The Benefits of Basic Rheometry in Studying Dough Rheology[1]

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Cereal Chem. 67(4):311-317

ABSTRACT

Bread doughs are viscoelastic bodies with explicit, nonlinear shear thinning and thixotropic behaviors. The commonly used empirical and descriptive rheological methods determine the consistency and extensibility of doughs by applying large deformation forces in a single-point measurement. They are therefore not suitable to describe dough flow properties. Flow properties can be determined by basic rheological methods in both destructive and nondestructive applications. The use of a viscometer for steady state flow and a rheometer for dynamic measurements of the strain and temperature-dependent dough characteristics are discussed. In addition, attention is drawn to the feasibility of using basic rheometry in the processing and product quality testing of flours. Finally a recording baking test is introduced and discussed as a promising method for monitoring not only how dough changes structurally during heating and cooling but also how those changes are influenced by various amounts and properties of relevant flour constituents and flour additives.

Besides chemistry, rheometry is a necessary and powerful technique for explaining and predicting the quality of cereal foods. Consequently, it has found use in a wide range of practical and scientific studies addressing the needs of breeders, traders, processors, and, particularly, researchers. During the past 60 years, a variety of instruments based on various principles and techniques has been developed and applied to the study of dough rheology. Comprehensive reviews of the instrumentation and techniques used in food rheology have appeared recently (Van Wazer et al 1963, Rasper 1976, Voisey and DeMan 1976, Bagley 1983). Based on the principles employed, techniques have been classified as empirical, descriptive, and basic (or fundamental) (Scott Blair 1958). Although most of the important knowledge of and experience in dough rheology has been obtained by the use of basic rheometry (Muller 1975), the instruments and methods belonging to the empirical and descriptive classes have found more acceptance and widespread usage. Basic rheometry, applied to more complicated food systems such as dough, has been found to be laborious, time-consuming, and often incapable of producing simple answers (Muller 1973). These are the main reasons for the somewhat poorer acceptance of basic rheometry than its empirical counterpart.

Recently, new fundamental rheometric approaches to dough rheology have been made. Increased use of computerization has opened unexpected possibilities for basic rheology and made it, once again, a promising technique for gaining new information and knowledge of the physical properties of dough during breadmaking (Abdelrahman and Spies 1986, Hibberd and Parker 1975).

This paper presents some aspects and feasibilities of using fundamental techniques for studying dough rheology.

DOUGH AND DOUGH RHEOLOGY

Bread dough is a viscoelastic material with explicit nonlinear behavior. It exhibits shear thinning and thixotropy. The thixotropy behavior of wheat doughs was described by Muller (1975) using a mechanical model consisting of classical spring, dashpot, and shearpin elements. Shear thinning is most obvious in the viscosity curves (as shown in Fig. 1). At low strains viscosity is high and dough structure seems to be intact. In contrast, high strains lead to a large disorientation and destruction of the dough's structure and, hence, to reduced viscosity. This mechanical destruction of dough polymers was studied by Bueche (1969), and a quantitative theory based upon the dependence of a critical molecular mass and the breakdown of polymer chains was proposed somewhat later by MacRitchie (1986).

[1]Adapted from a paper presented at the AACC 72nd Annual Meeting, Nashville, TN, November 1987.

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In terms of breadmaking, a dough will normally experience different mechanical stresses at different stages of the process. During dough mixing and development, the mechanical deformation is presumed to be larger than at the proofing stages or at oven rise (Bushuk 1985). This must be borne in mind when designing rheological means of testing, monitoring, and displaying wheat quality (Bloksma 1964, Weipert 1987). Recording mixers like the mixograph, farinograph, or resistograph employ a rather high deformation force (i.e., high strains) to develop and subsequently to demolish dough structure. Similar force levels are used to stretch the dough in an extensigraph or alveograph. Even without quantifying these deformation forces, it is clear that the forces and resulting deformations experienced by dough during the fermentation process are much lower and less destructive.

In a very simplified way, empirical and descriptive rheometric analysis can be defined as imposing high deformation forces and producing results in arbitrary, relative units. Normally, the force needed to destroy structure is considered to be the dough's "strength" and is correlated with the flour's baking behavior. Because, as a rule, only one deformation force is used, the result is a single-point measurement. For this reason, these mechanical instruments describe mechanical properties of dough and not detailed physical properties (Szczesniak 1988). In contrast, basic rheometry is capable of describing the physical properties of a material over a wide range of strains and strain rates. It produces not only a single-point viscosity value, but also a flow curve (stress vs. strain rate) expressing the flow properties of the tested material. By careful control of the geometry of the measured sample, and exact measurement of the stress and strain rate, the results are obtained in absolute physical units (i.e., Pa/sec, and Pa·sec). This allows direct comparison of results obtained by various testing

