RHEOLOGY

for
Slip Production
&
Slip Casting

Presented By:

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Why Slip Cast?

- Produce difficult shapes, especially hollow shapes with many details
- Productivity
- Material utilization - scrap
- Drying efficiencies - defect control
- Firing efficiencies - faster cycles, placing density
- Ease of producing varying batch sizes and formulas

RHEOLOGY

The study of the change in form and the flow of matter embracing, elasticity, viscosity, and plasticity.

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Rheology, But what is it really?

Rheology is the basic understanding of how a clay/water system's properties interplay between the raw materials, the chemicals, and the mechanics of mixing, storing, and forming processes

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Rheology, But what is it really?

Another way I like to describe rheology is;

the understanding of a slip's deflocculation and the control of its long term "gel."

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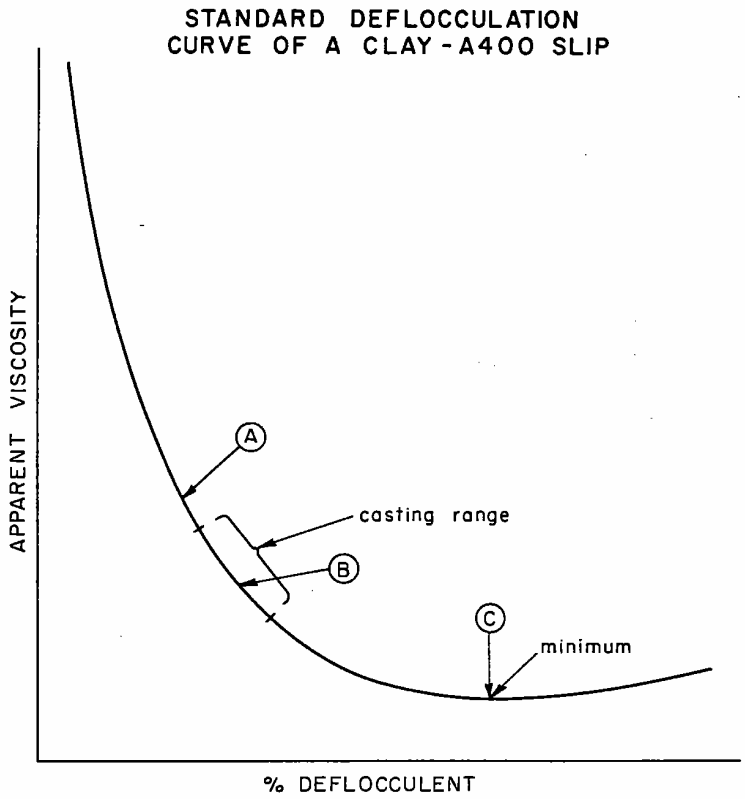

FIG. 3

Keys to Creating Good Rheology

1. Choosing good raw materials
2. Understanding your chemicals
3. Learning to make some physical property measurements
4. Understanding that producing slip is a dynamic process

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Raw Materials

- Understand what each raw material is used for,
  - Plasticity, strength
  - Vitrification
  - Thermal expansion
  - Sizing
  - Color
- Don't be afraid to experiment
  - seek advise
  - look for the best available material
  - don't get stuck on printed formulas

Chemicals, Keep it Simple!

- Deflocculants
  - Soda Ash
    - Sodium Hydroxide (hard water only)
  - Sodium Silicate
  - Darvan 811
- Sulfate Control
  - Barium Carbonate
- Flocculant
  - Epson Salt
    - Vinegar
    - Plaster

