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# The Effect of High Velocity Shear on Coating Properties

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Senior Thesis

Topic: The Effect of High Velocity Shear on
Coating Properties

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Richard Wilhelm

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I acknowledge gratefully the helpful suggestions of my thesis adviser, Dr. R. A. Diehm and the assistance he provided in obtaining materials.

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Senior Thesis

## Abstract

The chief reason for this work was to investigate the effect of a high velocity shear imparted to a NoKarb clay by a Cowles Dissolver at 5600 rpm.

After a 12 hour shearing period drawdowns were made of both the sheared and unsheared clays. Comparisons were then made with respect to brightness, opacity, gloss, Bekk Smoothness, Dennison Wax pick, and K and N Ink Holdout using a starch and a styrene butadiene adhesive.

## Delaminated Clays Prepared by High Velocity Shear

As a basis to do experimentation in the new field of delaminated clays a literature research was made in the following area: Standard clays with emphasis on kaolin, delaminated clays from an article presented at the May 10-13, 1965 Tappecoating conference in Portland, Oregon, comparison of properties imported to paper by standard clays versus delaminated clays, and a working knowledge in the field of clay adhesives, dispersants and clay viscosities.

In the paper industry today clays are used both as a filler and a coating agent. Clay will be considered as a coating in this case. Koolin clay is one of the most common clays in use in the paper industry as a coating material. It is a form of hydrated aluminum silicate ($A_2 O_3 .2SiO_2 \cdot 2H_2O$) (1). Clays in general involve two units or layers. One layer is centered around the cations of Al, Fe, or Mg. which have an actahedral coordination. The O - O bond is 2.60A for this layer. The second layer is centered around silicone. When these units or layers are combined the overall thickness is about 7.15A$^o$ (1).

The layer build up forms platelets which in turn combine to form larger particles or stocks of plates called vermicules. Through the use of the electron microscope and various experimentation methods it is thought that there is a critical particle diameter at which the clay particle itself presents a radical change in shape. Particle coarses than 2.0 micron are found to be cemented stacks of plates, vermiculer in shape while particles less than 2.0 micron average diameter are mostly flat, hexagonal plates with a thickness to diameter ratio of about 1/10. (1,2,6,11). Particles of diameter less than 2.0 micron have been found to provide a higher brightness, opacity, and gloss than the same clay with coarser dimensions. (1,2,5,6). Particles of the thin plate nature tend to align themselves parellet to the sheet surface and because they are of relatively uniform thickness, provide a smooth surface. Consequently brightness and gloss are increased by the specular rather than diffuse refelction of the surface. Opacity or hiding poveries also increased because with the small particle size and alignment of platelets there are a greater number of particles present per given solids concentration. A lower limit on the particle size of 0.24 micron also exists. Below this dimension the optical properties mentioned again decrease (5).

Using the above criterion as a tool for improving their product, the paper industry has been inclined to use coating clays with 70-90 per cent of their particles less than 2.0 micron to obtain the platelet shape. Naturally a clay of this nature is expensive but economical in that it improves the product. Particle size has become, therefore, an index for clay purchasing.

At the Tappi coating conference of May 10-13, 1965 a new exciting breakthrough in the clay coating field was announced. This announcement was the concept of delaminated clays.

Again because of its high gloss properties, excellent rheological behavior at high solids, and low cost, koolin was used as the starting point. An experimental device was used on a fairly coarse koolin fraction which separated the vermiculos or stacks into platelets having a thickness of the order of 0.2 micron. Little breakdown occurred in other planes; so the resultant clay porticles was of large diameter and very thin. It is supposed, therefore, that by controling the feed source a great variety of different diameter flat platelets can be obtained. The possibility exists that a feed clay of large diameter can be chosen to yield high resistance to oil penetration. The large diameter will facilitate the desired penetration while the flat platelets will still maintain a high value for the optical properties, gloss, brightness, and opacity. When a small diameter clay is fed to the delamination device the vermicules that do exist are cleaved into plate forms also. (6) Therefore delamination has possibilities in all types of clay fractions.

If delamination is plausible, it will provide a difinite advantage over conventional clays with respect to demensional control. Using the delaminated clay product, optical properties are controlled by the thickness dimension which is relatively uniform for a given clay fraction. The particle diameter can then be varied. A needly particle shape might be choosen for a brush up effect or a large diameter for improved holdout properties. The possibility of the uses of coarser clays could also mean lower cost for coating clays of high quality.

A GE brightness of about 90 and a high whiteness is obtained through the use of delaminated clays. Since coarser clays which generally contain a smaller percentage of discoloring impurities can be used effectively, delaminated clays yield a high brightness product that is well suited for surface coating with organic materials such as wax since yellowing is considerably reduced. Both calendered and uncalendered delaminated clay coatings are of higher brightness than concentrated clays. (6).

Opacity is also increased or maximized with delamiation. To reflect all wavelengths of light, particle thickness should be between 0.2 - 0.35 micron (one half the wavelength of visible light). Delaminated clays lie within this range while conventional clays are greater than the desired range in thickness in most instances. The thickness and diameter to thickness ratio of delaminated clays are also of dimensions which enable filters to be used as spacers between the clay plates. Very high opacity is obtained when delaminated clays are used in conjunction with $TiO_2$.

A smooth surface provided by the uniform thickness platelets also provide a mechanism for high aloss properties. Penetration qualities are also better than those of conventional coatings because per given area a system of large plates provides fewer patheways for penetration than does a smaller particle diameter system.

Through experimentation it is hoped that the above qualities of a delaminated clay can be verified. Along with the optical and penetration tests printing quality will be determined.

One problem which is expected in working with delaminated clays prepared by high velocity shear is a delatant system. Today in the coating field concentration of solids has increased from the 35-40 per cent range of the past to a 60-65 per cent and even a 70 per cent range. When this is combined with the large diameter platelet of the delaminated clay, a dilatent system is likely.

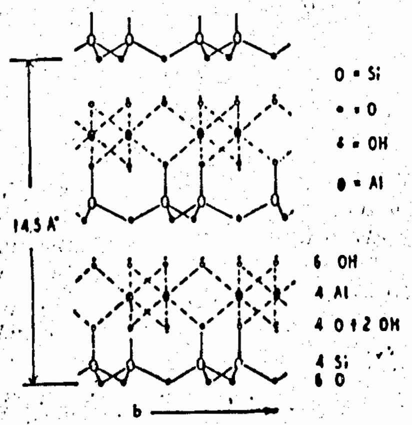
It is necessary, therefore, to have an adequate elementary understanding of viscosity in clay-water systems, clay-adhesive systems, and an idea of how dispersants affect viscosity.

Viscosity is generally of three types. (5) A Neutonian system is one in which the viscosity remains constant as shear rate increases;

a dilantant system shows an increase in viscosity with shear rate; and a thixotropic system shows a decrease in viscosity with increasing shear rates.

Particle shape has a considerable affect upon viscosity. (13,18,15, 4,5). A system with particle structureal arrangement that produces the least impediment to particle rotation in a relatively small volume of liquid produces the lowest clay viscosity. (18) Therefore, particles which are of the plate or needle form and have a long axis of rotation generally exhibit a highly dilatant viscosity with increased shear rate. As these particles begin to rotate, they are constantly colliding and the results is a high resistance to flow. Clays which produce the highest viscosities are the thinnest plates of kaolinite. (18) At low rates of shear a particle possessing a large surface area per unit of weight appears to be very viscous. This is caused by the unsatisfied valence forces which exist on the surface areas which cause small particles to form aggregates. However, at higher shear rates the system becomes thixotropic as the aggregates are broken and free rotation returns. Therefore, smaller particles tend in some cases to be viscous at low shear rates and thixotropic when shear is increased (4,12,15, 16) As the solids concentration of the suspension is increased, the system naturally tends to become more dilatant because the liquid volume for particle rotation is decreased. Consequently there are more collisions between particles and a greater resistance to flow resutls. (12) The delaminated clays present a particle with a long axis of rotation and at high concentration of solids combined with a high shear velocity which will be used, dilantancy might be a problem. Therefore, an understanding of dispersants is necessary.

