in castor oil is required. A simple dilution with methyl isobutyl ketone is the only sample preparation required.

4. Estrogenic hormones in tablets are extracted simply with N,N-dimethylformamide followed by dilution with methyl isobutyl ketone and filtration.

5. Accuracies in excess of 95% are obtained by simultaneously chromatographing replicates of standard and sample solutions on the same chromatogram.

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Technical Articles

Adaptation of Commercial Viscometers for Special Applications in Pharmaceutical Rheology II

Severs Extrusion Rheometer

By JOHN H. WOOD, GREGORY CATACALOS, and S. V. LIEBERMAN†

The Severs rheometer has been slightly modified to provide greater flexibility of use. Besides its normal use as a rheometer, it may be used to accept samples in collapsible tubes. Such samples undergo no change in thixotropic set before actual measurement. The apparatus can also be used to shear samples of up to 700-ml. volume in a manner comparable to a high-speed filler. The method of calibrating the filler shears is outlined. Commercial fillers show shears from slightly in excess of 10,000 seconds^{-1} to 100,000 seconds^{-1}. It is demonstrated that the combination of nozzle, piston, and filler geometry is such that each can become the point of critical shear, depending on the relative dimensions of the other parts.

IN THE pharmaceutical field, couette-type instrument rheology has been largely the standard of usage because any instrument with either a range of cups and/or bobs or of springs could be adapted to take the wide range of consistencies so characteristic of this discipline. The engineering profession and the polymer, plastics, and petroleum industries tended to adapt the classical Poiseuille capillary to their special needs by increasing the radius to tubes, and even pipes, and by using pressure to increase the driving force over that of gravity alone. Such an instrument, designed by Severs (1), is commercially available. Its use with pressurized dentifrice has been described elsewhere (2). This paper is intended to show some other possible adaptations for this useful and relatively inexpensive instrument.

As a rheometer alone it is flexible and covers a wide shear-rate range but this alone does not justify special note. It is, however, readily adaptable to give useful information in two fields where the couette instrument is not directly utilizable. The first of these is the study of thixotropic systems of slow recovery in which the mere process of loading the instrument with sample partially destroys the set. Many creams, pastes, and other semisolid systems fall into this category. Two types of measurement on such

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systems are then possible, conventional stress-shear rate determinations and the relative extrudibility of different formulations under constant stress. In this respect it becomes comparable to the modified De Waale plastometer described by Adler (3).

The second application, of considerable importance in industrial technology, is the application of the rheometer as a shear device to prepare samples of a known shear history for aging study. The properties of a thixotropic system of low recovery rate can be drastically changed by a subsequent shear hours or even days after original preparation. This generally is the commercial manufacturing and packaging procedure. Lotions and semisolid systems may be filled at varying times after manufacture. The filling shear will depend upon the type of equipment used, the rate of filling, and also for a given container rate, the container size filled. The calibration of a laboratory pseudofiller capable of encompassing such variables is then of practical value.

EXPERIMENTAL

The Rheometer.—The Castor-Severs extrusion rheometer, model A-100[1] was modified by the manufacturer to permit use over the range 0 to 200 p.s.i. A special sample tube of 700-ml. volume was supplied. It is 57 cm. long and 4 cm. internal diameter. This is approximately twice the length and volume of the usual rheometer. It has been found desirable to tee into the gauge line a manifold with a series of gauges for lower pressure ranges. Each is protected by a manual cut-off valve. (See Fig. 1.) Appropriate gauge calibrations were made primarily for internal self-consistency between gauges but also for absolute values. The instrument is supplied with nitrogen gas at 300 p.s.i. from cylinders. Flow times are measured with a foot pedal activated digital electric clock reading to 0.1 second. Density determinations are made in vessels suitable to the consistency of the material under investigation, fluid or semisolid. Three capillaries, 5.0 cm. long, are supplied. These have diameters of 0.6283, 0.3141, and 0.1556 cm.

