

These results are a preliminary account of comprehensive investigations at present being undertaken with respect to type of wave, range of materials, magnetic field-strength and frequency of the pulse. Velocity measurements are also being correlated with the observations on attenuation.

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¹ *J. App. Phys.*, 21, 10, 1067 (1950).

A New Surface Viscometer

OF the methods which have been used to measure the viscosity of surface films on a liquid substrate only one, the canal or surface-slit method, is amenable to rigorous mathematical treatment. Harkins and Kirkwood¹ derived an equation which could be applied to this method provided that certain modifications could be made to the apparatus as used by Joly². To measure the viscosity of dilute soluble films (to which the surface-slit method cannot be applied), a new method has been developed which is capable of rigorous interpretation.

The substrate (water or solution) is made to flow at a constant volume rate, V , through a horizontal channel of rectangular cross-section which it fills completely. The velocity, v_m , of an element of the surface along the centre of the channel may be measured by observing the passage of a floating particle of graphite between marked positions.

So long as there is no surface-pressure gradient, the flow velocity, v , satisfies, besides the Navier-Stokes equation, the boundary condition in the surface ($z = 0$):

$$\mu \partial^2 v / \partial x^2 + \eta \partial v / \partial z = 0,$$

where the distance, x , is measured across the channel and z vertically downward. For a channel of width a and depth b and a very small hydrostatic pressure gradient, A , in the direction of flow we find:

$$v_m = \frac{4Aa^3}{\pi^3} \sum' \sin \frac{n\pi}{2} \frac{\tanh(n\pi b/2a)}{n^3 a \eta \coth(n\pi b/a) + n^4 \pi \mu} \quad (1)$$

and

$$V = \frac{Aba^3}{12\eta} = \frac{8Aa^4}{\eta\pi^5} \sum' \frac{a\eta + 2n\pi\mu \tanh(n\pi b/2a)}{n^5 a \eta + n^6 \pi \mu \coth(n\pi b/2a)}, \quad (2)$$

where the sum is to be taken over all odd values of n . The ratio v_m/V is independent of A , and for $b \geq 3a$ simplifies to:

$$\frac{v_m}{V} = \frac{48 \sum' (-1)^{(n-1)/2} \frac{1}{n^3 + n^4 \pi \mu / a \eta}}{\pi^3 ab - \frac{96a^2}{\pi^2} \sum' \frac{1}{n^5} \frac{a\eta + 2n\pi\mu}{a\eta + n\pi\mu}} \quad (3)$$

The only unknown in this equation is μ ; for given values of a , b and η , it is a simple matter to plot the ratio v_m/V against μ . The measurement of v_m , to give less than 5 per cent error, must be confined to particles floating along the central 20 per cent of the channel surface.

To illustrate the sensitivity of the method, for $a = 0.153$ cm., $b = 0.60$ cm., and $\eta = 0.01$ poise,

the following table shows values of v_m/V corresponding to a range of values of μ :

$\mu \times 10^4$ (surface poise)	0	0.5	1	2	5	10	20
v_m/V	17.8	16.3	15.1	13.1	9.3	6.3	3.8

An experimental difficulty occurs in measuring the surface viscosity of some surface-active solutions. A negative surface-pressure gradient is set up along the channel, tending to retard the surface flow. If a barrier is placed across the surface of the channel before commencing the bulk flow, the surface pressures at the ends of the channel may be kept the same. When the flow has reached a steady state, the barrier is lifted and measurements of v_m are made after measured intervals. The value of v_m for zero surface-pressure gradient is then obtained by extrapolation. The form of the v_m versus time curve, and the difficulty of obtaining measurements at short intervals after lifting the barrier, sometimes makes this method impracticable and recourse is being made to a second method. After a period, v_m approaches a constant value, apparently indicating that a steady state with a constant surface-pressure gradient has been set up. By making further assumptions it is possible to make allowance for this back pressure (a measurable quantity) and to calculate the surface viscosity from the steady-state flow.

It must be assumed, with Harkins and Kirkwood¹, that the surface film is incompressible, that surface viscosity is independent of surface pressure and that there is no slip between surface film and substrate. Equations for v_m and V , obtained in the same way as the Harkins and Kirkwood equation in terms of a surface-pressure drop B , may be superposed linearly on the equations (1) and (2) to give equations for the flow when both hydrostatic and surface-pressure gradients are operative. The hydrostatic pressure gradient, A , is again eliminated between these equations to obtain an equation of the form:

$$VK_1 + BK_2 - v_m K_3 = 0,$$

where K_1 , K_2 and K_3 are analytical functions of μ , η , a and b . By plotting v_m/V against μ , a family of curves is obtained for various values of B/V .

Where the surface film is moderately close packed, for example, in condensed insoluble films and in concentrated soluble films, a back pressure develops so rapidly that extrapolation to zero back pressure is impossible and v_m becomes so small that accurate determination of its steady value becomes impracticable. This constitutes a major limitation on our method of measuring surface viscosity. For dilute gaseous films, soluble or insoluble, the method appears most promising.

A more complete description of the experimental methods and the mathematical treatment will be published later.

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¹ Harkins, W. D., and Kirkwood, J. G., *J. Chem. Phys.*, 6, 53 (1938).

² Joly, M., *J. Phys. et Rad.*, 8, 471 (1937).