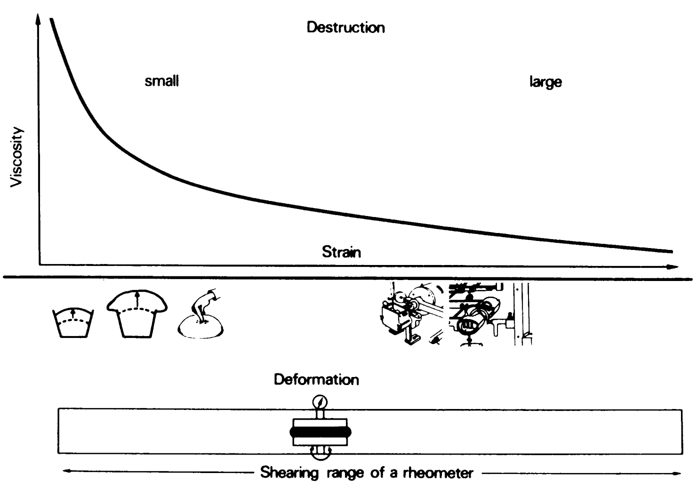

Fig. 1. Strain dependent properties of wheat doughs in comparison to rheometry.

instruments and researchers. The advantage of such measuring systems is not only in the absolute values obtained but also in the possibility of utilizing various strains (or deformation forces) to obtain a more complete view of a material's physical properties. Very low strains, which allow measurements but do not disturb or destroy inherent structure, are of great value in describing the time- and temperature-dependent changes in material. The usefulness of fundamental rheometry has increased due to the introduction of the dynamic oscillatory rheometers. These instruments simultaneously measure the elastic as well as the viscous components of a material's complex viscosity. Consequently, they enrich our knowledge of physical dough properties and how they change in the baking process.

THE APPLICATION OF BASIC RHEOMETRY TO DOUGH RHEOLOGY

Based on their measuring principles, basic rheometric instruments are either viscosimeters or rheometers (Gerth 1980, Muschelknautz and Heckenbach 1980). Viscosimeters record the torque and the shear rate in a geometrically defined gap during steady state shear flow. Based on calculations of its stress and shear rate, the viscosity of Newtonian (ideal) and non-Newtonian liquids can be calculated from analysis of the flow field between coaxial cylinders, plate and cone, or plate and plate devices. To describe the flow properties of a material, both stress-shear rate and viscosity curves are used. In addition to stress-shear rate and viscosity curves, rheometers measure the normal force within a system, its relaxation modulus, relaxation time, and compliance in unsteady flow. This allows rheometers to provide additional information (such as elasticity) on material undergoing testing. Dynamic oscillatory rheometers, a special kind of rheometer, can assess the frequency-dependent properties of materials being tested. By employing a sinusoidally oscillating deformation of known magnitude and frequency, the phase lag angle between stress and strain is measured and used to calculate the elastic (storage modulus or G') and viscous (loss modulus or G'') components of a complex viscosity η^*. This technique is capable of providing insight into the structure of the material being tested and has, therefore, opened a new vista in the future studies of dough rheology.

The baking process is usually divided into the cold (mixing, fermenting) and hot (oven) stages. Following this scheme, rheological techniques, as they apply to dough, may be divided into those that monitor the ambient temperature stages and those that are concerned with the heating and baking phase. During the cold stage, doughs can be tested for their strain-, time-, and concentration-dependent behaviors. Studies during the hot phase allow only the time- and temperature-dependent behaviors to be recorded. For each stage, the possibilities and advantages of using fundamental rheometry via a rotational viscosimeter or rheometer will be shown and discussed. At the same time, this paper introduces and discusses work done in this field in Europe in general, and at the Detmold research center in particular. This paper does not claim the pretension of completeness.

All of the following studies employed either a Rotovisco RV-3 equipped with SV II coaxial cylinders (Haake, Karlsruhe, West Germany) or an RMS and RDA-700 rheometer operating with plate and plate geometry (Rheometrics, Piscataway, NJ). Specific operating conditions are given in appropriate figure legends.

TESTING DURING THE COLD STAGE

The strain-, time-, or concentration-dependent characteristics of wheat doughs are studied at constant low temperatures (20–30°C) in order to describe their rheological behaviors during the processing stages before baking. Information important to the subsequent baking process, such as water absorption, mixing time and intensity, and "strength," is usually obtained from recording mixers (farinograph and mixograph) and tensile tests (extensigraph and alveograph). These techniques have several disadvantages. They are single-point measurements, use rather high deformation forces (i.e., high strains) that may lead to irreversible changes in dough structure, and require relatively large samples of flour or wheat. Consequently, their applications are somewhat limited.

