PRACTICAL INSTRUMENTS FOR RHEOLOGICAL MEASUREMENTS ON WHEAT PRODUCTS[1]

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ABSTRACT

Various commercially available instruments used by cereal technologists to measure the rheological properties of wheat and wheat products are presented. These instruments are discussed with the practical aspect in view, primarily as tools for quality control. Their possible uses in basic research application are also mentioned. The limitations of the instruments for adaptation to various measurements and uses are outlined.

Usually when terms such as rheology, wheat products, and instruments are used together in a presentation, one generally reflects on dough formation and terms such as elasticity, extensibility, absorption, softness, stickiness, etc. This is not absurd because the rheological properties of a dough are extremely important since they affect the quality of the finished product. But an important fact to remember is that dough is only present as an intermediate stage, whether from flour to bread, flour to cake, etc. Generally, a dough will be influenced by three phases or steps in the processing: mixing; fermentation or resting; and baking. However, there is another very prominent field of application that should not be overlooked—that is the finished product. This field is more concerned with the texture of the foods and their relation to sensory perception. Notwithstanding, these areas (dough and finished product) are interrelated and in some instances the same instrument and measurement may be used.

Demonstrating some of the physical characteristics of doughs is relatively easy. Measuring the characteristics demonstrated is more difficult, but defining the characteristics is extremely difficult. In an endeavor to define the behavior of doughs, cereal chemists have recently applied more of the principles of rheology. Rheology has been defined as the systematic investigation of the deformation and flow of matter (1). The deformation can be divided into two types: 1) the reversible deformation, called elasticity; and 2) the irreversible deformation, called flow.

If dough were a simple system or state, such as a gas, liquid, or solid, measuring and defining its characteristics would be easy. Dough is not a liquid, but it will flow. A dough is not a solid, but it is elastic. These two characteristics play an important part in the behavior and physical characteristics of dough. Bloksma (2) has described dough behavior by the rheological model shown in Fig. 1.

The complexity of both the components in wheat (proteins, carbohydrates, lipids, etc.), and the physical structure of the dough (macromolecular formation, etc.) adds to the perplexity of physical dough-testing methods. The problem is compounded when the human element factor is added to the equation and it is

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necessary to translate sensory perception to instrumental measurements. Abbott (3) and Kramer (4) have discussed the problems associated with sensory assessments and measurements of food texture.

The more widely used physical testing methods and instruments may be divided into two broad classifications:

I. Torque-measuring or viscosity-measuring instruments.
  A. Dough mixers
  B. Viscometers
II. Stress/strain, or elastic-measuring instruments.

There may be a third class, which may be designated as empirical since these are tests that measure the results attributed to the rheological property but not the property itself. These tests entail intermediate steps in preparing the sample before the test is performed, such as the Pelshenke, Zeleny sedimentation, gluten washer, etc.

The physical-testing instruments used give some information about the physical behavior of dough. However, insufficient information is derived to completely understand the physical behavior of dough. The empirical design of the instruments does not allow absolute rheological measurements of doughs or complete understanding of their physical characteristics.

Voisey (5) has suggested several methods of modernizing the present equipment with electronic sensing techniques to improve the performance of the instruments. Both Szczesniak (6) and Voisey (5) have suggested essentially the same components for a texture-measuring instrument and they should apply to all rheological instruments. These are: 1) a sample holder; 2) a driving force for deformation; 3) a way of recording the deformation force; 4) a means of detecting the deformation; 5) a method of recording the deformation.

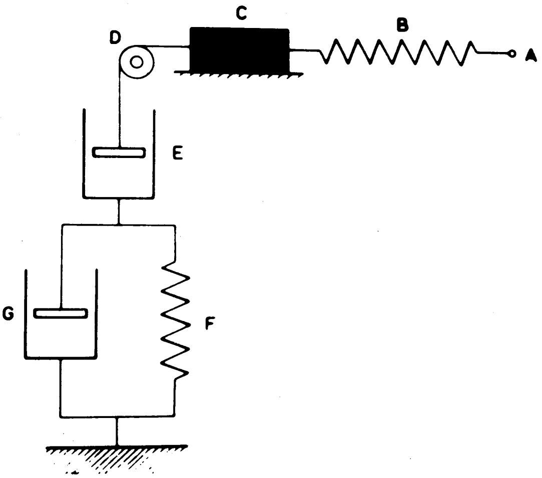

Fig. 1. Rheological model of dough behavior. **A**) point of force, **B**) temporary elastic deformation, **C**) frictional force related to yield value, **D**) point of transition to dough structural characteristics, **E**) viscous element of dough, **F**) elastic element of dough, and **G**) viscous element associated with retarded elastic element (F) as common in a Kelvin body.

There are approximately 10 instruments which are described in various texts on cereal and commonly used throughout the world. Some are universally used, while others have found more favor in certain areas because of their application to specific types of end products.

The application of rheological measurements may be twofold: basic, for a more fundamental understanding of the problems involved; and applied, for a tool to control a product or process without necessarily any knowledge of the fundamentals. In the latter case, the tester endeavors to resolve a series of measurements into a single, all-inclusive figure. It is with this concept that this paper was written.

I. Torque-Measuring or Viscosity-Measuring Instruments

A. Dough mixers

Under this category are the instruments which measure the general mixing behavior of the dough. This would include, in the broadest sense, the strength of the dough as related to such properties as: water-rate of imbibition; tolerance to mixing; time to maximum development; etc. Because of the individuality of each instrument, the order and magnitude could vary for a given series of samples tested.

1. Farinograph

The farinograph is the most universally used physical dough-testing instrument to measure the plasticity and mobility of the dough. It records the resistance dough offers to the mixing blades during a prolonged and relatively gentle mixing action at constant temperature by transmitting it to a

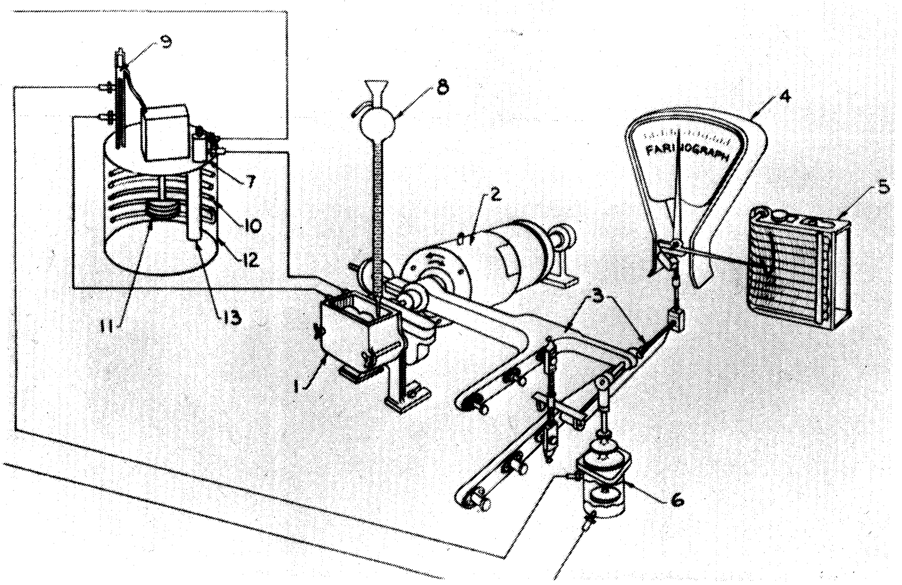

Fig. 2. Diagram of the basic parts of a farinograph.

dynamometer. The dynamometer, in turn, is connected to a lever and scale system and to a pen which traces a curve on a kymograph chart.

Basically, there are eight parts to a farinograph (Fig. 2): 1) mixing bowl; 2) dynamometer; 3) lever system; 4) scale system; 5) recording mechanism; 6) dashpot; 7) thermostat; and 8) buret.

The use of the farinograph for evaluating flours has been increasing steadily for the past several years. The farinograph indicates basically two important physical dough properties:

1. The absorption or amount of water required for a dough to have a definite consistency.
2. A general mixing profile of the mixing behavior of the dough or the tolerance of the dough to mechanical mixing abuse.

The curve shape or silhouette enables an experienced operator to classify farinograms by types without actual measurements. The operator can readily classify flours as to their mixing behavior by curve shape classification. There are seven basic types of curve shape classifications shown in Fig. 3, as adopted from the Farinograph Handbook (7).

I. Curve with short peak time and short stability.
II. Curve with short peak time and long stability.
III. Curve with medium peak time and short stability.
IV. Curve with medium peak time and long stability.
V. Curve with long peak time and short stability.
VI. Curve with long peak time and long stability.
VII. Curve with double peak, swayback, or dip in the early part of the curve.

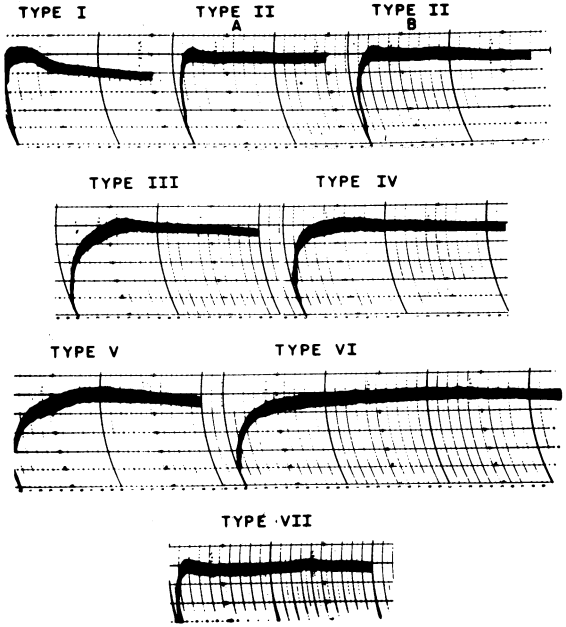

Fig. 3. Seven farinogram curve types.

The intermediate types of curves are only minor variations of the general types listed.

Except for specific instances, chemists use general type classification for evaluating dough behavior with the farinograph. Some have endeavored to assign specific values or readings to portions of the curve for numerical evaluation purposes. Today, there are six widely used curve readings. These include:

Arrival Time—is the time required for the top of the curve to reach the 500 Brabender unit (BU) line after the mixer has been started and the water introduced. This value is a measurement of the rate at which the water is taken up by the flour. Generally, for a given variety of wheat, the arrival time increases as the protein content increases.

Dough Development—is the time from the first addition of the water to the development of the dough's maximum consistency, or minimum mobility, measured to the nearest half-minute. This value is also referred to as "peak" or "peak time." When the top of the curve is nearly flat, the peak is determined by taking the mean of the midpoint of the top of the curve and the top of the arc of the bottom of the curve. Occasionally, two peaks may be observed; the second should be taken as the dough development time. This value gives some indication as to the development time or mixing time of the flour. Correlations have been found between the peak time and commercial mixer mixing time. When high correlations have been found between mixing time and peak time, a specific grade, type of flour, bake formula, and mill were involved. Usually, when any one of the above variables is changed, a different correlation factor is needed.

Stability—is the difference in time, to the nearest half-minute, between the time when the curve first intercepts the 500 BU line (arrival time) and the time when the curve leaves the 500 BU line (departure time). There is very little information in the literature comparing stability with baking results. However, it is generally accepted that the longer the stability of a flour, the more tolerance it has to mixing.

Tolerance Index (MTI)—is the difference in Brabender units from the top of the curve at the peak to the top of the curve measured 5 min after the peak. Two commonly used, closely related measurements are the *weakening area,* the area of a triangle scribed from the peak (center of the curve) to 15 min after the peak along the 500 BU line, down to the center of the curve at this point, and back to the peak; and the *drop off* or *20-min drop,* the difference in Brabender units from the 500 BU line to the center of the curve measured 20 min after the addition of the water. Flours with low MTI have a good tolerance to mixing, while flours with high MTI's are critical to mixing and especially to overmixing.

Departure Time—is the time from the addition of the water to when the curve leaves the 500 BU line. Long departure time indicates a flour with good tolerance to mixing.

Valorimeter Value—is an empirical, single-figure quality score based on the development time and the tolerance to mixing. This value is derived from the farinogram by means of a special template supplied by the manufacturers of the instrument. Generally, stronger flours have higher valorimeter values. This reading does not give a complete picture of the curve, however, and can be misleading. It is possible to have a flour which has a long peak, a relatively short stability and a rapid breakdown; and a flour with a short peak, a relatively long stability and a gradual rate of breakdown, with both giving the same valorimeter value. Yet these two flours are not comparable, as the first flour would require longer mixing but be critical to overmixing, while the second flour would require shorter mixing but have good tolerance to overmixing.

A typical farinogram is shown in Fig. 4, with the following readings:

Arrival Time - 2.5 min
Peak Time - 6.5 min
Stability Time - 11.0 min
Departure Time - 13.5 min
Tolerance Index - 30 BU
Valorimeter - 64 Units

Absorption—is the amount of water required by a given weight of flour to yield a dough of a given consistency. The usually accepted consistency corresponds to a curve that centers on the 500 BU line. The farinogram absorption value may be correlated with bake absorption within limits.