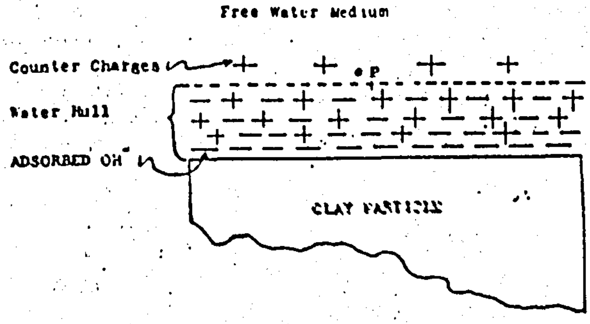
With the use of a dispersing agent a system containing both high solids concentration and low viscosity is possible. (12) Through X-ray diffraction clay has been shown to be of a crystalline nature. The most henerally accepted crystalline structure is as follows:



KAOLINITE

FIG. 1

The kaolinite crystal is built up of alternating layers of Si and Al bonded together by O and oH bonds. Since the Si to OH bond is of the secondary nature, it is the weakest bond of the crystal. Consequently, it is a natural cleavage plane. But clay platelets are hexagons and therefore a fracture must also exist in the vertical plane. This fracture ruptures primary valance bonds and leaves a positive active charge on the particle. Quickly OH anions are absorbed by the positive charges and they bring water molecules of hydration along. Therefore, a water hull surrounds the particles of clay. The particle now bears a net negative charge and will attract cations from the solution media, to balance its charge. These cation determine the degree of dispersion of the system (8,15,16,17).



If the cation is sodium for example, the water hull becomes larger because the hydratron of sodium is considerable. The stand off or equillbrium distance between the negative particle and the Ni is therefore increased. The effect is an increase in the negative charge of the particle with respect to the surrounding clay particle. A repulsion therefore exists between particles and dispersion results. Little shear is necessary to separate such a dispersed system. If an excess of sodium exists in the system more Na$^+$ enter the water hull be the law of mass action and a reduction in the negative charge results. Consequently dispersion effects are lessened by an excess of cation. When di-valent and tri-valent catrons are employed, dispersion is less because the equilibrium separation distance for these catrons is less and the negative charge of the clay particle is modified. It is also important to have an adequate number of OH $^-$ ions present for maximum despersion. (16) As the percentage of dispersant is increased, the fluidity will rise to a maximum and then drop off as explained above. The maximum point for adhesive is usually at a greater percentage than the clay. Therefore, it is important to add adequate amounts of dispersant for both systems. (16) The various phosphate dispersants appear to be about equal in the end result. However a greater concentration is required in some cases to reach maximum fluidity. Sodium pyrophosphate. seems to reach the maximum fluidity point at the lowest concentration (16). All phosphate onions are made up of phosphorus surrounded by a tetrahedral arrangement of oxygen atoms. Through the sharing of oxygen atoms it is possible to polymerize these phosphate groups. The resultant polymer is very stable and unaffected by pH or concentration charges as are many polymeric anions. Phosphates show no Tyndall effect also and this therefore lends to their disireability. Besmertnuk (14) claims that the formation of a complex of the phosphate with the surface silicon and aluminum atoms on the clay particle causes dispersion; however this is refuted in many several ways and the cetionic base exchange theory seems to be more prevalent. It should be noted here that as the concentration of the clay solids of a system is increased, the proper addition of dispersants in regard to amount is very important to get maximum fluidity from a clay slip. The fact then seems predominate that flow-characteristics of clay-water systems are influenced by concentration of clay solids, particle size and shape, and the ability of the clay to undergo a mechanism of base exchange. (4,12) When adhesives are added the system become more complex yet, and it is necessary to use a dispersant wisely.

In their experiment on delaminated clays Morris and Sennet used a latex adhesive. (6,19) Therefore an analysis of adhesives is necessary to determine their choice. Latex adhesives dispersions of usually 30-60 percent solids in water are generally water thin. Dispersed particles may vary in size from 0.05 micron to 2 millimicron. The most common dimension is from 0.1 to 0.2 millimicron. The latex possesses high stability and may be used after long periods of storage providing it isn't subjected to high or low temperature extremes. Latices usually have a negative charge and consequently are precipitated by di-valent and tri-valent catrons although mono valent catrons effect them little. The latex adhesive is used with a sodium pyrophosphate dispersant although it is affected by impurities in the clay sush as Ca$^{++}$, Mg$^{++}$, Al$^{+++}$ ions. When uncovered, a latex will skim over on the top and adequate covering must be used. In adhesive power, latex is equivalent to casein and upon aging it has superior quatlites along this line. Water resistance of the latex polymer also increases upon aging.. Becase latex is thermoplastic, a low Dennison wax test of 2.0 or 3.0 might be obtained and yet the paper is suitable for printing. The thermoplastic characteristic of latex presents some problems upon supercalendering because it tends to stick to the heated calender rolls.

The best results of a latex adhesive are obtained with mixtures of latex and protein or latex and starch. A latex-protein mixture such as styrene-butadiene in combination with protein yields a lower viscosity product than the protein used alone. In general a replacement of 20-50 percent of the adhesive with latex gives considerable improvement in paper properties. In mixing such a suspension it is important to add the protein before the latex or an excessively thick adhesive-clay system results. When added in the proper order, a low viscosity product is likely, When latex is used in conjunction with starch, a higher concentration of latex is required than with the protein, to overcome the harder and less water resistant film characteristic of starches. Starch latex mixures are also relatively unstable and must be stabilized with cosein or soya protein.

Casein is an adhesive which doesn't yield maximum strength or adhesive power when blended. It is commonly used alone. Casein possesses good adhesive strength, film forming properties, and hence good ink, varnish, and grease resistance. It also bonds readily to the stock, needs little heat for solution, and has a good finish after supercalendering. However, it also possessesa characteristic odor, has foaming tendancies is brittle, and is limited to 40-45 percent solids concentration, because of viscosity characteristics. (7)

It appears, therefore, that aside from supercalendering the properties of the latex-protein mixures are generally of the desirable character.

The Effect of High Velocity Shear On Coating Properties

Procedure:

I. Determination of the factors necessary for a desirable shear.

   A. Determination of possible solids concentration for optimum shearing for NoKarb Clay.

   B. Clay using TSPP dispersant at 62.0 per cent solids was sheared for 6.0 hours and sampled.

      1. The shear was continued for a total of 12.0 hours.

      2. Shearing was done in a Cowles Dissolver at 5600 rpm in a Tappi Disintegrator vessel.

   C. Tappi sedimentation T649 sm 54 was used to determine the particle size distribution at 6.0 and 12.0 shear points.

      1. The distribution at 12.0 hours shear was found satisfactory for analysis.

II. A series of standard drawdowns was prepared with unsheared NoKarb clay.

   A. Drawdowns were coated at an 18.0 pound coat weight for a 25-38-500 ream size at 40 and 50 per cent solids with 10 20 and 30 per cent Stayco M starch adhesive on the weight of the pigment.

   B. Brookfield and Hercules viscosity measurements were made for each coating slip.

   C. The coated paper was tested.

      1. Optical properties

a. GE Brightness - five readings per coating slip.

b. Tappi Printing Opacity - five readings per coating slip.

c. Bausch and Lomb Gloss - five readings per coating slip.

2. Other tests.

a. Dennison Wax Pick Test - three readings per coating slip.

b. K and N Ink tests, two minutes - five readings per coating slip.

c. Bekk Smoothness - three readings per coating slip, measured in seconds per 10 mm.

d. A dominant wave determination was made on the unsheared clay using the Tri-Stimulus Method.

III. A second 12.0 hour sheared clay was prepared.

A. The Tappi Disintegrator was replaced by a galvanized pail.

B. A larger sample was used.

C. Dispersion was done with the Cowles Dissolver at 5600 rpm.

D. A Tappi T649 sm 54 particle size distribution was run on the 12.0 hour sheared clay.

E. The pH was held at 8.0 with NaOH during the shearing and 60. per cent solids was kept.

IV. Drawdowns were made with the 12.0 hour sheared clay.

A. Paper was coated at 40.0 and 50.0 per cent solids using 10, 20, and 30 per cent Stayco M starch adhesive on the weight of the pigment.

B. An 18.0 pound coat weight per 25-38-500 ream size was used.

C. Brookfield and Hercules viscosity measurements were made for each coating slip.

D. The coated paper was tested.

1. Optical properties.

a. GE Brightness - 10 readings for each coating weight.

b. Tappi Printing Opacity - 10 readings for each coating slip.

c. Bausch and Lomb Gloss - 10 readings for coating slip.

2. Other tests.

a. Dennison Wax Pick - 3 readings for each coating slip.

b. K and N Ink tests - 5 tests per coating slip.

c. Bekk Smoothness - 3 readings per coating slip.

d. A dominant wave length determination was made using the Tri Stimulus method on the 12 hour sheared clay.

V. Drawdowns were prepared with the unsheared clay and the 12 hour sheared clay using styrene butadiene adhesive.

A. Paper was coated at an 18.0 pound coat weight per 25-38-500 ream size using 40 and 50 per cent solids with 10, 20, and 30 per cent adhesive on the weight of the pigment.

