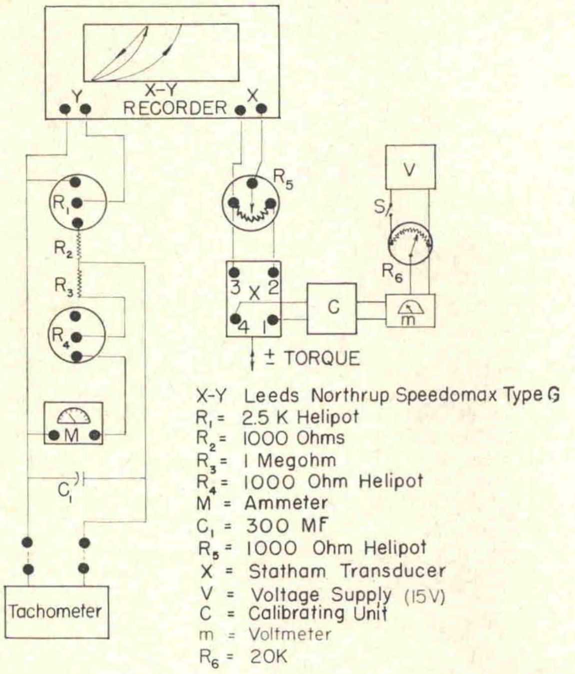

FIG. 9. Schematic of shear rate and torque recording system (Note: items V, R_6, and M are replaced by Hewlett-Packard model 721A power supply).

tachometer generator, obtained from the Esterline-Angus Company, Inc. The internal resistance of the tachometer is 2000 ohms. The maximum desirable armature speed is 1250 rpm. The generator is calibrated, to an accuracy of 1/2%, to develop an open circuit emf of 25.0 V at 1000 rpm of the armature. Precise adjustment is made by means of a movable magnetic shunt, attached to the pole pieces, which is capable of varying the generator output over a range of about ±3%. At the maximum "desirable" armature speed of 1250 rpm the generator develops an open circuit emf of 31.25 V. Since the maximum speed of the transmission is 1100 rpm the direct couple keeps the speed of the armature within the safe range of 1250 rpm maximum. The greater speeds of the cup are achieved by the various gear ratios, Fig. 5 and Table I. The circuit used to reduce the output of the tachometer generator to one (about 10 mV), that can be handled by the X–Y recorder, is shown in Fig. 9.

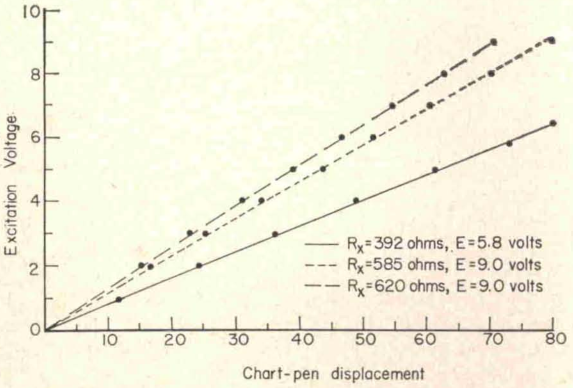

FIG. 10. Recorder-pen deflections versus transducer excitation voltage.

5. Torque Measuring and Recording

Torque is translated into an exact electrical equivalent by means of a complete balanced bridge (Statham transducer) of strain-sensitive resistance wire. Nine units consisting of ±0.15-, ±0.75-, ±1.5-, ±4-, ±8-, ±16-, ±24-, ±32-, and ±80-oz transducers are employed. The excitation voltage for this series of transducers ranges from 8 to 14 V. The above set of transducers and a Hewlett–Packard model 721A dc voltage supply, Fig. 9, permits measurement of forces ranging from about 1 to 2270 g.

After calibrating the transducer (Sec. 3, under Calibration) the deflection of the pen on the chart, for a given applied load to the transducer, can be controlled by either R_5 or R_6 in Fig. 7. When possible it is recommended that the excitation voltage remain that specified for the transducer by the manufacturer and that the upper limit of pen deflection be controlled by R_5. However, if one does find it more convenient to vary R_6 (the excitation voltage) instead of R_5, and because of the linear relationship between voltage and displacement, one can easily correct the data accordingly.

A typical plot of voltage with pen deflection is shown in Fig. 10, for a 4-oz transducer under a constant load but where R_5 or R_6 (excitation voltage) is varied. This plot points out specifically that R_5 and R_6 should have one setting and meter value, respectively, for each transducer, where the recorder is calibrated to full pen deflection at the load limit of the transducer. Subsequent data can then be compared meaningfully.

It has been found desirable to select an "R_5" value so that a near "full load" on the transducer will not cause more than 80 scale divisions (small) on the recorder chart. This affords a rapid check against over-loading which happens often in the case of rheopectic materials where viscosity increases with shear.

The force due to gravity of the bob varies slightly, apparently due to humidity and temperature changes, and is about 0.5 to 0.7 mg. In the 0.15- to 16-oz transducer range, accuracy and linearity of both the transducer and recorder is within 1% of full scale. The 32- and 80-oz transducers show a linearity, with applied torque, within 1.5% of full scale.

The transducers have identical basal dimensions and are easily replaced into an insert of a specially designed plate. The exact position of transducer in relation to the pressure (lever) arm on the bob shaft, Fig. 4, is easily repeated. This position is maintained during measurement.

A force F due to a torque on the bob and translated through the lever arm, Fig. 4, is related to the transducer by a "machine constant," $C = 67.24$ dyn/cm^2. A transducer constant k, Fig. 8, and the pen deflections Δx (chart divisions) are related to the experimental shear stress f by $f = kC\Delta x$.

