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Development of an Instrumental Test of Apple Sauce Graininess

Peter W. Voisey

Willard P. Mohr

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DEVELOPMENT OF AN INSTRUMENTAL TEST OF APPLE SAUCE 'GRAININESS'

Peter W. Voisey, and Willard P. Mohr,
Engineering Research Service, Smithfield Experiment Station,
Research Branch, Agriculture Canada, Trenton, Ontario, K8V 5R5.
Ottawa, Ontario, K1A 0C6.

1.0 Introduction

A textural characteristic of apple sauce commonly referred to as "grain" is an important quality characteristic which affects sensory reaction. Apple sauce quality has been studied by a number of workers (e.g. Wiley and Toldby, 1960; Toldby and Wiley, 1962) and textural characteristics established by sensory analysis. Recent work by Mohr (1973) has shown that grain differences in canned apple sauce from different apple varieties can be attributed to the distribution of particle sizes in the product. He also concluded that a distinction should be made between the terms "coarse" and "grainy" (commonly used synonomously in the literature) when describing desirable sauce texture. Large-sized particles were found to predominate in very "coarse" sauces, medium-sized particles in very "grainy" sauces, and small-sized particles in very "smooth" sauces. On eating, it was thought that in addition to the perceptible differences in particle size, the particles comprising "coarse" sauces felt relatively soft between the teeth whereas the particles comprising "grainy" sauces felt crisper. The mouthfeel property of "smooth" sauces can be described as "smooth", "very fine", "salvy", or "mushy". Sauces made from individual varieties possessed these characteristics to varying degrees and in varying combinations. "Grainy" sauces which did not have an excessive amount of the "coarse" component (i.e. intermediate particle sizes predominating) were considered by this author to have the most desirable apple sauce texture. "Smooth" sauces were considered the least desirable.

SUMMARY

Instrumental techniques for measuring the textural properties of apple sauce were examined including the universal cell of the Texture Test System, a newly designed oriface extrusion cell, an electronic recording viscometer and the back extrusion cell of the Ottawa Texture Measuring System. It was concluded that extruding apple sauce through an oriface is not practical to measure graininess of the sauce. The optimum test was the back extrusion cell using a 0.25 mm wide extrusion annulus. Results from the back extrusion test are presented together with sensory evaluations, distribution of particle size and microscopic analysis for several apple sauce samples. Results from each test are in general agreement.

There is a need to measure apple sauce texture instrumentally to study experimental treatments and control quality in production. A method was reported by Lanza and Kramer (1967) using the Kramer Shear Press (Kramer et al., 1951; Kramer, 1961) that is manufactured, together with a series of texture test cells by Food Technology Corp. (123000 Parklawn Drive, Rockville, Maryland 20852). The "Universal Cell" (Cat. No. CE1) was used. A cylindrical container 5.7 cm inside diameter and 7.6 cm high was closed at the bottom by inserting a circular disc with a 4.76 mm diameter hole in the center. The container was filled with apple sauce (blocking the hole during the process) and a close fitting piston forced into the container at 31.75 cm min^{-1}. The hole in the bottom was uncovered and the piston then extruded the product through the hole. This is a common technique for measuring rheological properties (e.g. Vasic and deMan, 1967). The force on the piston was recorded during the extrusion process and was shown to fluctuate about an approximately constant average force. The difference between the maximum and minimum force during extrusion (i.e. in effect under steady state conditions) was used as a textural index and found to correlate ($r = 0.8$ and 0.9) with sensory assessment of graininess. Because our preliminary tests could not duplicate this result, other methods were examined.

The particle size distribution, suspended in the liquid fraction, must affect the viscosity of the sauce. The use of an electronic recording consistometer, based on a Hobart mixer (Voisey and deMan, 1970) to measure sauce viscosity was, therefore, investigated.

The "back extrusion" principle was also considered because this involves extrusion and shear. The method consists of filling a sample container and recording the force required to force a loose fitting plunger into the container to extrude the sample through the gap between the container wall and plunger. This procedure was described by Hartman et al. (1963). A cylindrical back extrusion cell was developed for the Kramer Shear Press to test gels (Kramer and Hawbecker, 1966) and is now sold as an accessory integral with the universal cell (Cat. No. CE1, Food Technology Corp.) by providing a loose fitting plunger. Cylindrical back extrusion cells of different sizes have been used to test fresh peas (Bourne and Moyer, 1968; Voisey and Nonnecke, 1972), canned beet root (Shannon and Bourne, 1971), a range of canned foods (Voisey, 1970) and reconstituted instant potatoes (Voisey and Dean, 1971). This type of texture test cell is now available as a standard accessory for the Kramer Shear Press (now called the Texture-Test System, Food Technology Corp.), the Instron Testing Machine (Instron Corp., 2500 Washington St., Canton, Massachusetts 02021) and the Ottawa Texture Measuring System (Canners Machinery Ltd., Simcoe, Ontario)(Voisey, 1971B; Voisey et al. 1972). Different sizes are used (e.g. Voisey, 1971A) and variations of the design such as extrusion holes in the plunger (Spata et al., 1973) have been reported. The principle has the advantage that because there is a clearance between the plunger and sample container, the moving and stationary components of the texture test cell do not contact each other to introduce frictional errors in the force readings (Bourne, 1972). There is, however, still the effect of friction between the sample and test cell surfaces (Voisey and Reid, 1974).

The purpose of the work reported here was to compare the performance of the Texture Test System universal cell (Cat. No. CE1, Food Technology Corp.) with the back extrusion cell of the Ottawa Texture Measuring System and a measurement of consistency to develop an instrumental measurement of apple sauce texture.

2.0 Experimental Samples

Three samples of apple sauce were processed from different apple varieties at the Smithfield Experiment station and packaged in 19 oz cans. The samples were each rated for texture by an "expert" as follows:

Sample-Variety	Rating
Northern Spy	Grainy
T-412	Smooth
Richared Delicious	Coarse

In addition, a commercial sample (purchased at retail) was tested.

3.0 Sensory Tests

The four samples (unidentified) were evaluated by trained sensory judges to obtain a general opinion of their quality. The results were as follows:

3.1 Northern Spy

This sample considered "grainy" by an expert was found:

Very yellow in colour (yellowest of group)

Sticks to spoon - very adhesive

Coats the mouth - gluey sensation - does not disappear from mouth

Small granule size

Consistency - too thick

Sugar level satisfactory

Not as tart as commercial sample

3.2 T-412

This sample considered "smooth" by an expert was found:

Not as white as commercial sample

Mushy like baby food

Small granules resulting from fine sieve or blender too fine

Not enough sugar

Tangy taste

Liquid separates out

Thinner consistency than Richared Delicious and Northern Spy

Mouth feel is good

3.3 Richared Delicious

Golden in colour

Larger granules

Thicker consistency than commercial sample, but thinner than Northern Spy

Slightly adhesive

Less gluey sensation in mouth than Northern Spy, but has more than commercial

Very sweet

Distinctive flavour

3.4 Commercial Sample

Palest in colour (whitest of group)

Small bits included

Pours off spoon - sits up on spoon

Thinner than Northern Spy and Richared Delicious

Smooth texture

Can sense cell rupture when chewing

3.5 Summary

The sensory analysis indicated that the samples had different characteristics including texture and that the experts and trained judges tended to agree.

4.0 Determinations of Particle Size Distribution

A controlled washing technique was used to determine the distribution of particle sizes in each of the 4 sauce samples (Figure 1). The results proved that large-sized particles predominate in coarse sauce (A), medium-sized particles in grainy sauce (B), and small-sized particles in smooth sauce (C). This was anticipated from previous work (Mohr, 1973) since samples A - C represent sauce types of decreasing coarseness as judged subjectively. Particle size distribution of the commercial sample (D) resembled somewhat that of the A sample, with large and medium-sized particles predominating. Its total dry weight of washed pulp, however, was much lower than that of the other 3 samples. This would account for the thin consistency noted by the taste panelists. One possible explanation of this lower pulp content could be the use of large-sized fruits (largely a variety characteristic) and associated large cell size, resulting in a high moisture content relative to cell walls.