B. Testing was done as in section IV, D for the unsheared and 12 hour sheared clays.

VI. Conditioning of coated papers.

A. All coated sheets were supercalendered at 4 nips, 40 pli after a constant warm up of 3 hours to reach a constant temperature.

B. Samples were conditioned at 70 F and 50 per cent RH before testing.

## The Effect of High Velocity Shear On Coating Properties

In this experimental work a high velocity shear was imparted to a NoKarb clay using the Cowles Dissolver. The aim of the work was to see the effect a high velocity shear had upon the optical and physical properties of the clay.

Previous work had been done in the area of low velocity shear using a delaminating and fractionating combination by Horton, Sennett, and Drexel (6). The trio claimed that through shearing a greater number of particles could be obtained below a size of 2.0 microns. It is believed that in this size grouping the clay particles exist as flat hexagonal platelets. The ratio of thickness to diameter is believed to be about 1 to 10. With a greater number of such flat platelets in the coating it seems plausible that a number of changes could exist in the final clay product. First of all if all of the clay particles were platelets and they could be arranged on the surface of the paper sheet parallel to the surface, an increase in smoothness should result. By shearing the clay vermicules then it seems that the resultant coated sheet should have a considerable increase in smoothness. Provided that a smoother more uniform surface is produced a corresponding increase in gloss should result, because of the approach to a mirror like surface. Brightness and opacity should also yield somewhat of a change from the following consideration. If the clay produced is in the platelet form, there will be a greater number of particles or surface interfaces for a given coating weight. As a result more light should be refracted, reflected, and absorbed. Less would then be permitted to penetrate the sheet and brightness and opacity should show a slight increase.

Ink and oil penetration would be another property greatly affected by the particle seze and shape. If the coated sheet maintains a smooth surface, the ink should penetrate less. This seems logical because the number of faults and crevices in the furface would be reduced.

Another aspect which was considered was adhesive demand. With an increase in the number of particlesof a smaller size the RSV for a given sample is less and consequently a lower adhesive demand can be expected.

Viscosity for a sheared clay with a greater number of small particles should decrease because the volume swept out during each rotation of a particle would be less. The result would appear to be a clay with a low viscosity, possibly with a Newtonian character.

The clay used in the experimental work was a NoKarb clay produced by the Minerals and Chemicals Philipp Corporation. The unsheared clay contained 15.0 per cent of the particles less than 2.0 microns and after 12.0 hours of shear (see red line figure 1) → the percentage was increased to 40.0 per cent less than 2.0 microns. In the trial shear runI, 46.0 per cent of the particles were less than 2.0 microns, but this degrre of delamination wasn't obtained in Run II because a mixing container with smooth sides was used to accommodate a larger sample. The particle size distribution of the unsheared clay checks with the publicized data put out by the company. Therefore it can be assumed that the sedimentation method has given a fairly accurate particle size description in the other cases.

The clay from RunII (Figure 1) was used as the sheared clay throughout the research. Coatings were prepared at 40.0 and 50.0 per cent solids with 10, 20 and 30 per cent Stayco M starch on the weight of the pigment for both the sheared and unsheared clay samples.

Testing showed that the sheared clay produced a definite increase in smoothness of the sheet (Figure 2). It is also interesting to note that as the per cent starch increased the smoothness decreased. This smoothing effect is caused from a decrease in the number of bulky stacks of clay plates at the surface.

As expected K and N Ink results showed an increase in ink holdout with the sheared clay. The smooth surface and more uniform overlap of the clay platelets seems evident from the above considerations. (See figure 3)

The Dennison Wax Pick test revealed a considerable increase in coating strength with the sheared clay for both the 10.0 and 20.0 per cent adhesive ranges. At 30.0 per cent adhesive there was no change in the pick results. Therefore it seems that a combination of two things can be considered. First of all in the sheared clay there is a higher degree of overlap and a greater surface to surface bonding, and secondly because of the decrease in particle size there is a marked decrease in adhesive demand. From (Figure 4) it can be seen that the same pick number is obtained with the 50.0 per cent solids, 10.0 per cent adhesive sheared coating as with the 50.0 per cent solids, 20.0 per cent adhesive unsheared coating. The pick test is a combination of the strength of the base stock, the stock to coating bonding, and the coating strength. It appears that shearing of a clay will produce a stronger fiber to coating bond and a stronger coating itself.

Optical tests showed no apparent change with shearing of the clay. Brightness, opacity, and gloss remained constant within the accuracy of the data. A possible explaination is apparent however. The predominant wavelength for the two pigments determined by the Tri-Stimulus Method showed that the predominant wave length and purities of the unsheared and sheared pigments were approximately the same at 574 milli-microns. The purity was found to be 2.0 per cent in both cases. Horton, Sennett, and Drexel (6) showed that at a wavelength of 574 milli-microns their delaminated and conventional clays had approximately the same per cent reflectance. Therefore it seems plausible that for this clay, NoKarb, and increase in optical properties couldn't be expected. Further verification of this point would be needed however. (See figure 10)

Coatings were mixed at 10.0, 20.0, and 30.0 per cent styrene butadiene adhesive on the weight of the pigment for the sheared and unsheared clays to verify the increase in ink holdout. The results agreed with the above.

Optical properties showed no unaccountable change with the sheared and unsheared clay using styrene butadiene adhesive.

It can be concluded then that for a NoKarb clay sheared to a distribution with 40.0 per cent of the particles less than 2.0 microns there exists a definite increase in ink holdout and smoothness, adhesive demand is reduced, and no apparent changes occur in brightness , opacity, and gloss.

Both Hercules and Broolfield viscosity determinations were made on the clays at 50.0 per cent solids with starch adhesive. Unsheared and 12 hour sheared samples of pure clay at 70.0 per cent solids were run. From the data obtained the sheared clay had a considerably lower viscosity as can be seen form the Brookfield viscosity data in table II and in Figure 9 and the Hercules rheograms of Figure 6. However when samples with Stayco M starch were tested, the sheared clay showed a considerable increase in viscosity over the unsheared clay. (See Figures 7,8,11,12,13) From the rheograms of Figures of Figures 7 and 8 it is apparent that no generally undesirable viscosity properties resulted from the shearing. Both the unsheared and sheared clay slips show a slight thrixotropic character. Both the rheograms and Brookfield readings seem to indicate that at higher shear rates the sheared clay has no undesirable viscosity increase. Both clays were run on a labratory coater using a metering rod applicator without any noticeable difference in application quality.

At a time interval between 2.0 to 3.0 hours in both shear runs a decrease in pH was found and the per cent solids increased slightly. It seems possible that the heat and violent agitation used has some decaying effect upon the TSPP dispersant. A possible break down into phosphoric acid might have occurred. During coating slip preparation the sheared clay had a much greater tendency to flocculate than the unsheared clay. It is very possible that a dispersant breakdown had occurred during the shearing process. Addition of more dispersnat seemed to eliminate this tendency to flocculate.

A practical application of dealmination in the coating industry could receive some benefits. A trial run was made on a Keegan coater and no problems were encountered at low solids using a metering rod application. With an increase in smoothness, a higher ink holdout, and a lower adhesive demand this type of shearing could be applied well for a small batch batch operation in a temperature controlled mixing unit. After 6.0 hours of shearing, runI, showed a distribution of 38.0 per cent of the particles less than 2.0 microns. Therefore it is possible that with a very short interval of shearing, increases in ink holdout and smoothness could be obtained.