The farinograph is manufactured by the Brabender OHG, 41 Duisburg, Kulturstrasse 51, West Germany, and C. W. Brabender Instruments, Inc., 50 E. Wesley Street,South Hackensack, NJ 07606, USA, with representatives in over 60 countries throughout the world. The price of the instrument with bowl and thermostat is approximately $8,500.

2. Do-Corder

The do-corder shown in Fig. 5, is a heavy-duty version of the farinograph with variable speeds between 5 and 250 rpm, and a torque range up to 10,000 meter grams. If a farinograph mixer is used, the instrument will perform all tests normally attributed to a farinograph. With the do-corder developer head, the unit may be used to mechanically develop a dough and to study intensive mixing and continuous-type dough preparation. Trum and Snyder (8) and Seibel and

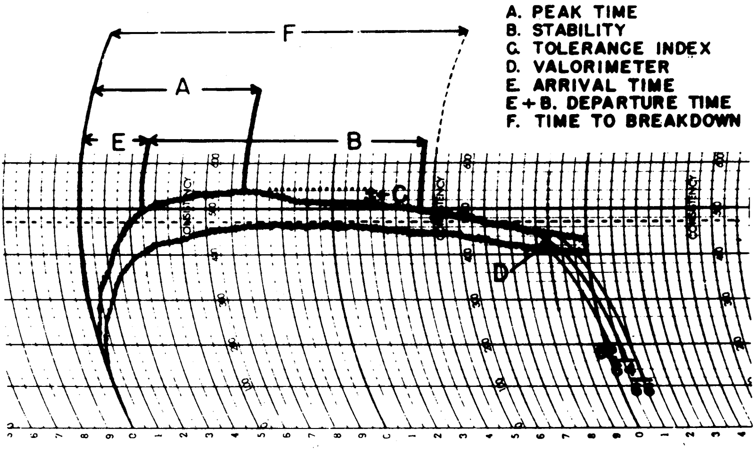

Fig. 4. Readings from a farinogram.

Crommentuyn (9) described the use of the do-corder for testing flours and dough ingredients.

The complete do-corder unit may be purchased from Brabender OHG or C. W. Brabender Instruments, Inc., for approximately $11,300. Also, a food extruder head attachment may be used with the instrument and would cost approximately $5,000, while the hardness tester head is approximately $1,150.

3. Resistograph

The resistograph is another high-shear recording dough mixer manufactured by the Brabender OHG. The instrument and its application are discussed by M. Brabender (10). It is similar to the farinograph, except that it has an extended range to permit measurement of higher work input, and a mixing bowl and head that combine blending with stretching, pressing, and kneading. This mechanism imparts high-shear and high-work input to the dough. The instrument is versatile, because it can also be used to make a standard farinogram by adjusting the measuring range in the scale head.

A constant dough quantity of 160 g is used to produce a resistogram. Since the resistograph mixer had a high-shearing action, the height of resistograms is in the range of the 600 BU line. The effective shear rate is 80% higher than the one of the farinograph mixer. The titration is made in exactly the same manner as for a

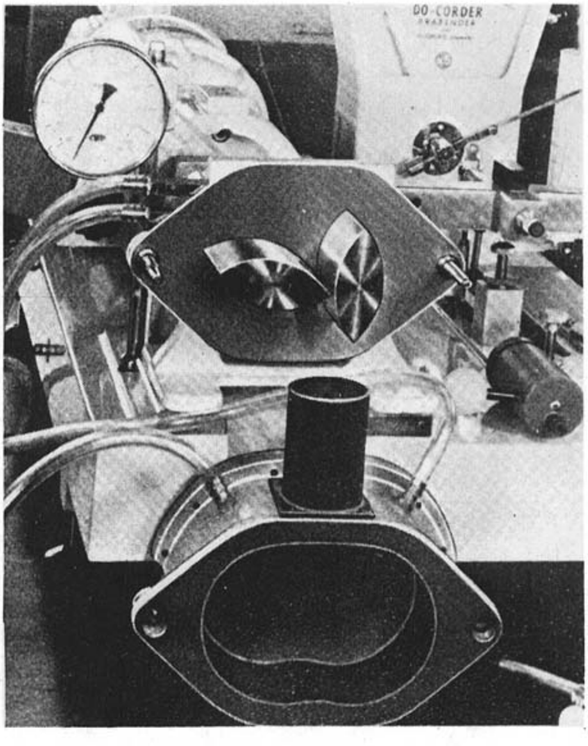

Fig. 5. Do-Corder mixing head.

farinogram. The length of time the instrument is run depends on the type of flour being tested.

Resistograms vary markedly with flours of varying quality. Strong flours show a sharp increase in mixing resistance and broadening in band width followed by an optimum and, finally, by a decrease in consistency and narrowing of the band. The optimum, a characteristic point, is the time it takes to reach this position, measured in minutes. Dough characteristics change considerably at this stage, and resistogram optimum is a most important parameter when evaluating doughs of strong flours.

Doughs of medium-strength and weak flours have two pronounced maximums in the resistogram. The first maximum characterizes the water-bonding and development of the dough and thus the dough development time. The second measures the stickiness and extensibility at the breakdown of the dough. Resistograms for a strong and weak flour are shown in Fig. 6.

The instrument may be purchased from Brabender OHG for approximately $9,000, with a type R-100 mixer.

4. Mixograph

A second type of recording dough mixer used is the mixograph. The mixing action of the mixograph, with a pull-fold-repull type of mixing action is much more severe than that of the farinograph. The five basic parts are shown in Fig. 7: 1) the mixing pins; 2) the mixing bowl; 3) the swivel base on which the bowl is placed; 4) the tension spring which may be adjusted to give different tensions on the swivel base suitable for the type of flour being tested; and 5) the kymograph or traveling chart on which the mixogram is scribed by a stylist.

A typical mixogram is shown in Fig. 8. The readings are as follows:

Peak Time—or time to maximum height of the curve. This time is similar to dough-development time of the farinogram. The longer the peak time, the more time required to develop the dough.

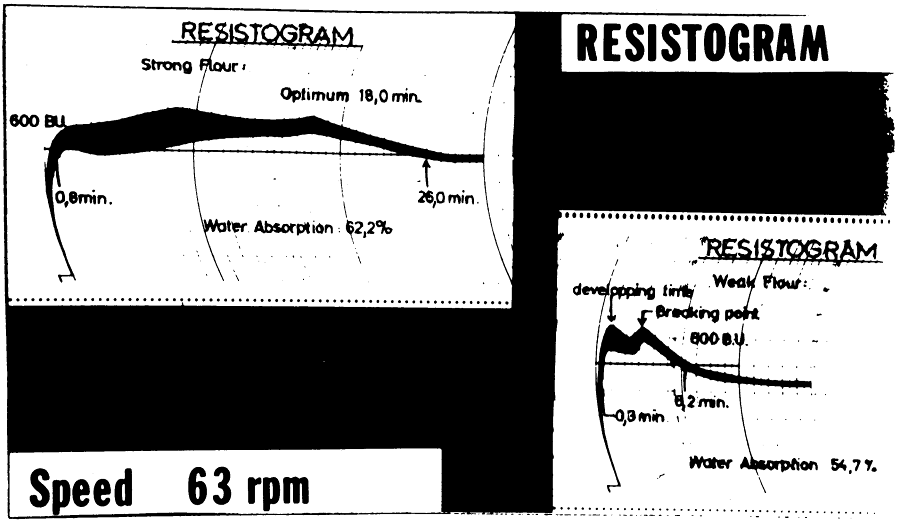

Fig. 6. Resistograms of strong and weak flours.

Area Under Curve—is the area scribed by the base line and a line drawn through the center of the curve until 7 min of mixing has elapsed. The greater the area, the stronger the flour and the greater its tolerance to mixing.

Maximum Height at Peak—is the height from the base line to the center of the curve at the peak. The mixograph is not as sensitive to absorption as the farinograph. This reading gives some indication of strength and also absorption.

Angle between Ascending and Descending Portions of Curve at Peak—is the angle scribed by drawing a line from the center of the curve at peak for a few minutes down the center of the curve in both directions. More tolerant flours will have larger angles.

Height of Curve at Specified Time after Peak or Start of Mixing—is a measure of the height of the curve at a specified mixing time. This reading is similar to the "tolerance index" or "drop-off" measurement of the farinogram. The higher values indicate a flour that is more tolerant to mixing.

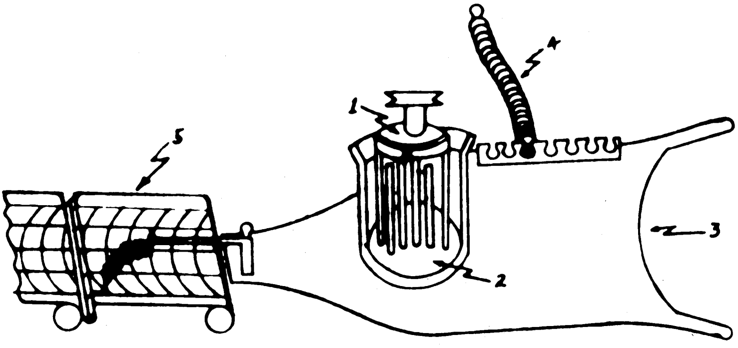

Fig. 7. Diagram of the basic parts of a mixograph.

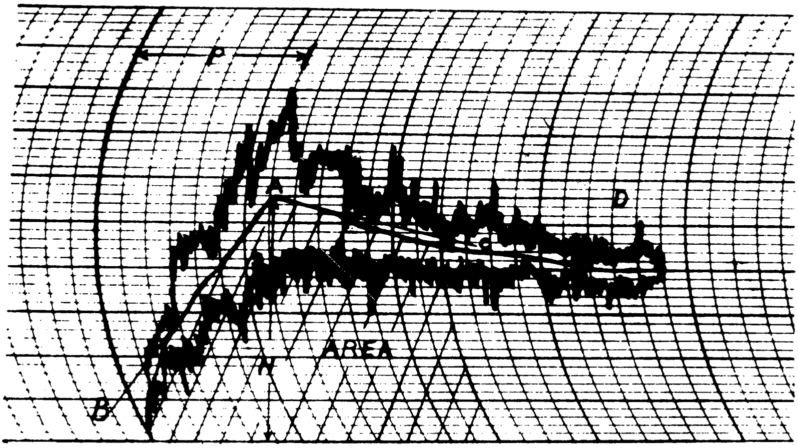

Fig. 8. Readings of a mixogram: **P**) Peak time, **Area** - shaded area under curve, **A**) maximum height of peak, Angle between ascending and descending portions as scribed by lines BAC, and Weakening angle - scribed by lines CAD.

Weakening Angle—is the angle scribed by drawing a line from the peak down the descending slope of the curve and a line horizontal to the base line at maximum height. This angle is a measurement of the mixing tolerance. The stronger flours have a smaller angle.

Absorption—is the amount of water required to produce a dough of a given consistency. It is the general practice to use the baking absorption for running the mixograph.

The mixograph is somewhat more limited than the farinograph because of the poorer temperature control and the system of measuring the resistance afforded the dough during mixing. Both instruments are useful tools in characterizing certain physical properties. An experienced operator knows the limitations of these instruments and relies on the general shape and pattern of the curve for evaluation rather than on specific readings or values. Because these instruments are continually mixing and stretching the dough beyond its elastic limit, very little information is obtained about the actual elastic properties of the dough. The information derived on the tolerance of the dough to mechanical mixing abuse should be used only as supplemental information in flour evaluation.

Finney and Shogren (11) described a 10-g mixograph that gave similar results as the larger 35-g model. They, as well as we, have found the instrument to be most useful in predicting mixing properties of dough from bread-wheat flours and durum semolina.

The instruments may be purchased from the National Manufacturing Company, 1218 North 22nd Street, P.O. Box 30226, Lincoln, NB 68503. The price of the regular 35-g mixograph recording dough mixer is approximately $750. The combination 10-g and 35-g unit is approximately $1,010.

5. Rheograph

The rheograph (Fig. 9) has had limited publicity because it was a recording dough mixer developed primarily for one baking company to help control their flour specifications. Tests were adapted for both cake as well as bread flours.

The instrument is basically a C-100 standard Hobart mixer adapted with a McDuffy bowl and a three-prong mixing pinhead enclosed in a temperature and relative humidity controlled cabinet. Seven hundred g of flour, 1% salt, and sufficient water to produce the proper consistency are used to make the test with the mixer set in the second-speed position after proper incorporation of ingredients. The instrument is run until the dough fatigues and smears on the walls of the mixing bowl.

A typical bread-wheat flour curve is shown in Fig. 10. The three most predominant readings obtained from the curve are: *Absorption*—is the amount of water required to give a consistency reading of 3 on the scale of the paper provided with the instrument. *Peak time*—is the time in minutes to minimum mobility on the curve. *Fatigue time*—is the time in minutes until the dough mass completely disorients, breaks down, and plates along the sides of the bowl.