Rheology of Thixotropes.—Because of the wide internal bore of the sample holder, paste-type samples can be examined if shears lower than those employed in loading can be ignored. Since such loading can be of quite low shear, this is frequently possible. More elegant, however, is the procedure of loading the sample upon preparation into conventional collapsible tubes of composition of lining compatible with the sample to be studied. Adapter plates were made by drilling a $^3/_8$-in. hole through an aluminum plate of the same dimensions as the capillary socket plate. The threaded portion of a tube cap was coaxially cemented over this hole with epoxy resin. For sample study, a tube was then uncapped, screwed into the plate, the end cut open, and the whole assembled into the rheometer with

[1] Burrell Corporation, Pittsburgh 19, Pa.

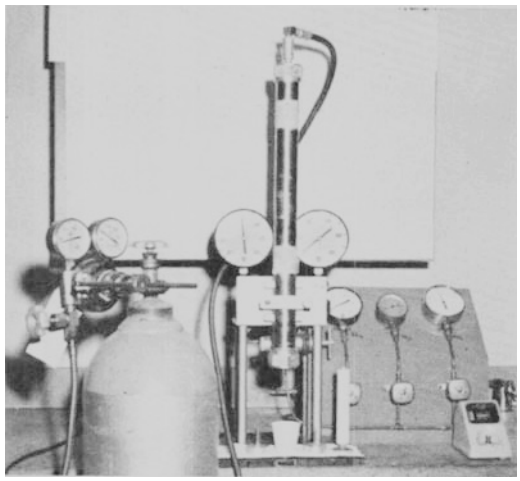

Fig. 1.—The modified Severs rheometer showing assembly and collapsible tube adapter.

the adapter plate immediately above the capillary plate. A light coat of vacuum grease is used between the two plates to prevent gas leakage. Conventional extrusion rheometry then follows. Alternately, by only using the adapter plate without the capillary, the pressure required for paste extrusion from a given sized tube may be determined for any desired delivery rates.

It has been found desirable, because of the large void space in the barrel, to prepressurize it while holding a finger over the end of the capillary. The timer is then foot activated as the finger is withdrawn. This is practical for pressures up to 100 p.s.i. The run is terminated instantly by releasing manually the extrusion pressure with the pressure release lever built into the apparatus. At the same time the timer is pedally stopped. The extrudate is caught and weighed in a tared container of suitable dimensions.

Rate of shear, D, is calculated from the equation

$$D = \frac{4Q}{\pi r^3} = \frac{4W}{\pi d r^3}$$

where Q is volume delivery per unit time, W the weight delivery per second, r is the radius of the capillary, and d the density of the extrudate.

The shearing stress, T, is given by

$$T = \frac{Pr}{2L}$$

where P is the driving pressure, and L is the length of capillary used.

Comparison values are shown in Fig. 2 for the measurement of a commercial dentifrice using each of the three capillaries in the extrusion rheometer. In addition, data were obtained from the Hercules Hi-Shear rheometer and from the D cup of the Drage Epprecht rheometer. In the latter case, the D cup was used alone and with each of the five sleeves available for it. The dentifrice system is highly thixotropic and is also pseudoplastic in rheology.

Pseudofilling.—The barrel is first charged with the sample. If the material under investigation is fluid, then the capillary is capped with a rubber plug; if the sample is semisolid then the bottom end is

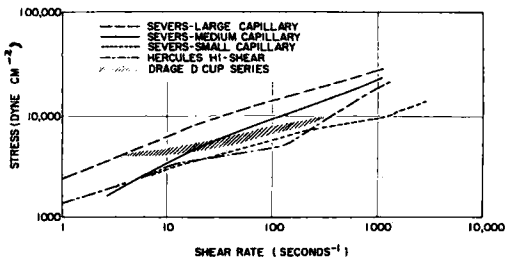

Fig. 2.—Rheograms run on an aged, strongly thixotropic, pseudoplastic dentifrice system with the Severs extrusion rheometer, the Hercules Hi-Shear rheometer, and the Drage Epprecht rheometer (D cup with sleeves).

capped with an end plate for loading and tamping, and the capillary is then put in place. Prepressurizing, as previously described, leads to the most consistent results. The appropriate volume, up to 700 ml. per charge, is then extruded at the desired rate, time of delivery and weight of extrudate being as before. For high rates of delivery, it is desirable to use two operators, one of whom notes the gauge pressure used and maintains its constancy. Under high flow rates, the diaphragm reducing system cannot deliver at sufficient rate to maintain the pressure preset at zero flow rate. If a series of points are obtained, then the resultant data also represent a high shear-rate rheogram. The samples made in this fashion are stored and monitored with passing time by low-shear measurements using our modified Brookfield system (4).