5.0 Microscopic Examinations

Light microscopic observation of the sauce samples corroborated the particle size distribution results. Although each sauce type was made up of particles of all 5 size groups, certain size groups tended to predominate and characterize each sauce type. Particles of the most commonly seen sizes are shown in Figure 2. Note that large-sized particles typify a coarse sauce (A, also D), medium-sized particles a grainy sauce (B), and small-sized particles a smooth sauce (C). Also note that each large-sized (>1.00 mm) particle is a cluster of many cells, each medium-sized (0.26-0.50 mm) particle is a cluster of several cells, and each small-sized (0.10-0.15 mm) particle is an individual cell or cluster of only a few cells. Cell size was similar regardless of particle size; it was also similar for the varieties studied, one possible exception being that the cells comprising particles of the commercial sauce (D) appeared slightly larger than those of A, B, or C.

6.0 Exploratory Instrument Tests

6.1 Electronic Recording Viscometer

A 19 oz. can of sauce was poured into the 4 1 bowl of the electronic viscometer (Voisey and deMan, 1970). The sample was stirred at speed number 2 (i.e spindle speed 90 - 95 rpm; paddle speed 300 - 317 rpm) and the torque recorded on a strip chart recorder with a pen capable of responding to 30 Hz full-scale signals. Typical results (Figure 3) show how the torque to mix the sauce builds up quickly and then fluctuates with a large amplitude about a constant mean torque. The mean torque and amplitude was a minimum for the grainy sample, increased for the coarse and was a maximum for the smooth sample. Thus, it appeared that the viscosity of the three samples (i.e. mean torque) was different and increased with decreasing particle size. As the particle size decreased, the amplitude also increased. It was concluded that the instrument was capable of discriminating textural differences but primarily on the basis of viscosity, a property related to particle size in the sauce.

6.2 Universal Cell of the Texture Test System

A universal cell (Cat. No. CE1, Food Technology Corp.) was installed in the Ottawa Texture Measuring System (Voisey, 1971B; Voisey et al., 1972). The piston was driven into the cell at a constant speed of 20 cm min^{-1} and the force required recorded to examine the procedure used by Lanza and Kramer (1967). Force was recorded on a fast response recorder (30 Hz). Tests were performed using 2.38 and 3.18 mm diameter extrusion orifaces. It was found impossible to reduce the oriface diameter further because it plugged. Typical records (Figure 4) show how the force on the plunger built up rapidly until extrusion through the oriface commenced (E). The force then reached a plateau and remained virtually constant apart from minor fluctuations about the mean. Reducing the oriface diameter increased the force required, but differences between samples were not indicated with the two oriface sizes tested. The large fluctuations about the mean that were affected by sample texture observed by Lanza and Kramer were not apparent. This was attributed to several facts.

1. The experimental samples may have had a smaller particle size than those tested by Lanza and Kramer and were more homogeneous and, therefore, did not produce similar force fluctuations.
2. The plunger used by Lanza and Kramer (1967) fitted the cell "snugly" and friction between the plunger and cell walls may have affected their result. The difference in diameter of the cell and plunger used in the experiment was 0.25 mm providing a 0.13 mm clearance which eliminated the possibility of friction between the plunger and cell walls. It is likely that the fluctuations observed by Lanza and Kramer were caused by particles trapped (or extruded) between the plunger and cell wall.
3. If the 4.76 mm diameter extrusion oriface used by Lanza and Kramer was used, it was found that no fluctuations in extrusion force occurred with the experimental samples.

4. The recorder of the Kramer Shear Press used by Lanza and Kramer had a full scale pen response time of 1.0 sec (Anon, Undated). That is, the Shear Press recorder had a slow response that tended to damp out the signals (compared to the 30 Hz type used in the experiment) and the recorded force fluctuations may not have been precise. The fluctuations reported were possibly average or major fluctuations (i.e. integrated) about the mean.
5. The force transducer used in the Shear Press by Lanza and Kramer had a capacity of 100 lb. The rigidity of this ring type transducer is not great. It deflects considerably under applied force, thus storing strain energy. Thus, any reduction in force resisting passage of the plunger allows a release of strain energy causing the ring to spring back to its original shape. This "bouncing" effect may also have affected the amplitude of the force fluctuations recorded. The transducer had a low natural frequency and may have vibrated at greater amplitude than the normal static amplitude caused by the test forces.

For the above reasons it appeared that the procedure using the universal cell was open to question. An improved extrusion cell design was, therefore, fabricated to further examine this point.

6.3 E.R.S. Extrusion Cell

A cylindrical cell (B, Figure 5) was made with a loose fitting plunger (P) to compress the sauce into the cell. "0" rings on the plunger sealed the clearance between the plunger and cell wall and prevented leakage during compression. A hole in the plunger (A) was provided to bleed off any trapped air and then closed by a stopcock. An extrusion oriface insert (E) was inserted in the bottom of the cell at the center. This was a free sliding fit in the cell body. The oriface insert was held in place by a 500 Kg force transducer (T), mounted on the cell body, via a tube (C). The force transducer was very rigid (1.13×10^{6} lb/in) and had a high natural vibration frequency and could thus sense rapid force fluctuations precisely. The force generated by extruding sauce through the oriface was reacted by the transducer and could thus be recorded. Expelled sauce was allowed to pass freely out of a large hole (H) in the tube (C). This arrangement eliminated the effect of friction between the plunger and cell walls from the measurement.

Tests were conducted with this cell using 2.38 and 3.18 mm diameter extrusion orifaces and a constant plunger speed of 13.4 cm min^{-1}. As before the force was recorded on a 30 Hz recorder. Details of the method are illustrated in Figures 8 to 11.

Typical results indicated that textural differences were not shown when using the 3.18 mm diameter extrusion oriface (Figure 6 A to D). The average force increased when the oriface diameter was reduced to 2.38 mm (Figure 6E to H) and the amplitude of the force flucturations increased for the experimental apple sauce samples. There was a dramatic indrease in the case of the commercial sample (Figure 6D cf. 6H). It was obvious that the textural difference between the commercial sample and the 3 experimental samples was large. The differences between the 3 experimental samples were small both in average force and amplitude of the fluctuations. Thus, it appeared that the oriface extrusion method could not discriminate between coarse, grainy and smooth apple sauce. It was also obvious that the oriface size was critical. As noted previously, smaller orifaces plugged. It was assumed that as the oriface size was reduced, the effect of the particles on the flow through the oriface was increased. Because of the practical limitations it was not possible to reduce the oriface sufficiently to show differences between the three experimental samples. The oriface extrusion test procedure was, therefore, discarded.

The force during extrusion fluctuated at frequencies ranging from 4 to 10 Hz pointing out the need for high frequency response sensing and recording systems to record these rapidly changing maximum and minimum forces (i.e. amplitude) with any degree of precision. The frequency of fluctuations might provide an additional means of quantifying the textural characteristics.

6.4 Back Extrusion Cell

The 60 mm diameter back extrusion cell of the Ottawa Texture Measuring System was used (Voisey, 1971B; Voisey et al., 1972) and installed in the OTMS which forced the plunger into the cell at a constant speed of 20 cm min^{-1}.

There are several plunger parameters that can be varied to change the performance of the back extrusion cell. The product is extruded through the annulus between the cell and plunger. Thus, the amount and rate of shear imposed on the sample in the extrusion passage depends on the width (i.e. clearance) and length (i.e. piston thickness) of the passage. Exploratory tests were, therefore, done using plungers with a) parallel sides; b) tapered sides; c) thicknesses ranging from 9.5 to 25.5 mm thick; d) clearances ranging down from 2 mm (Figure 12). The discrimination of textural differences was optimized by a) minimizing the clearance and b) reducing the plunger thickness.