The flow or stress-strain curve obtained as result of increasing the shear rate in a rotational viscosimeter describes the flow properties of dough over a large range of strain. Not only can the the consistency at any point of the curve be described but also information on dough properties such as stiffness, slackness, and stickiness, as usually evaluated in a sensory test. By continuously increasing the shear rate at 2.5 rpm/min, the resulting shear stress will increase until the flow curve flattens and falls. The fall results from the dough tearing away from the rotating sensor. Because it is possible to record a flow curve only if sufficient adhesion exists between the dough and sensor, the shear rate at which contact is lost can be considered as a numerical value for dough stickiness. This value and the apparent viscosity at a characteristic shear rate seem to be useful for determination of the processing value of wheat flours (Weipert 1976). Based on the results of studies with a rotational viscosimeter, Weipert (1976) developed a novel method for evaluating the processing properties of wheat using a small (10 g) sample of flour or meal. The method has been accepted by wheat breeders (Vettel 1980, Spanakakis and Weipert 1985), and its practicability for use with American wheats has been established (Weipert and Pomeranz 1986). A satisfactory correlation exists between the shape of the curve and baking results of the tested flour. This correlation allows the investigator to eliminate the evaluation of numerical criteria such as viscosity or stickiness. Obtaining useful information simply by looking at the curve without calculating these specific values is advantageous for practical use. This, as well as the fact that a small sample of flour or meal can be used with equal success, make this method simple and efficient for quality evaluation in the early stages of cereal breeding.

The flow curves with wheat dough will normally follow the power law equation:

$$\tau = K \cdot D^n \qquad (1)$$

where τ is the tangential stress, K is the viscosity coefficient, D is the shear rate, and n the flow index. The relationship is curvilinear, but can be linearized by the use of the log form:

$$\log \tau = \log K + n \cdot \log D \qquad (2)$$

Because both K and n are significantly influenced by the water content of the dough (Quendt et al 1974) it is possible to calculate the "optimal" water absorption for a dough of given consistency and flow properties from a flow curve produced using that flour. The dependence of dough consistency and dough properties on water content in doughs produced from flours of different qualities is illustrated in Figure 2. Increasing the amount of water added to the flour during mixing decreases dough consistency. In addition, the flow curves from flours of high quality changed little in their initial slope and stayed steep. Those of poor quality flour showed an opposite trend with increasing water content (Weipert 1977, 1987).

This technique utilized in Figure 2 does not produce exactly perfect stress-strain curves because it neglects the relaxation of the normal stress in the dough and because the shear rate is not exactly defined at every point of the curve. Even so, it deserves attention and evaluation as a simple, time- and cost-saving rheological method.

Dynamic techniques based on use of the rheometer offer more specific information on dough physical properties. The newest techniques apply a defined angular strain at a specified frequency to dough between two parallel plates. Scans of both strain and frequency are possible and the results are capable of displaying changes in the elastic (G' or storage modulus) and viscous (G'' or loss modulus) component of the dynamic measured viscosity. The theory, application, and limitations of this technique have been reviewed by several authors (Smith et al 1970; Bohlin and Carlson 1980; Le Grys et al 1981; Navickis et al 1982; Faubion et al 1985; Zanger 1979; Dreese et al 1988a,b).

One of the advantages of a dynamic rheometer is the large range of shear amplitude possible (Fig. 1). By using small and large strains in a frequency sweep, it was shown (Weipert 1987) that doughs are sensitive and complex systems. Specially increasing the testing frequency at either low or high strain leads to a significant decrease in viscosity due to the shear thinning behavior of wheat dough. The sensitivity of dough systems can be further demonstrated by the results shown in Figure 3 in which strain (magnitude) was increased from 0.1 to 50% during testing. Increasing the strain decreased the complex viscosity, while the storage and loss moduli increased. This result is due to dough's shear tendency to thin. At low strain, G' (the elastic component) was much higher than the loss modulus (G''), behavior typical of an elastoviscous solid-like body. However, at high strains, the dominance of the elastic component of the response was reduced until, in the region of 10% strain, the loss modulus (G'') or viscous component had became predominant. The dough systems at high strains bear resemblance to a viscous liquid with little elasticity.

The deformations caused by high strains are, as shown in a frequency sweep from low (1%) and high (50%) strains, only partly reversible (Weipert 1987). Contrary to this, at very low strains (<0.25%) dough exhibits linear viscoelastic behavior (Fig. 4). This finding is very important for two reasons. First, the mathematical equations and consequent evaluation of physical properties in the linear range are both easier and more reliable than in the nonlinear region. Secondly, linear behavior under low strains strongly implies that the small deformation is not injurious to the dough's structure. Both facts argue for the benefits of using such basic methods in recurrent or continuous measurements of dough physical properties. By using these techniques, it may be possible to monitor the time-dependent changes in dough as well as the influence and action of such parameters as temperature or additives (Weipert 1987).

Practical consideration of how high or low strain conditions should be chosen to ensure sensitive measurement without damaging or changing the dough or gluten specimen have been investigated by Le Grys and colleagues (1981). That work utilized and recommended the use of stresses at the high end of the range reported here (0.25–0.37%). However, the new generation of dynamic rheometers is capable of taking reliable measurements at lower strains, i.e., those in the linear viscoelastic region. Therefore such small strains (0.20%) have been used in more recent work involving continuous measurement (Weipert 1987, 1988).