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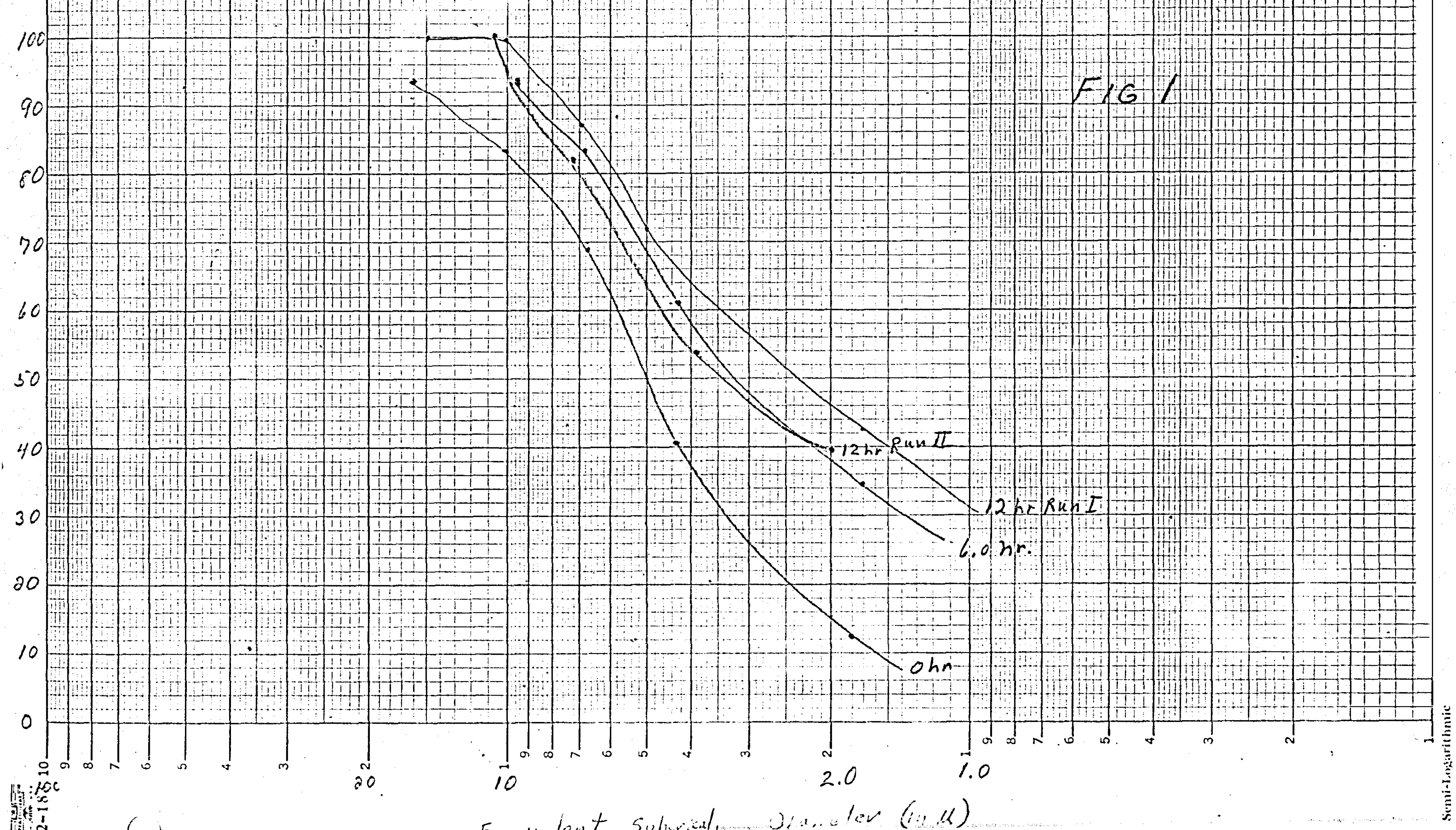
| | >10 | 5-10 | 2-5 | <2 |
|---|---|---|---|---|
| 0hr | 16 | 34 | 35 | 15 |
| 6.0 | 5 | 27 | 30 | 38 |
| Run I 12.0 | .9 | 28 | 26 | 46 |
| Run II 12.0 | 5 | 31 | 24.3 | 39.7 |

