RADIOISOTOPE METHOD OF DETERMINING THE EFFECTIVE VISCOSITY OF DISPERSE SYSTEMS UNDER VIBRATIONS*

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A radioisotope apparatus and procedure have been developed for recording the motion of a control ball with a gamma radiator and for determining the effective viscosity of a disperse system under vibrations.

The treatment of disperse materials in a vibration field can be optimized only if the rheological properties of such systems are taken into account.

The interlayer processes in disperse systems and the physicomechanical properties of such systems under vibrations were examined by the radioisotope method, both the apparatus and the procedure having been described in [3-6]. Results of viscosity measurements in a disperse system by means of gamma rays were reported in [7]. In that case the geometric locations of an indicator ball were measured discretely, i.e., at instants of its passage through the sensitivity zones of two detectors installed at a definite distance between them.

The authors studied the motion of an indicator ball and the rheological properties of disperse systems under vibrations.

As the test material we used an aqueous cement suspension with a dispersivity of the solid phase equal to 5000 cm^2/g and with the water: cement ratio varying from 0.25 to 0.30. The tests were performed under harmonic vibrations in the horizontal plane at a frequency of 3000 per minute and with an amplitude $A = 0.05$, 0.22, or 0.30 mm. The radioisotope apparatus (Fig. 1) was suitable for recording the location of a control ball (diameter $d = 5.5$ cm, density $\rho_S = 4.0$ or 7.8 g/cm^3) during its motion through the water–cement mix. A ball contained inside a bead with cesium-137 isotope emitting gamma rays at a 0.66 MeV

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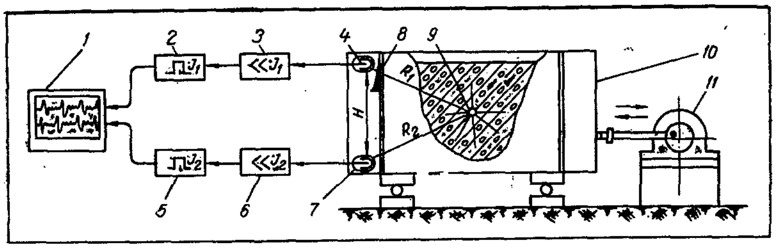

Fig. 1. Schematic diagram of the radioisotope apparatus: 1) model N-102 loop oscillograph; 2, 5) pulse shapers; 3, 6) cathode followers; 4, 7) radiation detectors; 8) lead shield; 9) control ball; 10) vessel; 11) shaker.

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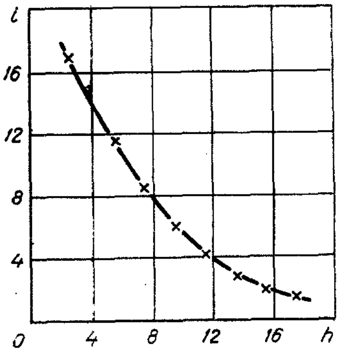

Fig. 2

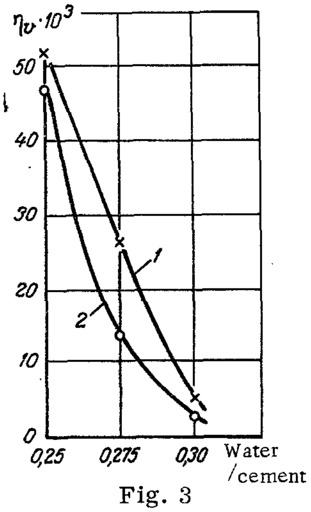

Fig. 3

Fig. 2. Ratio of radiation intensities at the detectors ($i = I_2/I_1$) as a function of the ball immersion depth (h).

Fig. 3. The effective viscosity of an aqueous cement suspension as a function of the water: cement ratio, with $p_T = 7.8$ g/cm^3 and an oscillation frequency of 3000 min^{-1}; 1) amplitude 0.22 mm; 2) 0.3 mm. η, P.

TABLE 1. Density of Aqueous Cement Suspension as a Function of the Water : Cement Ratio

Water:cement ratio	ρ_s, g/cm^2
0,250	2,18
0,275	2,13
0,300	2,10

energy level and a $2.33 \cdot 10^{-7}$ R/sec$^{-1} \cdot$ m^{-1} powerful exposure dose. Such a ball with isotope was placed inside the 20 × 20 × 20 cm vessel 10 (Fig. 1), which was then filled with the test material. The model STS-5 radiation detectors 4 and 7 were spaced 16 cm apart.

The gamma radiator in these tests could be assumed equivalent to a point source, inasmuch as its active component was much shorter than its distance to the detector. Electric pulses from each radiation detector were transmitted to the respective cathode followers 3 and 6, then to the pulse shapers 2 and 5 with the model N-102 recording oscillograph 1 at the output. In this way, signals from the two detectors were recorded at definite intensities along with time-base pulses. A displacement of the point source of gamma rays could be measured by the ratio of radiation intensities from the two detectors with respect to a certain base level. With the distance from the point source to the first and to the second detector R_1 and R_2, respectively, and with the corresponding radiation intensities recorded by them I_1 and I_2, we have, according to [8], the ratio of radiation intensities $i = I_2/I_1$ expressed as