The new technique, dynamic stress-strain analysis utilizing a variety of instrumental systems, has been applied quite intensively in attempts to characterize wheat and gluten quality (Zanger 1979; Bohlin and Carlson 1980; Le Grys 1981; Faubion et al 1985; Dreese et al 1988a,b). The chief advantage of this approach is its ability to differentiate between the dynamic storage and loss moduli. This allows for greater precision and objectivity in the description of dough properties.

Besides dough consistency, which can be adjusted and optimized by farinograph water absorption, the physical properties measured by tensile test (extensigraph, alveograph) and those evaluated by sensory analysis can have significant influences on baking results. In breadmaking, flours producing doughs with balanced tensile and elastic properties are required to ensure optimal baking performance. This balance and its effects can be demonstrated using dynamic rheological tests. The tensile and elastic properties can be described by the viscosity and loss tangent (G''/G') of the dough. Sweeps of both strain and frequency (Fig. 5) showed differences in storage and loss moduli of doughs having differing sensory properties. The wheat variety Okapi, which produces a resistant and poorly extensible dough (described sensorially as stiff and snappy) had a high G' and low G''. Because the difference between the two was high, the loss tangent as a quotient of G'' and G' values was low. The wheat variety Rektor, which mixes

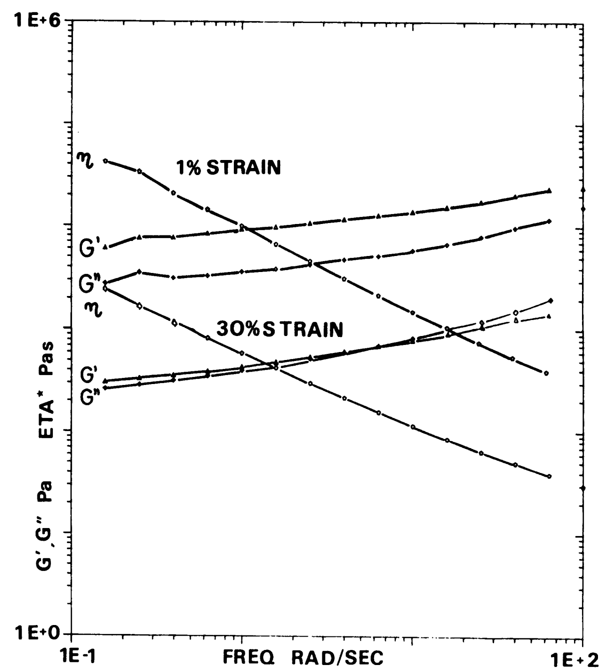

Fig. 3. Frequency sweep of wheat dough at low and high strains. Dough from 10 g of flour of wheat variety Monopol, dough yield 158, prepared in a small mixer and tested in Rheometrics RMS plate-plate geometry (reprinted with permission from Weipert 1987).

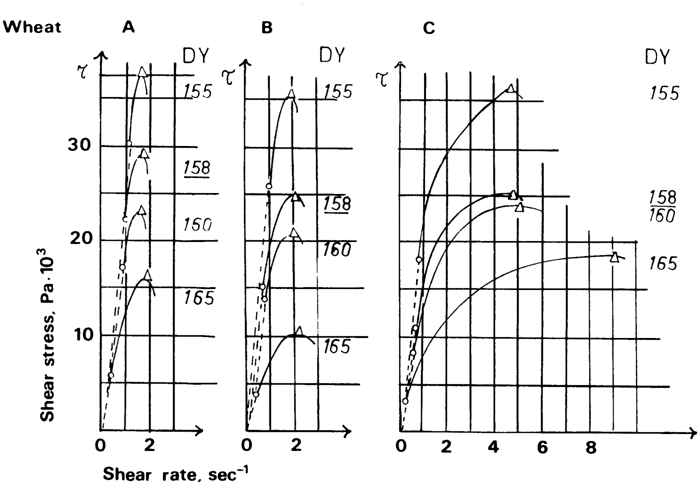

Fig. 2. Viscometer flow curves from wheat doughs as influenced by wheat quality and water content (**DY** = dough yield expressed as the total of 100 g of flour + water). Wheat **A** good, **B** medium, **C** poor quality (reprinted with permission from Weipert 1987).