It was assumed that this was because as the extrusion gap was reduced, the effect of particles flowing into and through the extrusion passage on the force needed to move the plunger was maximized. That is, the effect of particle size on shearing force increased disproportionately with respect to the viscous effects of the liquid fraction.

The optimum combination found by trial and error was:

Test cell: 60 mm diameter

Plunger: 59.49 mm diameter and 9.5 mm thick

Plunger speed: 21 cm min^{-1} (maximum press speed)

Full scale chart reading: 40 Kg

There was evidence that at the small clearance used (0.25 mm) the plunger occasionally touched the cell wall. This did not appear to affect the force probably because the area of contact was small and the sample provided lubrication (Voisey and Reid, 1974).

7.0 Comparison of Samples

Thirteen replicates of each of the 3 experimental and one commercial sample were tested. From the records the maximum, minimum and mean force during extrusion were estimated. A textural index:

$$\frac{\text{Maximum - Minimum}}{\text{Mean}} \times 100\%$$

was calculated for each sample.

Typical results (Figure 7) showed that there were differences in both the average force and amplitude of the force fluctuations during extrusion. The curves were similar in appearance to those obtained with the extrusion oriface, but the amplitude differences were accentuated. This was because the sauce was forced through a narrow gap (0.25 mm cf 2.38 mm diameter) that did not plug because the length of the gap (i.e. annulus) was 189 mm. The force fluctuations again occurred at frequencies up to 10 Hz.

A summary of the results (Table 1) showed that the coarse and grainy samples were similar to each other in texture but quite different from the smooth sample. The commercial sample was different from the experimental samples. It appeared that the calculated index provided better discrimination between textural characteristics than maximum, minimum or mean force. Variation of reading for each sample and for the 4 samples was similar.

8.0 Conclusions

The measurement of apple sauce grain, a textural property, is difficult because it depends on the particle size within the test sample. Separating the effects of this from the over-all effect of differences in sample viscosity in an instrumental test is a problem. It appears that the fluctuations of force during extrusion provides a means of doing this but the dimensions of the extrusion space are critical. As the dimension through which the sauce is extruded is reduced, the effect of particles flowing on the force required to maintain flow increases. The Texture Test System universal cell does not appear suitable because the extrusion hole cannot be made small enough to accentuate the effect. The back extrusion cell appears suitable when a 0.25 mm wide extrusion annulus is used. Because the fluctuations in force caused by the particles are rapid, a means of recording these rapid changes accurately must be used.

Further work is needed to confirm that the back extrusion reading (0.25 mm gap) correlates with sensory and microscopic evaluation of apple sauce grain over a greater range of samples. The data obtained shows that smooth sauce can be easily distinguished from grainy and coarse products.

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Acknowledgement

The authors wish to thank Mrs. E. Larmond of the Food Research Institute, Ottawa for performing the sensory analysis.

Table 1. Summary of results giving mean readings for 13 replicate tests on each sample for the Back Extrusion test. Force in Kg and C.V. in %

Sample	Richared Delicious	Northern Spy	T-412	Commercial
Texture rating	Coarse	Grainy	Smooth	-
Maximum force	31	35	15	31
C.V.	12	10	12	11
Minimum force	16	18	11	12
C.V.	10	17	14	9
Average force	23	25	12	20
C.V.	11	16	14	11
Index[a] %	66	67	34	92
C.V.	16	16	16	12

[a] $\frac{\text{Maximum - Minimum}}{\text{Mean}} \times 100\%$

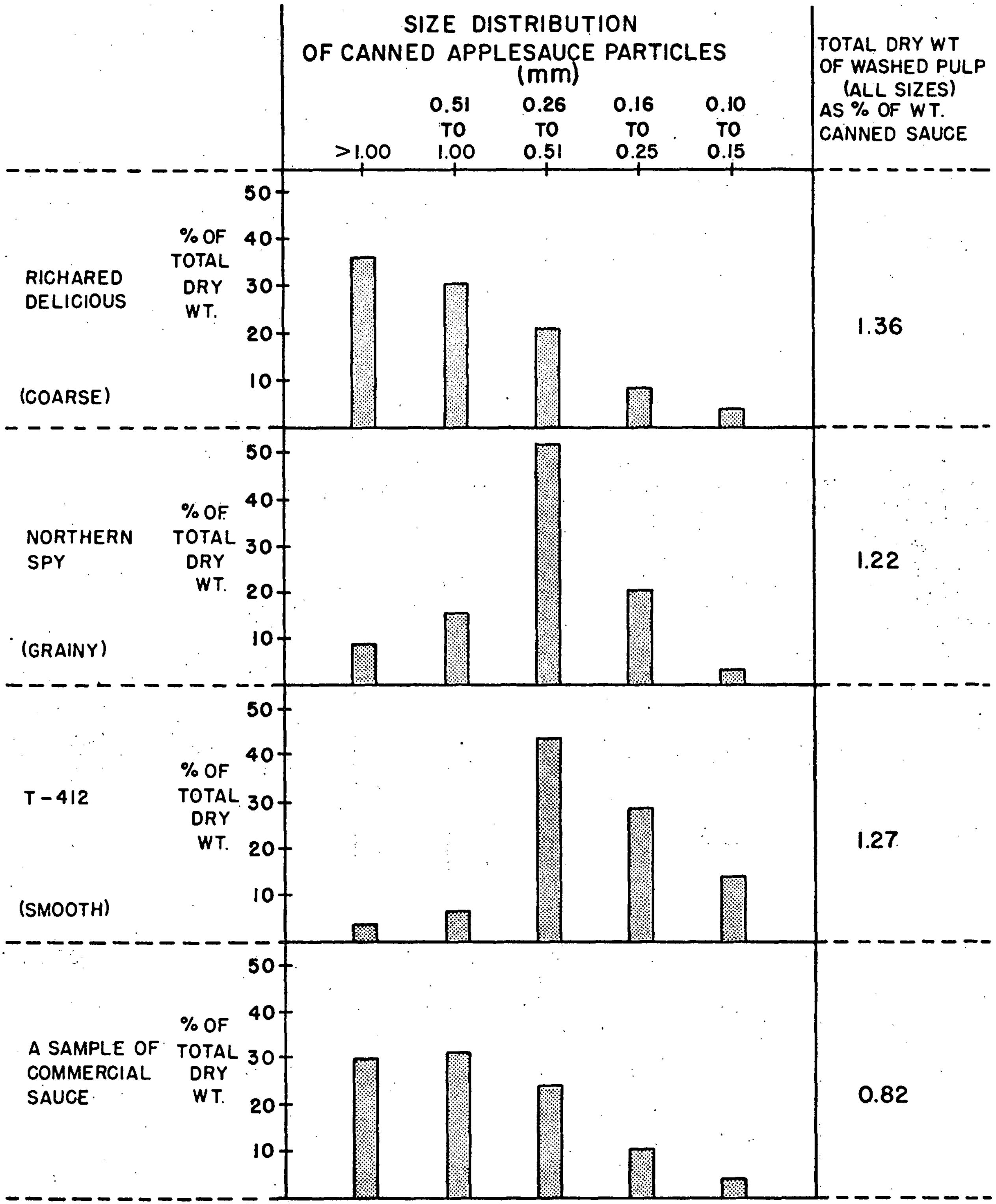

FIG. I . PARTICLE SIZE DISTRIBUTION AS DETERMINED BY A CONTROLLED WASHING TECHNIQUES.

