Microwave Utilization in the Rapid Determination of Flour Moisture[1]

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ABSTRACT

A microwave-oven moisture-determination system was compared with a standard air-oven method for determination of moisture in hard, soft, and whole wheat flours. Sample size, drying time, and microwave energy level were optimized for each flour to produce the greatest moisture removal possible without charring of the sample. After optimization, the microwave method was compared with a standard air-oven method for each type of flour over a normal range of moistures. Results indicate that the microwave system gives a slightly, but consistently lower, value for moisture when compared to the air-oven method. The degree of difference is on the order of 0.5%, and is sufficiently consistent to allow a tabular correction to agree with air-oven values. Thus, it appears that the microwave system may provide a rapid method for moisture determination in flour.

A relatively recent entry in the continuing search for rapid, accurate moisture-determination systems is the microwave oven with internal balance and data-handling microprocessor. This method has proven quite useful for determining moisture in materials having relatively high moisture contents, such as meat products (Kolar 1978) and a variety of dairy products.[2] Steele (1976) briefly discussed moisture determination in self-rising flour, using a microwave oven. He noted that values for the flour were consistently lower than those for an air-oven method, while values for materials with higher moisture contents showed less variation between air- and microwave-oven moisture determinations. Other references to determination of flour moisture with microwave-oven systems are scarce, particularly those dealing with flour from different classes of wheat. The current study covers the determination of optimum sample size, energy level, and time for moisture determination in hard, soft, and whole wheat flours.

MATERIALS AND METHODS

Microwave moisture analyses were done with an AVC model MP microwave oven with internal electronic balance and digital microprocessor (CEM Corporation, P.O. Box 9, Indian Trail, NC 28079). Duplicate moisture samples were run according to AACC method 44-15A (1980). Flour samples milled from hard red winter wheat were collected from the Kansas State University pilot mill. Whole wheat flour samples were milled from hard red winter wheat, also on the Kansas State University pilot mill. A commercial cake flour was used for soft wheat flour samples.

Microwave moisture trials were all run using 10 × 12.5 cm glass fiber pads as sample supports. The pad was first placed on the balance within the oven cavity and tared automatically, with the tare value being stored in the microprocessor. The flour sample was then placed on the pad, and the total weight less the tare was automatically recorded as initial weight. Both the time of microwave exposure and the quantity of microwave power were set before the above steps were taken, leaving only initiation of the run once the sample was in place and the oven door shut.

During initial runs establishing sample size, time, and power, as well as collecting information for drying curves, sample weight was manually recorded from the digital readout every 12 sec for the first 3 min of each run. For the remainder of each run, sample weight was recorded every minute. Later runs made for comparison with the air oven did not have intermediate data collected, and only the final value as calculated by the microprocessor was recorded.

Early results indicated that a flour sample size between 2 and 4 g would be optimal. Sample sizes of 2, 3, and 4 g (±0.25 g) were chosen to determine the effect of sample size within a reasonable range for the different flours. Sample layer thicknesses were 1.05, 1.35, and 1.66 mm for the 2-, 3-, and 4-g samples, respectively. The layer thickness did not vary among flour types.

Evaluation of drying curve data resulted in selection of an 8-min time limit for use in comparing microwave data with air-oven duplicates.

Power input on the oven's variable scale was marked in percent from 10 to 100. We determined that our oven at 100% produced 648 W. The manufacturer confirmed that the oven is designed to produce a minimum of 550 W, but the actual power of individual ovens may be above that figure. Thus, the meaning of percent power in terms of actual wattage varies from oven to oven. For this study, we chose three power settings defined in terms of the temperature rise in 1 L of water after 2 min. For reporting purposes, the temperature rise was converted to watts.

Our first study compared results at three power settings, 415, 328, and 213 W, with sample sizes of 2, 3, and 4 g for all three flours, hard red winter, whole wheat, and soft wheat. Exposure time during this study was extended to 15 min, with collection of sample weight data at intervals as discussed earlier. These data were used in preparation of drying curves from which we determined the time necessary for an accurate moisture determination.

