TDS-244
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Measurement and Understanding of Yield Value in Personal Care Formulations

What is Yield Value?
Yield value is a measurable quantity similar to, but not dependent on, viscosity. It can be thought of as the initial resistance to flow under stress, hence, it is also referred to as yield stress. Carbopol® polymer gels exhibit a yield value that allows them to be useful in a variety of applications.

What Does Yield Value Do?
Yield value is a property critical to achieving certain physical characteristics, such as:

Suspension - Particles dispersed in a medium will remain suspended if the yield value of the medium is sufficient to overcome the effect of gravity or buoyancy on those particles. On a label, the phrase "Shake well before using" can be read as "Needs a higher yield value".

Emulsion - Insoluble liquid droplets can be prevented from rising and coalescing with yield value. (i.e. hand creams, sunscreens, hair conditioners)

Foam - Gas bubbles can also be suspended and uniformly distributed in a liquid medium using yield values as a formulating tool. (i.e. shampoos, hair mousses, shave creams)

Surface Cling - With enough yield value, a gelled liquid will not drip or run down a vertical surface. (i.e. hair sprays, face masques)

As examples, to suspend large mineral oil beads in a bath gel, it might take a Brookfield yield value of 300 - 450. Whereas to stabilize a mineral oil/water emulsion might require a Brookfield yield value range of only 100 - 200. Similarly, to suspend mica in a shampoo could call for a Brookfield yield value of 130 - 200. Suspending larger particles of pumice in a foot scrub could require a Brookfield yield value in the range of 250 - 300.

How is Yield Value Measured?
The most common way to measure yield value is the Brookfield yield value extrapolation method. A Brookfield RVT viscometer is used to measure the torque necessary to rotate a spindle through a liquid sample at speeds of 0.5 to 100 rpm. Multiplying the torque reading by the appropriate constant for the spindle and speed gives the apparent viscosity. Spindle speed corresponds to shear rate. Yield value is an extrapolation of measured values to a shear rate of zero. Brookfield yield value (BYV) can be calculated by the following:

$$\text{BYV*, dyn/cm}^2 = \frac{2r_1\,(\eta_{a1} - \eta_{a2})}{100} \quad \text{(Eq.1)}$$

Where, η_{a1} and η_{a2} = apparent viscosities obtained at two different spindle speeds, r_1 and r_2, respectively.
*Only when $r_2/r_1 = 2$

If spindle speeds of 0.5 and 1 rpm are used:

$$\text{BYV, dyn/cm}^2 = \frac{(\eta_{a1} - \eta_{a2})}{100} \text{ or BYV, Pa} = \frac{(\eta_{a1} - \eta_{a2})}{1000} \quad \text{(Eq.2)}$$

Yield value (stress) can also be measured using a cone-and-plate rheometer. Shear stress is measured as a function of shear rate. The resultant curve is fitted with what is called the Casson Rheological Model:

$$\sigma^{1/2} = \sigma_y^{1/2} + (a\gamma)^{1/2} \quad \text{(Eq.3)}$$

Where, $\sigma \equiv$ shear stress, $\gamma \equiv$ shear rate, and $\sigma_y \equiv$ yield stress

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How is Viscosity Different from Yield Value?

Viscous suspensions can and will collapse. It is a common misconception that if the viscosity of a product is high enough, it can be used to suspend. *Actually, a higher viscosity only slows down the rate of particle movement.* Yield value is required to create a stable suspension.

Table I demonstrates the relationship between yield value of a sand suspension and suspending ability.

Silica sand with an average particle diameter of 0.6mm was placed in gels made from various thickener types at different concentrations. The data suggests that a critical Brookfield yield value between 90 and 124 is required to produce a stable sand suspension. This clearly demonstrates that yield value, not viscosity, is the influencing factor in suspension performance.

How Do Carbopol® Polymers Compare in Yield Value?

It can be seen below in Figure 1 that each of the polymers maintains a useful yield value throughout the most common pH use range. They differ in their relative strengths depending on their type and degree of crosslinking. The data presented show that the polymers with a higher degree of crosslinking have higher relative values, as given for Carbopol® 940. Those with a lesser degree of crosslinking show lower relative values, as given for Carbopol® 941. Figure 2 shows the yield value efficiency of Carbopol® ETD and Carbopol® Ultrez polymers.

What Common Factors Affect Yield Value?

The yield value achieved with Carbopol® polymers can be changed by adding materials that affect the swelling of the polymer. Some materials that can cause a change in polymer swelling are alcohols, polyols, and cations. Each of these materials may have the effect of reducing the yield value of the system. The other primary factor affecting the yield value is the density of the medium. In this case, the dissolution of other polymers, polysaccharides for instance, may increase the medium density and lower the required yield value. Some systems can have more complex interactions of these two effects. Examples of this type can commonly be seen in surfactant formulations, further covered in TDS-224.