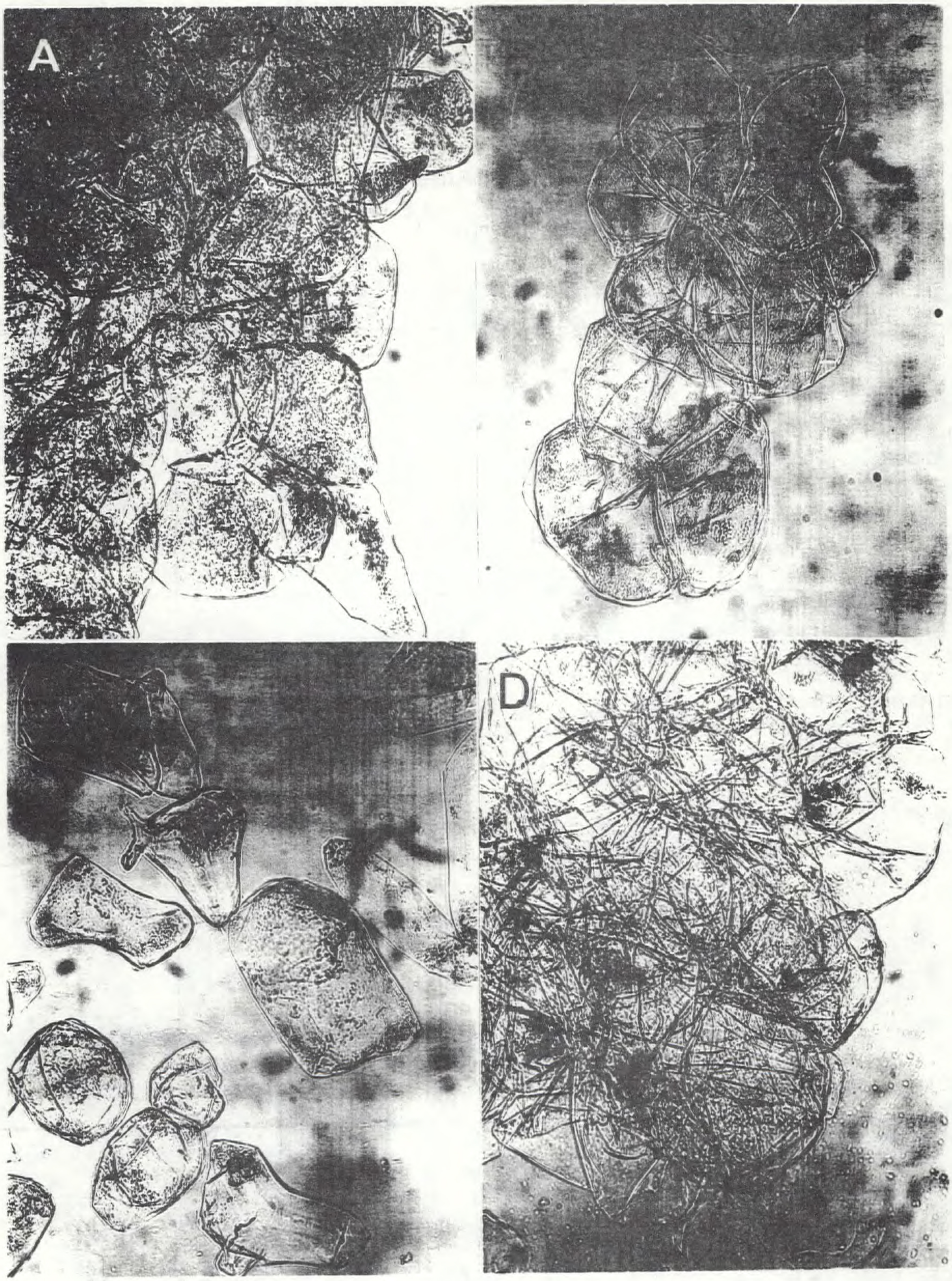

Figure 2. Typical applesauce particles as seen in the light microscope. A. Richared Delicious (coarse); B. Northern Spy (grainy); C. T-412 (smooth); D. commercial.

These particles are clusters of cells. A and D show only the edges of large-sized particles which are clusters of many cells. B shows a medium-sized particle which is a cluster of several cells. C shows small-sized particles which are mostly individual cells.

(all at magnif. X 75)

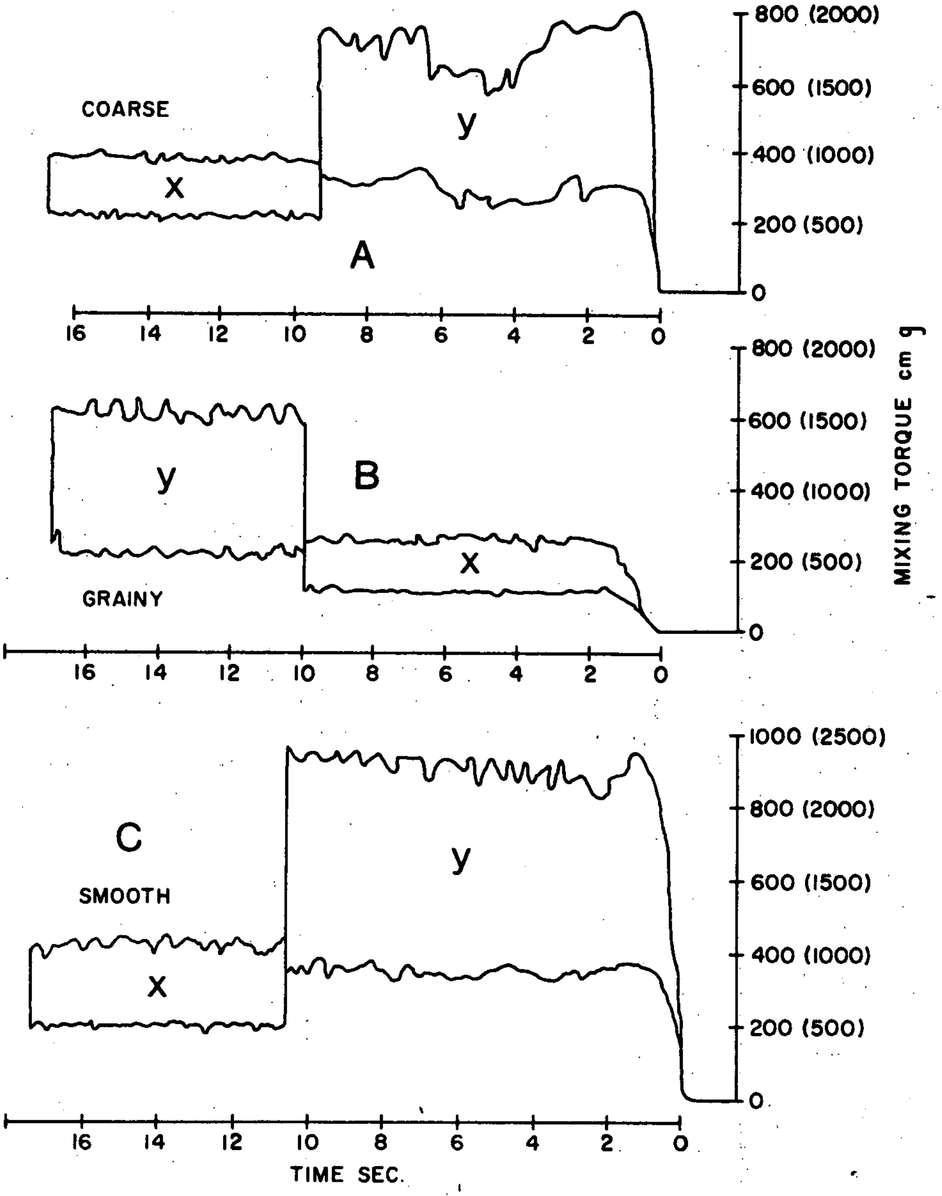

Figure 3. Typical records obtained with electronic recording viscometer showing only the envelope containing the maximum and minimum torque during mixing. The sensitivity of the torque sensor is 1000 cm g in zone X and 2500 cm g in zone Y. A. Richared Delicious (coarse); B. Northern Spy (grainy); C. T-412 (smooth).