For the calibration of the equivalent shear of a filler, a full shear range set of samples are obtained by delayed filling of a thixotropic material whose "set" is partially broken by any shear at a time, days or hours, subsequent to making. Samples are simultaneously obtained from the filler. By using the exponential plot of aging behavior (5, 6), points of corresponding age and shear are compared directly for the rheometer prepared and the conventional filler samples (see Fig. 3). Equivalent shears of the filler are then noted as indicated in the graph by the solid triangles for points of identical rheological behavior. Usually the average of at least two periods of delayed fill and several periods of post-filling aging are obtained. Laboratory samples, pseudofilled equivalent to high-speed production filling, may thus be obtained for a wide range of shears to examine the effect of filling shears on subsequent rheological properties as part of a laboratory process study.

With a Colton 175–63 single nozzle filler, a study was made in the above manner of the resultant equivalent shear for two different operating speeds, two delivery piston sizes, and three filling nozzles, to permit an evaluation of whether the primary shear zone was in the piston or the orifice. Similarly two high-speed production fillers were also examined under their normal operating conditions.

RESULTS AND DISCUSSION

Rheology.—In the rheologic examination of highly thixotropic pseudoplastic systems, it is generally of sufficient utility to consider comparisons between samples made with only one measuring system. However, when two or more measuring systems are used, especially in a conventional couette system where the cup and bob ratios are changed, nonsuperimposable rheograms are obtained. Two phenomena, acting in opposition, are responsible for this. The first of these is the relaxation time of the thixotrope. The longer the time of applied shear, the greater the thinning that occurs. In a couette instrument the shear thinning at any shear rate is an integrated history of all the shear that has preceded. The measurement of a thixotropic index by the fall in torque with time is always complicated by the inability to measure the zero time value. In the capillary method, the length of the capillary sets the duration of the shear time for a given shear rate; therefore, a similar problem exists. However, the capillary is continuously using new sample so that a rheogram becomes independent of the rate at which increasing shear-rate points are taken.

The second consideration is correction for slippage either at the wall or internally. For the pseudoplastic system, which is not time dependent, Wilkinson (7) and others have outlined methods of calculation where data for various cup and bob ratios or different capillary radii are extrapolated to give measurements of torque and shear rate at the wall as the limiting case. From these extrapolations, true equations of flow may be derived.

However, for the thixotrope, the dimensions enter in a consideration of relaxation. The higher the shear-rate gradient, the greater the shear dependent thinning that occurs during a measurement. This is clearly shown in Fig. 2 for both types of measuring systems. In the couette type, as the Drage cup-to-bob ratio approached unity by the use of closer sleeves, the torque decreased for any given shear rate. For the Hercules, in which the

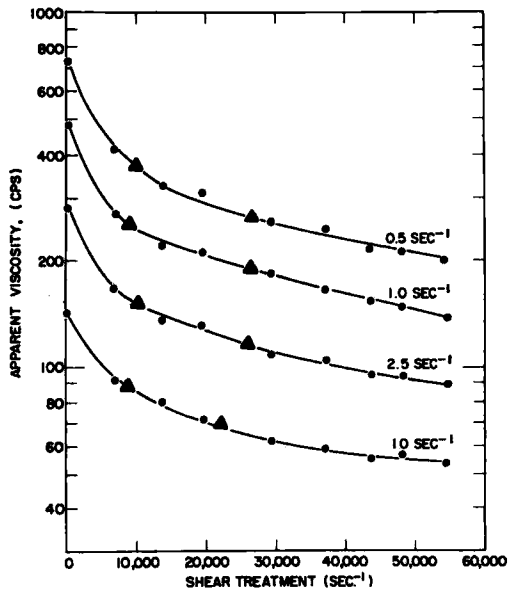

Fig. 3.—Apparent viscosities at different shear rates of a thixotropic lotion pseudofilled at various rates of shear, 2 days after manufacture. (Measurements were made after 7 days.) The triangular points represent equivalent behavior of material filled on two commercial fillers.

ratio is 0.95, the torque is even lower. Similarly decreasing radius of capillary resulted in lower torque for any given shear rate.