The second study compared air-oven and microwave-oven values for the three flours at different moisture levels. The flours were tempered to various moistures in the 11–14% range by mixing with appropriate amounts of water, then allowing the sample to equilibrate under refrigeration in sealed glass jars for several days. Samples were remixed occasionally during the equilibration period. Following equilibration, each sample was remixed prior to subsampling for moisture determination. Air-oven moistures were done according to AACC method 44-15A. Microwave moistures were run 8 min at 415 W with a 2-g sample for soft wheat flour and a 3-g sample for both hard red winter wheat flour and whole wheat flour.

RESULTS AND DISCUSSION

Larger samples required somewhat longer drying times and were more prone to charring because of excessive heat buildup within the sample layer. Samples smaller than 2 g became increasingly difficult to work with as the absolute amount of moisture lost decreased without a corresponding decrease in random variability of measurement, thus leading to increasing coefficients of variation. Charring occurred in all flours at the 415 W and 4-g combination, as well as in some other combinations (Table I). The lowest power setting (213 W) apparently was unable to remove a

TABLE I
Charred Samples[a] at Various Sample Sizes and Powers

Flour Sample Size (g)	Power (W) 213	328	415
2	...	...	...
3	...	...	s
4	...	hs	hsw

[a] h = hard red winter flour, s = soft wheat flour, and w = whole wheat (from hard red winter) flour.

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[2] M. Collins. 1981. CEM Corporation, personal communication.