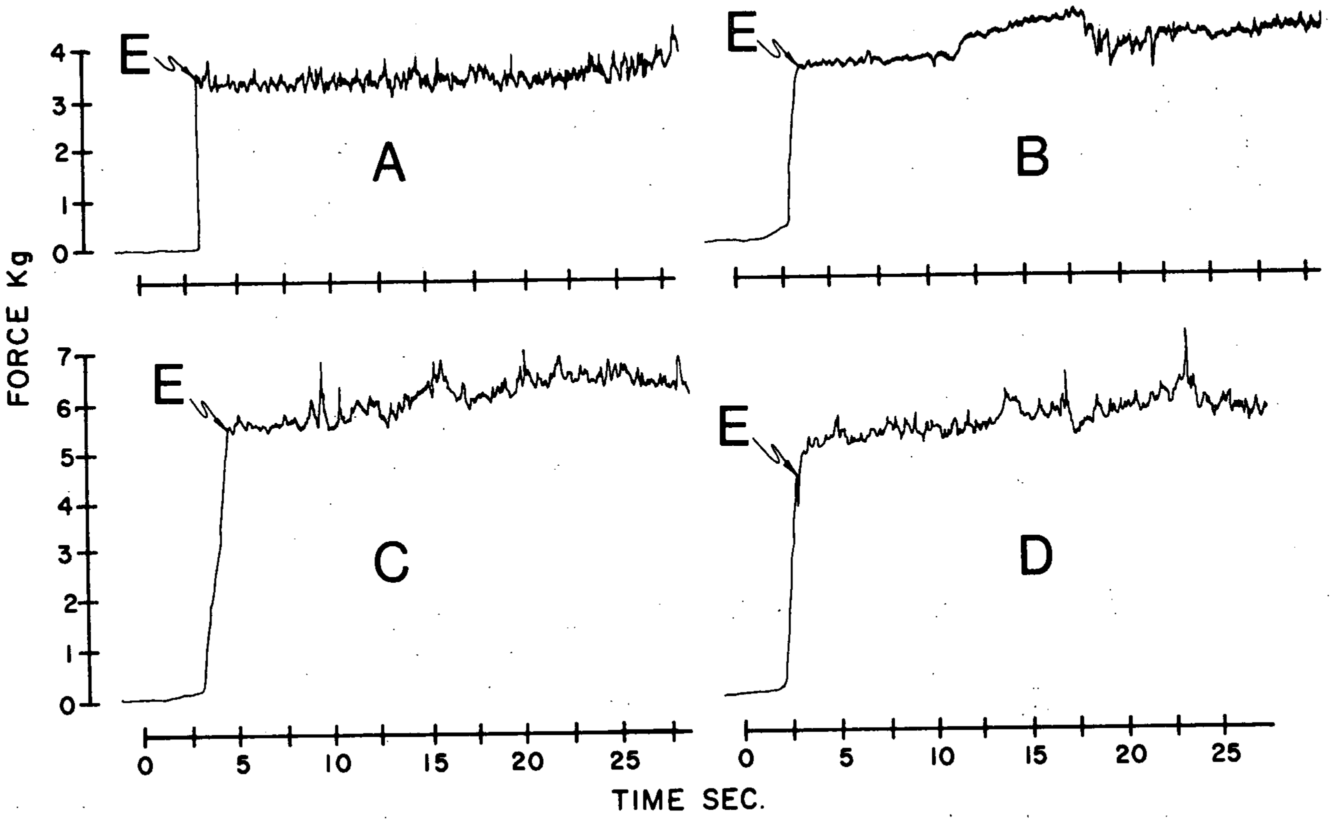

Figure 4. Typical records obtained with universal cell of the Texture Test System at 20 cm min^{-1}. A and B. 3.18 mm diameter extrusion oriface. A. Richared Delicious (coarse); B. Northern Spy (grainy). C and D. 2.38 mm diameter extrusion oriface. C. Northern Spy (grainy); D. T-412 (smooth); E. Point at which extrusion through oriface started.

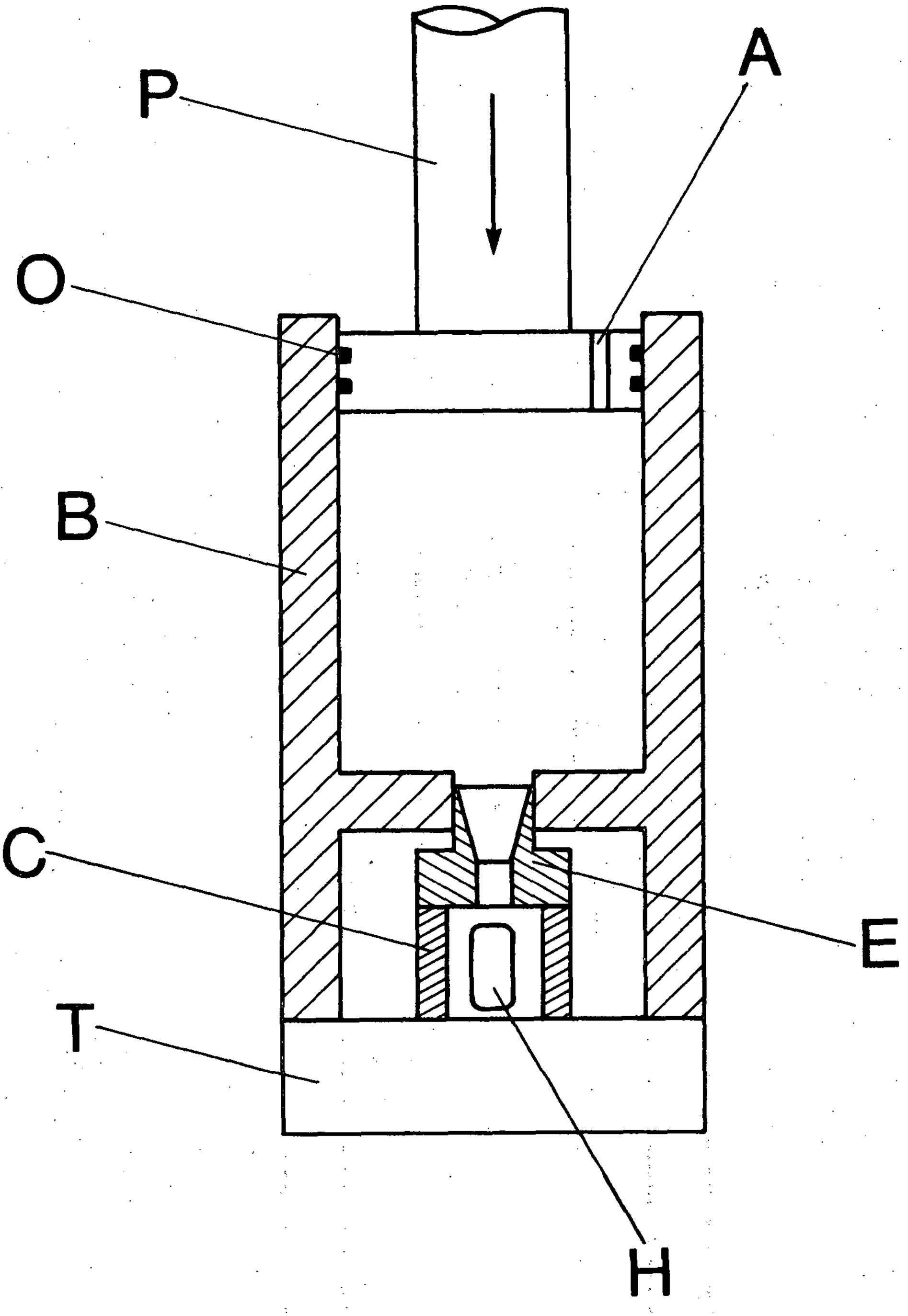

Figure 5. E.R.S. extrusion cell. A. air vent closed by stopcock; B. cell body; C. tube supporting oriface insert on force transducer; E. oriface insert; H. hole in tube for sample exit; O. "O" rings sealing plunger; P. plunger; T. force transducer capacity 500 Kg.