FIG 1



12-188

# BEKK SMOOTHNESS TEST FOR UNSHEARED AND SHEARED CLAY AT 50% SOLIDS AND 10, 20, & 30% STARCH ADHESIVE

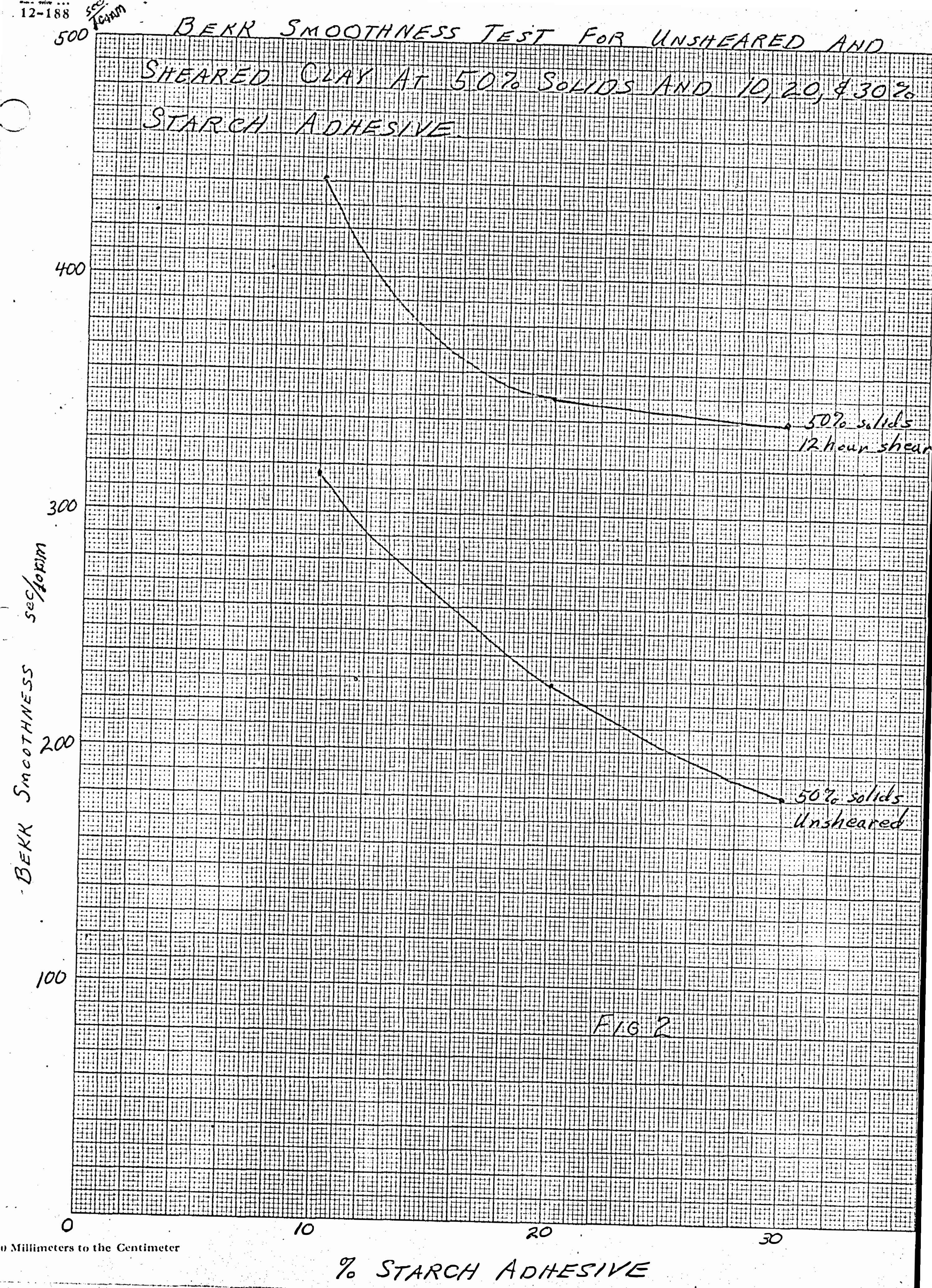


FIG 2

10 Millimeters to the Centimeter

K&N %

# K&N INK HOLDOUT FOR UNSHEARED AND SHEARED CLAY AT 50% SOLIDS AND 10, 20, & 30 % STARCH ADHESIVE LEVELS

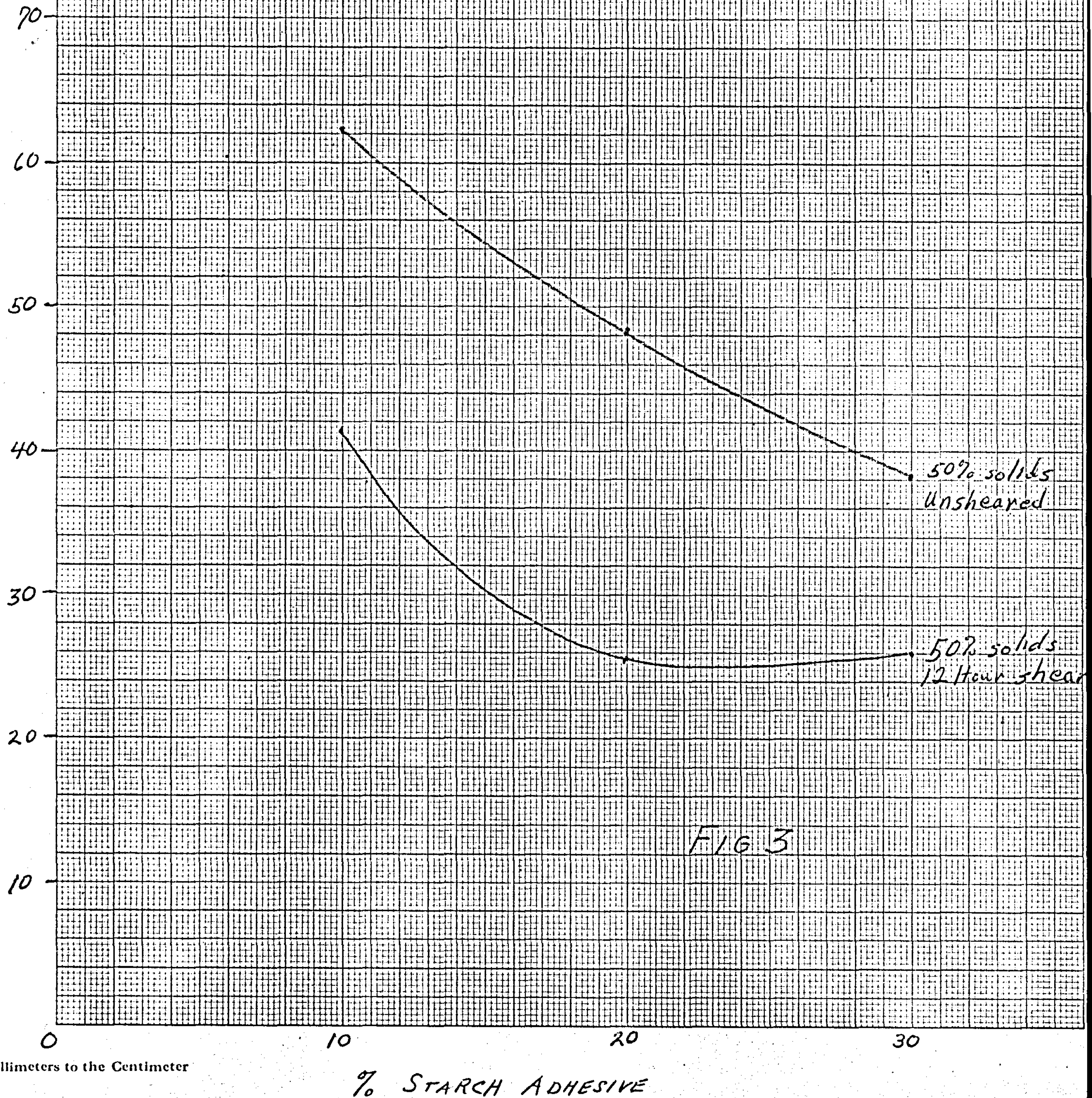


FIG 3

% STARCH ADHESIVE

12-188 Wax #

DENNISON WAX PICK TEST FOR UNSHEARED AND SHEARED CLAY AT 50% SOLIDS AND 10, 20 & 30% STARCH ADHESIVE.

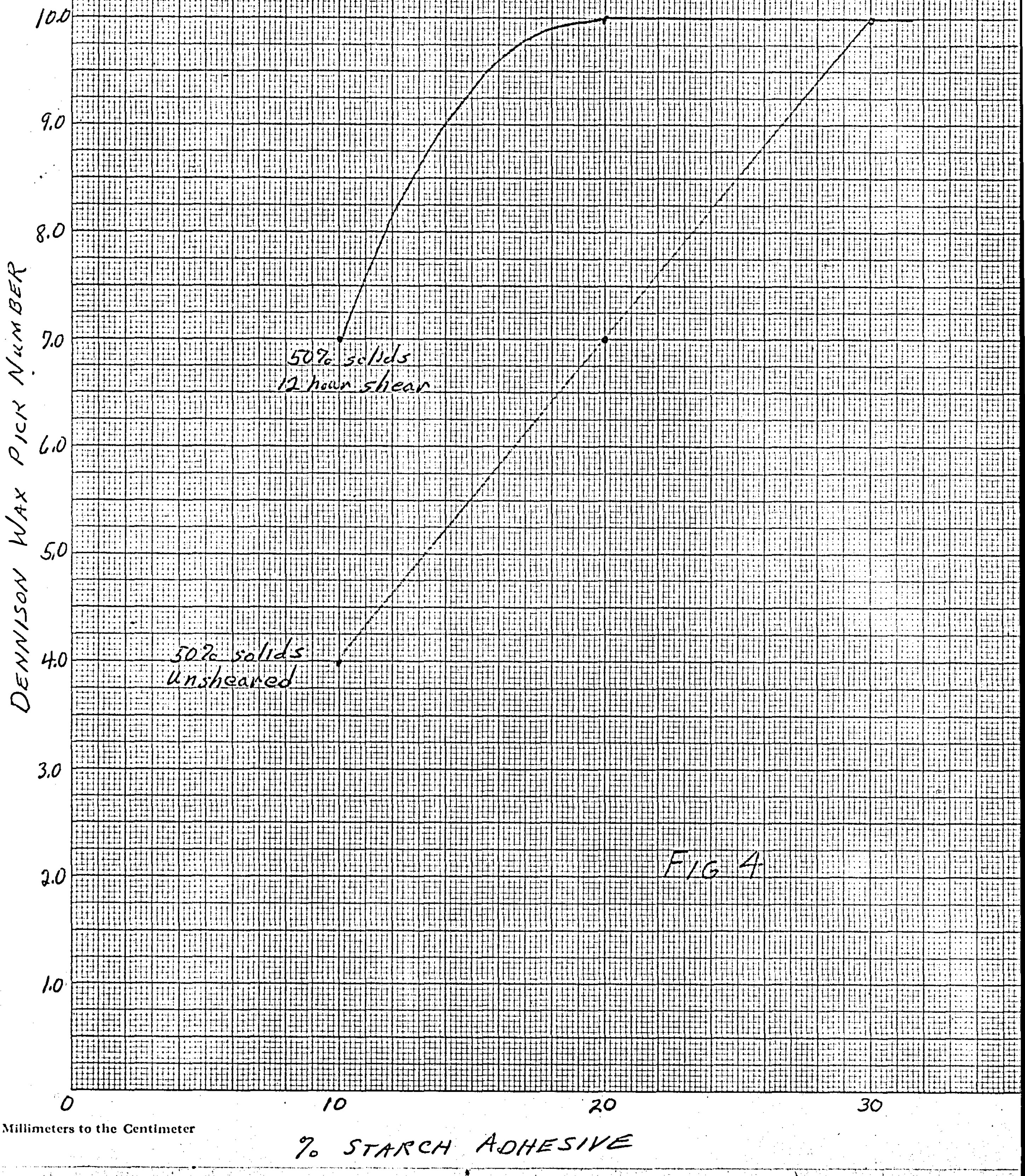


FIG 4

10 Millimeters to the Centimeter

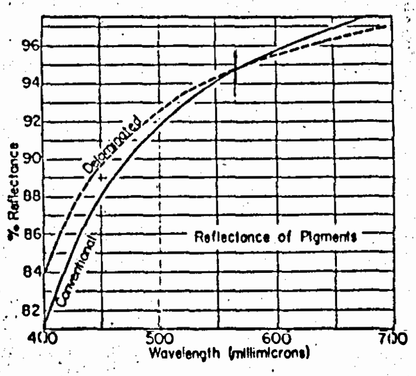


Fig. 10. Reflectance curves of conventional and delaminated clay pigment

FIG 10 FROM REFERENCE
NUMBER (6).