The nature of the mixing action and amount of work input into the system affords another means of measuring flour dough behavior under high-shear mixing.

The baking company backing the instrument claims success in controlling large plants by adapting the information obtained from the rheogram to production practices. Since only a limited number of the instruments have been made, any additional information could be obtained from Interstate Brands Corp., P.O. Box 1627, Kansas City, MO 64141.

Kilborn and Tipples (12,13,14), have written a series of articles on factors affecting mechanical dough development. Hoseney and Finney (15) discussed some of the contrary views on mixing. Marston (16) and Tsen (17) have reviewed chemical development of dough. Some of the ideas or conclusions expressed may be divergent but it should be remembered that the final objectives of the investigators may also be different.

B. Viscometers

This category contains many kinds of viscometers which are commonly used to measure viscosities of pastes, batters, and suspensions. There are recording viscometers similar to the Brabender Amylograph as well as the nonrecording, such as the MacMichael or Zahn Viscometers. They may be of relatively simple construction as the Zahn Viscometer, or more intricately designed such as the

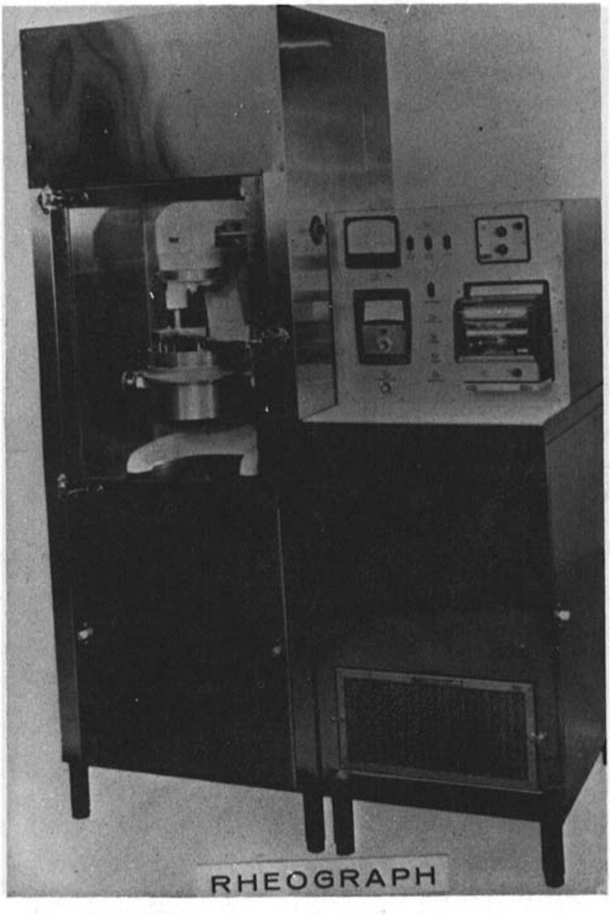

Fig. 9. The Rheograph.

amylograph. Each type will perform equally well for the specific measurement it was developed to make.

The measurement of resistance to rotation of a spindle or cylinder immersed in the test material is the basis for several of the viscometers. Most of these instruments are classed as torsion viscometers since the results are obtained by a measurement of the torque on the rotary part of the instrument. The measurement of torque by a calibrated spring on a spindle rotating at a constant speed in the test material gives the resultant viscosity.

Other viscometers are those in which the test material is rotated around a spindle or cylinder. Most viscometers of this type are also classified as torsion instruments since the torque exerted on a stationary spindle by the rotating test material is a measure of the viscosity or consistency.

Still another type of viscometer, employs the principle of Stokes' law by causing an object to fall through the test material. The rate at which the object will pass through the material is determined not only by the viscosity of the material but by the configuration of the object, which will remain constant for the test apparatus.

The simplest viscometers are those which allow the test material to pass through a given orifice. The time required for a specific amount of material to pass through is recorded.

1. VISCO/amylo/GRAPH

The amylograph does not actually measure dough characteristics. However, the information it provides can point out, in some instances, the cause of peculiar dough behavior. The amylograph measures the change in viscosity of a flour-

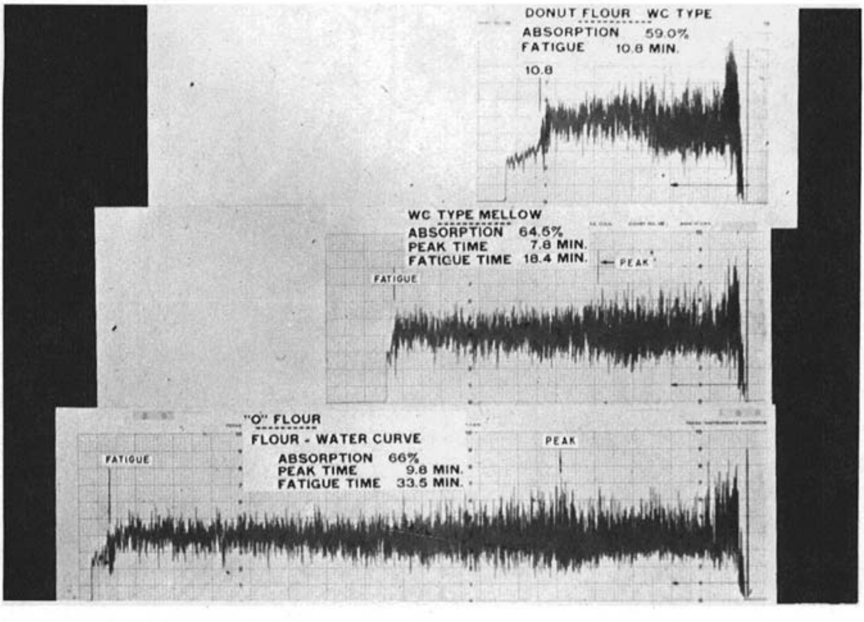

Fig. 10. Rheograms of three bread-wheat flour types.

water suspension as the temperature is raised at a uniform rate. The height of the amylogram (amylogram peak) is related to the gelatinization characteristics of the starch and the α-amylase activity.

The basic parts of the amylograph are shown in Fig. 11. The container bowl (1) and the stirrer (2) are made of stainless steel. The stirrer is connected to a highly sensitive interchangeable measuring spring cartridge (3). The bowl is rotated at a uniform speed (4) and the stirrer deflects, depending upon the viscosity of the test material. The resistance encountered is transmitted to the spring system and continuously recorded by the recording mechanism (5). The container is heated by a radiant source (6). Temperature inside the container is controlled by a thermoregulator (7) extending into the material. Cooling is effected by a cooling probe (not shown) immersed in the material. A solenoid valve controls the supply of water from the top. The thermoregulator is set to the desired temperature. When increasing or decreasing temperatures during a test, a synchronous motor (not shown) drives the thermoregulator up or down by the gear train (8). A pilot light (9) indicates heating. The main switch (10) serves to turn the instrument on and off. The entire system is programmed by a preset timer (11) which monitors your test run, automatically shuts off the system, and triggers an alarm buzzer advising of test completion.

The sensing element consists of a plate to which seven pins are attached

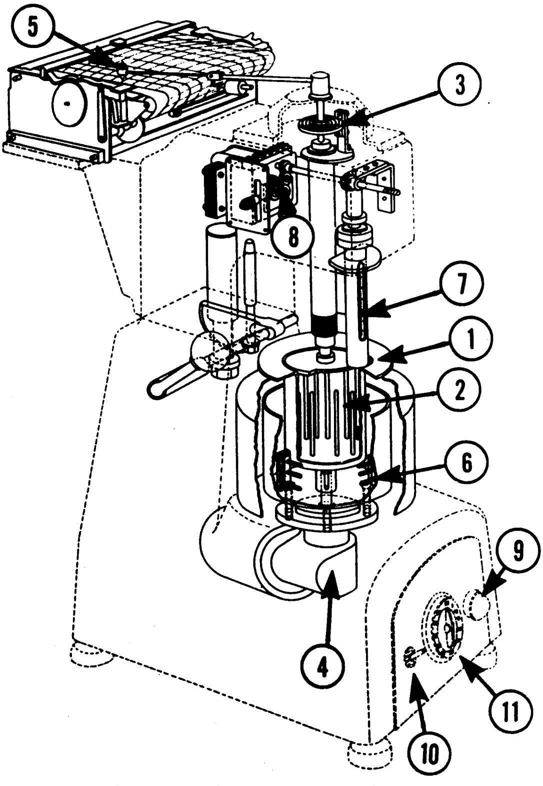

Fig. 11. Diagram of the basic parts of an amylograph.

extending into the test slurry. This element also acts as a stirrer, and is an extension of a shaft which is connected to a calibrated spring. The drag of the shaft against the resistance of the calibrated spring-cartridge weighing system depends on the viscosity of the test slurry and is recorded on chart paper in torque units of cm g along the width of the paper which travels at the rate of 5.0 mm per min. While industry is accustomed to these "Brabender units," conversion to centipoises (cP) is based on 2.43 cP = 1 cm g. The VISCO/amylo/GRAPH covers the range of 0 to 5,000 cP.

The range of the instrument may be increased by the addition of weights to suppress the zero or by substitution of a cartridge of different sensitivity. Two standard cartridge ranges are available: 350 and 700 cm g. Other nonstandard cartridges are also available on request.

Cooling may be provided for by solenoid-controlled tap water at the rate of 1.5° C per min. Standard heating range is 20° to 97° C. In special cases, the instrument can be supplied for temperatures from 25° to 150° at 2.5° C per min.

Shear rate on variable-speed models can be changed by varying the speed of bowl rotation. Two models offer constant speed ranges of 75 rpm. A third model offers a variable speed range of 25 to 150 rpm.

A given amount of flour (usually 100 g, 14% moisture basis) in a citric acid-disodium phosphate buffer solution (pH 5.3 and 460 ml of buffer) is placed in the bowl. The instrument is turned on with the thermoregulator engaged. The temperature is raised at a rate of 1.5° C per min. During the heating cycle, two reactions take place; the viscosity of the suspension increases as the gelatinization temperature of the starch is reached, while at the same time the starch gel is liquefied by the amylase activity. The point is ultimately reached at which the liquefication rate is greater than gel formation and the viscosity begins to decrease. There is thus a peak viscosity which is read in arbitrary Brabender units on the amylogram. A typical amylogram is shown in Fig. 12. Higher amylogram

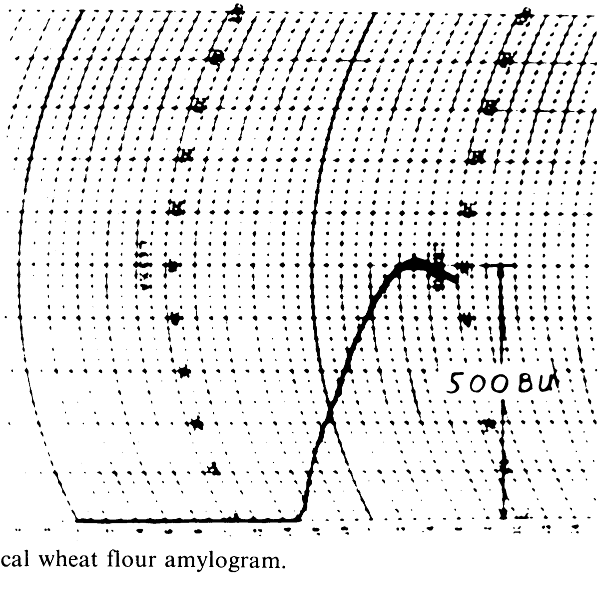

Fig. 12. Typical wheat flour amylogram.

values indicate less amylase activity and, conversely, lower amylogram values indicate higher activity. Extremely low values or high activity will cause slackening of the dough, especially during fermentation. The amount of slackening depends on the starch damage of the flour.

The amylograph was originally designed for measuring the diastatic activity of rye. The amylogram values were found to be closely related to baking quality. Higher amylogram values were associated with better baking-quality rye flours.

The VISCO/amylo/GRAPH has been adapted to many types of material. A typical amylogram of a corn starch is shown in Fig. 13. What occurs during swelling and gelatinization under conditions similar to the actual processing can be observed. A − B is a reflection of the viscosity during temperature increase, prior to onset of gelation; B is onset of gelation; B − C shows the gelation period where viscosity increases due to the swelling and thickening of the suspension; C reflects the maximum viscosity of the gel, which is sometimes called the peak; C− D indicates viscosity at constant temperature, while continuing to stir; D is minimum viscosity after a time interval of constant temperature; and D − E displays an increase in viscosity under conditions of constant temperature decrease.

Another development is the "Rapid Amylogram" which produces a starch curve in a fraction of the time necessary for the standard amylogram (3 to 5 min). For this "rapid" method, an additional sample bowl with a special sensor/stirrer is used. Instead of the direct radiation heat, water in the annulus around the bowl is the heat transfer medium.