That the large capillary is capable of giving readings with minimal thixotropic breakdown is then evident from Fig. 2. Extrapolation procedures would indicate that the truly undisturbed readings are in excess of those found even with the large capillary.

The capillary type of measurement has another virtue. Most couettes are confined optimally to slightly over two decades of shear. In practice a given capillary is useful for almost four decades of shear rate.

Using the collapsible tube system, one restriction is necessary. The neck size must be such that a negligible portion of the shear occurs there relative to the measuring capillary.

The case shown here, the highly thixotropic dentifrice system, shows the worst possible disagreement between instruments. Normally the agreement is much more consistent and the dependency on dimensions far less critical. For nonthixotropic pseudoplastic substances, excellent agreement between measuring systems of the capillary and couette type is the general rule.

Pseudofilling.—In Fig. 3, for a cosmetic antiperspirant lotion, we see the agreement obtainable for four shear rates of measurement for the apparent shear exerted by a filler as determined by the rheological properties measured at a later date. Similar agreement was obtained between other test situations of different ages before filling and also different ages for post examination. In this way we concluded that one production filler filling 1-oz. bottles exerted a shear equivalent to approximately 25,000 seconds^{-1} while another filling 1$^1/_2$-oz. bottles gave only 12,000 seconds^{-1}, thus emphasizing the role played by filler dimensions. This was subsequently shown in detail with the Colton filler.

An examination of the equivalent shear of the Colton filler operating at full speed with full and partial stroke is given in Table I. For reduced speeds, for those nozzle, stroke, piston combinations examined the apparent shear was proportional to the delivery rate. Using the small piston, with either full or partial stroke, the primary shear zone appears to be in the region from the piston to the orifice for the large and medium orifices. The small orifice, however, either contributes to or becomes the most significant shear zone. With the large piston, it is evident that the medium orifice now contributes significantly to the shear imposed, and it is not clear whether this applied to the large orifice too. Admittedly full speed, full stroke, filling is not a commercial practicality, but these data do demonstrate the role filler shear can play in subsequently important rheological properties. The data of Table I also emphasize that filling conditions set what part of the machine becomes the source of primary shear.

TABLE I.—EFFECT OF MACHINE VARIABLES ON APPARENT SHEAR OF A COLTON FILLER

		Small Piston Delivery		Large Piston Delivery	
Stroke	Nozzle	Rate, Gm./sec.	Shear, sec.$^{-1}$	Rate, Gm./sec.	Shear, sec.$^{-1}$
Full	Large	58	37,000	143[a]	53,000
	Medium	58	37,000	171[a]	105,000
	Small	58	47,000	142[a]	112,000
Partial	Large	36	29,000	93	16,000
	Medium	37	28,000	92	54,000
	Small	38	36,000	85	78,000

[a] Possible sample loss due to splashing at such high flow rates.

Only an extrusion type rheometer is practically capable of applying shears in the range found for commercial fillers. Being able to collect samples that have been subjected to known shear rates in quantities suitable for study is a distinct advantage to the modified Severs described here.

SUMMARY

The commercially available Severs rheometer is shown to be applicable directly, and by minor adaptation, to rheological problems of concern in the properties of lotions and semisolids. By the use of samples stored in collapsible tubes of suitable composition almost "undisturbed" rheological measurements of thixotropes may be made.

The bulk preparation of samples prepared under various known rates of shear permits calibration of the apparent shear of commercial filling equipment and the study of shear dependency in the laboratory. The shear rates for filling may range from 10,000 sec.$^{-1}$ to 100,000 sec.$^{-1}$. The critical dimensions to shear in a commercial piston filler vary with the piston and orifice tube sizes used.

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