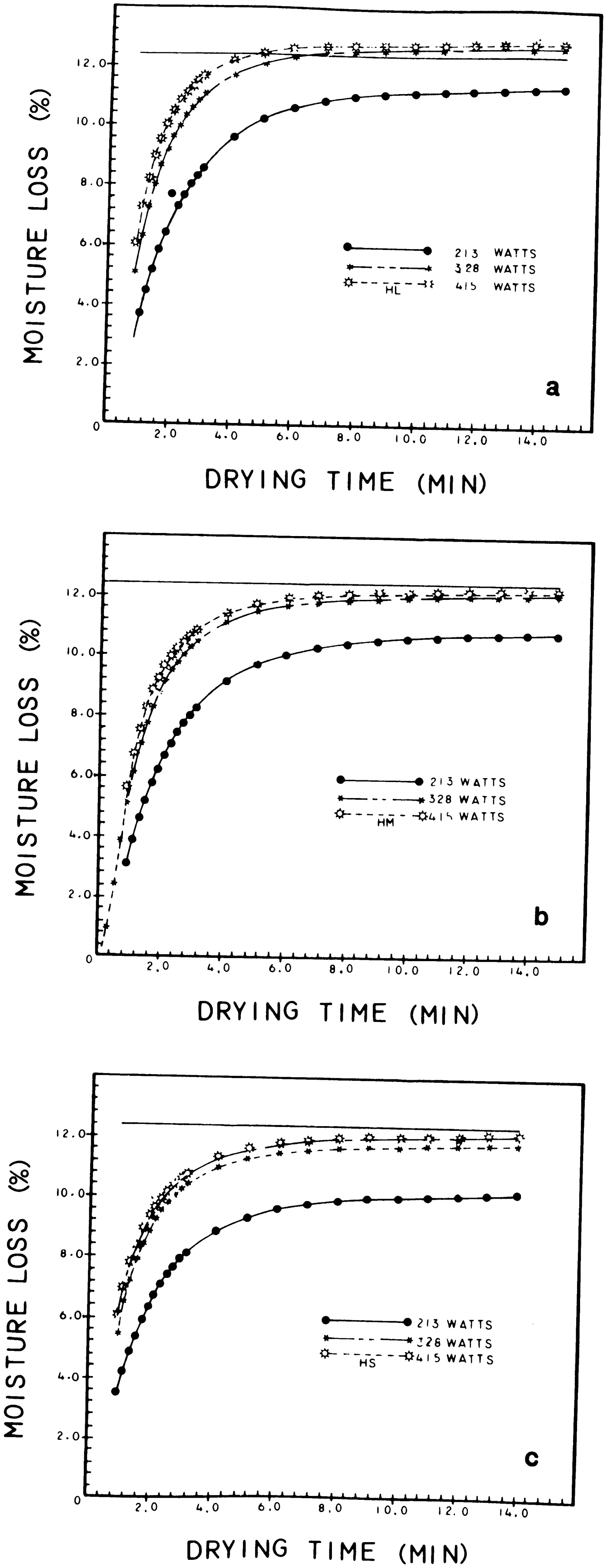

Fig. 1. Effect of increasing power on moisture removed by the microwave oven. Flour from hard red winter wheat: **a,** large (4-g) sample; **b,** medium (3-g) sample; and **c,** small (2-g) sample. Straight line = air-oven moisture value.

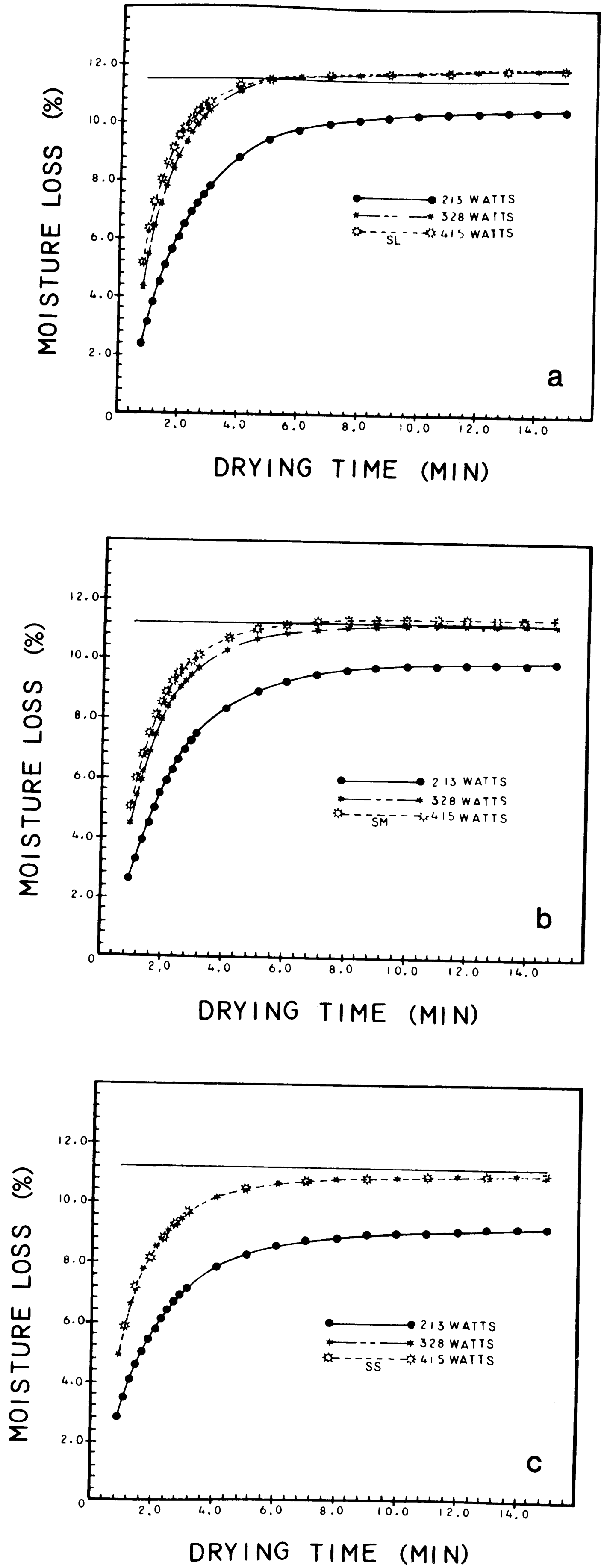

Fig. 2. Effect of increasing power on moisture removed by the microwave oven. Flour from soft wheat: **a,** large (4-g) sample; **b,** medium (3-g) sample; and **c,** small (2-g) sample. Straight line = air-oven moisture value.