Sample size is 21 g of flour or 22 g of bran mixed with 90 cc of water as in the standard amylogram test procedure. The sample bowl is inserted in the temperature-controlled water bath of the larger bowl.

Swell amylograms, too, can be made with this new system. Instead of the standard 5 mm per min, the chart paper moves 10 mm per min.

Additional equipment necessary for the "Rapid Amylogram."

(1) One large bowl for temperature controlled water bath.

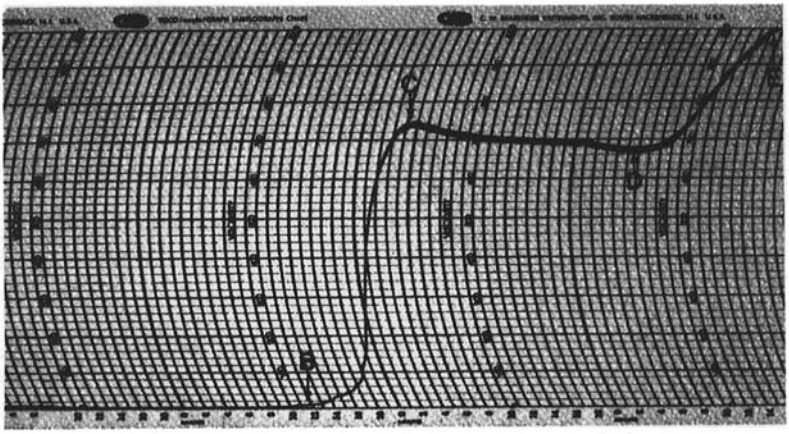

Fig. 13. Typical corn starch amylogram.

(2) One small sample bowl.
(3) One special sensor/stirrer.
(4) One set of chart paper transport gears.

These instruments can be ordered from C. W. Brabender Instruments, Inc. or Brabender OHG. The price of the VISCO/amylo/GRAPH is approximately \$3,700 and the same instrument with the large water bowl for the "rapid" method is approximately \$3,800.

2. MacMichael Viscometer

The MacMichael Viscometer (Fig. 14) is a torsion viscometer in which the sample is rotated about the spindle. The instrument operates on torsion principle. A plunger is suspended by torsion wire, and immersed in liquid to be tested. This is contained in a cup which is revolved at constant speed on a rotating hot plate. The plunger and supporting spindle turn with cup until restoring force in twisting wire just balances drag on plunger, due to viscosity of sample; spindle then stops turning and amount it has turned is read from disc graduated in arbitrary "degrees M" (each is 1/300 of a circle). By standardizing the instrument against solutions of known viscosity, readings can be converted directly to cP.

The viscometer has a stable base with cast-in handles, bubble level, and two

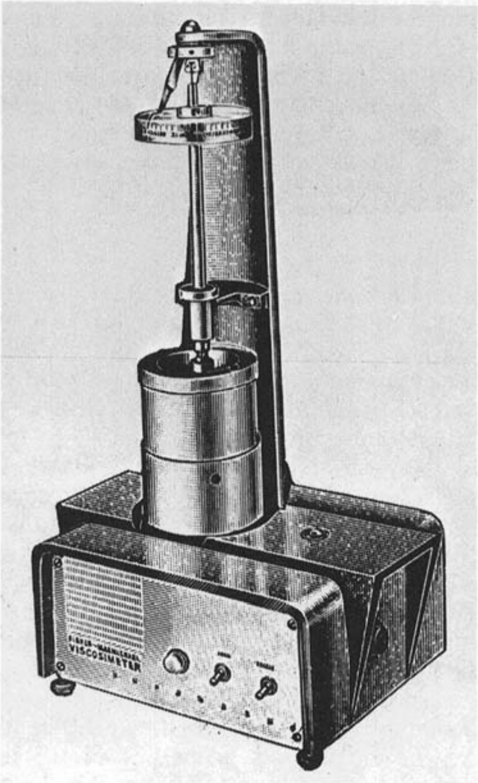

Fig. 14. The MacMichael Viscometer.

leveling feet. A dashpot on the spindle can be filled with oil or glycerin to reduce oscillations. The base contains electrical circuits and controls for rotating hot plate on which cups are mounted. Thermostat with screwdriver adjustment can be set to maintain any sample temperature up to about 300° F. The motor is governor-controlled and can be adjusted for speeds from 10 to 38 rpm by means of a graduated knob.

Because of many combinations possible with different plungers, two sample cups and different sample depths, one torsion wire will serve to measure a wide range of viscosities. Wires of B & S gauges from 16 to 34 can be used to measure viscosities from that of water to over 1 million cP. Results are obtained quickly and accurately, and are readily converted into absolute units (cP).

In a dilute lactic acid solution, flour gluten swells considerably and starch to a limited extent; this increases the viscosity of the flour-water suspension. The increase is related to the swelling properties and quantity of gluten present in the test flour. The test assumes that changes in viscosity due to starch are relatively constant; it is a valid assumption only if particles of damaged starch are either totally absent or present in a constant quantity. Damaged starch changes the total value measured by the MacMichael Viscometer. Thus, there are instances where the value reflects both a protein and a starch variable.

The test is most generally used in evaluation of soft wheat flours in which the range in protein content is rather narrow and the measurement probably reflects primarily the condition of the starch. Apparent viscosity in a soft wheat flour can be increased by regrinding, and this increase is correlated to the increase in starch damage. When flour protein remains constant, the changes in viscosity are a measurement of the type and severity of grinding during the manufacturing process, *i.e.*, starch damage changes due to the severity of grinding.

The instrument is advertised in several scientific supply catalogs and costs approximately $650.

3. Brookfield Viscometer

The Brookfield Synchro-Lectric Viscometer shown in Fig. 15 is the type of instrument in which the sample cup is stationary and the bobbin is rotated. "The Synchro-Lectric Viscometer rotates a cylinder or disc in a fluid and measures the torque necessary to overcome the viscous resistance to the induced movement. This is accomplished by driving the immersed element, which is called a "spindle," through a beryllium copper spring—the degree to which the spring is wound, indicated by the position of the red pointer on the viscometer's dial, is proportional to the viscosity of the fluid for any given speed and spindle.

"The viscometer is able to measure over a number of ranges since, for a given drag, or spring deflection, the actual viscosity is proportional to the spindle speed, and is also related to the spindle's size and shape. For a material of given viscosity, the drag will be greater as the spindle size and/or rotational speed increase. The minimum range of any viscometer model is obtained by using the largest spindle at the highest speed—the maximum range by using the smallest spindle at the slowest speed.

"Measurements made using the same spindle at different speeds are used to detect and evaluate the rheological properties of the test material. Flow properties are determined with the Brookfield Synchro-Lectric Viscometer due to the many speeds at which its spindles can rotate. Such nonNewtonian properties as pseudoplasticity, plasticity, and dilatency can be readily detected—flow curves of thixotropic materials can be obtained." —

Instruction Manual and Information Brochure.

Kitterman (18) recently compared the results from MacMichael and Brookfield Viscometers for acidulated flour-water suspensions. He found a correlation coefficient of $r = 0.97$ between the two instruments.

The viscometer can be purchased from the Brookfield Engineering Laboratories, Inc., 240 Cushing Street, Stoughton, MA 02072, for approximately $1,000.

4. Stromer Viscometer

The Stromer Viscometer shown in Fig. 16 is similar to the Brookfield since the cup is stationary and the bobbin moves, but determines the viscosity by measurement of time required for definite number of revolutions of the rotor when immersed in the sample. The test cup is maintained at desired temperature by means of water or oil bath. The revolution counter is attached to the spindle of the rotor which is driven through a series of gears by a falling weight.

The instrument is easy to calibrate and check. Viscosities can be determined and recorded in absolute unit cP by means of a calibration table prepared by the user. The instrument is well adapted for many uses as its readings are independent of specific gravity of fluid.

The weight box, which is filled with lead shot, can be adjusted from 35 g (empty) to 160 g (full). Test cups and rotors should be used only at temperatures below 148° C (300° F) as solder is used in their construction.

A pulley arm attached to the dust cap on the center spindle housing permits use of the instrument with pulley arm to the right of the instrument or at the front. In either position, the dial is directly in front of the operator for convenient reading.

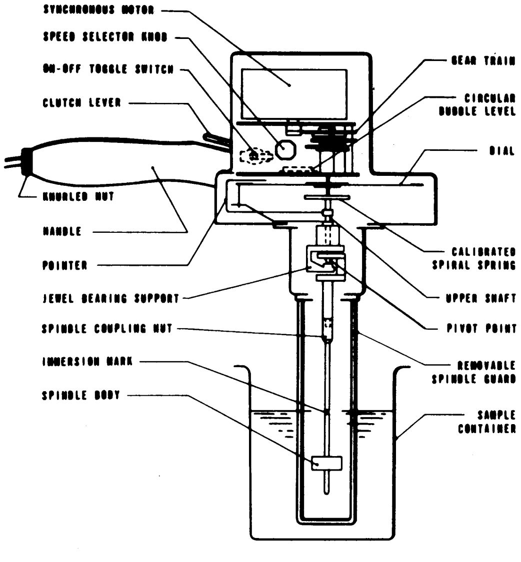

Fig. 15. The Brookfield Viscometer.

The viscometer has been used for a wide range of materials and temperatures. It is advertised in several scientific supply catalogs and costs approximately $350.

5. Perten-Hagberg Falling Number

The Perten-Hagberg Falling-Number apparatus (Fig. 17) uses the principle of Stokes' law, except that a special-designed stirrer is used in place of a falling sphere.

The Falling-Number method by Perten-Hagberg is one of the quickest, cheapest, and most reliable methods for the determination of the α-amylase activity and hence the extent of sprout damage. It affords a continuous control of the α-amylase activity essential to the grain trade, flour mills, and bakeries. Because of the uniform shape of the stirrer, any difference in the rate of travel time through the suspension is proportional to the α-amylase activity.

The falling-number apparatus utilizes the principle of the rapid gelatinization of a flour suspension with subsequent measurement of the liquefaction of the starch through α-amylase enzyme activity.

There are several models, which differ only in the degree of automation, but the method of operation is essentially the same for all models:

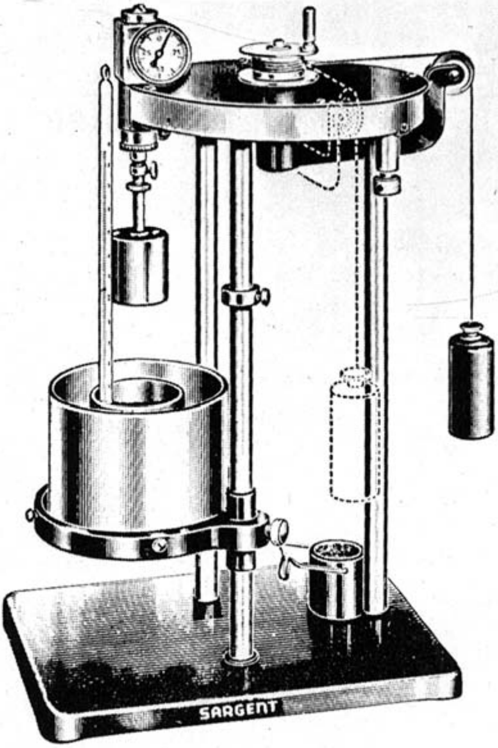

Fig. 16. The Stromer Viscometer.

(1) The water in the bath is brought to a boil and during the test must always boil briskly.
(2) Place 25 ml distilled water at 20° C into a viscometer tube.
(3) Weigh out 7.0 ± 0.05 g of the ground grain or flour and transfer it into the viscometer tube.
(4) Mix the flour and water thoroughly in the viscometer tube by placing a stopper in the tube and inverting it 30 or 40 times during a 30-sec time lapse.
(5) Remove the stopper and push down to the liquid level with the viscometer stirrer any flour adhering to the sides of the viscometer tube.
(6) Place the viscometer tube together with the viscometer stirrer into the boiling water bath through the hole in the lid.
(7) Start the timer immediately when the viscometer tube touches the bottom of the rack and secure the viscometer tube.
(8) After exactly 5 sec after the immersion of the viscometer tube, commence stirring the suspension by hand at the rate of 2 stirs per sec; 1 stir = 1 up movement and 1 down movement (*i.e.*, 4 movements per sec). It is important to keep this exact speed of stirring.
(9) After a total of 59 sec, the stirrer is lifted to the uppermost position, and exactly 60 sec from the start of the timer, the stirrer is released, and the microswitch for time measuring is turned into position beside the viscometer stirrer.
(10) When the stirrer has dropped by its own weight so that the lower edge of the upper stop is at the same level as the top of the stopper, the timer stops automatically and the alarm sounds.
(11) Note the falling-number value held on the counter, and remove the viscometer tube and viscometer stirrer from the boiling water bath.