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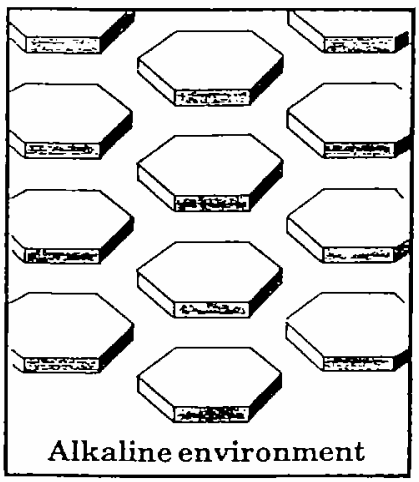
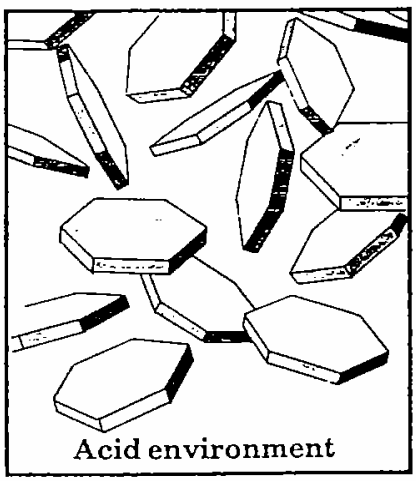
Deflocculated



Flocculated



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Chemicals, Keep it Simple!

- General Chemical Parameters (of dry batch weight)
  - Soda Ash 0.05-0.1%
  - Sodium Silicate 0.2- 0.4%
  - Barium Carbonate 0.01-0.03%

Slip Production is a Dynamic Process

All knowledgeable and experienced slip makers understand that daily physical measurements dictate what change options you have in order control your rheology.

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Slip Production is a Dynamic Process

Your chemistry needs to be changed according to your raw material variations. Your physical measurements will lead to the answer.

What is the raw material most overlooked?

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Slip Production is a Dynamic Process

What is the raw material most overlooked?

WATER

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Physical Property Measurements

- Specific Gravity
- Viscosity
- Cast
  - Rate
  - Feel
  - Drain quality
    - measure volume
  - Firming time

If you are just beginning - Chart your data to narrow your parameters

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Physical Property Measurements

Specific Gravity -

This is the most primary of measurements. The easiest way to explain is as follows.

A. Weigh an empty (250 - 500ml) container and record the weight in grams.

Physical Property Measurements

B. Fill the empty container with room temperature water and reweigh in grams.

C.Take the dried empty container and fill with slip poured through a sieve(40mesh). Record the weight of the container and slip.

Physical Property Measurements

D. Calculate the Specific Gravity as

$$\frac{\text{Weight of container with Slip - weight of container}}{\text{Weight of container with water - weight of container}}$$

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Physical Property Measurements

SPECIFIC GRAVITY CONVERSION TABLE
FOR SLURRIES & SLIPS

Calculated at 30°C (86°F), Water at 8.301 lbs/gal, Clay and other body materials at 2.60 g/ml – specific gravity

Specific Gravity	Ounces per Pint	Pounds per Gallon	% Solids	Pounds Body per Gallon	Pounds Water per Gallon
1.00	16.60	8.30	0.00	0.00	8.30
1.10	18.26	9.13	14.77	1.35	7.78
1.20	19.92	9.96	27.08	2.70	7.26
1.30	21.58	10.79	37.50	4.05	6.74
1.40	23.24	11.62	46.43	5.40	6.22
1.50	24.90	12.45	54.17	6.74	5.71
1.55	25.73	12.87	57.66	7.42	5.45
1.60	26.56	13.28	60.94	8.09	5.19
1.65	27.39	13.70	64.02	8.77	4.93
1.70	28.22	14.11	66.91	9.44	4.67
1.75	29.05	14.53	69.64	10.12	4.41
1.76	29.22	14.61	70.17	10.25	4.36
1.77	29.38	14.69	70.69	10.38	4.31
1.78	29.55	14.78	71.21	10.52	4.26
1.79	29.71	14.86	71.72	10.66	4.20
1.80	29.88	14.94	72.22	10.79	4.15
1.81	30.05	15.02	72.72	10.92	4.10
1.82	30.21	15.11	73.21	11.06	4.05
1.83	30.38	15.19	73.70	11.20	3.99
1.84	30.54	15.27	74.18	11.33	3.94
1.85	30.71	15.36	74.66	11.47	3.89
1.86	30.88	15.44	75.13	11.60	3.84
1.87	31.04	15.52	75.60	11.73	3.79
1.88	31.21	15.61	76.06	11.87	3.74
1.89	31.37	15.69	76.52	12.01	3.68
1.90	31.54	15.77	76.97	12.14	3.63

