NOTE

Dough Temperature Changes During Mixing in a Mixograph[1]

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In one of the earliest publications on the mixograph, Swanson and Working (1933) noted the importance of temperature. Temperature was controlled during mixing by Malloch (1938) and Voisey et al (1966), but the absence of a readily available, controlled-temperature mixograph made this difficult in normal practice. Temperature's effects on mixogram curves have been studied by many investigators, mainly where room temperature was the major concern (Baig and Hoseney 1977, Shelke and Walker 1990). Their results showed significant effects on the mixograms for both soft and hard wheat flours. We also know, from baking practice, that accurate control of the mixed dough's temperature is an important factor in bread production (Pyler 1988).

One of the questions remaining unanswered, however, is how dough temperature changes during mixing in a mixograph. The object of this work was to study dough temperature changes during mixing and their correlation with the resulting mixograms.

MATERIALS AND METHODS

Flour and Starch

General Mills All Trumps high-gluten flour (moisture 11%, protein 14.45%, ash 0.568%) and untreated commercial wheat starch (Midsol 50, Midwest Grain Products, Atchinson, KS) were used.

Mixing and Temperature Recording

Mixing was done on an 89.3-rpm 35-g Mixograph (National Manufacturing Division, TMCO Inc., Lincoln, NE). The mixograph was connected to a computer that automatically collected the data and calculated the mixing parameters (Gras et al 1990, Walker and Walker 1990).

Compared with the aluminum bowl base, dough is a relatively poor heat conductor. It forms a "pillar" (Fig. 3 in Swanson and Working 1933) between a small part of the bowl bottom and the dough guard on the rotating mixer head. The temperature near the center of the dough pillar appears to be more affected by flour and water starting temperatures, hydration, and work input during mixing than by the environmental temperature.

A type K thermocouple was mounted inside one of the aluminum mixing bowl's stainless steel pins by drilling a hole from the bottom to half way up the exposed length of the pin, where it was soldered in place. This was designed to measure the changing temperature of the dough while it was being mixed. A model 50 datalogger (Electronic Controls Design, Inc., Milwaukie, OR) was connected to the thermocouple, and dough temperatures (to the nearest 0.1°C) were recorded at 1-sec intervals while the mixogram was being recorded. The computer programs that analyzed and graphed the mixing and temperature data were custom written by AEW Consulting, Lincoln, NE.

Experimental Procedure

High-gluten flour was replaced with 0–15 g of wheat starch, so that the net protein content was reduced from 14.45 to 8.26% (14% mb). The water absorption level was calculated according to the following equation (Finney 1945): absorption = (1.5 × protein %) + 42. Flour-water mixograms were prepared at room temperature (24–26°C), with all the ingredients starting at room temperature. The dough temperature curves were simultaneously recorded by the datalogger. Two percent (flour-weight basis) salt was added to one flour sample and one flour-starch mixture sample, and the resulting changes in the temperature and mixing curves were observed.

RESULTS AND DISCUSSION

In a mixogram (Fig. 1A), the cross-hatched area beneath the curve midline between 1 min left of peak and 2 min right of peak is proportional to the work input during that time. Figure 1B is the curve of dough temperature vs. mixing time, taken simultaneously with Fig. 1A. Four relatively distinct regions in the temperature change curve can usually be identified. In region I, the temperature rises by about 3.5°C during the first 10–15 sec. Region II has a much slower temperature increase for an additional 2–3 min. In region III, the curve follows an almost straight line, with a much steeper slope than in region II. The slope in region III decreases with lower protein contents. This region typically lasts 3–4 min and corresponds to the peak and widest part of the mixogram (Fig. 1A). The mixogram midline peak seems to occur at the center of region III. Region IV shows a slower temperature increase during the last 2–3 min. It is not always linear nor as well-defined as that of region III.

One possible explanation for the change in dough temperature pattern follows. When water is quickly added to the flour at the start of mixing, the surfaces of the flour particles rapidly hydrate (Hoseney and Finney 1974) and the dough temperature rises rapidly (region I). According to Pyler (1988), this heat of hydration results from the change in energy levels of starch and protein molecules, involving energy release and a temperature rise. When flour is diluted with starch, this region in the curve shows relatively little change, probably because the main contributor to flour heat of hydration is starch, which is already about 70% of the content in flour. Replacing protein with additional starch does not affect the temperature rise much.