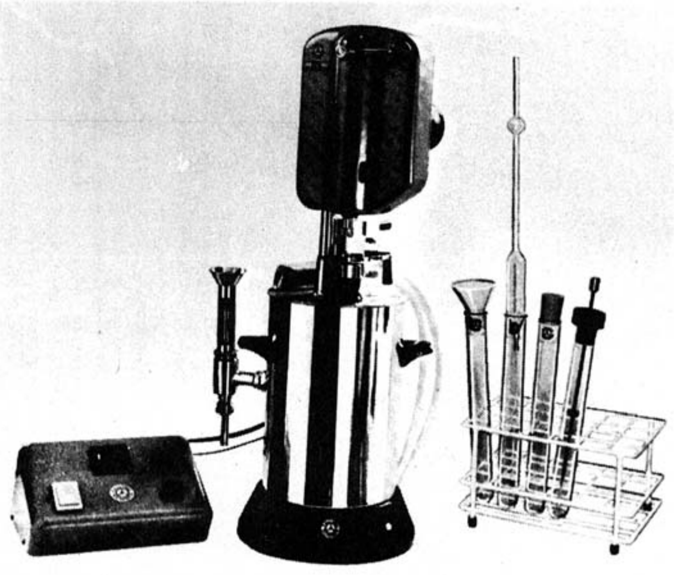

Fig. 17. The Perten-Hagberg Falling-Number apparatus.

(12) Press the "set zero" button on the counter and the apparatus is again ready for use.

The falling-number value from the counter is equal to the *stirring time* plus the *dropping time*.

The Perten-Hagberg Falling-Number apparatus may be purchased from Falling-Number AB, Box 32072, S-126 11 Stockholm 32, Sweden, and ranges in approximate price from $3,400 for the fully automatic unit Type A, to $795 for the hand-operated unit Type ST.

6. Hoeppler Viscometer

The Hoeppler Viscometer is shown in Fig. 18 and more closely duplicates the basic principle of Stokes' law. Operating on the falling-ball principle, the absolute viscosity of gases or liquids is determined by measuring the time required for a ball, made of glass or steel, to fall through a column of the sample enclosed in a precision glass tube (bore of tube about 16 mm, length about 200 mm). The time interval measured by a stopwatch with an accuracy of 0.02 sec, will give an accuracy of 0.1%.

The instrument is equipped with a leveling stand for free inversion of the tube and jacket unit while maintaining a 10° tube angle. The sample is placed in the tube and the tube inverted. Time required for the ball to fall through the column is recorded and converted to cP.

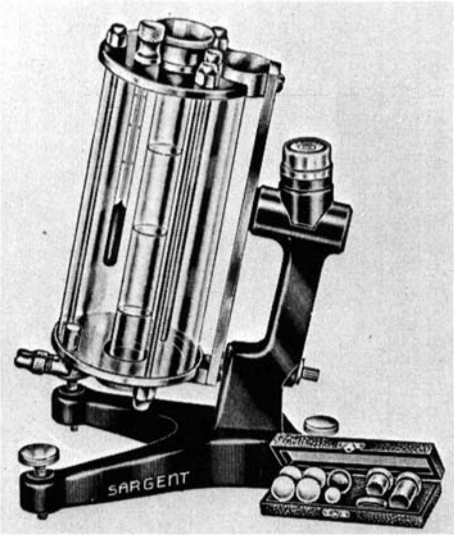

Fig. 18. The Hoeppler Viscometer.

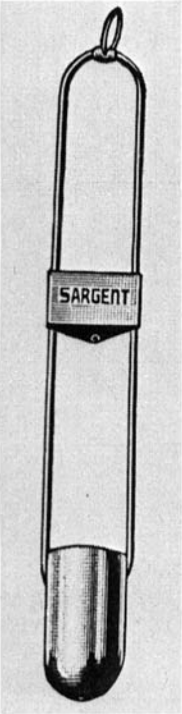

Fig. 19. The Zahn Viscometer.

All parts in contact with the sample are of heat-resistant chemically inert glass, gold, or corrosion-resistant steel alloy. Temperature control, needed for utmost accuracy, is maintained by circulation of water from a constant-temperature bath through the tubes provided in the jacket.

A set of six calibrated balls is used to cover a range from 0.01 to 25,000 cP. Also, a special tungsten ball will increase the range up to 200,000 cP. The instrument is much more useful for measuring viscosities of solutions than suspensions.

The viscometer is advertised in many of the scientific supply catalogs and costs approximately $400.

7. Zahn Viscometer

The Zahn Viscometer shown in Fig. 19 is a portable, relatively simple instrument consisting of a bullet-shaped, stainless-steel cup having a volume of 44 cc, and a precision-drilled orifice in the bottom for liquid to flow through. It has a long, wire-looped handle with a small ring at the top for holding to ensure vertical alignment of the cup during measurement. The cup is immersed in the liquid to be tested and lifted out by the ring. Time is measured by a stopwatch from the moment the rim of the cup breaks the surface of the liquid to the moment there is a sudden break in the continuous flow of liquid through the orifice.

Five orifice sizes are available. The manufacturer recommends the choice of orifice size which gives Zahn readings between 20 and 40 sec. Paints and varnishes are the usual products measured with this viscometer but it is also used in the egg processing industry to check viscosity of egg white prior to spray drying. Viscosity control is necessary for efficient atomization.

Of more interest to the cereal chemist is its use for controlling uniformity of liquid egg white for baking tests—particularly angel cake tests. Fresh egg white is a mixture of very thick white and thin watery white which does not lend itself to uniform sampling and which produces erratic results when whipped to a foam. To make a uniform egg white sample for laboratory use, a batch of freshly-broken egg whites is milled for 30 to 60 sec in a Waring-type blender at low speed (controlled with a rheostat set at 40 volts). To eliminate air incorporation and foaming, the bottom of an Erlenmeyer flask is held on the surface of the liquid. Milling in this manner is sufficient when the blended sample flows through a Zahn No. 2 cup in 20 sec or less. The milled egg white will have a shorter whip time than the unmilled and aliquots of the same batch of milled sample will perform in the same manner.

Maintenance is important. The cup should be properly cleaned between uses, and care taken not to damage the cup, and particularly the orifice.

There is no general formula to convert Zahn seconds to other viscosity terminology. If conversion is desired, a worker can construct his own curve from test data but results will apply only to the liquid tested.

The device may be found advertised in several scientific supply catalogs and costs approximately $40 for each cup size.

8. Simon "Research" Water Absorption Meter

The "research" water absorption meter (Fig. 20) is not generally considered a viscometer, yet it does measure flow rate; therefore, may be considered as one.

The apparatus is easily operated and the results reasonably reliable and accurate when the test is carried out under controlled conditions. The principle on which the method is based is comparatively simple. Doughs, either yeasted or unyeasted, are made with known amounts of water and are relaxed for standard periods. The doughs are extruded by a fixed pressure through a nozzle of carefully-controlled dimensions. The rate of flow is determined by means of a micrometer dial gauge and stopwatch.

Three miniature doughs are made up from the flour sample to perform the test. Each dough is made up with a different quantity of 2.5% salt solution, usually 14 ml, 15 ml, and 16 ml, and 28 g of flour. For a yeasted dough, 0.35 g of baker's yeast is added prior to mixing the dough either mechanically or by hand. The mixed doughs are placed in separate containers and allowed to ferment for 3 hr at 80° F.

After fermentation, the first dough of the batch is then placed on a glazed surface and flattened with a spatula to remove the gas, then cut into strips to allow ease of loading into the gun of the water absorption meter. The gun is

Fig. 20. The Simon "Research" water absorption meter.

screwed into position and a weighted piston is then released down the gun which extrudes the dough through the small hole in the base of the gun. The length of time taken for the piston to travel (against the resistance of the dough) 1 cm down the gun (*i.e.*, one revolution of the meter) is recorded. The same process is carried out on the other two doughs and it should then be seen that the dough containing the most water takes the least time to extrude and vice versa.

A graph of the three results is made on prepared logarithmic graph paper and is plotted as extrusion time in seconds against amount of water added. A straight line is drawn through the three points and the correct water absorption is taken as that point at which the line cuts the 50-sec line. The points should be distributed above and below the 50-sec line and if the above water absorptions give points all above or all below the 50-sec line, the test should be repeated with amended water absorptions. When the dough is being packed into the gun, air bubbles and heavy pressure should be avoided. When testing flours that are not normally subjected to fermentation, *e.g.*, biscuit flours, it is normal practice to use an unyeasted system. The test is carried out exactly as given previously, but the following differences are made: 1) no yeast is used; 2) a relaxation time of 1 hr, not 3 hr, is allowed between mixing and extruding.

The above methods are obviously flexible and can be adjusted to suit the needs of any particular laboratory. For instance, the 50-sec extrusion time, while generally taken as a standard, may mean that the dough is a little too slack or a little too tight for a particular requirement and the extrusion standard time can be altered to suit requirements. In the same way, the time and temperature of fermentation can be altered to deal with shorter or longer fermentation doughs.

The absorption indicated by this test is also the amount used for testing flours in the Simon "Research" Extensometer described later.

The equipment is sold by Simon Controls & Instrumentation, Ltd., P.O. Box 31, Stockport Cheshire, England SK3 ORT, for approximately $365, F.O.B. English Port.

II. Stress/Strain Measuring Instruments

The stress/strain measuring instruments are designed to measure the elasticity and extensibility of a dough. They apply a force on a dough at a given rate and direction. Unfortunately, the dough is extended or deformed beyond its elastic limit and ruptures. The area under the time-extension curve usually recorded by these instruments, is well defined up to the point of rupture. The area is proportional to energy required to deform the particular dough mass.

1. Brabender Extensograph

The extensograph is an instrument designed to measure the extensibility of dough. Although this instrument is not widely used as a routine quality control tool, it has found rather extensive application in research. The instrument measures the force required to stretch a piece of dough (resistance to stretching), and the time required to stretch the dough to the breaking point (extensibility). The dough to be stretched is formed into a cylinder approximately 1 in. in diameter and 5 in. long. The basic parts of the instrument are shown in Fig. 21. The dough is usually mixed in the farinograph using a 3.0% salt solution. It is rounded, formed, placed in a cradle, and rested for the desired period at a constant temperature (30° C) before being run on the extensograph.

A typical extensogram is shown in Fig. 22. The four readings normally made on the extensogram are:

Resistance to Stretching—is indicated by the maximum height of the curve in Brabender units or the height after 5 cm of stretching on the extensogram. The former is referred to as maximum resistance, while the latter is referred to simply as resistance.

Extensibility—represents the length of the curve in centimeters from start of stretching until the dough breaks.

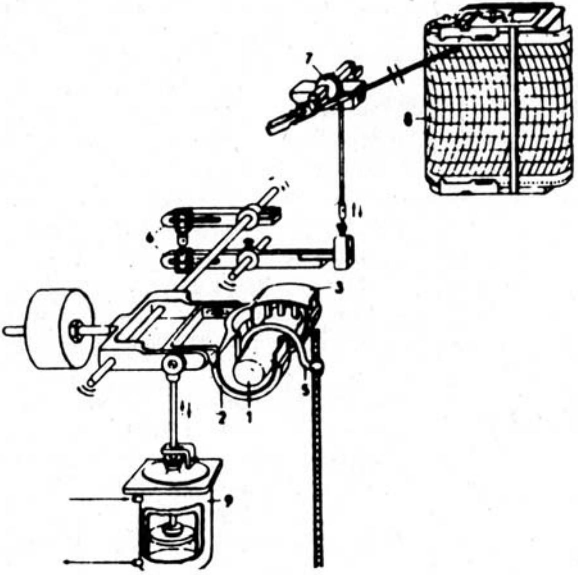

Fig. 21. A diagram of the basic parts of an extensograph: **1**) dough piece; **2**) cradle; **3**) cradle clip; **4**) motor; **5**) stretching hook; **6**) leveling system; **7**) scale head; **8**) recording arm and kymograph; and **9**) damper.

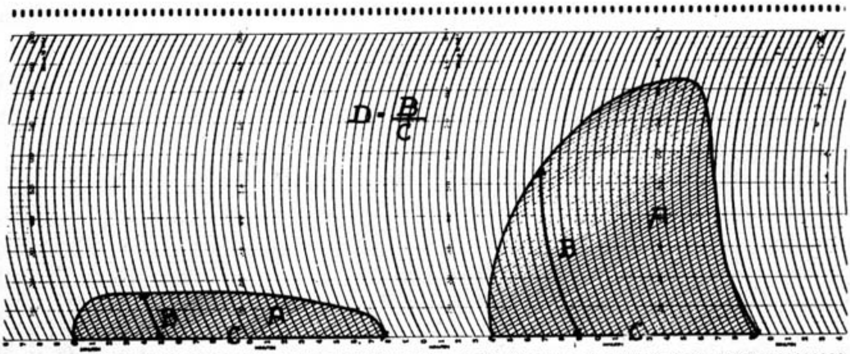

Fig. 22. Typical extensograms: **B** - resistance to stretching measured at 5 cm; **C** - extensibility; and **Area** - shaded portion under the curve.

