Measurement of Some Rheological Properties of Plastic Fats with an Extrusion Modification of the Shear Press

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Abstract

An extrusion attachment for the Lee-Kramer shear press is described. With this instrument some rheological properties of lard, margarine and shortening were measured. These included extrusion pressure and specific work of extrusion. By variation of extrusion speed and size of orifice a variety of rates of deformation could be obtained. When the rate of deformation was plotted against the specific work of extrusion, curves were obtained which were nearly straight beyond deformation rates of about 1 sec^{-1}. The tangent to these curves represents the apparent viscosity. By measurement of the hardness before and after extrusion the work softening resulting from the extrusion could be measured. Some possible uses of the technique are discussed.

Introduction

The rheological properties of plastic fats, such as lard, shortening, margarine and butter are of interest from the point of view of their behavior during the manufacturing process as well as the way in which the products perform during actual conditions of use. There is a variety of instruments to measure some of the commonly used rheological characteristics of fats (1), many of these are penetrometers of some kind. In the AOCS methods (2) the cone penetrometer has been the instrument of choice. However, in addition to hardness or consistency, there are a number of other rheological characteristics which are of interest in respect to plastic fats.

In a study of the effect of mechanical treatment on the rheological properties of some fats it became desirable to determine the extrusion characteristics of fats. An attachment was designed for the shear press, which was successfully used in this work. This is an instrument designed for measuring the rheological behavior of a variety of foods and has been used with meat, vegetables, fruits, cheese and many other foods. In its standard form it is not suitable for plastic fats but, with the extrusion attachment, it can be used to measure work of extrusion, as indicated in this paper. The rheological behavior of plastic fats is complex, combining the properties of Bingham and pseudoplastic substances (3).

Many factors determine the rheological behavior of fats, and some of these have been studied in detail, e.g., crystal size (4,5), solid fat content (6), and polymorphic forms (7). During technical processing some of these variables may be influenced and may lead to alteration of the rheological properties of the fat. As extrusion is commonly used in the practical handling of fats, it was felt that an instrument such as the one described in this paper would be a valuable addition to the instruments available for the study of fat rheology and could yield results which could be helpful for the understanding of some technical processes.

Experimental

The instrument used was a Lee-Kramer shear press, model SP-12 with electronic recording attachment. The standard shear cell was replaced by an extrusion attachment, the parts of which are shown in Fig. 1. It consisted of a brass plunger which could be attached to the bottom of the proving ring; the plunger fitted by means of an O-ring into the extrusion dies. The dies were 3¼ in. long. The top end of the dies was sharpened to facilitate filling of the dies with the fat samples. Bottom plates had sharp edged orifices of 2, 4 and 6 mm. During the extrusion the dies were supported by a steel plate with a hole, which fitted into the frame of the shear press. The extruded fat could be collected in a dish placed under the supporting plate. The complete assembly in the shear press is shown in Fig. 2. The operation of the whole unit is represented schematically in the block diagram of Fig. 3. The proving ring used in the extrusion experiments had a load range of 0–500 lb, and the sensitivity was selected to give a full-scale recorder deflection for a 50-lb load. The speed of the plunger is continuously adjustable with the speed control valve, but, as no exact speed indication mechanism exists in the shear press, a set of sliding contacts was

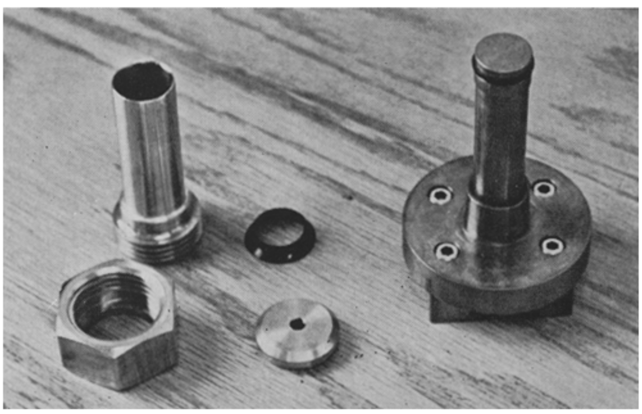

FIG. 1. Constituent parts of the extrusion attachment.

