RHEOLOGY OF FOODSTUFFS*

By

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It would clearly be pointless in this lecture either to attempt to list all the papers that have been published on a vast variety of foodstuffs, nor even selecting only a few, to describe in detail to a Budapest audience, the apparatus that is commonly used for testing a few of the principal products that have been intensively studied. Under Professor Telegdy-Kováts, pioneer work has been and is being done here in this field. What will be attempted will be to suggest the fundamental reasons for doing such tests and to propose some sort of classification of the kind of tests that can profitably be done. Why are rheological tests on foodstuffs done at all? For three principal reasons: (1) to ensure that raw materials are suitable for processing. For example, wheat grains that are too hard or too soft will not mill properly. (In this connection, I am especially happy to read of a recent agreement between my country and Hungary on co-operation in the study of this problem). (2) It is often necessary to test intermediate products. Again taking bread-making as an example, the rheological properties of a flour-dough are clearly very important in defining the quality of the loaf that can be made from it. (3) Finally, we have the finished product. Here one is generally concerned with the reaction of the consumer. This differs widely in different countries and at different times.

Thus the French seldom spread jam on their bread and are therefore much more interested in flavour than in the texture, especially the size of the holes. As a young man, I was sent to France to study what differences in the rheological properties of the doughs are correlated with the different textures required in France and in Britain to produce the sort of bread which is wanted in each country.

Three types of test can be done. The first attempts to make standard test-pieces and to subject them to simple stresses or strains, so as to measure "physical properties" (as described in the earlier lecture) or at least properties changing in a more or less controlled manner during the tests. Such tests are not always appreciated by the man in the factory but they can be valuable because they make it possible to link rheological properties with, for example, chemical constitution. Much work (which will be briefly described in a moment)

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has been done in Budapest and elsewhere on flour doughs. The second type of test is an imitative instrumental test. This may be only approximately imitative, as is the case with the Chopin Extensimeter ("Alveograph") or as closely resembling the mastication process as possible, for example the various "artificial jaw" instruments used for testing meat and other products.

The third type of test is "subjective": that is to say that a panel, either of experts in the industry or of members of the general public, is asked to score a series of samples for some such quality as hardness, brittleness, toughness, etc.

These three types of test will now be discussed briefly in turn. The first pioneer in testing flour doughs using as "fundamental" method was KOSUTÁNY [1] working in Budapest. He describes an apparatus designed by Rejtő in which dough samples, cut into shapes of rectangular cross-section, were stretched on a series of low-friction metal rollers. He showed that the shape of the stress-strain curves were characteristic of the quality of the dough. Many years later, SCHOFIELD and SCOTT BLAIR [2] used a similar method, but replacing the metal rollers with a bath of mercury and using cylindrical samples. A rather complex model of viscous ("dashpots") and elastic elements ("springs") was proposed to account for the rheological behaviour of the dough.

Unfortunately later work by HALTON [3] showed that the rheological data so obtained did not correlate well with the assessment of quality by skilled bakers. The reason was probably that the cylindrical test-pieces used were prepared by forcing the dough by means of a plunger through a metal tube and the process no doubt destroyed much of the structure that should have been measured. Halton found that a sphere of dough could be made by much less drastic manipulation and, if two prongs were placed in the middle of this sphere and then gradually drawn apart to form a "band" of dough, much better correlations could be obtained. Nevertheless, the mercury-bath method was subsequently used in many laboratories, especially in Italy [4] and USA (by BAILEY et al. reference too numerous to list), who also used other methods. Much more recently, SHELEF and BOUSSO [5] in Israel have modernized the mercury bath method and proposed an even more complex model for flour dough than that of SCHOFIELD and SCOTT BLAIR.

The two principle "imitative" methods used in industry for testing dough depend on the measurement of pressure and volume of a bubble blown in a flat slab of dough (invented by Chopin and now often known as the alveograph) and a measure of the work needed to mix the dough in a standard mixer. The pioneer in the latter work was again a Hungarian: HANKÓCZY [6] but the method was commercialized by a German Firm and the instrument is often known as the "Brabender Farinograph".