FIG 6

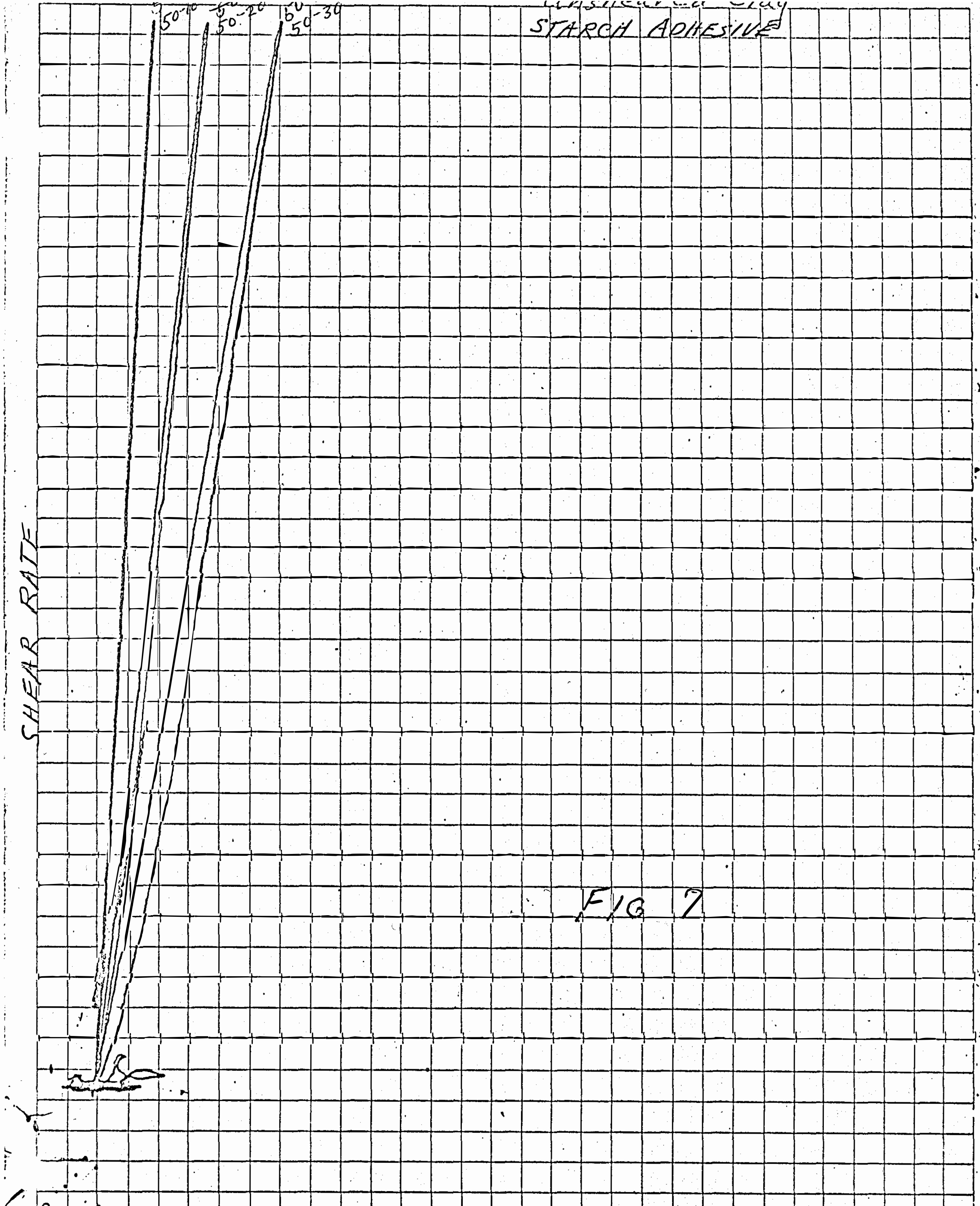
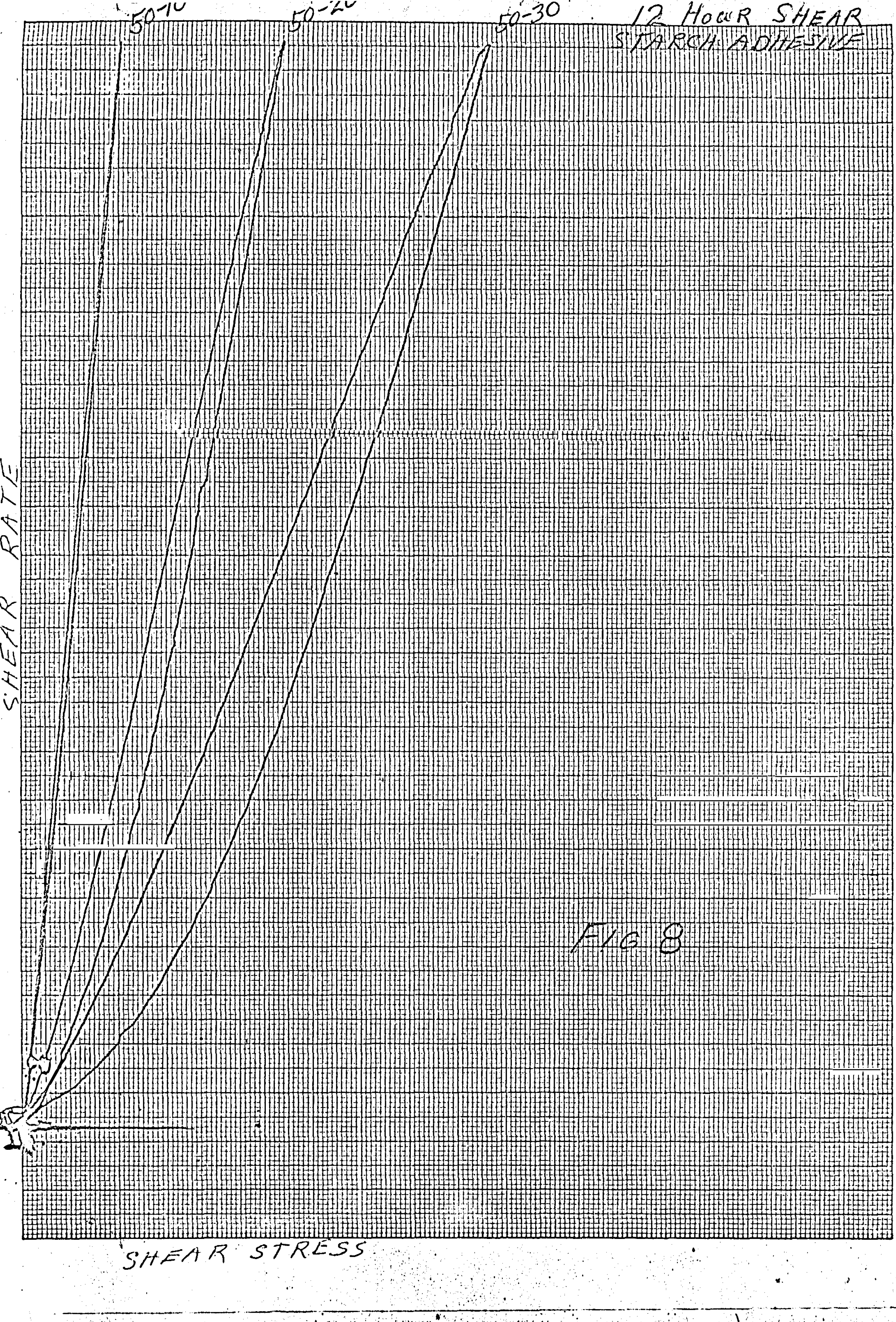
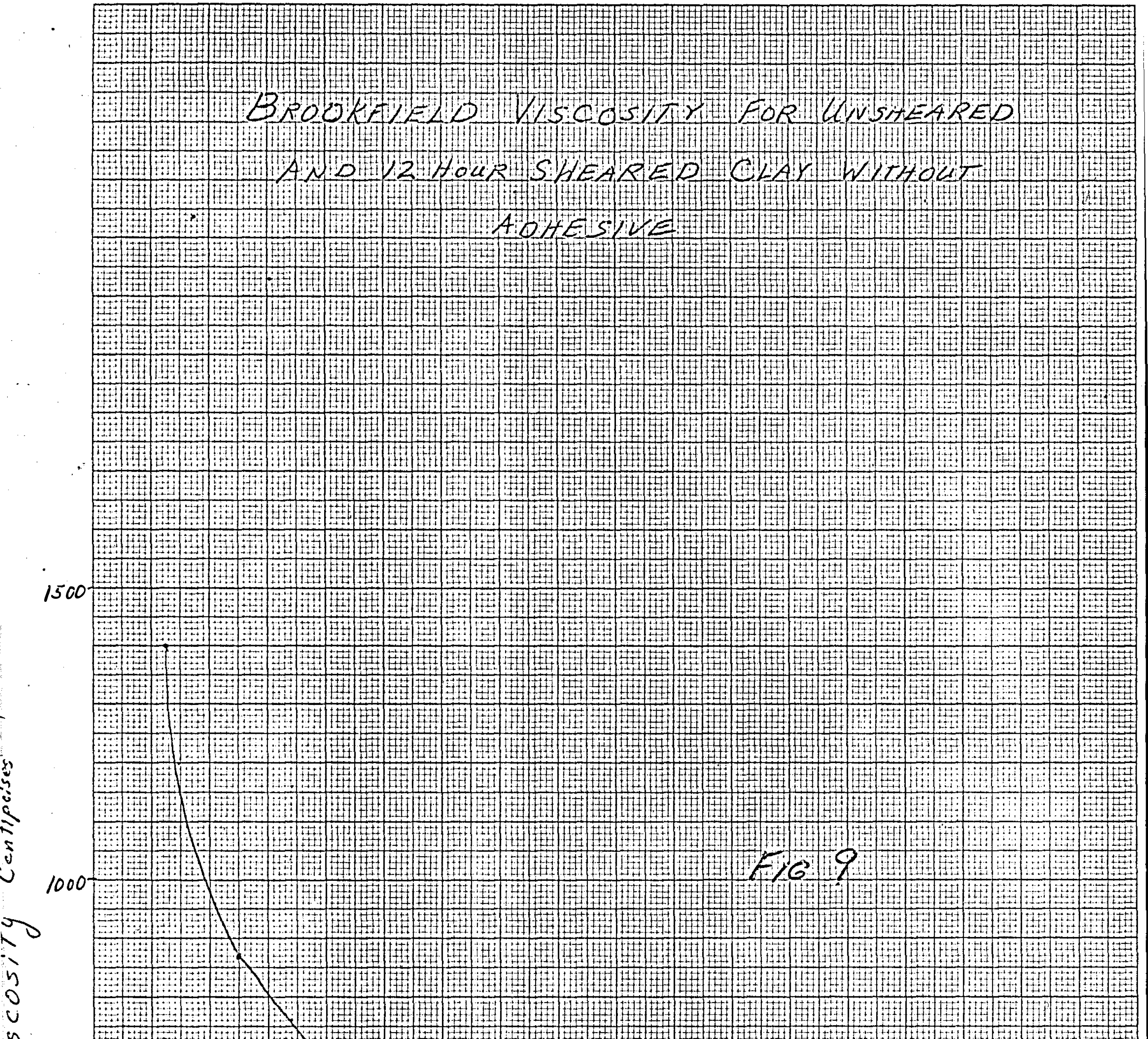