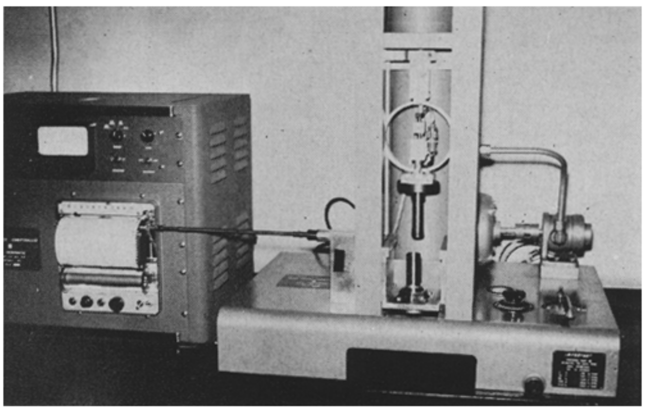

FIG. 2. Extrusion attachment installed in the shear press.

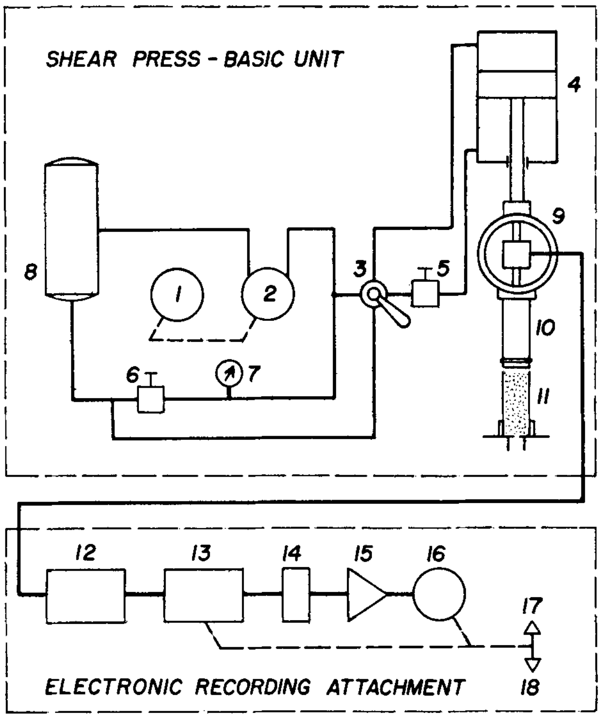

FIG. 3. Block diagram of the operation of the shear press with extrusion attachment: *1*, electric motor; *2*, gear pump; *3*, directional valve; *4*, cylinder; *5*, speed control valve; *6*, pressure control valve; *7*, hydraulic pressure indicator; *8*, receiver; *9*, proving ring; *10*, extrusion plunger; *11*, extrusion die; *12*, preamplifier; *13*, measuring circuit; *14*, chopper; *15*, servo-amplifier; *16*, balancing motor; *17*, indicating pointer; *18*, recording pen.

attached to the piston rod. Exact timing of a preset distance was accomplished with an electric stopwatch. The speed was variable from 0–12 in./min (30 cm/min). All experiments were performed in a thermostatically controlled room maintained at 15C, and the fats were allowed to equilibrate overnight. In this work four extrusion speeds were used, 0.04, 0.18, 0.40 and 0.60 cm/sec. Combined with the 3 different orifice sizes, a total of 12 different speeds of extrusion were obtained. All measurements were performed in triplicate, the weight of the extruded fat was determined, and results were expressed on a 1-g basis. There was no noticeable change in temperature of the fat after extrusion so that the extrusion can be considered to have taken place under isothermal conditions.