Note:

1. For slurries at 15°C (59°F), Water=8.329 lbs/gal. Multiply table "lbs/gal" by 1.003. Multiply corrected "lbs/gal" by 2 for corrected "oz/pint".
2. For slurries at 40°C (104°F), Water=8.272 lbs/gal. Multiply table "lbs/gal" by 0.997. Multiply corrected "lbs/gal" by 2 for corrected "oz/pint".

   In both 1 and 2, refigure "pounds body per gallon" and "pounds water per gallon" by use of "% solids" and corrected "lbs per gallon".
3. For clay at 2.50 specific gravity, multiply "% solids" by 1.026.
4. For clay at 2.70 specific gravity, multiply "% solids" by 0.977.

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Physical Property Measurements

Viscosity -

A variety of measuring methods have been discussed in various articles from a veterinarian's syringe, to a flask with a rubber stopper, to the drip method. However, I prefer the PVC pipe(8 to 10 inches), one end capped with a 3/16 inch hole drilled in the center.

Physical Property Measurements

Viscosity -

Take the PVC tube and plug the hole. Precisely measure 250 or 300 ml of water into the "flow tube." Mark the interior of the tube so the same amount of slip can be measured on each test. The head pressure height will effect the final reading.

Physical Property Measurements

Viscosity -

Fill the slip to the determined mark in the flow tube, with your finger over the hole. Place the flow tube on a stand above a 250 ml graduated cylinder. Remove your finger and record in seconds (using a stopwatch) the time of flow between 50 and 250 ml.

Physical Property Measurements

Viscosity -

The time measured will eventually be an excellent guideline in determining the amount of deflocculant needed to obtain the viscosity for the type of cast you desire.

Physical Property Measurements

Cast -

In the beginning, you will need to establish a casting rate relative to the Specific Gravity and Viscosity. This will help in establishing daily parameters to produce the slip and aid in resolving casting problems when they occur.

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Physical Property Measurements

Cast -

Take a simple “cup” mold and cast it for a fixed time. Then drain and measure the weight of the piece after a fixed time for firming. Qualify the weight by observing the drain cleanliness and feel for moisture uniformity. This information in conjunction with Specific Gravity & Viscosity will yield you the total picture of rheology.