Table I
Effect of Yield Value on a Sand Suspension

Exp	Thickener	Concentration %	Brookfield Viscosity (mPa·s (cP), 20 rpm)	Brookfield Yield Value	Suspension Performance
1	Carbopol® 941 polymer	0.15	2,900	500	Stable
2	Carbopol® 934 polymer	0.25	6,350	410	Stable
3	Gum tragacanth (Homogenized)	3.00	9,740	276	Stable
4	Gum tragacanth (set 2 months)	3.00	-	144	Stable
5	Carbopol® 934 polymer	0.18	2,420	136	Stable
6	Carbopol® 941 polymer	0.10	1,950	124	Stable
7	Carbopol® 934 polymer	0.15	1,600	90	48 hours
8	Locust bean gum	2.50	22,800	80	8 hours
9	Polyethylene oxide	1.50	2,040	40	3 hours
10	Sodium CMC	1.50	5,900	36	3 hours
11	Guar gum	1.50	8,040	32	4 hours
12	Sodium Alginate	2.50	8,360	16	2 hours
13	Methyl cellulose	2.00	3,200	2	1.5 hours

Figure 1
Comparison of Carbopol Polymers
Yield Value versus pH, as 1.0% Wt Mucilages

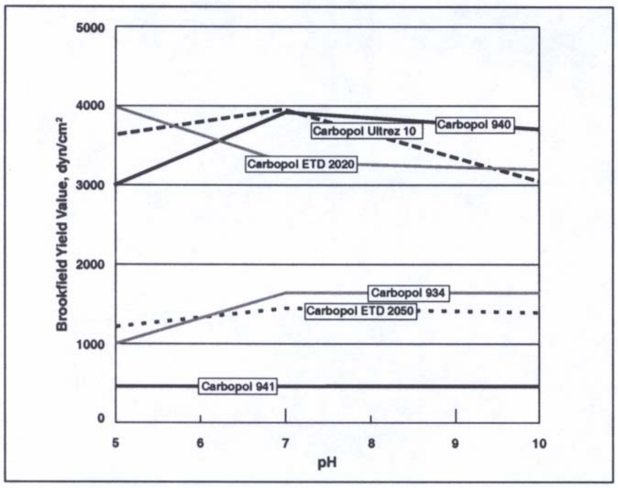


Figure 2
Comparison of Carbopol Polymers
Yield Value versus Wt %, at pH of 7

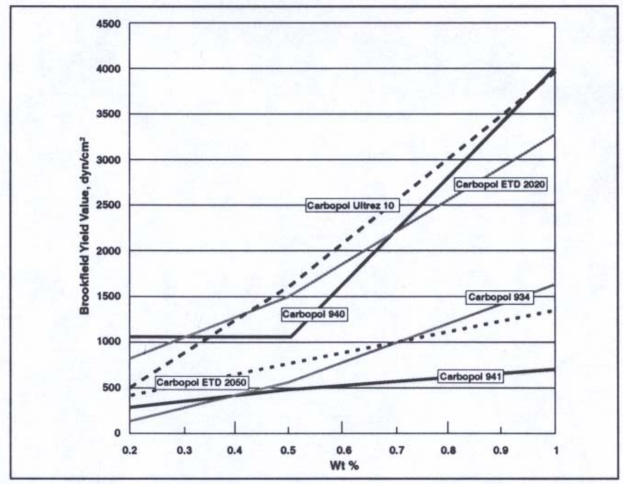
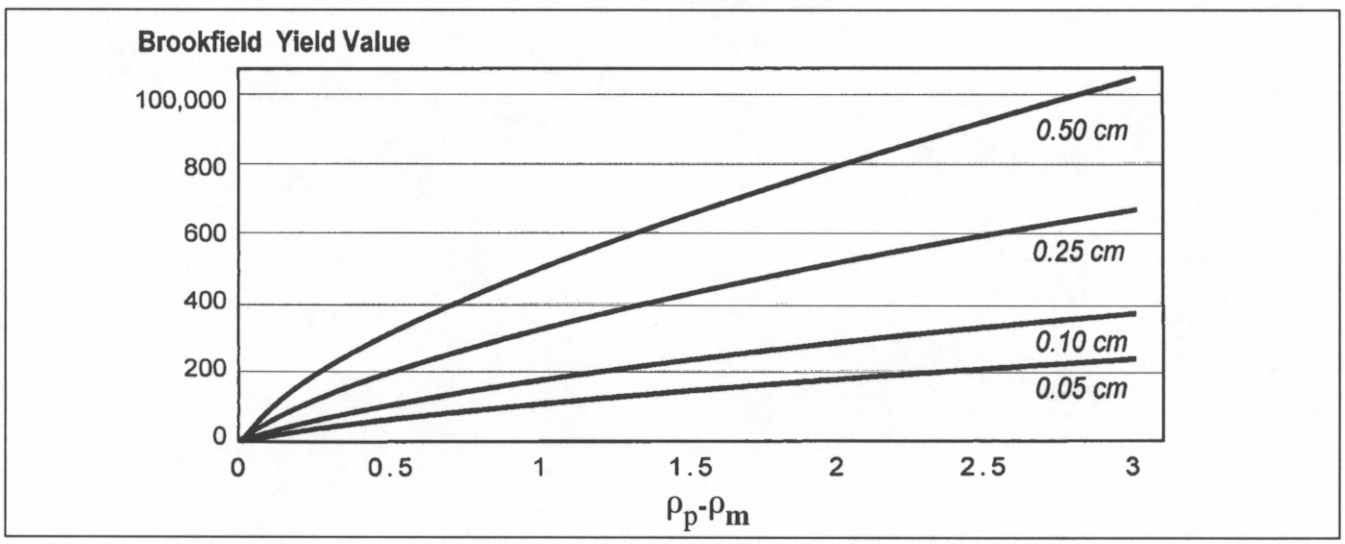


Figure 3



Can Yield Value for a System be predicted?

A simple approximation of the required yield value for a system can be obtained if the density of the medium and the size and density of an assumed spherical particle are known:

Yield Value, dyn/cm^2 = 4/3R (ρ_p-ρ_m)g

where **R** ≡ radius of the particle, in cm

ρ_p ≡ density of particle, in g/cm^3

ρ_m ≡ density of medium, in g/cm^3

g ≡ acceleration due to gravity ($980\ cm/s^2$)

Figure 3 shows how yield value is a function of the density difference (ρ_p-ρ_m) between the particle and the medium, and of the particle size (radius).