FIG 7



12 Hour SHEAR
STARCH ADHESIVE

FIG 8

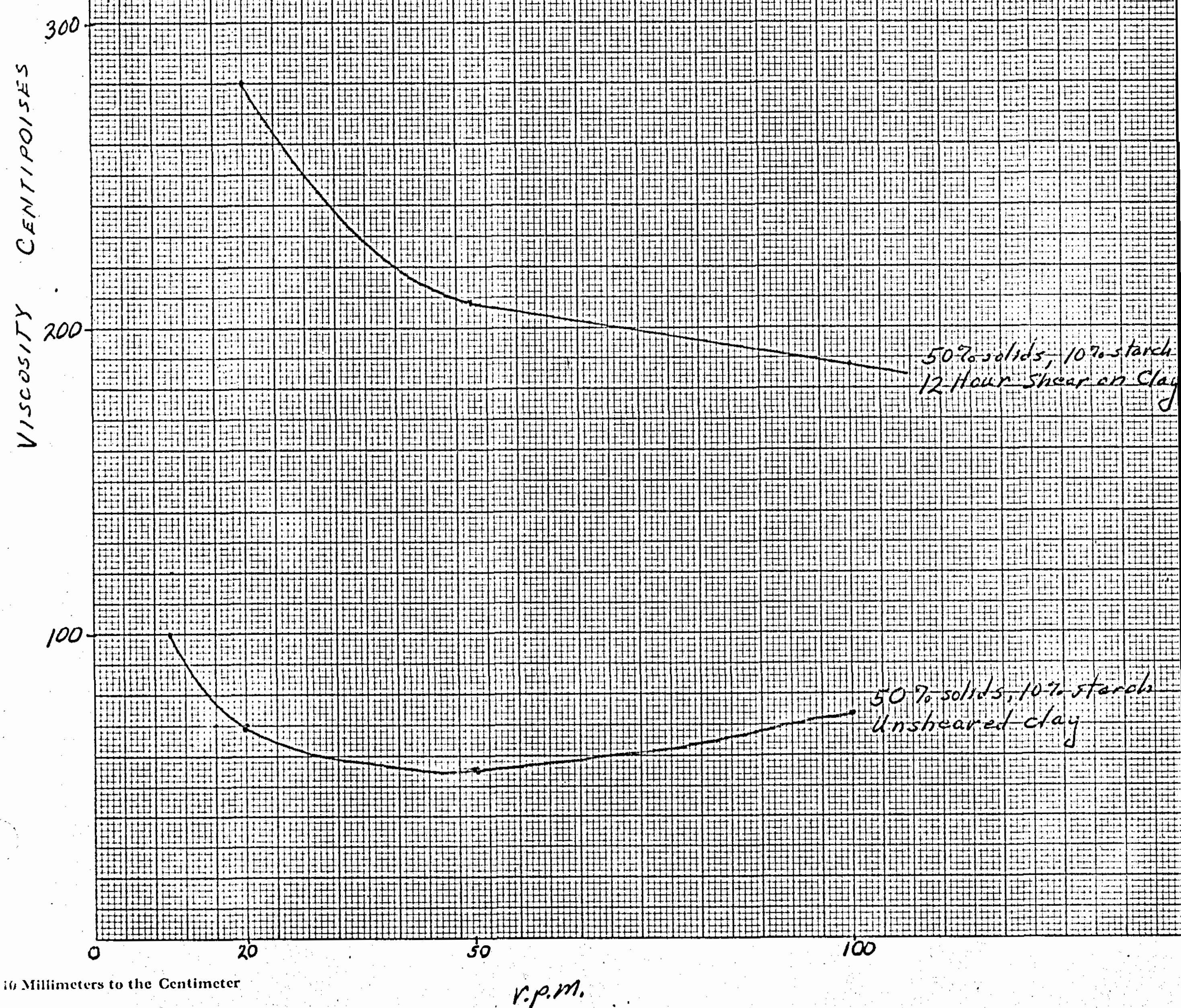


BROOKFIELD VISCOSITY FOR UNSHEARED AND 12 HOUR SHEARED CLAY WITHOUT ADHESIVE

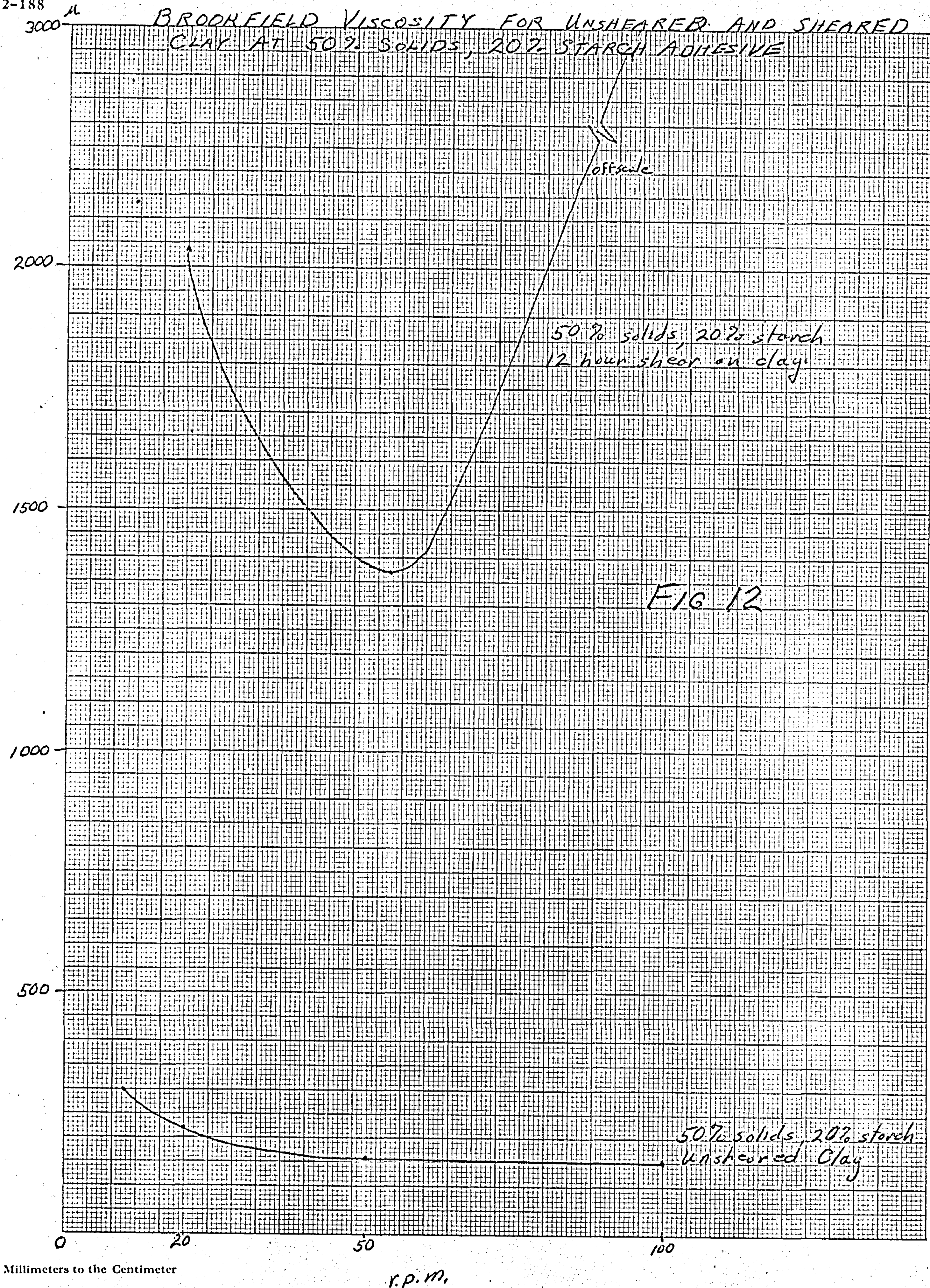
FIG 9

# BROOKFIELD VISCOSITY FOR UNSHEARED AND 12 HOUR SHEARED CLAY AT 50% SOLIDS, 30% STARCH ADHESIVE

FIG 11



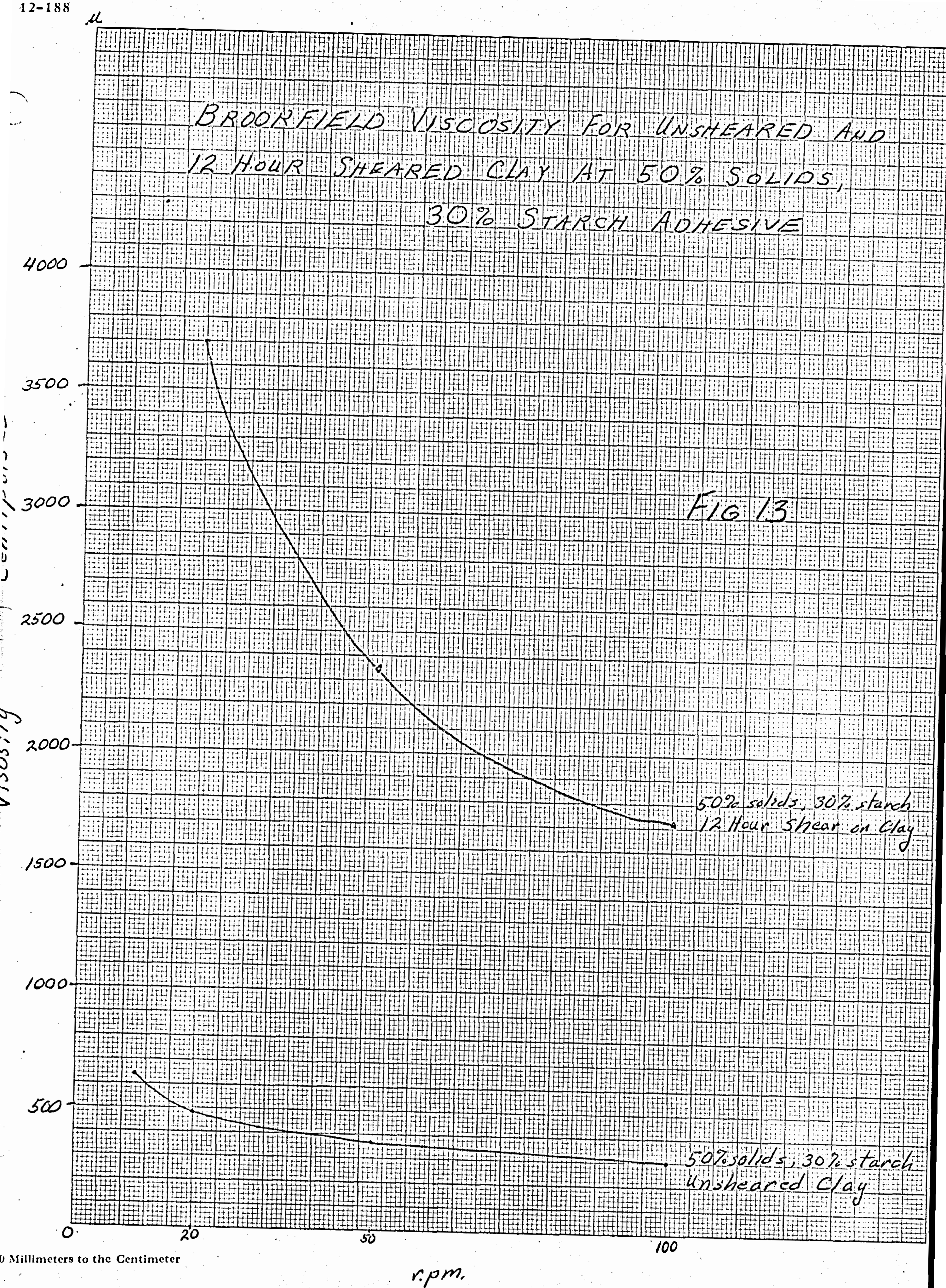
12-188



BROOKFIELD VISCOSITY FOR UNSHEARED AND SHEARED CLAY AT 50% SOLIDS, 20% STARCH ADHESIVE

FIG 12

10 Millimeters to the Centimeter



BROOKFIELD VISCOSITY FOR UNSHEARED AND 12 HOUR SHEARED CLAY AT 50% SOLIDS, 30% STARCH ADHESIVE

FIG 13

# DATA SUMMARY FOR STARCH ADHESIVE

| Sample Description | G.E. Brightness | Tappi Printing Opacity | 75° Bausch & Lomb Gloss | Dennison Wax Pick | K & N Ink Holdout | Bekk Smoothness sec/10ml | Coat Wt. #/(25×38-500) |
|---|---|---|---|---|---|---|---|
| 12 hour shear<br>40% solids<br>10% starch Adh. | 80.7 | 91.3 | 37.6 | 6 | 42.8 | 551 | 17.0 |
| 12 hour shear<br>40<br>20 | 78.3 | 89.1 | 24.7 | 11 | 27.3 | 327 | 17.5 |
| 12 hour shear<br>50<br>10 | 81.1 | 90.6 | 35.2 | 7 | 41.5 | 442 | 17.8 |
| 72 hour shear<br>50<br>20 | 81.3 | 88.4 | 23.6 | 10 | 25.7 | 349 | 18.2 |