$$i = I_2/I_1 = (R_1^2/R_2^2)\exp\left[-\mu(R_2 - R_1)\right]. \tag{1}$$

On the basis of the ratio of intensities averaged by the detectors over a sufficiently short time interval, one can, according to formula (1), almost continuously record the geometric location of a point source during a linear motion. In order to increase the sensitivity of this method of recording, it is necessary to increase the ratio of intensities at the detectors, and this is achieved by reducing the irradiation level of the upper detector 4 relative to that at the lower detector 7 by means of a variable-thickness lead shield 8 (wedge with a 2 cm base and a 10 cm height). In this case, during a vertical downward displacement of the control ball with the source, the intensity of gamma radiation at the upper detector (I_1) decreases owing to its larger distance from the source (R_1) and because of the extra attenuation of radiation by the shield material. At the same time, the radiation intensity at the lower detector (I_2) increases owing to its smaller distance from the source (R_2). Furthermore, a proper design of the shield profile will make it possible to trim this relation as desired, and also to reduce the recording error due to the variation in the properties of the medium during vibrations generated by the shaker 11.

In Fig. 2 is shown the ratio of radiation intensities at the detectors, as a function of the ball depth (diameter 5.5 cm, density 7.7 g/cm^3) in selected aqueous cement suspensions.

TABLE 2. Ball Velocity ($\rho_S = 7.8$ g/cm^3) in Aqueous Cement Suspensions at Various Vibration Amplitudes (Frequency n = 3000 per min)

Water:cement ratio	Vibration amplitude, mm	v, cm/sec
0,250	0,05	0,170
0,250	0,22	0,183
0,250	0,30	0,202
0,275	0,22	0,358
0,275	0,30	0,641
0,300	0,22	1,956
0,300	0,30	2,059

In order to determine the displacement h of a control ball within a definite time period, we have statistically evaluated a number of pulses shown on an oscillogram within a measurement time of 0.1 sec. This ensured an average error of ionizing-radiation measurements of not more than 10%, as required for the given source of gamma rays under the given test conditions. The relation between the ball immersion depth h and the ratio of gamma-radiation intensities ($i = I_2/I_1$) recorded by the detectors for the given aqueous cement suspensions can be expressed as

$$h = 10{,}55 - 0.55\,i + 13{,}8/i, \text{ cm.} \tag{2}$$

The density of the aqueous cement suspensions was measured by the method shown in [3]. A layerwise check of the density in the mixtures during vibrations indicated no stratification of the mass. The parameters of vessel and mixture vibrations were compared by tracking the vibrations of a ball (density 1 g/cm^3) in water. The tests indicated a near-coincidence, under the given conditions, between the pad vibrations and the ball vibrations, which more or less agreed with the test results in [9].

The density of the mixture is tabulated (Table 1) as a function of the water : cement ratio.

It was found in the course of the experiment that during steady-state vibrations the control ball moved at a constant velocity $v = dh/d\tau$.

This confirms the results obtained in [10] with a slotted vibroviscometer, indicating that vibrations cause the structure of aqueous cement suspensions to break down throughout the volume and isotropically. In Table 2 are shown the values of the mean ball velocity in an aqueous cement suspension at different water : cement ratios and at different amplitudes of volume vibrations (frequency n = 3000 per minute).

An inspection of Table 2 will show that, as both the water : cement ratio and the vibration amplitude increase (at a constant frequency), the average ball velocity also increases. Analogous results were obtained also with a ball of a 4.0 g/cm^3 density.

Since the density of an aqueous cement suspension does not vary during vibrations, at fixed water : cement ratios, hence the velocity of the mix may in this case be assumed zero. It has been shown in [5, 10] that disperse systems under vibrations behave like Newtonian fluids and that, therefore, the application of this test method to structurized systems is perhaps limited by an ultimate breakdown of the structure. Thus, the effective viscosity of a suspension η_V can be defined on the basis of the Stokes equation, in this case ($d = 5.5$ cm, $g = 981$ cm/sec^2):

$$\eta_v = 1649\ (\rho_S - \rho_s)/v, \text{ P,} \tag{3}$$

with ρ_S denoting the density of the ball material (g/cm^3), ρ_S denoting the density of the suspension (g/cm^3), and v denoting the ball velocity (cm/sec).

The effective viscosity of an aqueous cement suspension as a function of the water : cement ratio is shown in Fig. 3 at vibration amplitudes 0.22 and 0.30 mm of a ball of a 7.8 g/cm^3 density. An analysis of test data shows that, as the water : cement ratio increases, the effective viscosity of the suspension decreases and at a water : cement ratio −0.3 the system viscosity is hardly affected by the vibration amplitude. These conclusions are supported by data in [10, 11].

Thus, the contactless radioisotope method is useful for studying the rheological properties of disperse systems under vibrations.

NOTATION

W/C	is the water : cement ratio;
d	is the diameter of the control sphere;
ρ_S	is the density of the control sphere;
ρ_s	is the density of suspension;
R_1, R_2	are the distances from the point source to the upper and to the lower detector, respectively;
I_1, I_2	are the radiation intensities recorded by the upper and by the lower detector, respectively;

$i = I_2/I_1$ is the ratio of radiation intensities;
μ is the linear coefficient of gamma-radiation attenuation;
h is the depth of ball immersion;
v is the average velocity of control ball;
τ is the time;
η_V is the effective viscosity of the system;
g is the acceleration of gravity.

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