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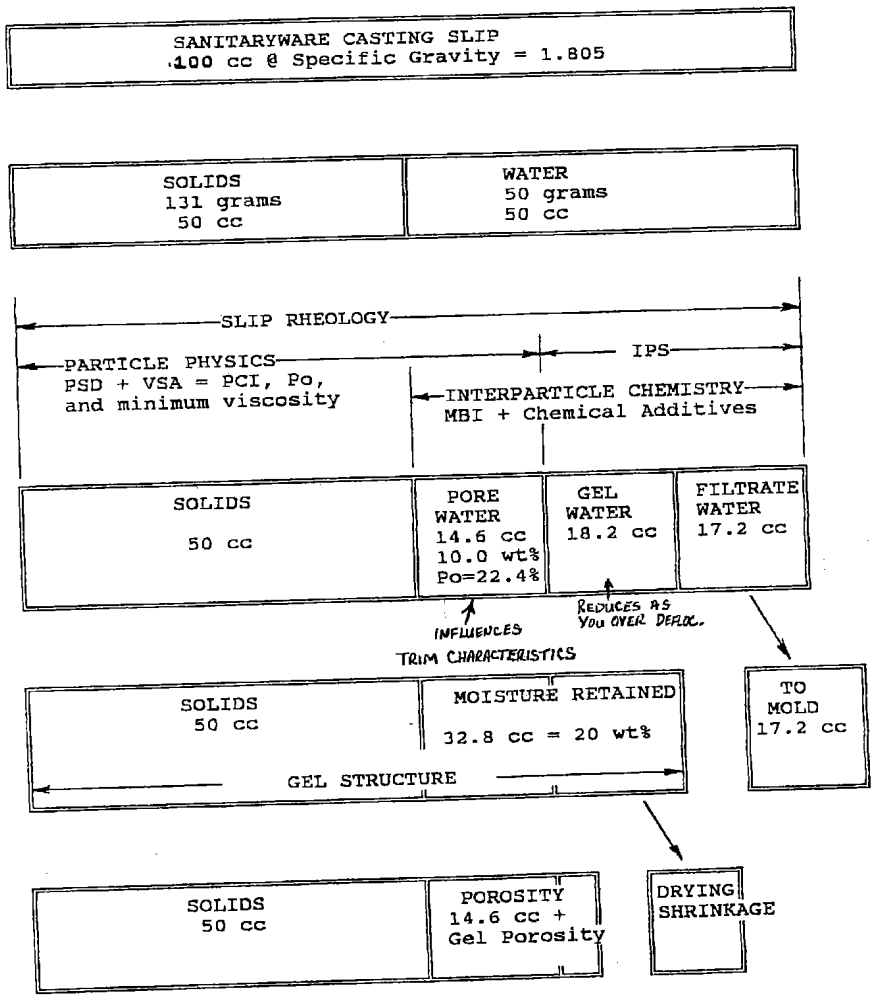
Figure 4. A Model For Slip Casting



PSD = Particle Size Distribution
VSA = Volume Surface Area
PCI = Particle Crowding Index

MBI = Methylene Blue Index
IPS = Interparticle Spacing

RHEOLOGY
in
Summary

In one word:

Balance

Balance between your Raw Materials & Chemistry

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RELATIONSHIPS BETWEEN THE VARIABLES AND THE PROPERTIES OF THE CASTING SLIP AND THE CAST

I	II	III
INCREASING COLLOIDS	INCREASING SULFATE	INCREASING ELECTROLYTE
↓ Fluidity*	↓ Fluidity*	↑ Fluidity*
↓ Rate of Cast	↑ Rate of Cast	↓ Rate of Cast
↑ Plasticity	↑ Plasticity	↓ Plasticity
↓ Hardness*	↓ Hardness*	↑ Hardness*
↑ Thixotropy	↑ Thixotropy	↓ Thixotropy
↑ Drying Time	↑ Drying Time	↓ Drying Time
	↕ Chemical Stability	

* Modifiers: ↑ Fluidity ---- ↓ Slip Density

↑ Hardness --- ↑ Sodium Silicate / Soda Ash

↑ Increases

↓ Decreases

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Common Problems Associated with Qualities of Slip

Even after the most careful steps in preparing slip, occasionally problems arise in the performance qualities. Listed below are some common deficiencies that can be related to slip quality and suggested methods to improve performance:

Deficiency Quality	Solution
(1) Ware has sufficient to rapid casting rate, but drains slow. Piece is soft and distorts or requires lengthy drying time.	(1) Increase fluidity of the slip by adding sodium silicate to improve drain quality. If specific gravity is 1.80 or higher, add water to reduce in the range of 1.78. Excessive sodium silicate additions with little improvement in fluidity may indicate high soluble sulfate. If true, add 0.01% - 0.03% barium carbonate to the slip based on the total weight of the dry ingredients of the batch size.
(2) Ware casts slowly but drains very clean. Cast piece is brittle and difficult to trim smoothly.	(2) Reduce sodium silicate additions to subsequent batches. Current slip batch can tolerate 0.01% Epsom salts addition based on total weight of dry material to increase viscosity.
(3) Upon removal from the mold cast surface peels off leaving coarse interior exposed particularly on solid cast section of fine detail molds - hands, feather tips, etc.	(3) Increase ball clay content 1-2% at expense of talc to reduce permeability of cast structure. Insure that slip fluidity is sufficient for drain quality but not overly fluid.
(4) Discolored spot on fired piece that has noticeably thin glaze coverage or none at all.	(4) This defect is referred to as a "hard spot" or "cast spot". Insure that slip does not enter mold under high velocity. Direct slip to the bottom of the mold by use of a funnel which prevents slip splash. Increase viscosity of the slip by reducing amount of sodium silicate on subsequent batches.