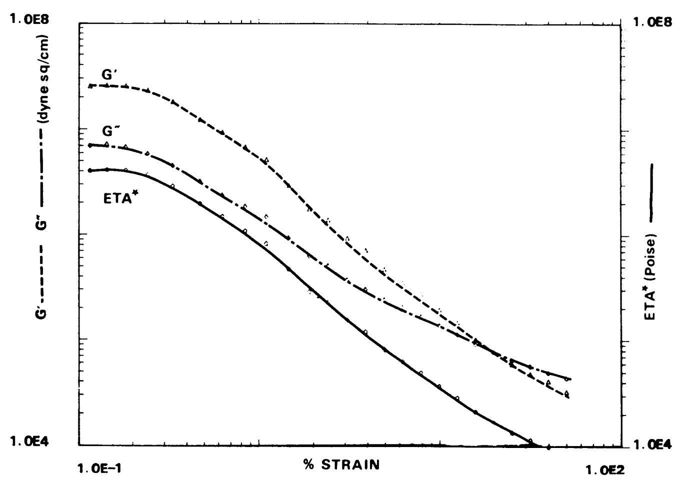

Fig. 4. Strain sweep from 0.1 to 50% of wheat dough (variety Rektor) at constant frequency (1 Hz) showing the dependence of viscosity, storage, and loss moduli on strain (reprinted with permission from Weipert 1987).

to a more extensible but still elastic dough (termed normal and silky sensorially) gave lower values for both G' and G'' and a lower difference between the two. The combination of high G' and low G'' reflects a more rigid and stiff material whose loss tangent is small. These results are consistent with baking tests results that showed Okapi flour possessed the lower processing value. When the same tests were applied to other wheat varieties with doughs of different sensory and processing properties, it was determined that doughs characterized as moist and slack possessed lower complex viscosity and a higher loss tangent than doughs described as having a short texture and dry surface appearance (Weipert 1987).

DOUGH RHEOLOGY DURING HEATING

The term dough rheology is normally connected with physical properties measured during the mixing and proofing of a dough at the relatively low temperatures encountered during fermentation. However, the differences in dough's physical properties do not disappear at the end of this "cold stage" of the process. They retain at least some of their flow characteristics until late in the baking process and the consequences of any differences are reflected, in part, by differences in the baked bread crumb. The consistency and the flow properties of the dough are considered to be primarily protein or gluten dependent. However, the effect of starch gelatinization on bread baking performance has, for the most part, been assessed using water-rich slurries in technically limited instrumental systems such as the Visco-amylograph. Starch gelatinization does not take place under the same conditions in a slurry as it does in a dough of reduced water availability. Because of this, Weipert developed a method (1975) to record the temperature-associated changes in dough consistency using a universal rotational viscometer (Rotovisco, Haake) with coaxial cylinders (SV II) operating at a very small but constant shear rate. With this system, the viscosity changes in a dough can be recorded continuously over a range of temperature increases and decreases (30–100–30°C). The resulting viscosity curve resembles the amylogram and is a reflection of the biochemical and physical reactions that take place during baking. This experimental approach, continuous rheometry during baking, has helped both to describe and to understand the baking process. Oven spring and loaf volume related behavior have yet to be described satisfactorily.

This technique has found its main application in the study of rye doughs. The resulting viscosity curves or dough viscograms show (Fig. 6) that addition of α-amylase does not change dough viscosity prior to heating. However, it lowers peak viscosity during heating dramatically. The addition of salt and lactic acid lowers the initial viscosity at ambient temperature but inhibits the activity of amylase. These findings provide fundamental support for previously described phenomena and are in accordance with bakers' experience with rye dough systems. More unexpected was the fact that the enzymes pentosanase and protease, when added to dough, lower its initial viscosity at ambient temperature as well as peak viscosity (Fig. 7). The greatest effect was observed when protein, pentosan, and starch-degrading enzymes were present simultaneously.

These findings support the commonly held belief that rye and wheat doughs are complex systems in which component interactions and mutual effects are important. Of these, water-binding capacity may be of utmost importance. Apparently, by binding water and covering starch granules, pentosans somehow protect starch from starch-degrading enzymes. Support for this hypothesis can be found in scanning electron micrograms of bread crumb (Pomeranz and Meyer 1986, Weipert 1983) and in the fact that rye flours of different quality (i.e., enzyme activity) have different starch-pentosan optima (Weipert and Zwingelberg 1980a,b); thus,

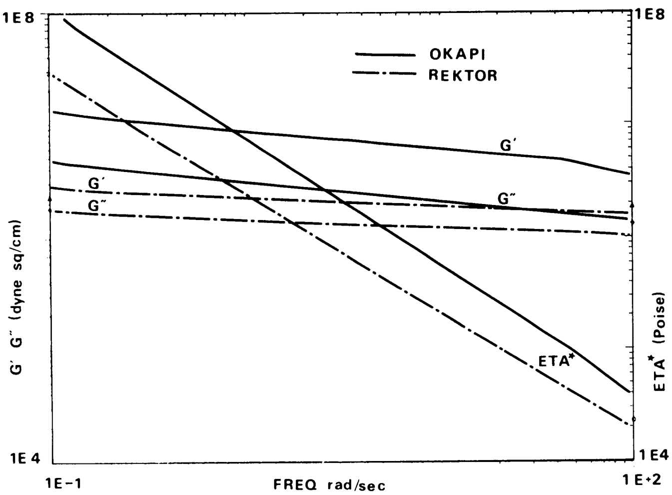

Fig. 5. Frequency sweep from 0.1 to 100 rad/sec at 1% strain with wheat flour doughs having different sensory properties. Variety Okapi (stiff and snappy); variety Rektor (normal).

