

# Rheological Behaviour of Mineral (Clay) Suspensions

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**Abstract:** In this research, a rotating cylinder viscometer was designed and fabricated to study the structure formation of particles in a mineral suspension and its influence on the relative viscosity  $\eta/\eta_0$ . It is known that the value  $\eta/\eta_0$  is affected by the concentration of suspended mineral particles in an aqueous media. The relative viscosity  $\eta/\eta_0$  thus obtained is related to the volumetric concentration of suspended particles by the equation  $\eta = \eta_0 + k\phi$ , where the value  $k$  depends on particle behaviour in aqueous medium and is related to the shape, zeta potential and the volume % of particles. By this method it is possible to classify the suitability of surface active minerals in mineral deposits on the basis of the  $k$  factor. The rotating cylinder viscometer consists of a cylinder, of known dimensions, immersed fully in a mineral suspension so that it can be rotated by applying a mechanical couple (Force X distance) acting on the cylinder by two identical falling weights which are tied to each other by an inextensible string. Initially the cylinder is made to rotate in water of known viscosity by fully immersing it, thereafter in the known suspension. From the rates of rotation, the viscosities can be compared and hence the  $k$  values.

**Keywords:**  $k$  factor, Relative viscosity, Zeta potential

## 1. Introduction

One of the most important parts of this research work is the derivation of the viscosity formula for a rotating disc. Therefore, for simplicity sake we consider a cube of flexible material with its base fixed placed on a horizontal table (Figure 1).

When a shear force is applied to the horizontal upper face of the cube in time  $t$  (say) it will be displaced as shown, i.e. the point  $E$  goes to  $E'$ .

Then the shear =  $\frac{EE'}{AE}$

Rate of shear =  $\frac{\{EE'/AE\}}{t}$  ..... 1

and is known as the velocity gradient (Moore, 1965)

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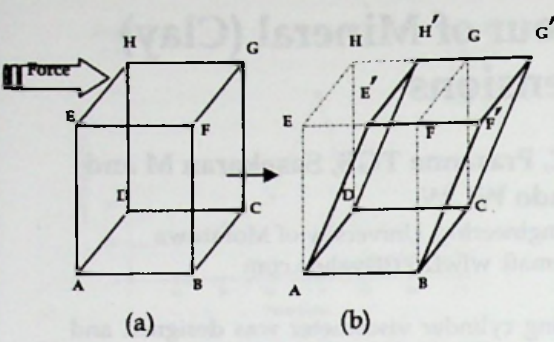


Figure 1. Deformation of a fluid cube under a shear force

Velocity gradient =  $d(r\omega) / dr$ , ( $a < r < b$ )

Velocity gradient =  $\omega + r \frac{d\omega}{dr}$  .....3

Rate of shear =  $\left\{ \omega + r \frac{d\omega}{dr} \right\} - \omega$  .....4

Rate of shear =  $r \frac{d\omega}{dr}$  .....5

And,

Viscosity ( $\eta$ ) =  $\frac{\text{shear stress}}{\text{rate of shear}}$  .....6

In the case of the rotating cylinder viscometer, a shear force is applied to the suspension by a torque  $\tau$  of the cylinder. When the radius of the cylinder is  $r$ , effective height of the cylinder submerged is  $l$  and the viscous force is  $F$ , then

$\tau = 2\pi r^2 l F$  .....2

$\eta = \left\{ \frac{\left( \frac{\tau}{2\pi r^2 l} \right)}{r \frac{d\omega}{dr}} \right\}$  .....7

$\int_a^b \frac{\tau}{r^3} dr = \int_0^\omega (2\pi\eta l) d\omega$  .....8

On solving this expression, we have

$\omega = \frac{\tau \left( \frac{1}{a^2} - \frac{1}{b^2} \right)}{4\pi\eta l}$  .....9

Outer cylinder (stationary) radius  $b$

Rotating cylinder of radius  $a$

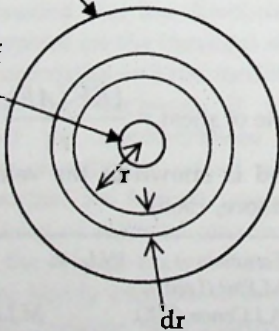


Figure 2. Plan view of rotating cylinder in clay suspension container

Where  $a$  = radius of the rotating cylinder  
 $b$  = radius of the container.

It is assumed that there is no movement of liquid at this point of the outer cylinder.

The torque is given by the mechanical couple. If the radius of the pulley on which the inextensible string is wound is  $r$  and the mass of the falling weights is  $m$ , then the torque will be

$\tau = mg.r$  .....10

By substituting this value of  $\tau$  in the equation (9), we have

$$\omega = \frac{mgr}{4\pi\eta l} \left[ \frac{1}{a^2} - \frac{1}{b^2} \right] \dots\dots\dots 11$$

Using this equation viscosity of a fluid can be determined with the results obtained from the viscometer and hence the relative viscosity. From the graph of relative viscosity Vs volume percentage of solids, the k value can be determined.