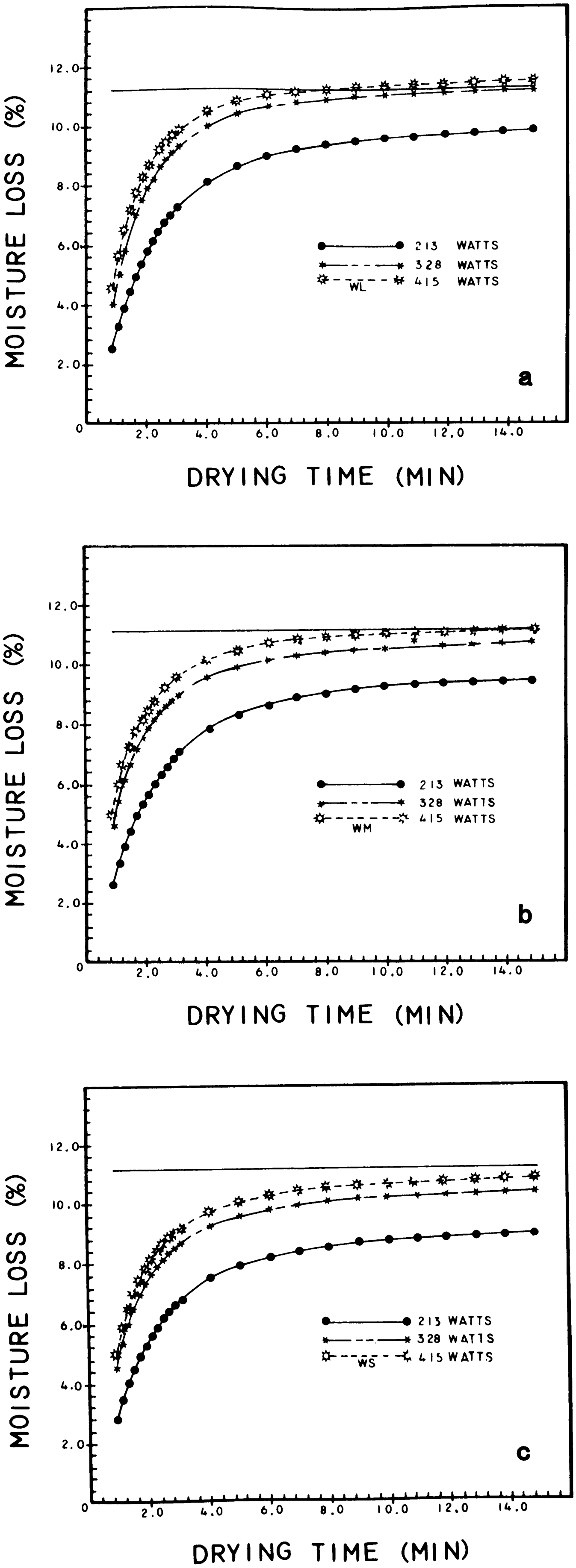

Fig. 3. Effect of increasing power on moisture removed by the microwave oven. Flour from whole wheat flour: **a,** large (4-g) sample; **b,** medium (3-g) sample; and **c,** small (2-g) sample. Straight line = air-oven moisture value.