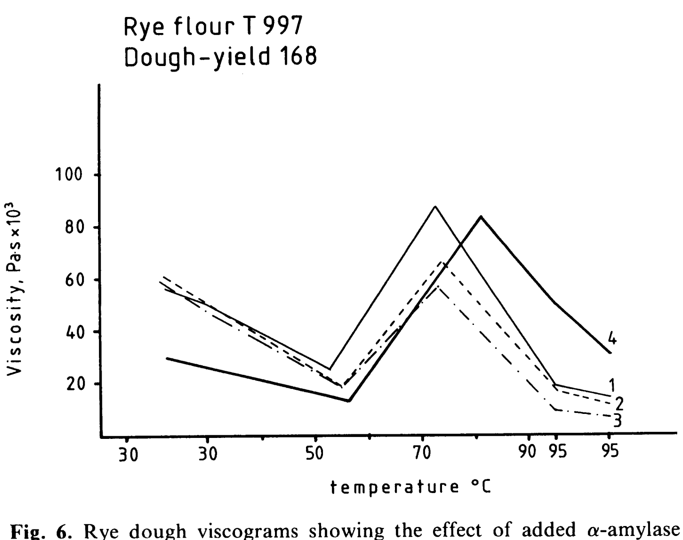

Fig. 6. Rye dough viscograms showing the effect of added α-amylase and acidulating agents. Control without additives (**1**); plus 10 SKB-units/10 g of flour α-amylase (F 25, Röhm) (**2**); plus 20 SKB-units/10 g of flour α-amylase (**3**); plus 10 SKB-units α-amylase, 2% salt, and 0.6% lactic acid (**4**).

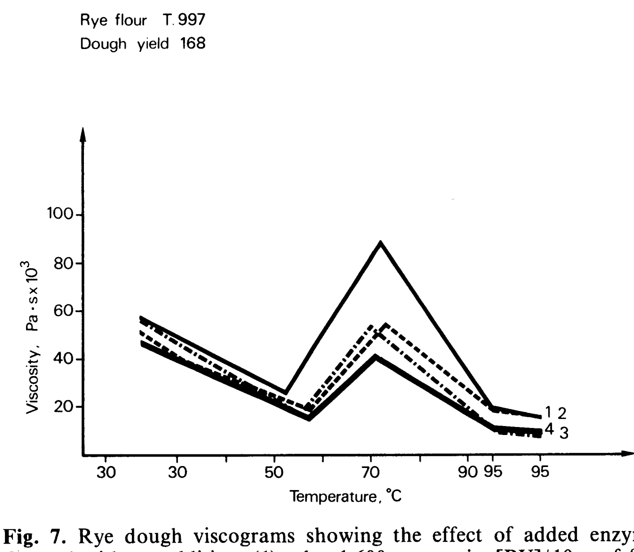

Fig. 7. Rye dough viscograms showing the effect of added enzymes. Control without additives (**1**); plus 1,600 pent-units [PU]/10 g of flour pentosanase (HE, Rohm) (**2**); plus 20 PU/10 g of flour protease (Veron P, Röhm) (**3**); plus pentosanase, protease, and α-amylase (10 SKB units/10 g of flour) (**4**).

a good quality rye requires a pentosan-starch ratio of approximately 1:16. In rye damaged by sprouting, this optimum ratio is reduced to as little as 1:12 or even 1:10. The method discussed above proved to be successful when it was used to study the changes in rye, wheat, and other doughs resulting from the addition of enzymes and improvers during simulated baking (Wassermann and Dorfner 1977, Le 1983, Pezoa 1983). Although many of the relevant and important reactions occur during the dough and heating stages, a weak point of the method is its inability to obtain reliable results either in the region of dough temperatures above 95–100°C or in cooled bread crumb. At higher temperatures and, to a greater extent, in the course of cooling, the specimen contracts and loses contact with the bob in the rigid, fixed gap between the coaxial cylinders. This causes inconsistent results in temperature-dependent tests beyond 80°C using both cone-plate and a plate-plate systems (Bloksma 1980, Davies 1986).