Here one must include a word of warning about the use of such methods. It is important not only that the instrument should give reliable and reproducible results but also that these should correlate with what the practical man wants to know.

During the visit to France already referred to, it was found that at that time (1937) many varieties of wheat were being tested in order to try to make France independent of having to import wheat from countries other than her own (then) possessions in North Africa. But as a rule, the test-plots were too small to produce enough flour to make a loaf and the quality of each variety was judged solely on the basis of the Chopin data. Fortunately, quite a large mass of data was available giving bakers' and millers' assessments of quality of flours which were available in sufficient quantities and which had also been tested with the Chopin instrument.

Correlation coefficients were then calculated and there was found to be no significant relation between the former and the latter scores. (Of course the possibility must not be overlooked that the population studied was not typical). Incidentally, it was in the course of this work that, so far as I can find out, the possible significance of the amino-acids cystine and cysteine in relation to dough consistency was appreciated [7]. This work has been widely developed since, especially here in Budapest by Professor TELEGDY-KOVÁTS and his colleagues. They have also used many rheological methods, including measuring the penetration of a metal sphere, a method originally also practiced by KOSUTÁNY [8].* This method has also been used by the Israeli team.

The use of a "mixer" to measure properties of dough was probably first introduced by HOGARTH in 1890 (see a very interesting historical survey by SWANSON [9]) but, as already stated, the first systematic study was made by HANKÓCZY.

Concerning bread itself, my audience is already well aware of the work on TELEGDY-KOVÁCS, LASZTITY et al. [10]. Others also have measured firmness and crumbliness of the final product. The Hungarian workers proposed a fairly simple model of dashpots and springs in series and in parallel — a combination of the Kelvin and Maxwell models.

I have taken my illustrations mainly from breadmaking, partly because more work has been done on dough and bread than perhaps on any other foodstuff, and partly because of the importance of wheat in the Hungarian economy. But the study of butter raises an interesting theoretical point. PRENTICE (my ex-colleague) made many instruments for measuring the "spreadability" of butter, including one in which the butter was actually spread on a plastic surface. The results of those tests were compared (using Multiple Factor Analysis) with the judgments of both a trained panel and a large group of housewives and it was found that, though many of the correlations were high (including that of the "spreader") the best test of all was a measurement of the force needed to extrude the butter at a constant rate through a short metal tube [11].

* If only brief mention is made of the impressive amount of work recently published by TELEGDY-KOVÁTS, and his colleagues, it is because this is naturally already well-known to the audience at the present lecture.

I and my ex-colleagues at Reading, England, published much work on the rheology of butter and cheese which cannot be discussed here. It is well summarized in a little book by Margaret BARON [12]. The consistency of cheese is important, of course, not so much for the "mouth-feel" as because it helps to control the population of moulds and bacteria that produce good and bad flavours and odours. Meat is particularly difficult to test rheologically because of the difficulty in preparing a suitable homogeneous testpiece and most of the standard tests are imitative (e.g. the Warner—Bratzler machine, the Sale tenderometer, Proctor's tenderometer, etc.). In Sweden, DRAKE [13] has used a novel method (also for many other foodstuffs), measuring electronically the noise produced by the jaws in chewing foodtuffs.

Many experiments have also been done on the number of "bites" required to get meat to a consistency convenient for swallowing.

A note of warning: it is important to distinguish between what STEVENS [14] has called "ordinal" and "interval" measurement scales. When a measurement is made on an instrument, the distances between the units are equal; e.g. for temperature, $11° - 10° = 1°$ and also $10° - 9° = 1°$. But when subjects judge a material, say for hardness, and score "very hard, hard, medium, soft, very soft", if we now rate these with numbers 1—5, we must remember that 5—4 is not necessarily equal to 4—3 etc. Strictly speaking, one should not use correlation coefficients (and this would exclude Factor Analysis) for such data. In fact, this rule is often broken and quite good results may be obtained, presumably because the spacing of the subjective scores does approximate to an equal interval scale; but this cannot be assumed.

In conclusion, attention should be drawn to a recent book by SHERMAN [15] which gives, not only a very useful introduction to general rheological theory but also a very full account of rheological work as applied to foodstuffs and also in the pharmaceutical industry.

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