Penetrometer hardness was measured according to AOCS method Cc 16–60 (2), and results were reported in 0.1 mm as well as in kg/cm^2 as proposed

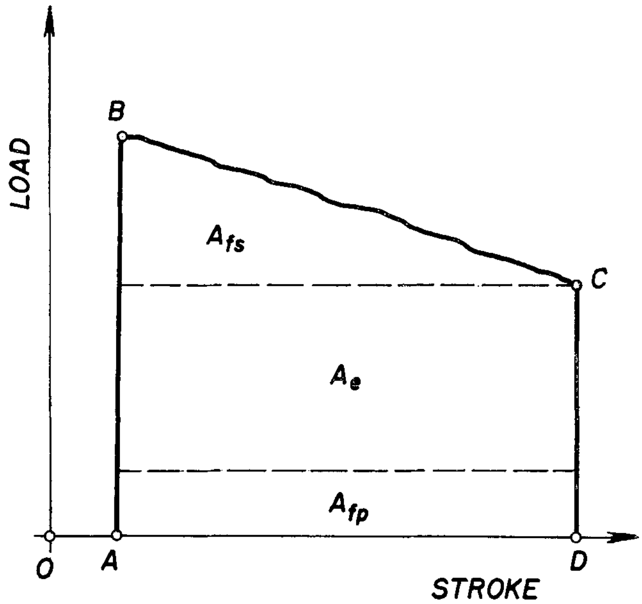

FIG. 4. Typical extrusion diagram obtained with the shear press and extrusion attachment: A_e, area of extrusion; A_{fs}, area of friction sample; A_{fp}, area of friction of extrusion plunger.

by Vasić and deMan (8). Work softening was calculated from

$$\frac{\mathrm{Ho} - \mathrm{Hw}}{\mathrm{Ho}} \times 100\%$$

where Ho and Hw represent the hardness of the unextruded and extruded samples, respectively.

Three types of fat products were used, lard, shortening, and margarine, which were commercial products obtained locally.

Results and Discussion

The form of a typical extrusion diagram is shown in Fig. 4. The upper part of the diagram, A_{fs}, represents the work used for friction between the sample and the inner surface of the extrusion die; A_{fp} represents the work used for friction between plunger and die. The area A_e was found by repeating the stroke with the empty die after each experiment; this gave a measure of A_{fp}.

The extrusion pressure was calculated as the ratio of the average force during the extrusion, which was taken from the extrusion diagram and the cross-sectional area of the extrusion die, which was 4.15 cm^2. The specific work of extrusion is defined as the work required to extrude 1 g of butter through the

TABLE I

Speed of Extrusion, Rate of Deformation and Specific Work of Extrusion Obtained with Lard, Shortening, and Margarine, Using the Extrusion Attachment to the Shear Press

No.	Plunger speed cm/sec	Orifice diam. mm	Speed of extrusion cm/sec			Rate of deformation sec^{-1}			Specific work of extrusion kg cm/g		
			Lard	Margarine	Shortening	Lard	Margarine	Shortening	Lard	Margarine	Shortening
1	0.04	6	0.64	0.64	0.64	0.07	0.07	0.07	0.81	0.64	0.21
2	0.04	4	1.56	1.75	1.85	0.16	0.18	0.19	0.93	0.64	0.28
3	0.18	6	2.30	2.14	2.22	0.25	0.23	0.24	1.11	0.74	0.28
4	0.04	2	0.47	0.45	0.47	0.41	0.41	0.39	1.27	0.81	0.40
5	0.40	6	5.16	5.33	5.25	0.56	0.58	0.57	1.29	0.83	0.34
6	0.18	4	6.07	6.36	5.98	0.62	0.65	0.61	1.40	0.81	0.32
7	0.60	6	8.59	8.51	8.34	0.94	0.93	0.91	1.58	0.91	0.31
8	0.40	4	13.0	13.1	12.9	1.33	1.34	1.31	1.75	1.08	0.40
9	0.60	4	18.0	18.6	19.7	1.83	1.88	2.01	1.97	1.18	0.49
10	0.18	2	28.7	26.1	24.6	2.71	2.57	2.32	2.52	1.50	0.63
11	0.40	2	54.9	55.3	52.4	5.19	5.23	4.96	3.30	1.90	0.82
12	0.60	2	82.7	78.4	81.4	7.82	7.41	7.70	4.20	2.10	1.15