## 2. Methodology

Samples of clay were taken from two different locations; Dediawela and Boralessamuwa clay deposits to study the rheological properties. The samples were separately dispersed in water and sieved through 500 micron sieve. The undersize was further concentrated by allowing it to settle. After settling it was further divided into five portions and there after each portion was diluted by the ratio 1:1,1:2 up to 1:5, respectively. The volume % of particles in the suspension was calculated using the powder density of clay and the pulp density of the suspension. The angular velocity of the shaft of the viscometer (Figure 3) was measured at small time intervals by counting the time taken by the falling weights to travel through predetermined spacings with respect to a vertical scale. (Figure 4).

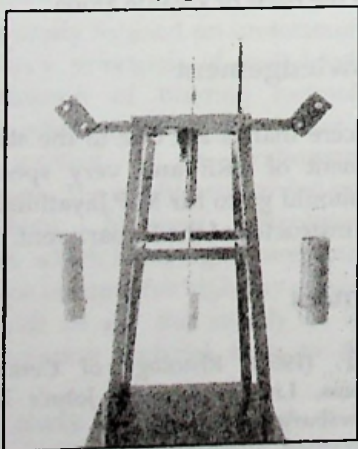


Figure 3. Exmerimental Set Up

For each sample dilution, the test was repeated ten times and the angular velocity which remained as a constant value for a long period of time was taken to calculate the viscosity. The viscosity of water was also measured by substituting water for the slurry. From these determinations, the ratio of viscosity of the suspension to that of water was calculated for various diluted suspensions, whose solid volume percentages were known. The results of these determinations are given as follows.

## 3. Results and Discussion



Figure 4. Conducting the Exmeriment

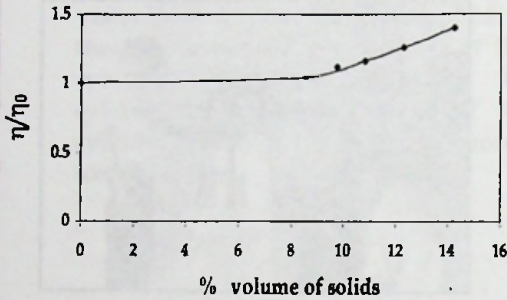
In the case of water, for which % volume of solids = 0,  
 rpm value = 292,  
 Hence viscosity  $\eta_0 = 0.008152 \text{ kgm}^{-1}\text{s}^{-1}$   
 .....using the equation (11)

Table 1. Relative viscosity results for Dediawela clay

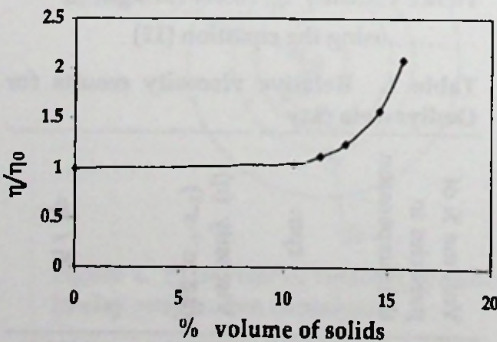
Volume % of particles in the suspension	rpm	Viscosity ( $\eta$ ) ( $\text{kg m}^{-1} \text{s}^{-1}$ )	$\eta / \eta_0$
14.24	208	0.011444	1.403846
12.29	232	0.010261	1.258621
10.80	252	0.009446	1.158730
9.76	261	0.009120	1.118774
8.56	280	0.008502	1.042857

**Table 2. Relative viscosity results for Boralesgamuwa clay**

Volume % of particles in the suspension	rpm	Viscosity ( $\eta$ ) ( $\text{kg m}^{-1} \text{s}^{-1}$ )	$\eta / \eta_0$
15.74	140	0.017003	2.085714
14.59	185	0.012867	1.578378
12.99	235	0.010130	1.242553
11.74	260	0.009156	1.123077
10.46	278	0.008563	1.050360



**Figure 5. Plot of  $\frac{\eta}{\eta_0}$  Vs % volume of solids for Dediyaawela clay**



**Figure 6. Plot of  $\frac{\eta}{\eta_0}$  Vs % volume of solids for Boralesgamuwa clay**

The gradient of the graphs (Figure 5 and 6) will be the k value for each sample. In both clays, the relative viscosity ( $\eta/\eta_0$ ) remains nearly 1 for dilute suspensions, but at higher solid volume concentrations the curves turn upwards (Figure 5 and 6). From these curves, it is evident that their gradients are different, showing that it is an inherent property of the clay. Therefore this technique can be used as a method of identifying different types of clay used in industry.

k value for Dediyaawela clay = 0.0697  
 k value for Boralesgamuwa clay = 0.2291

### 5. Conclusion

In this research we have noted that different types of clay can be assessed for industry on the basis of k value. The k value can be determined by the equipment we have designed.

### 6. Suggestions for further research

It is suggested that this research should be continued for samples of clay obtained from different locations in Sri Lanka using the same apparatus and thereby classifying various types of clays on the basis of k value alone.

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### References

Moore F, (1965). Rheology of Ceramic Systems, Livesey Ltd., St John's hill, Shrewsbury, pp. 2-14.