Using a stop watch, the slip is timed as it flows out of the cup, stopping the timing at the first break in the stream. Each casting slip will have its own unique time, and there is no standard reference to use for comparison. An inexpensive viscometer can be purchased at any paint supply store.

### SCOOTER’S OFF-WHITE CASTING SLIP

Cone 6–10 Oxidation/Reduction

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
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</thead>
<tbody>
<tr>
<td>Custer Feldspar</td>
<td>25 lbs</td>
</tr>
<tr>
<td>FC340 Ball Clay</td>
<td>18</td>
</tr>
<tr>
<td>Greenstripe Fireclay</td>
<td>11</td>
</tr>
<tr>
<td>Opticast or Velvacast Kaolin</td>
<td>21</td>
</tr>
<tr>
<td>Pyrophyllite</td>
<td>2</td>
</tr>
<tr>
<td>Silica</td>
<td>12</td>
</tr>
<tr>
<td>Fine Mesh Grog</td>
<td>1</td>
</tr>
</tbody>
</table>

100 lbs

Start with 30% water and adjust to achieve a specific gravity of 1.78

Start with .35% Darvan 811 and adjust until the correct deflocculation is achieved. Casting a small test sample and timing the casting for optimum wall thickness is the only way to determine if the specific gravity and viscosity are correct. Every slip is different.

Specific gravity should start at 1.80 and end at between 1.75–1.78: Add small amounts of both water and Darvan until the correct numbers are reached. Blunge between additions so that the materials are completely dispersed. Adding small amounts of materials will help prevent going too far on that bell curve and over deflocculating or thinning the slip with too much water.

Viscosity should around be 31 seconds.

### TOM SPLETH CASTING SLIP

Cone 9-10 (from Cushing’s Handbook)

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Custer Feldspar</td>
<td>18 %</td>
</tr>
<tr>
<td>Ball Clay</td>
<td>8</td>
</tr>
<tr>
<td>Grolleg</td>
<td>30</td>
</tr>
<tr>
<td>Pyrophyllite</td>
<td>12</td>
</tr>
<tr>
<td>Velvacast</td>
<td>12</td>
</tr>
<tr>
<td>Silica</td>
<td>20</td>
</tr>
</tbody>
</table>

100%

Add:

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darvan 7</td>
<td>0.35 %</td>
</tr>
<tr>
<td>Water</td>
<td>40.00 %</td>
</tr>
</tbody>
</table>

### Troubleshooting the Mix

- If too much deflocculant is accidentally added, the slip becomes thixotropic and should be discarded. While an undisturbed slip will show signs of thixotropy (For example, a good casting slip remains fluid after being agitated and while in use, but when allowed to stand without disturbance it gels, thus preventing settling of the materials. Mixing will make the slip more fluid.
- If the specific gravity is too high, water can be added in small amounts, but note this will also affect the viscosity.
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- Check specific gravity and viscosity before each use.
- Always sieve any casting slip before use to remove the LOI (loss on ignition) and related tramp materials.