| 12 hour shear<br>50<br>30 | 81.6 | 88.9 | 23.0 | 10 | 26.2 | 340 | 17.7 |
| | | | | | | | |
| Unsheared<br>40% solids<br>10% starch adh | 82.6 | 90.6 | 39.0 | 3 | 65.1 | 321 | 15.0 |
| Unsheared<br>40<br>20 | 83.2 | 89.3 | 24.6 | 8 | 50.4 | 264 | 16.6 |
| Unsheared<br>40<br>30 | 84.5 | 88.2 | 17.4 | 10 | 37.2 | 181 | 16.8 |
| Unsheared<br>50<br>10 | 82.5 | 91.2 | 37.5 | 4 | 62.4 | 317 | 18.4 |
| Unsheared<br>50<br>20 | 82.5 | 90.0 | 25.0 | 7 | 48.4 | 228 | 19.4 |
| Unsheared<br>50<br>30 | 82.4 | 87.9 | 16.7 | 10 | 38.3 | 181 | 17.8 |

TABLE II

## BROOKFIELD VISCOSITY SUMMARY

| Coating Description | Spindle Number | 10 rpm | 20 rpm | 50 rpm | 100 r.p.m. |
|---|---|---|---|---|---|
| Unsheared<br>50% solids<br>10% starch adh. | 2 | 100.0 | 70.0 | 56.0 | 74.0 |
| Unsheared<br>50<br>20 | 2 | 300.0 | 220.0 | 160.0 | 152.0 |
| Unsheared<br>50<br>30 | 2 | 640.0 | 490.0 | 360.0 | 308.0 |
| 12 hour shear<br>50<br>10 | 2 | – | 280.0 | 208.0 | 194.0 |
| 12 hour shear<br>50<br>20 | 3 | – [illegible] | 2020.0 | 1380.0 | offscale |
| 12 hour shear<br>50<br>30 | 4 | – | 3700.0 | 2380.0 | 1720.0 |
| Unsheared<br>70% solids<br>Pure Clay | 2 | 1400.0 | 870.0 | 505.0 | 358.0 |
| 12 hour shear<br>70<br>Pure Clay | 2 | 160.0 | 110.0 | 124.0 | 206.0 |