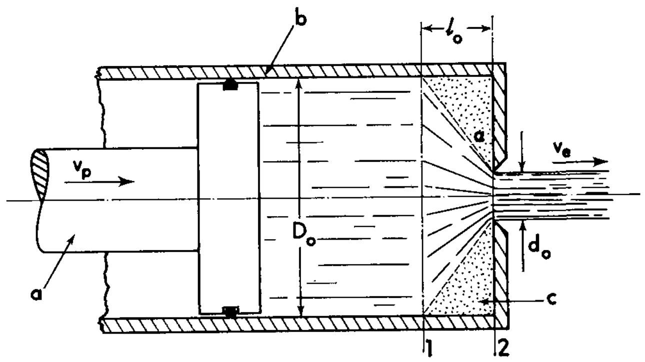

FIG. 5. Schematic representation of the flow of fat during extrusion: a, extrusion plunger; b, extrusion die; c, zone of immobilized material.

orifice in the bottom plate of the sample die. It was calculated from

$$W = \frac{1}{G} \cdot [A_t - (A_{fs} + A_{fp})] \cdot c \text{ kg cm/g}$$

where W = specific work of extrusion, in kg cm/g; G = weight of the extruded sample, in g; A_t = total area of the extrusion diagram, in cm^2; A_{fs}, A_{fp} = area corresponding to the friction of sample and plunger respectively, in cm^2; and c = conversion factor which represents the ratio of readings and actual values of force and stroke of extrusion plunger, in this case 2.21 kg cm/cm^2.

It is possible to calculate the rate of deformation of the fat during the extrusion. The rate of deformation is the change in velocity of the fat, indicated schematically in Fig. 5. The initial velocity of the fat in front of the plunger is V_p. From the section 1 to section 2 the fat is accelerated to the velocity of the extruded fat V_e. The rate of deformation is defined by

$$R = \frac{V_e - V_p}{l_o} \text{ sec}^{-1}$$

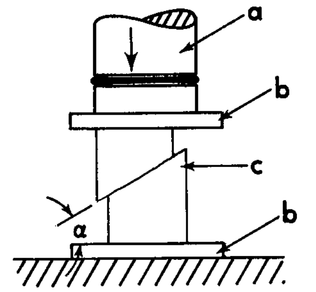

FIG. 6. Behavior of a cylinder of fat during compression: a, extrusion plunger; b, aluminum plates; c, sample.

To determine the distance l_o, the angle α has to be known. To find this angle, cylindrical samples of a variety of fats, 1 in. in diameter and 1½ in. high, were subjected to a compression test. The shear press was used for this experiment at 5C, and the samples were compressed at low velocity, 0.04 cm/sec, between two metal plates. All of the fats tested (lard, shortening, butter, margarine) showed a remarkably uniform behavior. The samples fractured along a plane very near a 45° angle with the horizontal, as represented in Fig. 6. On the basis of these results the angle α of Fig. 5 was assumed to be 45° and value of l_o for the different sizes of orifice is now given by

$$l_o = \frac{D_o - d_o}{2}$$

The velocity of extrusion is given by

$$V_e = V_p \left(\frac{D_o}{d_o}\right)^2 \text{ cm/sec}$$

Results of the measurements performed on lard, margarine, and shortening are given in Table I. The results are listed in the order of increasing rate of deformation. A plot of rate of deformation vs. specific work of extrusion resulted in the curves of Fig. 7. It is evident that, beyond a value of rate of deforma-