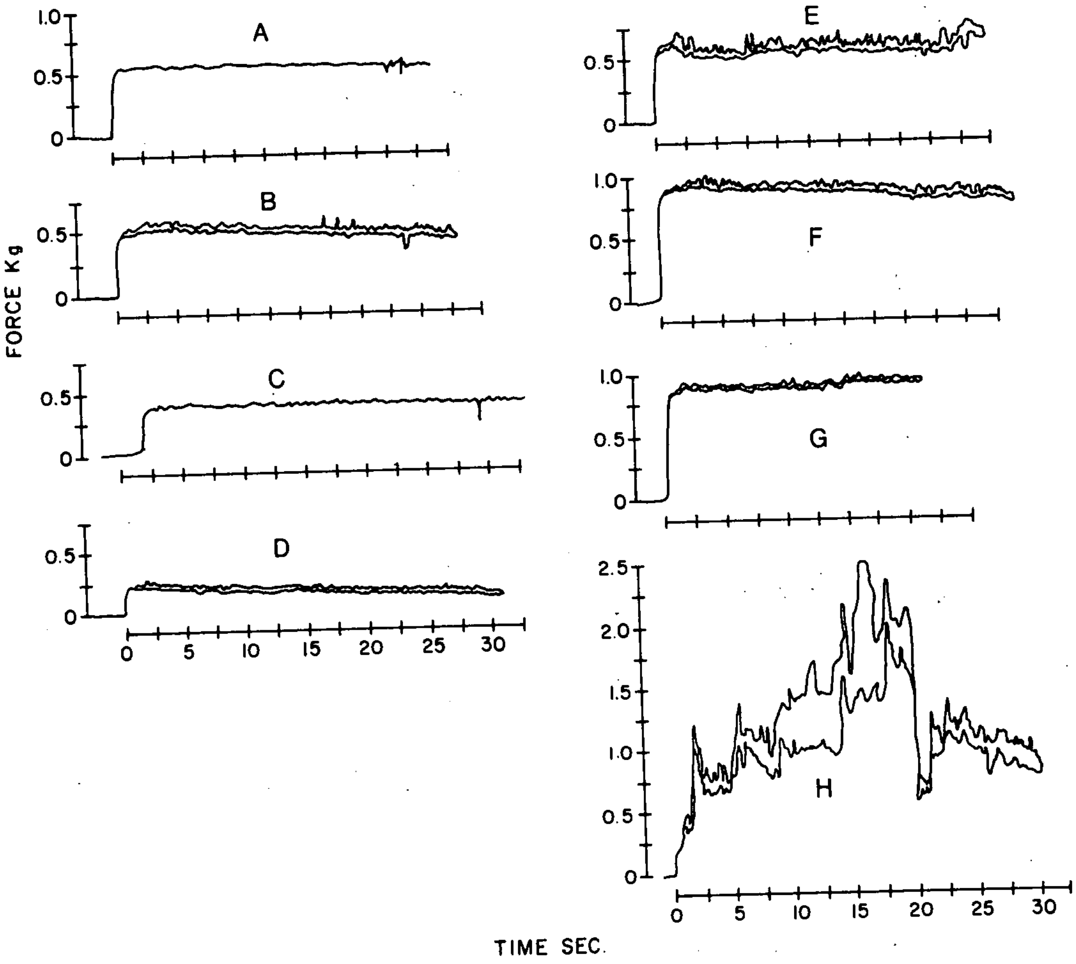

Figure 6. Typical results from E.R.S. extrusion cell showing the envelope enclosed by the maximum and minimum force during extrusion. A to D. 3.18 mm diameter oriface; E to H. 2.38 mm diameter oriface. A and E. Richared Delicious (coarse); B and F. Northern Spy (grainy); C and G. T-412 (smooth); D and H. commercial sample.

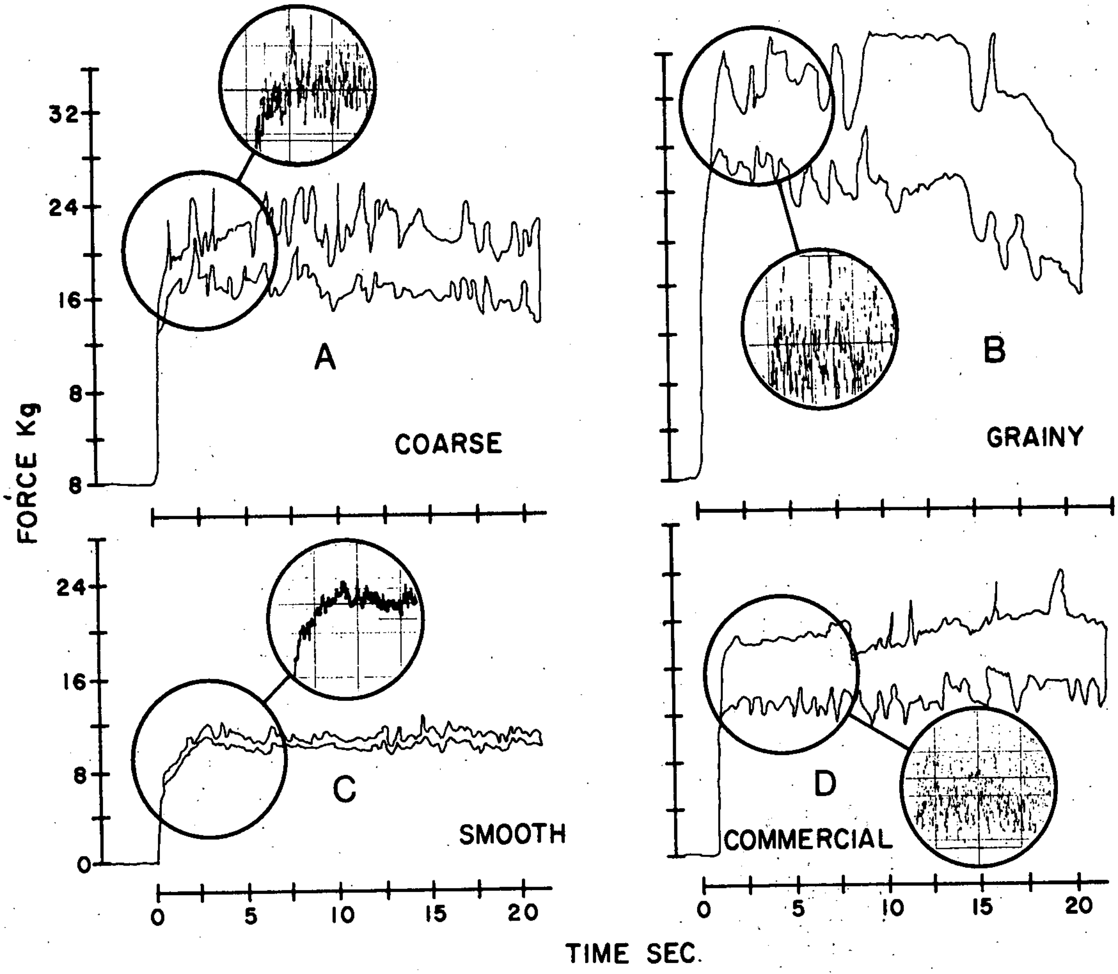

Figure 7. Typical results for back extrusion test. A. Richared Delicious (coarse) B. Northern Spy (grainy); C. T-412 (smooth); D. commercial. Only the envelope enclosed by the maximum and minimum force during extrusion is shown. An inset on each curve shows a portion of the actual record.