As mentioned previously, doughs are viscoelastic bodies possessing differing but pronounced elastic components. This fact was used as the basis for a novel method to measure rheological properties continuously during the heating and cooling of a dough (Weipert 1988). The presence of elasticity in the dough can be observed and measured as the appearance of normal stress (σ) in the measuring system. Using a rheometer (e.g., the Rheometrics RDA-700) in which the normal stresses can be measured continuously and a preset normal stress can be applied and held constant by the means of an auto tension, it is possible to record the viscosity changes that occur in the course of heating and cooling. The plate-plate geometry and an auto tension capability provide a steady preset normal stress by adjusting and correcting the measuring gap. The continuous adjustment of the measuring gap ensures a steady contact between the plates and specimen. This, in turn, provides a reliable measurement and record over a wider range of temperatures. In a test with wheat dough, the gap width was corrected from an initial setting of 1.9 mm during heating to 2.2 mm, then back to 1.5 mm by the end of the cooling stage of the test (Fig. 8). In a rigid system, without tension correction, no values could have been measured once the specimen had contracted below the volume occupied in a 1.9-mm gap.

Basic rheometry using dynamic oscillatory techniques operating at constant, small strains during sample heating and cooling seems to be equally as useful as related dynamic tests employing strain sweeps. Absolute values of G', G'', and their ratio (loss tangent) are useful in explaining the changes that occur during the course of fermentation and baking processes. A method employing these techniques, the "recording baking test" (Weipert 1988), can be used to monitor the baking behavior of different doughs as well as the mode of action of added improvers or active compounds. In comparison with the dough viscogram, the recording baking test describes the rheological properties of doughs through the full length of the baking process. The analyses can be carried out continuously from the start of dough fermentation to the end of baking. The resultant plots of G', G'', or complex viscosity again resemble the amylogram. However, their final values, those describing the baked bread crumb, are as much as two log cycles higher than those of dough at the start of the test (Fig. 8). This increase is due to starch gelatinization in the water-limited dough system.

As previously discussed, the rheological differences between doughs from wheat with different processing properties were identified by using the strain and frequency sweep dynamic analysis (Figs. 3 and 5). These differences vary as well under the constant small strain conditions (frequency 1 rad/sec, 0.2 % strain), found in the recording baking test (Weipert 1987). In tests with doughs from genetically different wheats, differences were found in rheological properties. Specifically, G' was much higher for the variety Caribo (which possessed a short snappy dough) than for variety 108/50 (a moist and slack dough).

The progress of starch gelatinization due to heating can be observed at characteristic temperatures for each of the recorded G' curves. Additional and equally important information can be obtained from analysis of changes in the loss tangent. Figure 9 shows that at lower temperature, the Caribo dough possessed a lower loss tangent, indicative of more solid-like behavior. The doughs produced by 108/50 had high loss tangents, indicative of more liquid-like behavior. After starch gelatinization and other heat-induced structural changes in baked doughs, all samples had higher G' values and higher viscosities but lower tangents. This characterizes bread crumb as a more elastic and solid system than the dough prior to the baking process. The differences between wheat varieties in the tangents of their baked crumb are less significant. However, they are still in the same rank order as that of their doughs at ambient temperature.

Using the recording baking test, the rheological activity of additives and active substances can be monitored. Adding ascorbic acid at 2 g/100 kg of flour when mixing a dough, results in an increase in storage modulus but a decrease in loss tangent over the entire range of the curves (Fig. 10). In contrast, the addition of recommended low levels of bacterial protease and fungal α-amylase cause softening (reduction in both G' and G'') of both the dough and its baked crumb. The comparison to control dough without additives is given. The effect of given additives is obvious both before and after starch gelatinization and shows

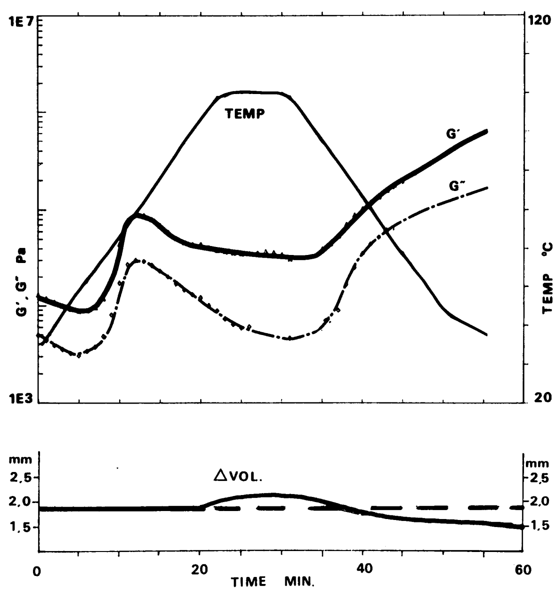

Fig. 8. Temperature sweep 30–100–30°C. Test conditions were 3% strain and 10 rad/sec with Rheometrics EMS and plate-plate geometry. Dough from variety Caribo at farinograph absorption.