Area Under the Curve—is the area scribed by the curve above the base line. It is possible to have two doughs with exactly opposite characteristics and yet giving the same value, which can be misleading. For example, one dough might be very resistant to stretching with short extensibility, while another might be very extensible with little resistance to stretching. The latter dough would be very weak and extremely pliable, and the former would be very tough and extremely bucky.

Ratio—is the calculated quotient of the resistance to stretching (B) divided by the extensibility (C) or $D = \frac{B}{C}$. The "ratio value" would eliminate any confusion which might arise from just an "area value," since the flours mentioned previously with a greater resistance to stretching would have a high-ratio value while the one with little resistance would have a low-ratio value.

The Ratio Value—in combination with energy, indicates the boldness and stability of the dough during fermentation. Flours with a low-ratio value are mostly very extensible considering their resistance to stretching and their doughs, on fermenting, quickly become soft and flowy. If the ratio value is too high it indicates that resistance to stretching, compared with extensibility, is too great and, on fermenting, the doughs tend to be short. They will become tight and their texture will suffer as they do not have the strength to stand up to fermentation.

Area and Ratio Values—are the two extensogram values that assess by characterizing the stretchability of a dough.

Desirable doughs give good resistance to stretching, but also are relatively extensible. A dough with too much resistance to stretching is tough, bucky, and difficult to machine. Doughs with too much extensibility are weak, slack, and may not machine at all. The extensograph allows an opportunity to observe some changes which may occur during fermentation. Extensograms may be run at various fermentation times when a quantity of dough is initially mixed, making possible a study of oxidation requirements within limits, once data have been correlated with certain conditions.

The instrument is sold by Brabender OHG and C. W. Brabender Instruments, Inc., for approximately $7,500.

2. Chopin Alveograph

The alveograph is another type of instrument similar to the extensograph but not as widely used. This instrument or the earlier model Chopin Extensimeter is used more extensively in Europe than in the United States. In the use of this instrument, the dough is formed into a small round flat disc, placed on a plate and, with air pressure, is blown into a bubble to the breaking point. A diagram of the alveograph is shown in Fig. 23. The main parts are 1) *water reservoir* which, when placed on the top bracket, furnishes the pressure for blowing the bubble, 2) *water receptacle bulb* to which the water from the reservoir runs. This bulb is calibrated in milliliters and the amount of water required to break the bubble may be measured. (The rate of flow of water between the water receptacle bulb is regulated by the size of the capillary placed in the line.) 3) The *retaining plate* holds the dough while the bubble is being blown. This plate also contains a removable cover cap to form the dough to the proper thickness. 4) A *recording manometer* registers the air pressure required to blow the bubble.

The one value recorded which is not obtained from the alveogram drawn by the recording manometer is:

Volume of water (G) in the measuring cylinder. This is sometimes referred to as the extensibility of the dough.

A typical alveogram is shown in Fig. 24. The readings obtained from an alveogram are similar to those from an extensogram as follows:

Maximum height of the curve (H) measured in ml and is similar to the resistance to stretching; also maximum pressure.

Length of the curve (L) measured in ml is the extensibility.

Area under the curve (W) with again the same problem existing for this reading as for the area under the curve of the extensogram.

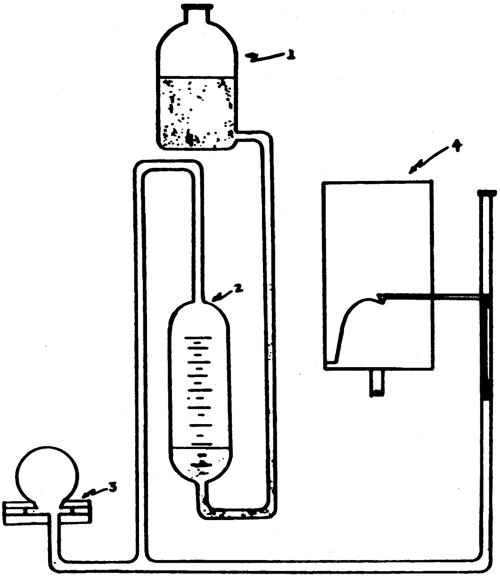

Fig. 23. Diagram of the basic parts of the Chopin Alveograph.

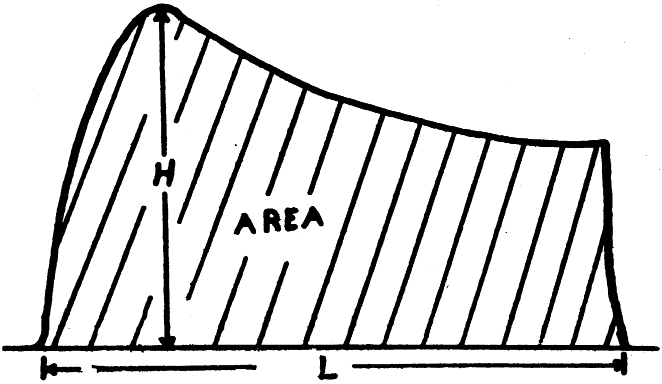

Fig. 24. Typical alveogram.

The alveograph shows a high correlation with protein content of the flour or wheat, especially within a given class or type. The higher the protein content, the higher the curve height. Although the extensigraph and alveograph do not agree exactly, they do reveal information about the dough-handling properties (machinability) and the state of oxidation or oxidation requirements. Also, the dough extensibility is related to loaf volume and a flour with a balanced relation between resistance to deformation (P) and extensibility (L) produces a maximum loaf volume with well-proportioned interior grain structure.

The instrument may be purchased from M. Chopin & Cie, 5 rue Escudier, 92100 Boulogne-Billancourt, France, for approximately $1,900.

3. Simon "Research" Extensometer

This testing equipment consists of two main units, the mixer-shaper unit and the "research" extensometer. The "research" extensometer is shown in Fig. 25. It is also used in conjunction with the "research" water absorption meter, described in the previous section. The apparatus should be set up in a room that is well controlled for temperature and, if possible, humidity.

The "research" extensometer is the actual strength measuring unit of the

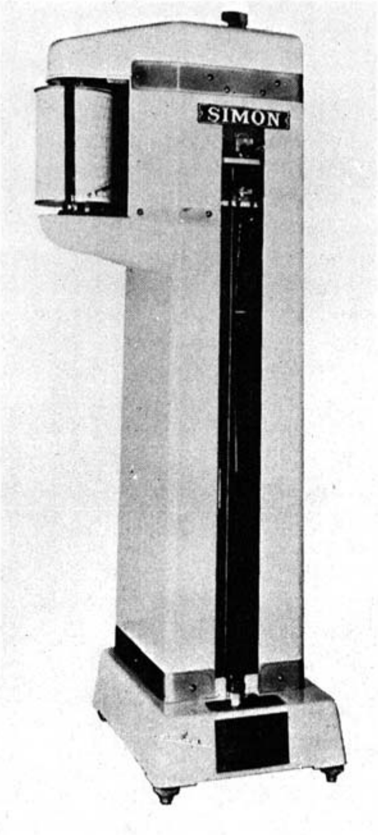

Fig. 25. The Simon "Research" Extensometer.

equipment which consists of one fixed pin and one movable pin. At the start of the test the dough is "spiked" on to the pins when they are both together at the top of the apparatus. When the electric motor is started, the lower pin gradually moves downward, driven by a long worm gear, and stretches the dough. The force exerted on the upper pin is transmitted by a lever system to the pen which records the dough characteristics on to a slowly revolving drum to which is attached a sheet of graph paper. When the dough breaks, the motor is stopped. This apparatus can be used on either a yeasted dough or on an unyeasted dough.

The recommended procedure for the yeasted dough is as follows:

The water absorption for the flour is first determined on the "research" water absorption meter. (It is also possible to determine absorptions by other means.)

A dough of desired quantity is then made up with 1.45% salt and 1.25% yeast. The dough is mixed to development in a Simon "Majorpin" mixer (other suitable mixers may be used).

The dough is allowed to ferment at 80° F for 3 hr. After fermentation, three 75 g pieces of dough are divided from the bulk dough for testing in the extensometer. The remainder of the dough is rounded, allowed to rest for 15 min, moulded and panned, proofed for 45 min at 80° F, and baked.

The three 75 g pieces of dough removed from the bulk dough are allowed to recover for 15 min under cover at 80° F, moulded in the shaper section of the Simon Mixer Shaper unit and proofed for a further 45 min at 80° F. The first of the three doughs is then impaled centrally on the split pin of the Simon Extensometer and stretched. The other two dough pieces are stretched in the same way so that a set of superimposed strength curves is obtained. The average of the three curves shows the resistance and extensibility of the dough.

For the unyeasted method, 280 g of flour is mixed with the predetermined amount of water for a fixed time (a total of 5 min if a Simon "Majorpin" mixer is used). Remove the dough mass from the mixer and divide this immediately into five 75-g pieces. Place the five pieces on a relaxation tray and allow the pieces to relax for 55 min in the constant temperature cabinet set at 80° F. At the end of the relaxation period, the dough pieces are moulded. Allow exactly 60 sec between moulding each test piece. After moulding, replace each test piece on the relaxation tray so that the "tails" are at the top and bottom. Immediately press the dough piece down firmly five times with the dough flattener, and cover immediately after with the dough cover.

Exactly 5 min after moulding, transfer each test piece from the relaxation tray to the extensometer with the assistance of a palette knife. The dough pieces are stretched in turn at intervals of 60 sec. This ensures that each test piece receives exactly 5 min relaxation time. The dough pieces are placed centrally on the extensometer pins, ensuring that the dough piece fits exactly around the pins, and also that the dough is halfway along them.

Note: If a cabinet is not available in which the temperature and relative humidity are controlled, the dough pieces should be kept covered as much as possible to exclude air and thus prevent skinning. The dough pieces should be handled lightly and as little as possible during the test.

Typical curves are shown in Fig. 26 for flours of widely differing strength. Curve A is that of a typical biscuit flour. The dough was unyeasted and had been relaxed for 1 hr after mixing; the curve displays the low resistance and high extensibility required in biscuit flours.

The remaining curves in Fig. 26 are those of doughs subjected to a standard 3-hr yeast fermentation, and they, therefore, show the strength of the doughs at a time corresponding to the oven-setting stage in bakery technique. Curve B displays the low extensibility and poor general strength commonly found in low-grade flour, Curve C is that of a typical satisfactory bread flour, and Curve D illustrates the high resistance and adequate extensibility of a strong flour milled from hard red spring wheat.

The instrument may be purchased from Simon Controls & Instrumentation, Ltd. previously mentioned. The approximate cost of the Simon "Research" Extensometer is $1,200, and the complete unit (including shaper and absorption meter) is $3,400.

Like the farinograph, mixograph, and other recording dough mixers, the extensograph, alveograph, and "research" extensometer measure only one phase of dough behavior. These instruments subject the dough to a continuous stress/strain to and beyond the elastic limits, therefore, the information derived from the data is limited. The experienced operator judges the extensograms and alveograms more by the general pattern or shape of the curve than by specific readings from the curve.

III. Fermentation or Gas Testing Apparatus

These are instruments which measure the amount of gas produced during fermentation of the dough or may even differentiate between the gas which is retained and that which is lost. The instruments control many of the parameters during fermentation, and may automatically "punch" the dough or "knock it back," as well as record various physical changes which may take place while the test is made. All these instruments use a dough-containing yeast for making the test. Whether or not other baking ingredients are used in the test is at the discretion of the operator.

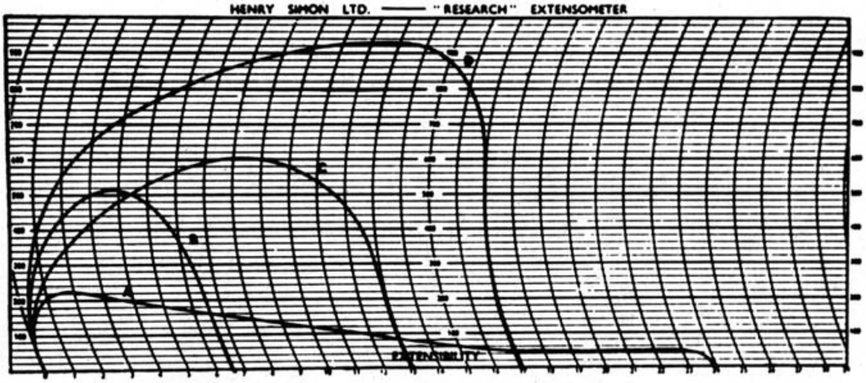

Fig. 26. Extensograms for four types of flour: **A**) soft wheat, unyeasted flour; **B**) low-grade, yeasted, poor strength flour; **C**) satisfactory, yeasted bread flour; and **D**) strong, yeasted, hearth type flour.

1. SJA Dough Tester

The instrument shown in Fig. 27 is a more sophisticated model of the SJA Fermentograph, which recorded the evolution of carbon dioxide in a dough during fermentation. This instrument combines and records the gas evolution and dough behavior separately on the graph while the dough ferments.

Another model is the SJA Mark II which has a single compartment to test only gas retention of a 150-g dough sample. The fermentation chamber has an adjustable thermostatic control for constant heat and maintains a constant relative humidity at about 90%.