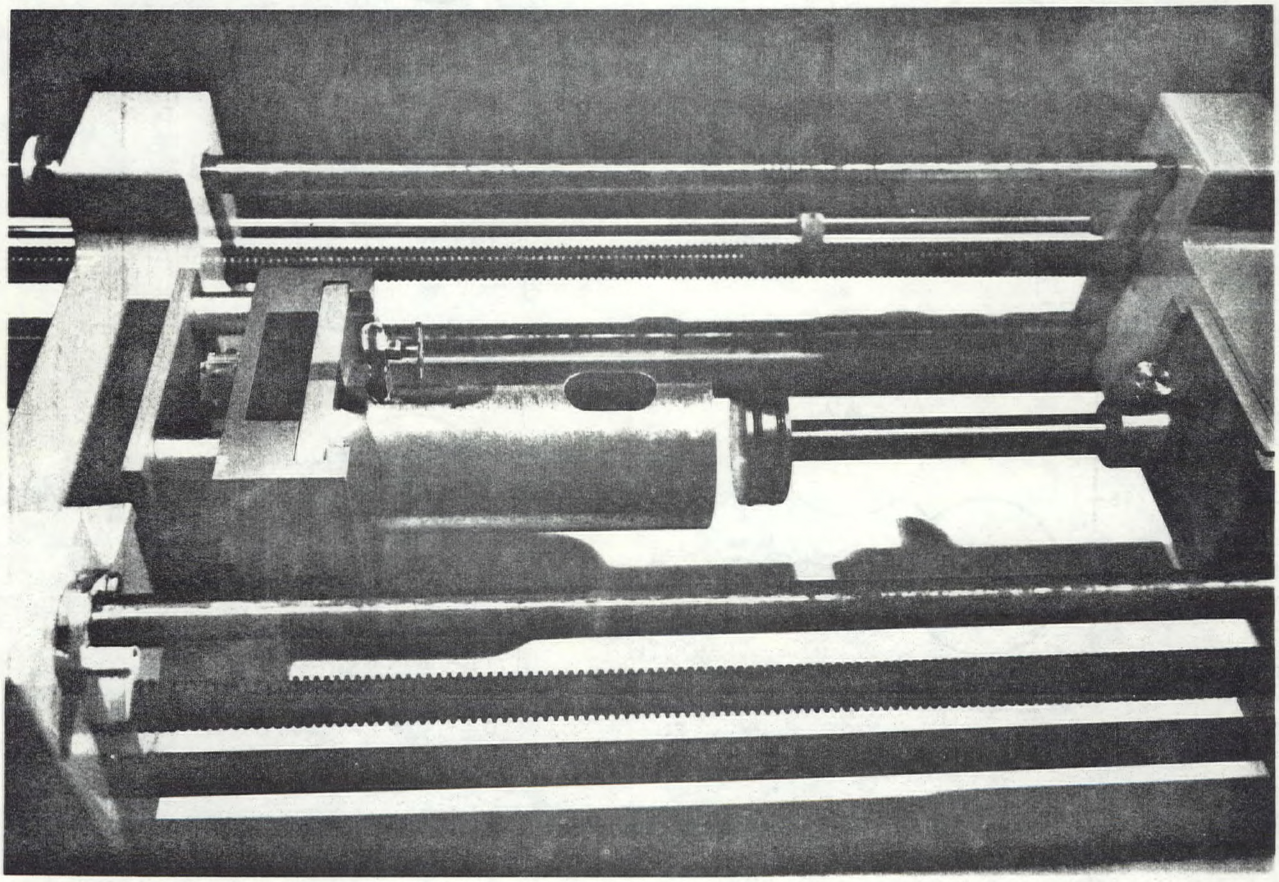

Figure 8. E.R.S. extrusion cell installed in a horizontal constant speed (screw drive) press.

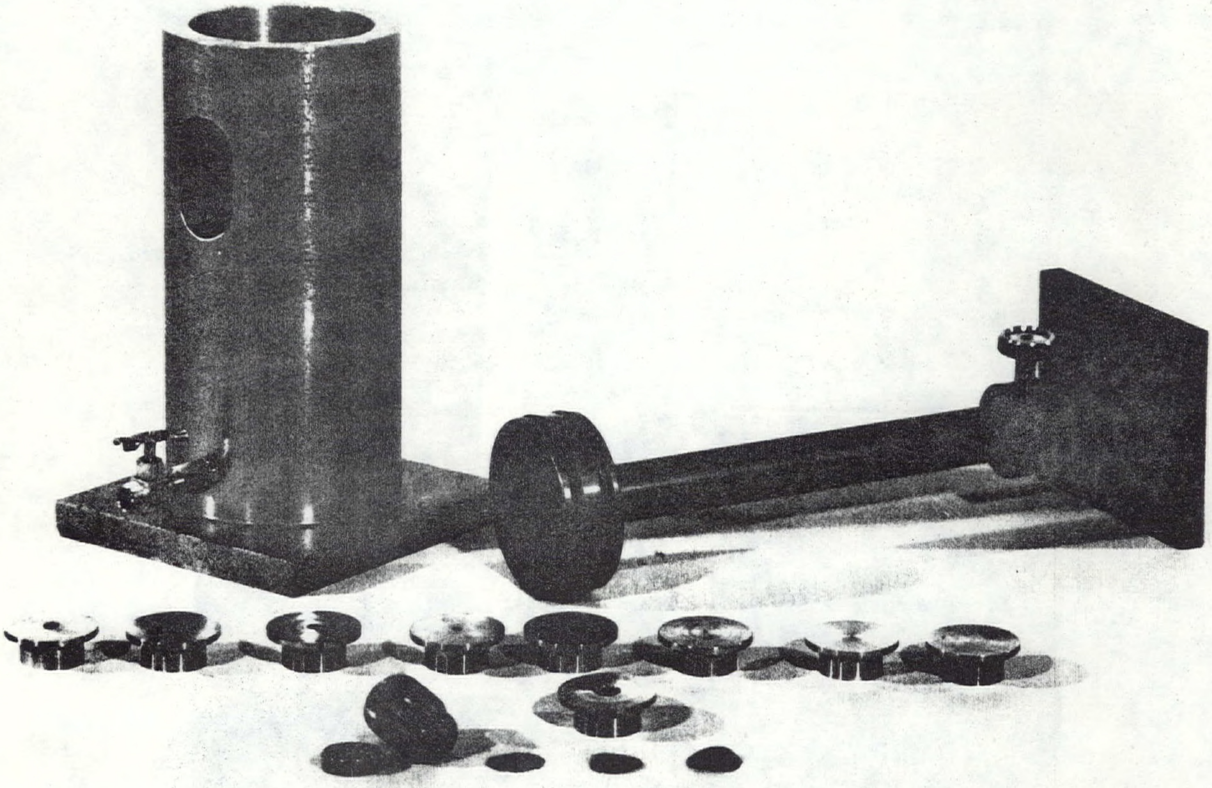

Figure 9. The E.R.S. extrusion cell disassembled showing the various orifaces (and mesh screens) evaluated.