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As mixing proceeds, the free water is gradually absorbed and the hydration rate slows. In the meantime, the protein is only beginning to develop into a partially elastic but still flowable gluten. At this stage, the temperature profile is relatively flat (region II). When high-gluten flour was diluted with starch, region II was shortened, indicating that less protein was available to develop into gluten. When salt was added to high-gluten flour, however, region II persisted longer, indicating that salt had delayed protein development. Salt also caused an increase in the slope of region III, indicating that more work was required to develop the dough. This agrees with other reports that the general effect of adding salt is to increase dough development (mixing) time (Hlynka 1962) and dough consistency (width of the curve) throughout the mixing process, even after dough breakdown begins (Hoseney 1984, Danno 1984). As mixing continues, the dough develops, demonstrating both elasticity and viscosity. The resistance to extension requires more mechanical work to develop the dough to its peak resistance. During this stage, the temperature curve (region IV) shows an increase related directly to increasing protein concentration (Fig. 2).

A good correlation between the region III temperature increase rate (slope) and the mixograph work input (area under the curve) was also found. Figure 3 shows that this correlation not only holds for the high-gluten test flour with various starch dilutions (solid circles), but also for a number of other flours with different protein contents (open circles). We also noted that the mixogram peak time corresponds to the center of region III of the temperature curve, and the average peak height correlates with the region III slope.

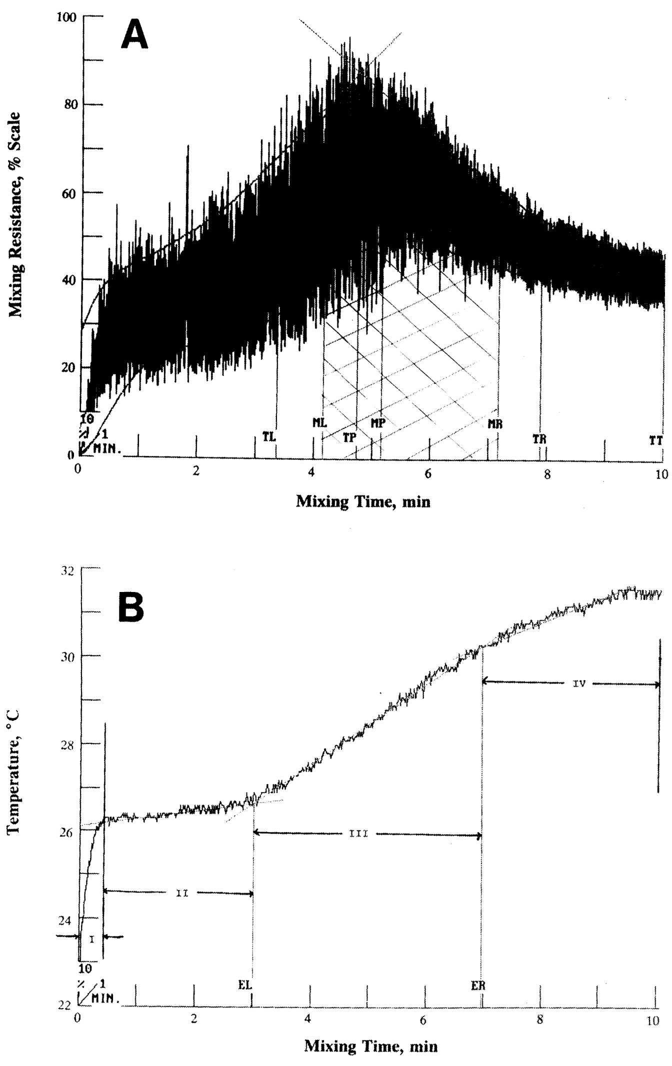

Fig. 1. Typical mixogram (**A**) with cross-hatched area correlated with the slope of the mixing temperature curve (**B**), region III. TT = total time, T = top line (envelope), M = midline, E = envelope, L = left of peak, P = peak, R = right of peak.