A dough of 100% flour, 57.1% water, 1.43% salt, and 1.78% yeast is made up for the test. The time required to run the test will depend on the strength and type of flour, but usually ranges from 1 to 3 hr. The gas produced to expand the dough (while the dough ferments) is measured as increased volume of the dough mass, and the gas which escapes from the dough is entrapped and measured as buoyancy change.

A typical chart obtained from the dough tester is shown in Fig. 28. A dough from a good flour will have a large increase in volume and still retain the gas produced during fermentation.

These instruments may be purchased from Falling Number AB, Stockholm, given previously. The price of the SJA Dough Tester Mark II is approximately $3,400.

2. Chopin Zymotachegraph

The Chopin Zymotachegraph (Fig. 29) measures the gas production during fermentation of a dough. The instrument measures the gas produced in dough and also indicates the amount of gas escaping from the dough. Measurements are

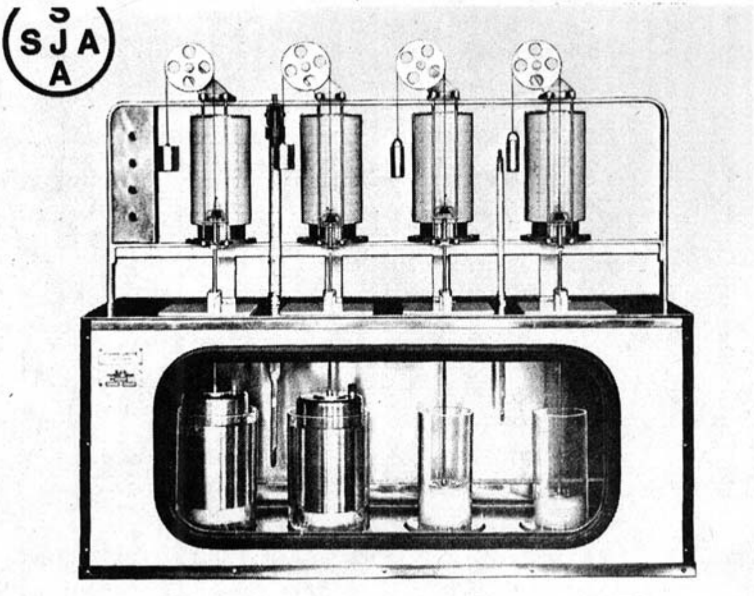

Fig. 27. SJA Dough Tester.

made every 2.5 min during the 6-hr test period, and are recorded automatically on the chart paper.

The operation principle of the apparatus is based on expansion of the dough. As the dough ferments and expands, the increase in volume increases the

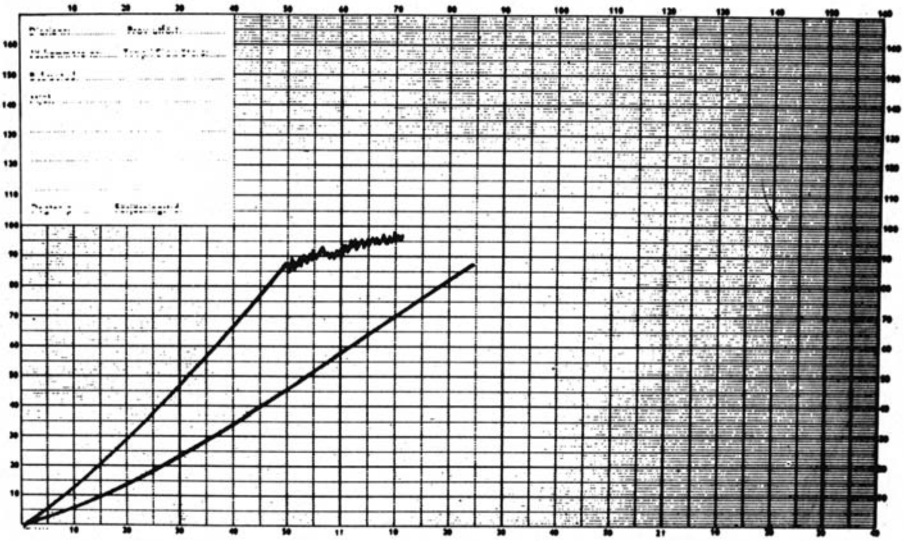

Fig. 28. Typical dough-tester chart.

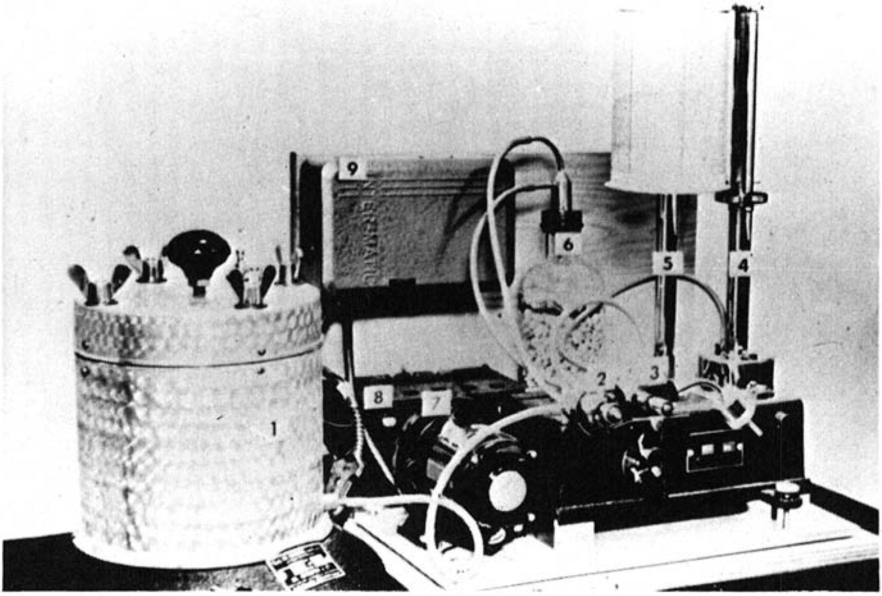

Fig. 29. A Chopin Zymotachegraph.

pressure in the fermentation chamber. The chamber is connected by a short, flexible tube to a recording manometer. A special valve gear is in the system, which contains pumice blocks with a 22% caustic potash solution. The valve gear slowly rotates and every 2.5 min opens the system to the atmosphere at which time the pen will drop to the base line of the curve. The valve system is designed so that pressure measurements are taken directly from the fermentation chamber and then from chamber to manometer system/absorption bottle, etc. The carbon dioxide given off by the dough will be absorbed in the caustic potash, thus causing a lag between total and actual pressure. This lag usually does not occur until after about 2.5 hr fermentation time has elapsed and the difference is proportional to the amount of carbon dioxide which escapes from the dough. A typical curve is shown in Fig. 30, while an outline curve is shown in Fig. 31. The dough is made up of 2% salt and 2% yeast, with the amount of water predetermined by alveogram values and a special table furnished by the manufacturers.

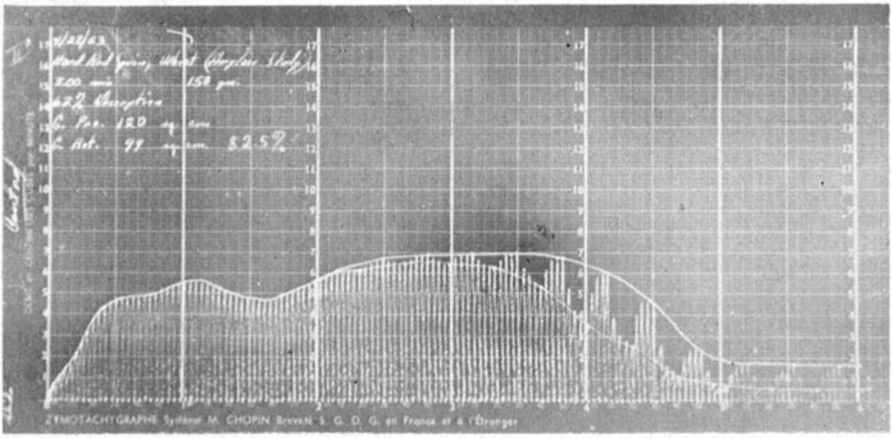

Fig. 30. A regular zymotachegram.

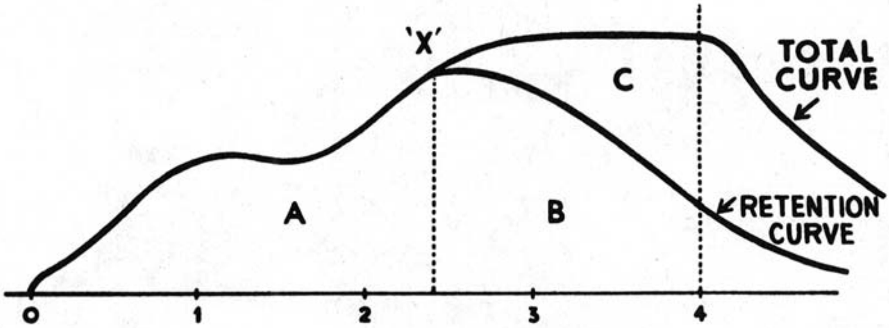

Fig. 31. An outlined zymotachegram: **A** - volume of gas initially produced and retained; **B** - volume of gas retained by dough; **C** - volume of gas escaped from dough; and A + B + C is total volume of gas produced during fermentation.

Chopin interprets the curve by dividing it into two parts:

Total gas volume (V)

$$V = 15 \times S \times \frac{D_1}{D}$$

where: D = total test time in min.
D_1 = test time as indicated by the drum
S = total area under curve (A + B + C)

Retention coefficient (R)

$$R = \frac{S - C}{S} \times 100$$

where: S = total area
C = area above retention curve and total curve

A good flour has a very high retention coefficient, while a poor flour may be as low as 50%.

The instrument may be purchased from M. Chopin & Cie of Boulogne-Billancourt, France for approximately $950.

3. Expansograph

The expansograph (Fig. 32) test is carried out with fermenting dough under water, under conditions similar to commercial practice. The total amount of gas produced is not measured, only the gas retained by the dough or the dough volume during fermentation is registered in the form of a curve.

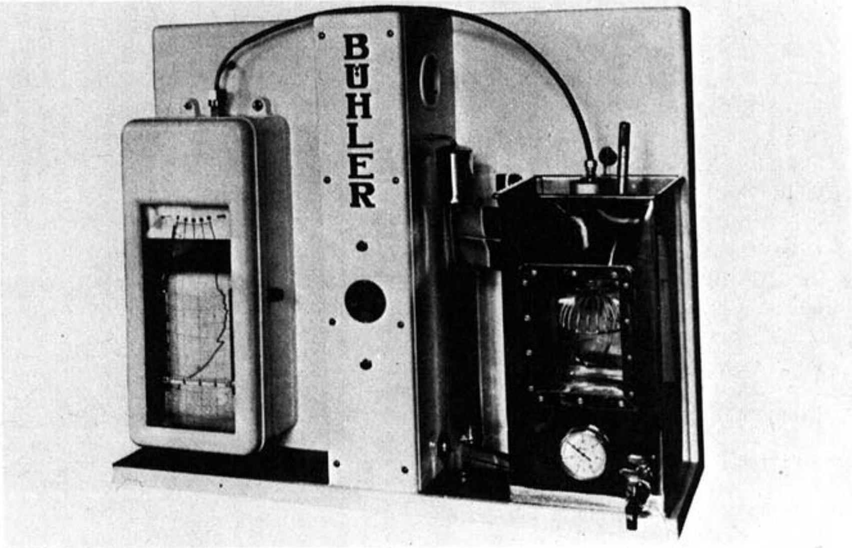

Fig. 32. The Buhler Expansograph.

Dough, consisting of 20 g of flour mixed with 2.5% yeast, 50-55% water, and 2.0% salt, is kept at a constant temperature of 30° C (86° F) during fermentation in a vessel filled with water. Because of the expansion of the dough, the water level rises. The gas-retaining ability of the dough thus determines the water level. This level is measured and recorded by a precision manometer. The test usually requires from 3 to 5 hr. The MLU-800 Expansograph is heated electrically with the temperature automatically regulated by means of a built-in thermostat. One control thermometer is located in the waterbath; the other in the fermentation vessel.

Typical curves are shown in Fig. 33 for three different quality flours. The maximum dough volume or the height of the curve is not the only important data obtained, but also the curve in relation to time. A dough that is capable of holding a large volume of gas over a longer period of time is much less susceptible to collapsing and is more acceptable in baking practice than a dough that collapses quickly after attaining the same volume.

Not only flours can be tested with this apparatus, but also wheat ground to a fine meal. It has, in fact, been adopted as an automated wheat meal test.

The instrument may be purchased from Buhler-Miag, Uzwil, Switzerland or Buhler-Miag, 8925 Wayzata Blvd., Minneapolis, MN 55426, for approximately $4,000, F.O.B. New York.