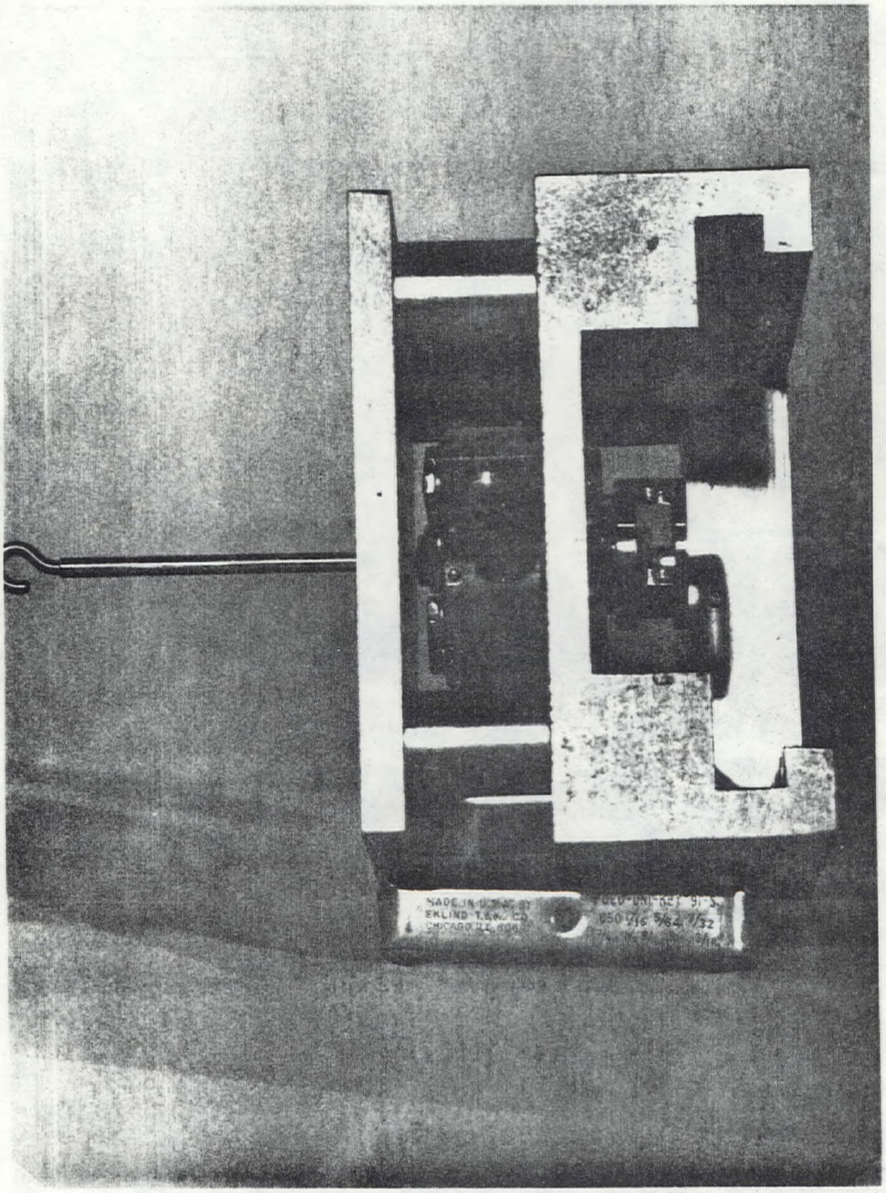

Figure 10. The transducer used to measure the force on the oriface of the E.R.S. extrusion cell.

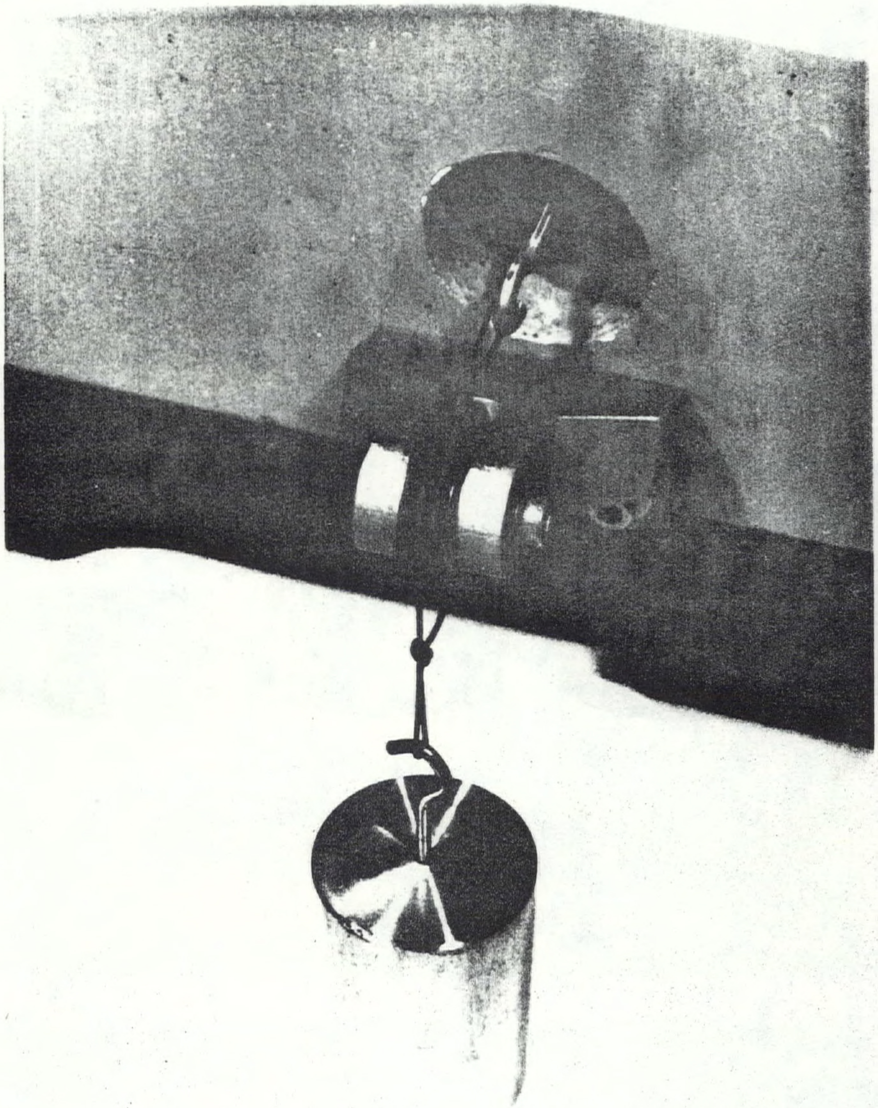

Figure 11. Method of calibrating the force transducer.

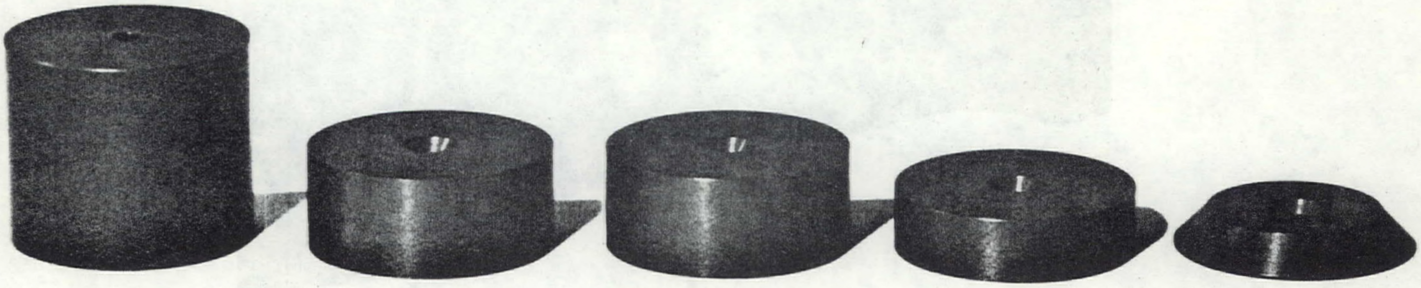

Figure 12. Some of the back extrusion pistons evaluated.