VISCOSITY

The measurement of the consistency of a slip which gives a numerical value to its resistance to flow.

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THIXOTROPY
or
Gelation Characteristics

The tendency of a slip to increase in viscosity when left undisturbed, due to a build-up of structure within it, and which can only be destroyed by agitation.

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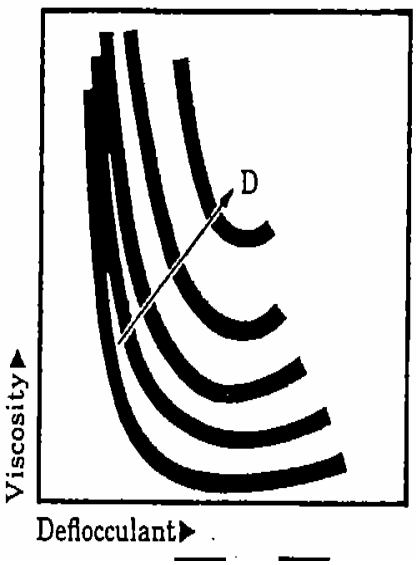
Effect of density



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The effect of water on thixotropy

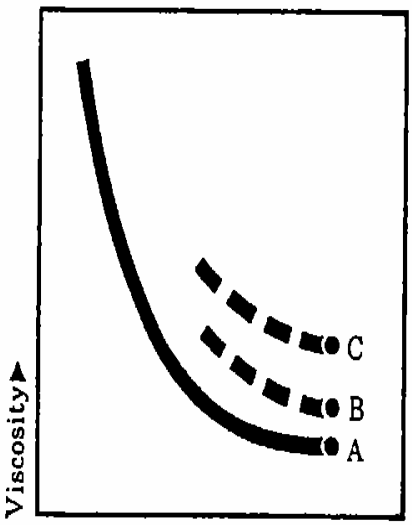

Fig 3.

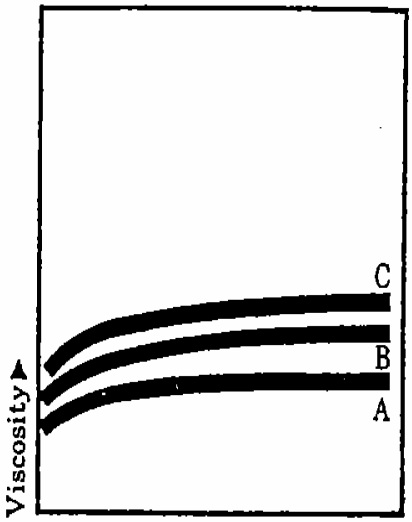

Fig 4.