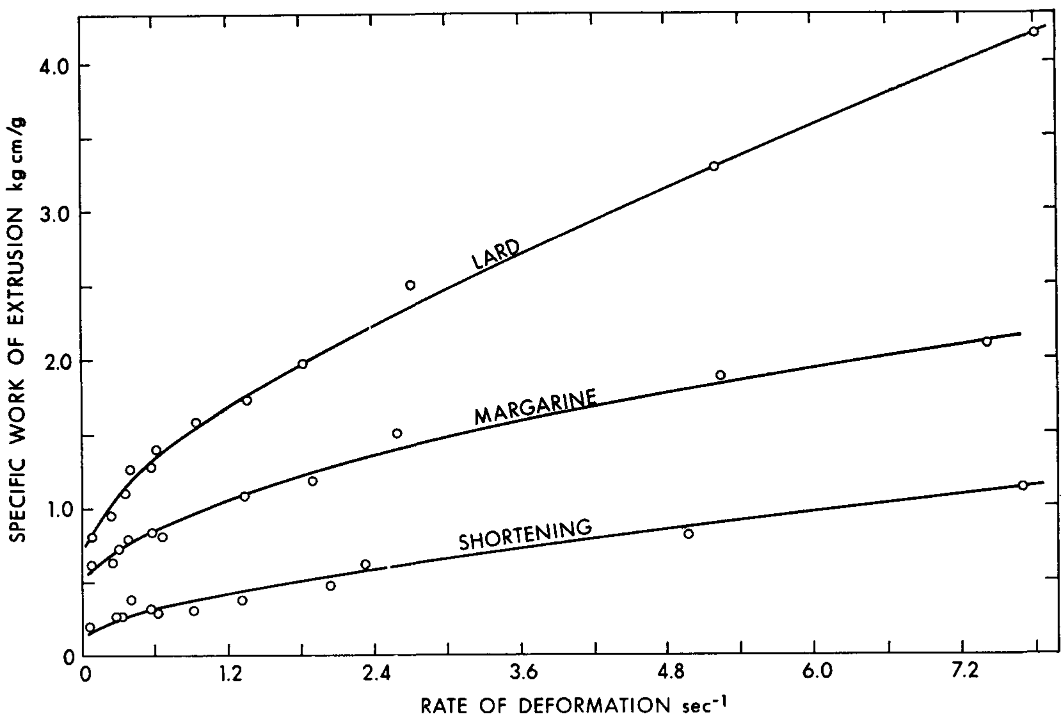

FIG. 7. Plot of rate of deformation vs. specific work of extrusion for lard, margarine and shortening.

TABLE II

Extrusion Pressure, Specific Work of Extrusion, Hardness, and Work Softening of Three Samples of Plastic Fat Products, Measured at 15C[a]

	Lard	Margarine	Shortening
Extrusion pressure, kg/cm^2	1.13	0.98	0.38
Specific work of extrusion, kg cm/g	1.43	1.08	0.49
Hardness, 0.1 mm, before extrusion	119	75	186
Hardness, 0.1 mm, after extrusion	202	134	246
Hardness, kg/cm^2, before extrusion	0.084	0.181	0.039
Hardness, kg/cm^2, after extrusion	0.032	0.068	0.016
Work softening %	62	63	59

[a] Extrusion carried out at a plunger speed of 0.40 cm/sec and with the 4-mm diam orifice.

tion of about 1 sec^{-1}, the rate of deformation is proportional to the specific work of extrusion, as is apparent from the straightness of the lines. The inclination of the tangent to the curves of Fig. 7 therefore represents the apparent viscosity of the fat involved.

By measuring the hardness of the fats before and after extrusion, the work softening which results from the extrusion process can be calculated. The extruded samples were collected in small sample cups. The results of such measurements are presented in Table II. The work softening obtained with three products of dissimilar hardness was remarkably similar, about 60%. With the equipment and procedures outlined in this paper it is possible to study mechanical treatments of plastic fats which involve extrusion of the product through perforated plates. The results of such a study on butter are reported elsewhere (8).

In the method described in this paper measurements are carried out at constant speed and extrusion force is recorded. This procedure has been reported to have advantages over methods which use constant load (1,9) although the latter may be preferred in some applications (10). For laboratories where a shear press is available, a relatively minor expenditure for the manufacture of the extrusion attachment may make the instrument suitable for rheological study of fats.

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