EXPERIMENTAL RESULTS

1. Structure

The results reported here were obtained on the mineral attapulgite using a cylinder set #1. With the use of the automatic controls, the viscometer recorded a continuous flow curve in 30 sec with a peak rate of shear of about 700 sec^{-1}.

Figure 11(a) shows the structure of attapulgite as worked out by Bradley.[21] The substitution of Al^{3+} for some of the Si^{4+} is probable, and it is considered that substitution of Al^{3+} for either Mg^{2+} or Si^{4+} or both should weaken the structure.

The chemical analysis (volatile-free basis) of the material (specific gravity 2.36) used in this study is: silicon (SiO_2), 67.0%; aluminum (Al_2O_3), 12.5%; magnesium (MgO), 11.0%; iron (Fe_2O_3), 4.0%; calcium (CaO), 2.5%; other, 3.0%. The bulk density (tamped volume weight) was approximately 0.56 g/cc and the surface area approximately 210 m^2/g on a moisture-free basis. The particle size distribution determined by centrifugal sedimentation is given in Fig. 11(b).

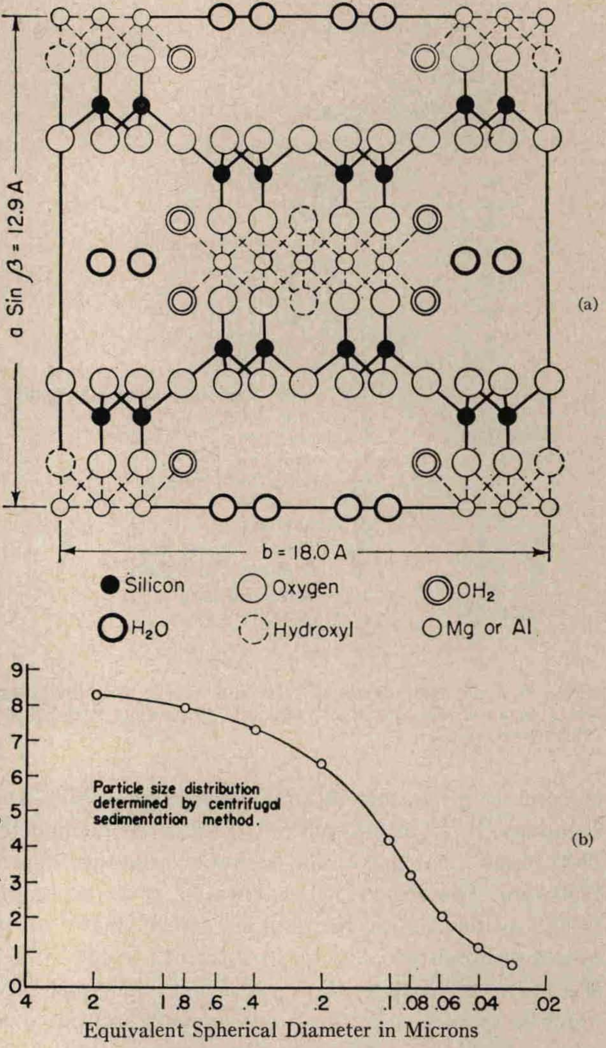

FIG. 11. (a) Structural model of attapulgite and (b) particle size distribution.

2. Viscometer Calibration

A photograph of a strip of recorder chart, Fig. 12, shows the procedure which was used to record the data. The response of the transducer to loading and unloading is recorded in Fig. 12(a). The "histogram" indicates the accuracy in the response of the transducer to changing load during increasing and decreasing shear rates.

A calibrated 98% glycerol "standard" gave the flow curves shown in Fig. 12(b). The ordinate and abscissa are drawn, only in Fig. 12(b), to show the actual values for shear rate $\dot{s}$ and shear stress f, respectively. However, these ordinate and abscissa values are the same for the curves in c, d, e, and f. In Fig. 12(b) the up and down

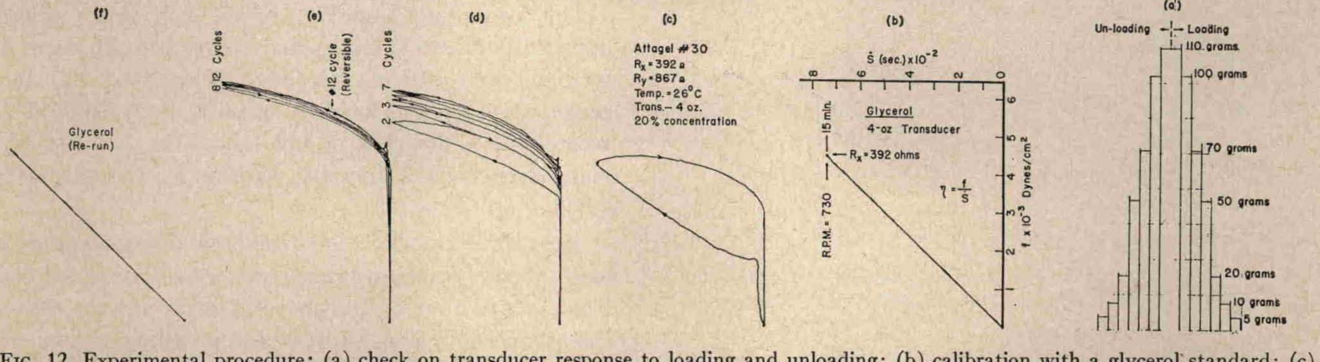

FIG. 12. Experimental procedure: (a) check on transducer response to loading and unloading; (b) calibration with a glycerol standard; (c) first 60-sec cycle for attapulgite suspension in water; (d) decreasing rheopectic loops for successive cycles; (e) continuation of cycling to reversibility; (f) standard re-run for a check on machine operation.

---

[21] W. F. Bradley, Am. Mineralogist **25**, 405 (1940).