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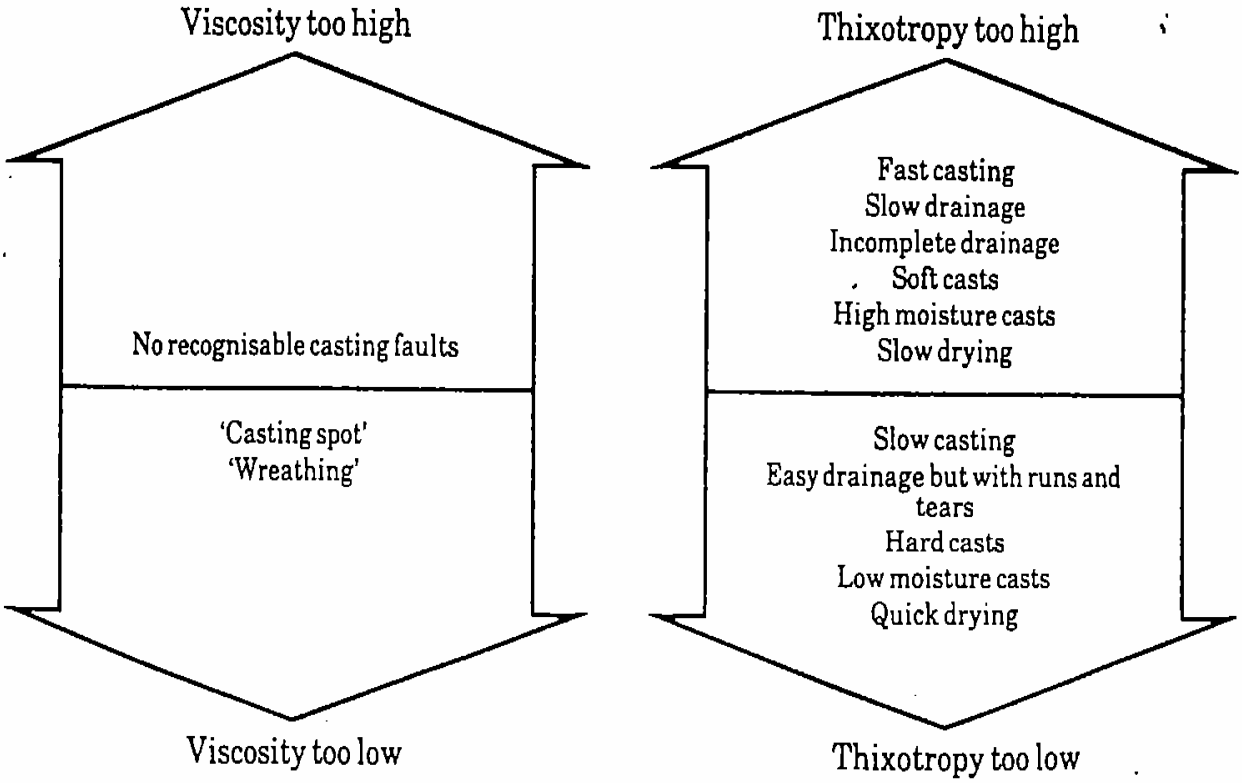
What are the noticeable faults if viscosity or thixotropy levels are incorrect?



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The effect of alkali on thixotropy

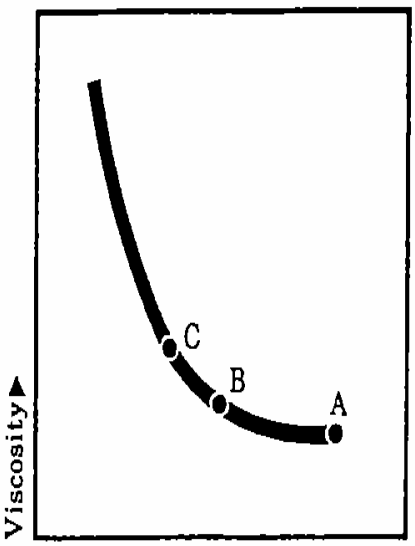

Fig 1.

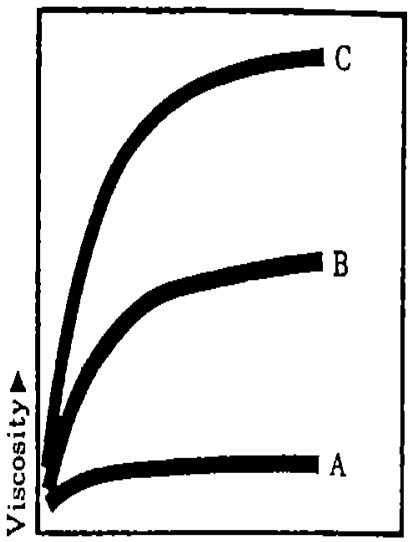

Fig 2.

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