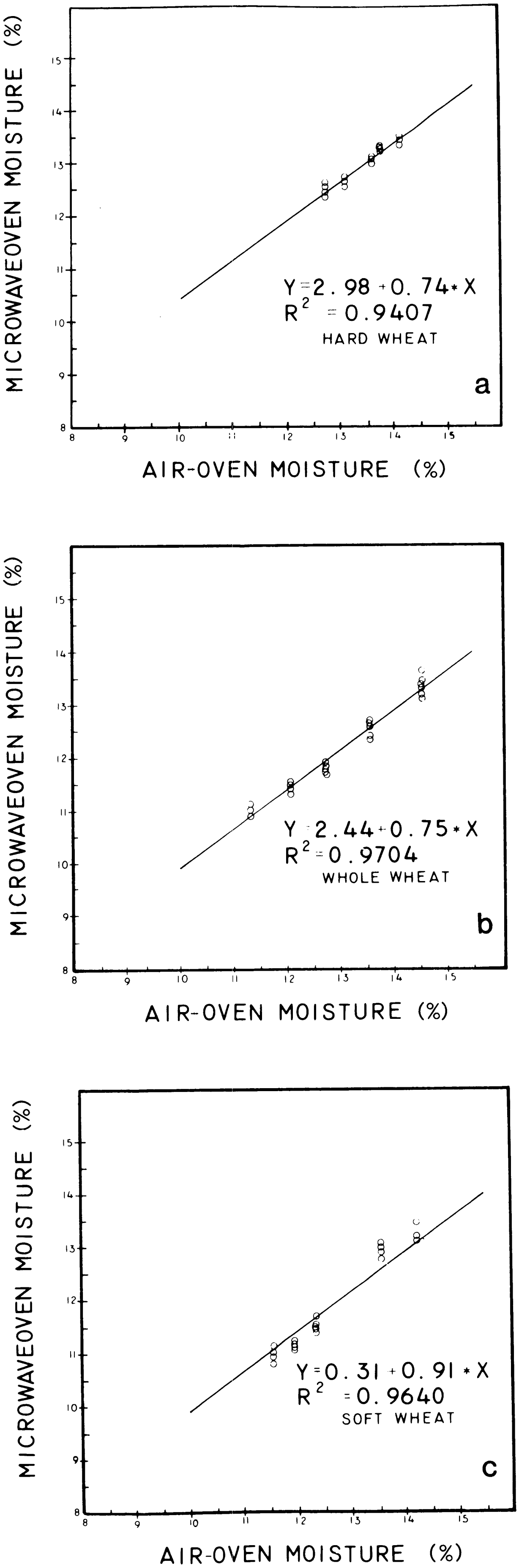

Fig. 4. Air-oven moisture vs microwave moisture for: **a,** hard wheat; **b,** whole wheat; and **c,** soft wheat flours.

significant portion of the moisture from samples, as in all cases it gave moisture values 1–3% below both air-oven value and microwave-oven values determined at the two higher power settings.

Figures 1, 2, and 3 demonstrate typical data for this study. Cumulative moisture loss over the 15-min exposure time in the microwave oven is plotted for each of the three sample sizes at both the high- and low-power settings. The only microwave curve that exceeds the air-oven value line is that of the large sample size, which was charred, at high power. Throughout the study, samples with microwave moisture higher than the air-oven moisture were charred. Throughout the study, moisture level indicated by microwave-oven determination increased for a given sample, with increases both in sample size and power. The effect of increasing power may be a factor of the degree of binding of water to various components of the flour. Thus, some water may be bound tightly enough to limit its reaction with the microwave field. This would reduce the heating effect normally associated with rapid rotation of water molecules in a microwave field and reduce vaporization of water, resulting in lower moisture determination.

In each graph in Figs. 1, 2, and 3, the increase in power from 213 to 328 and 415 W resulted in additional moisture being lost from the sample. Additionally, it appears that the effect is nonlinear and that a threshold of some sort exists between 213 and 328 W, as the increase of power to 428 W had only a marginal effect on moisture loss.