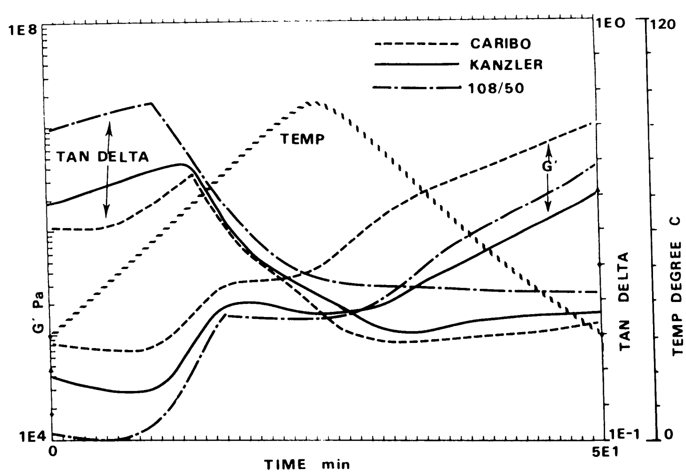

Fig. 9. Recording baking test showing the differences of G' and tan delta for wheat doughs of different sensory properties and crumb structure in the course of starch gelatinization. Varieties used were Caribo (stiff), Kanzler (normal), and 108/50 (soft and slack). Test conditions 0.2 strain, 1 rad/sec, plate-plate geometry on a Rheometrics RDA 700 rheometer.

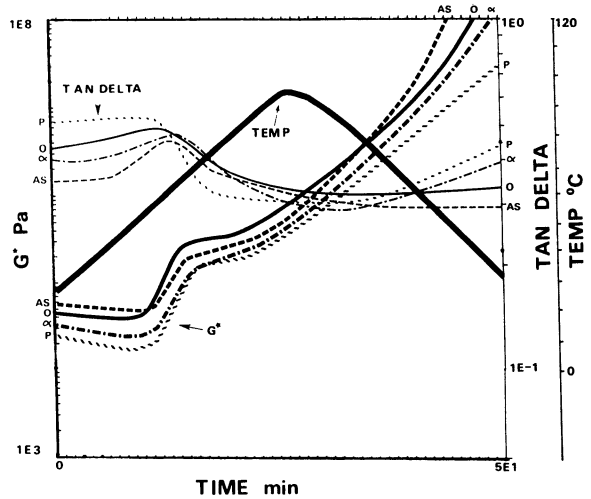

Fig. 10. Recording baking test showing the influence of ascorbic acid (**AS**, 0.0002 g/10 g of flour), protease (**P**, 0.01 g/10 g of flour, Veron P), and α-amylase (α, 0.001 g/10 g of flour Veron F 25) on the complex modulus G' and tan delta of Okapi wheat dough at 55% water absorption. The Rheometrics RDA 700 rheometer was operated with plate-plate at 0.2% strain and 1 rad/sec.

the softening of the crumb by the addition of enzymes as well as the strengthening resulting from ascorbic acid. The response to these additives of both yeasted and flour-water doughs from flours of differing quality was identified and discussed in detail previously (Weipert 1988).

CONCLUSIONS

The empirical and descriptive rheometric techniques currently used in cereal laboratories apply rather high deforming forces to doughs as a single-point measure. Basic rheometry offers techniques capable of applying a wide range of deforming forces and of monitoring the changes in dough's physical properties as a stress-strain curve (multiple-point measure). Although basic rheometry includes instruments with widely differing working principles (compression, extension, and capillary flow), rotational viscometers and rheometers have found the most general acceptance. In these instruments, deformation is by shearing. The simpler (and, therefore, less expensive) viscometers are able to describe the physical properties of a material under conditions of a steady state flow in terms of its viscosity. Due to their design, rheometers are further able to measure and record normal stresses, creep, and stress relaxation under conditions of unsteady flow. Dynamic rheometers, which apply oscillatory shear, allow separate assessment of the elastic and viscous components of complex viscosity. Consequently, viscometers and rheometers are efficient and versatile instruments that have opened new possibilities for studying viscosity-related problems in the science and processing of cereals.

In summary, the benefits of the use of basic rheometry in dough rheology include exact, defined measurement and results in absolute physical SI units; ability to use an extremely small sample; separation and separate recording of elastic and viscous components of the material's complex viscosity; flexibility in the choice of the level of deforming force; the possibility of continuous measurement throughout a simulated baking process; and use of the same instrument for several applications.

These benefits make basic rheometry a powerful tool for monitoring the consistency and structural changes in dough during the course of breadmaking and in bread itself. The influence of flour constituents and additives can be studied in model systems and the results transferred to the bread production process. From this point of view, and taking into account the purchase and operating costs, this technique is likely to be widely received in scientific laboratories. The day-to-day evaluation of flour quality and properties in practical breadmaking will, however, remain confined for the present time to the old and trusted conventional (empirical and descriptive) rheometry.

ACKNOWLEDGMENTS

The author wishes to thank A. Frank, H. Michel, and Rheometrics Europe as well W. Marquardt, Haake, for offering facilities to carry out a part of this work as well as for useful discussions.

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[Received May 9, 1989. Accepted November 29, 1989.]