The temperature continues to increase, passing the peak time, until the break point of the mixogram curve slope is reached (MR, Fig. 1A). After this, the rate of temperature increase slows and enters region IV. This region has the same curve shape as a purely viscous system (e.g., a silicon oil mixture). At this stage, the dough is badly overmixed; it has lost much of its elastic property and has become a wet, sticky mass.

SUMMARY AND CONCLUSIONS

We have attempted to relate dough temperature changes during mixing to the mixogram by measuring temperature changes in dough continuously and simultaneously while the mixing curve was being recorded. We found five results. First. the dough

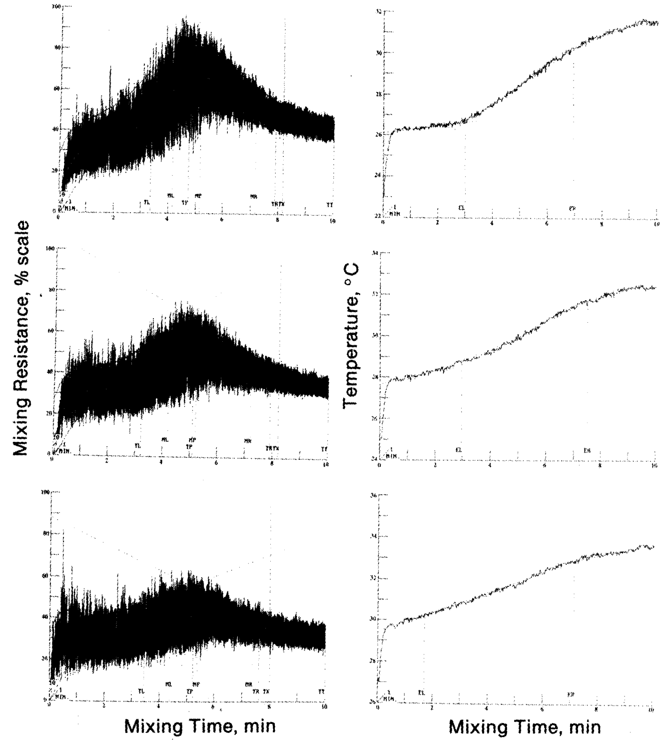

Fig. 2. Mixograms for flour-starch blends (protein content 14.45, 11.97, and 10.31%, respectively) and their temperature curves (0.89, 0.68, and 0.52 degrees/min, respectively, in region III).

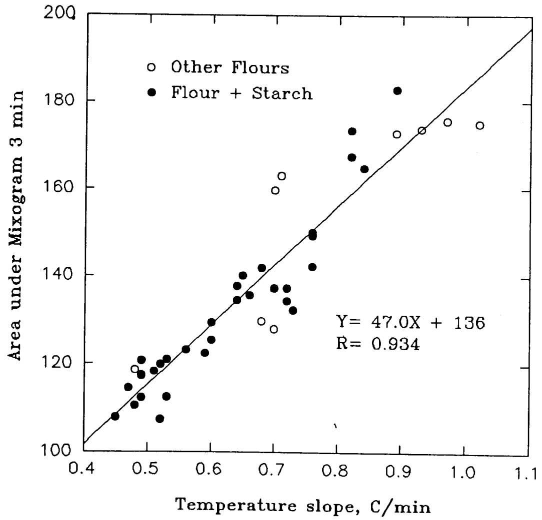

Fig. 3. Area under the mixing curve (% mixing resistance × min) for the 3 min near the peak correlation with the dough temperature rise rate (slope) in region III. Solid circles = high-gluten test flours. Open circles = flours with different protein contents.

temperature change during mixing strongly follows the mixogram curve; the higher the flour protein content, the more work input and the greater the temperature rise. Second, the area under the mixing curve for the 3 min surrounding the peak correlates well ($r = 0.93$) with the temperature rise rate (slope) of region III. This holds for flours that have been diluted with starch and for other flours with different protein contents and strengths. Third, the flour heat of hydration and the mechanical work input during gluten development (near the mixing curve peak) are the two main causes for the temperature rise. Fourth, salt's effects on mixing are also clearly shown by this method. Fifth, this defined pattern of increase in dough temperature implies possible practical applications in predicting mixing strength by temperature changes alone or by using temperature rise to control commercial-scale mixers. Additional work with a more sophisticated bowl and more flours will be required to verify this potential.

ACKNOWLEDGMENTS

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