The effect of increasing sample size was consistent for all three flours at all power settings. The major point of interest is that the effect of increasing sample size was nearly linear for each power setting. As the samples were evenly spread on glass fiber pads and the larger, and hence thicker, samples first lost more moisture and then with greater thickness tended to char, it seems that a heat-retention mechanism may explain the data.

After essentially all water is gone from a sample, other components such as lipid may continue to react in the microwave field, although to a much more limited extent than water. This reaction will result in heating. In the case of smaller samples, this heat can be radiated rapidly enough to prevent a sufficient temperature rise to produce charring. As the sample size and, in this study, sample thickness, increase, the rate of heating exceeds the rate of radiation and eventually results in a temperature high enough to char the sample.

Before the charring point is reached, additional moisture is driven off because of thermal heating. This accounts for the higher moisture values found with increasing sample size. The possibility exists that volatile materials other than water are lost due to thermal heating prior to charring. This is, of course, a risk in any thermal moisture determination. Once charring begins and smoke is visible, there is no doubt that materials other than water are lost. Over the short period of time that an uncharred microwave oven sample is at an elevated temperature, it seems unlikely that more than minor amounts of nonaqueous volatiles are lost.

For this study we hoped to find an optimum power setting and time that would precisely duplicate air-oven moisture values, while remaining somewhat independent of sample size. It appears, however, that use of sufficient power to achieve a moisture-removal level comparable to the air-oven in an acceptable amount of time, say less than 10 min, limited the sample size to a maximum of 3 g that could be run long enough to achieve a level drying curve without charring. In the case of soft wheat, even a 3-g sample charred, resulting in the use of a 2-g sample for further soft wheat moisture determinations. Originally this was thought due to the finer particle size associated with soft wheat flour, which might pack more densely, leading to a more rapid buildup of heat within the sample layer. To confirm this theory, a sample of hard red winter wheat flour was milled until its particle size range and distribution were similar to that of the soft wheat flour. Unexpectedly, this sample followed the same charring pattern as did the parent flour. This indicates that there is some difference other than particle size which is responsible for the variation in charring patterns among the three flours tested. Further work to resolve the nature of this difference was determined to be outside the scope of the present paper. Reducing power below the 415-W level resulted in drying curves that leveled off at moisture values unacceptably below air-oven values for duplicate samples. From the first study, we settled on 3-g samples run for 8 min at 415 W for both hard red winter wheat flour and whole wheat flour. Soft wheat flour was also run for 8 min at 415 W, but a 2-g sample was used.

In the second study, the tempered samples were analyzed by both microwave and air ovens. Figure 4 shows the regression lines and associated statistics for each of the three wheat types. Standard deviation from the regression line for each sample was: hard red winter, 0.10; soft, 0.19; and whole wheat, 0.16. In each case the correlation of air-oven and microwave-oven values is quite good. The microwave values run slightly below air-oven, more for the soft and whole wheat samples than for the hard wheat sample. Although the correlation between air oven and microwave moisture values are quite good over the range shown, it is obvious that the regression lines deviate from the 45° line they would be expected to follow. This indicates that the variation between air-oven and microwave moisture increases as the original moisture of the flour increases. This appears to be true for all three flours and to about the same degree. Reasons for this are not obvious. It appears that over the range of moisture normally of interest in flour, this nonuniform variation between the air-oven and the microwave moisture is not a serious problem for industrial measurement. It would, of course, have to be taken into account in any laboratory use of the technique.

CONCLUSION

The microwave-oven system described appears to have some merit as a rapid analytical technique for determination of moisture in flour. A sample size variation limited to 0.25 g on either side of 3.0 g gave acceptable results in this study. Variation of ±1.0 g appears to cause unacceptable error. Each microwave-oven system should be individually calibrated with reference to the actual power in the cavity rather than depending on the power scale installed on the oven. Microwave moisture values appear to run slightly but consistently lower than air-oven values, so individual installations will require correction to maintain maximum similarity to air-oven values.

ACKNOWLEDGMENT

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