4. Brabender Maturograph

The maturograph (Fig. 34) is used to determine the proofing properties of the dough. In a temperature- and humidity-controlled cabinet, the various phases of fermentation are recorded automatically.

Doughs to be tested can be prepared according to a standard or variable recipe, *i.e.*, those containing regular baking ingredients or simply yeast, flour, and water. However, they have to be mixed with a defined mixture (farinograph, do-corder) at the same consistency and under the same test conditions.

Depending on the dough-making properties, the dough stays in the fermentation cabinet for a certain time. Between proofs, the dough (150 g) is rounded in the ball homogenizer and manual handling is reduced to a minimum.

The maturograph records the fermentation behavior of the dough after the proofing time by means of a sensing probe which touches the dough. With the help of an additional loading on these sensing probes, which occurs periodically, the elasticity of the fermenting dough is recorded.

The sensing probe and counterweight are connected by a steel band. It is guided over a pulley which is arranged frictionless. The weights are so adjusted that the sensing probe contacts the dough with a weight of 5 g. The increasing volume of the fermenting dough lifts the sensing probe. Its movement is

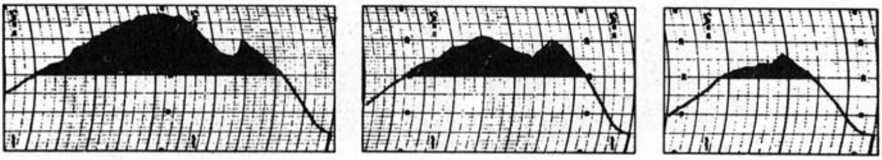

Fig. 33. Typical expansograms: **1)** good quality flour; **2)** medium quality flour; and **3)** poor quality flour.

transmitted by the pen arm and recorded on the strip chart recorder. As soon as the volume of the dough increases to 200 Maturograph units (switchable to 100 units for weak flours), a cam disk equilibrates the counterweight via lever arm and drops the full weight of the sensing probe on the dough for a short period. Under this pressure the sensing probe penetrates into the dough. The depth of penetration depends on the elasticity of the dough and its gas pressure.

This cycle is repeated every 2 min and produces the typical zigzag form of the maturogram. The curve rises until maximum dough maturity is reached and drops thereafter.

According to the manufacturer, four criteria of the maturogram (Fig. 35) can be expressed in figures in addition to the behavior of the curve.

Final Proofing Time—is the time in minutes from the start of the final proof to the first drop of the curve after the maximum, *i.e.*, the time needed to obtain optimum fermenting maturity.

Proofing Stability—is evaluated with a stencil in the range of the curve's maximum. This provides the time tolerance in minutes during which the loaf has to be put into the oven for optimum baking volume.

Elasticity—is the band width in the range of the maximum peaks and shows the elasticity of the dough.

Dough Level—is the value in maturograph units from the zero line to the maximum peak of the curve.

The maturograph may be purchased from Brabender OHG or C. W. Brabender Instruments, Inc., for approximately $8,000 and the ball homogenizer (dough rounder) for $1,600.

5. Brabender Oven Rise Recorder

The oven rise recorder shown in Fig. 36 records the change in volume of a

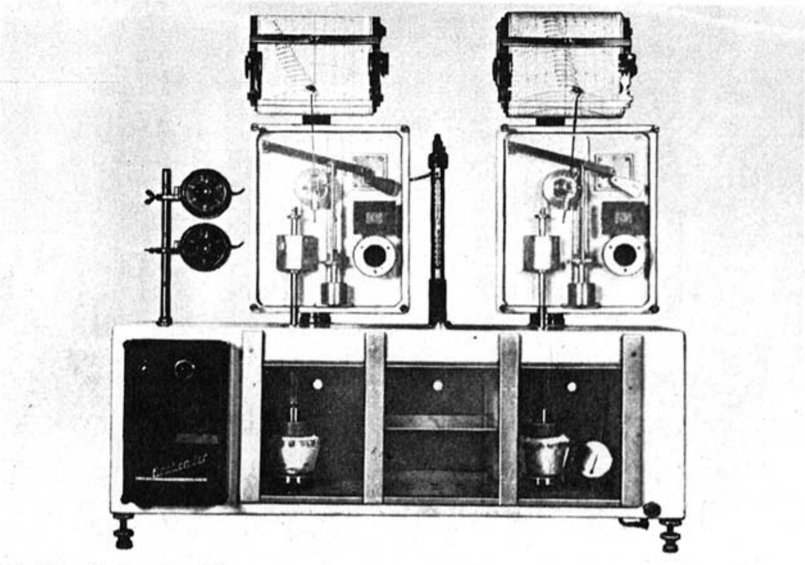

Fig. 34. The Brabender Maturograph.

dough during baking. Due to exact heat transfer the temperature can be determined at any point of the curve.

The maturograph is used to obtain the final proof time when the dough has to be put into the oven. A separate piece of the same dough has rested in the fermentation cabinet of the maturograph. This dough encounters the same fermentation time as the other piece, however, without the periodical loading being applied. At the point of maximum maturity, this dough enclosed in a metal basket is immersed in the oil bath of the oven rise recorder.

The suspension hook is connected to a scale head which in turn is linked to the strip-chart recorder. The oil temperature is controlled by the thermoregulator and increased from 30° to 100° C within 22 min. A circulation pump ensures that the temperature is kept uniform throughout the oil bath.

The volume of the dough increases as does the temperature and the piece ascends in the oil bath. This action is sensed by the scale system and recorded in oven rise units on the strip-chart recorder.

A standard baking formula is usually used to test the flours, however, other ingredients may be added to observe their influence on the results. A simple flour, water, and yeast formula might also be used for certain tests.

A typical curve is shown in Fig. 37. The manufacturers recommend the following criteria for an oven rise diagram:

Dough Volume—is the height of the curve at the beginning of a test and indicates the volume of the dough at the start of the baking period.

Baking Volume—is the height of the curve at the end of the test, *i.e.*, after 22 min the final volume of the baked goods is indicated.

Oven Rise—is the difference between final volume and dough volume.

Final Rise—is the measurement from the middle of the curve after 11 min and represents the curve of the baked goods in the range of higher temperatures. The

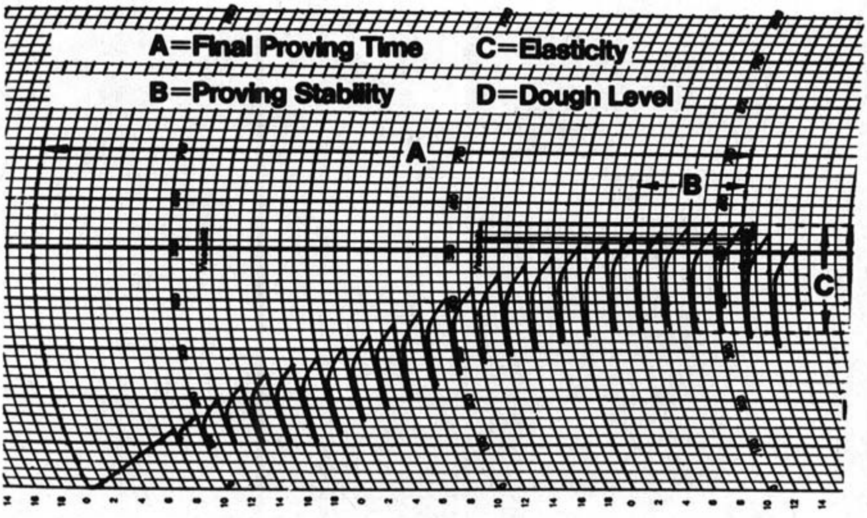

Fig. 35. Typical maturogram: **A)** final proofing time; **B)** proofing stability; **C)** elasticity; and **D)** dough level or maximum height.

suppression and shrinkage of the baked goods is recorded numerically.

Peaks—are shown when gas has escaped. They occur at different temperature ranges. The temperatures indicate flour quality. Weak flours peak at low temperatures and early in the testing run.

The temperature applied to a dough during baking is not gradual as is the case for this instrument, although the temperature rise within the dough will be gradual. The differences in temperature lag, and immersing the dough in oil as opposed to the hot, moist air of an oven, is not an exact duplication of the baking process and must be considered while performing the test. It does, however, provide the operator with a measurement of baking behavior of the dough under those conditions.

This instrument may be purchased from Brabender OHG or C. W. Brabender Instruments, Inc., for approximately $7,000.

SUMMARY

No direct comparison of data between baking results and specific readings

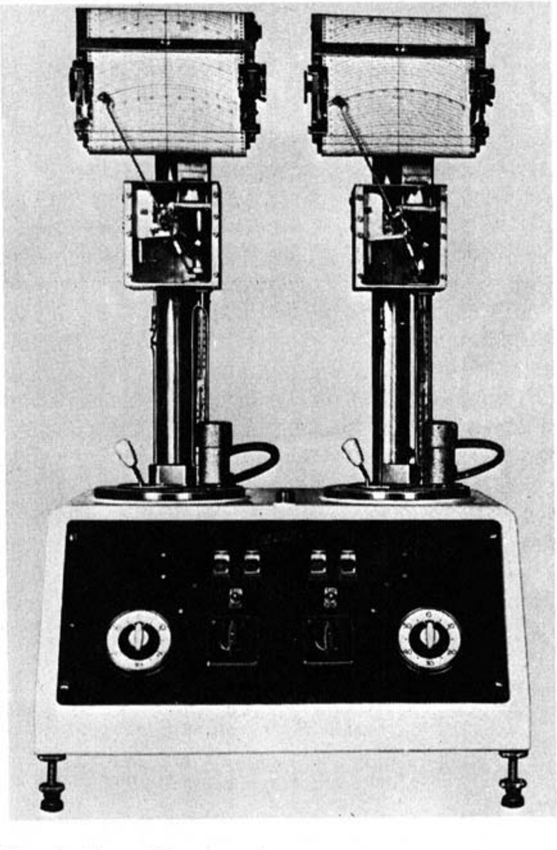

Fig. 36. The Brabender Oven Rise recorder.

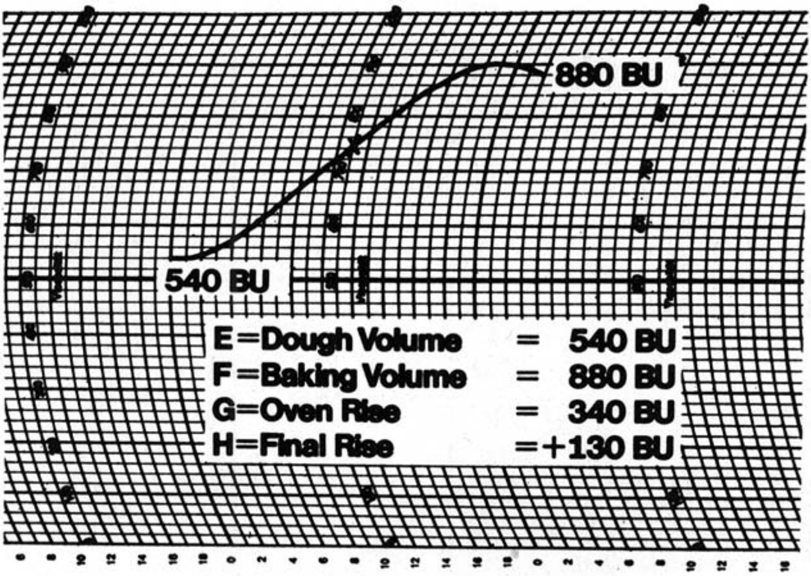

Fig. 37. Typical oven rise recorder curve: **E**) dough volume; **F**) baking volume; **G**) oven rise; and **H**) final rise.

obtained on the various physical testing instruments has been presented. The various types of instruments, their functional parts, and the general relation of the information obtained with baking results have been discussed. The value of direct comparison of such data is questionable because of the different procedures used in baking and the operation of the instruments. The samples tested as well as the purpose of the experiment, must be known for the proper evaluation of the data. Data and conclusions derived from one set of conditions may be completely changed if variations are introduced in the flour, baking procedure or instruments of even the same type.

It is very important in interpreting the results from the various instruments that the history of the sample being tested be known. Care should be exercised in comparing the data between different laboratories and the limitations of the instruments be taken into consideration.

The complexity of the dough system has been emphasized. Each instrument does give some information about the physical behavior of the dough, but no one instrument, nor even all the instruments, give the complete picture of the rheological properties or physical characteristics of the dough system.

As Dr. Bloksma (19) succinctly stated, "This variety of interpretations shows that we are still at the very beginning of an understanding of how the composition of dough and its structure determine rheological properties."

Acknowledgments

Thanks are due to the following companies for supplying the information and approximate cost of the instruments: C. W. Brabender Instruments, Inc. and Brabender OHG; Buhler-Miag, Inc.; Falling Number AB; M. Chopin & Co.; National Manufacturing Co.; and Simon Controls and Instrumentation, Ltd.; also Brookfield Engineering Laboratories, Inc., and Interstate Brands Corp. for previous correspondence.

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