Convection Heating Studies of Water-Syrup Layered Systems [a, b]

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THE ANALYTICAL TREATMENT of convection heating is usually restricted to the case of a homogeneous fluid in which temperature is the only source of the density differences that cause convection currents. In a previous paper *(2)* the authors presented evidence for the existence of product-induced density gradients (stratification) in syrup-packed products. In these products density differences are caused by selective dilution of the added syrup. This phenomenon suggested the possibility that stratification of the syrup would inhibit convection. A first-approximation criterion for no convection was presented in a previous paper *(3)*. In the present study, convection heating in a model system was investigated to show what can happen to the heating characteristics of a liquid under conditions of restricted convection.

A reproducible model system that truly represents the behavior of a food product is not easily obtained. Foods undergo irreversible changes during heating and cannot be heated repeatedly with the same results. Any system that does not undergo irreversible changes can be measured, in principle, again and again with reproducible results, but the results are not directly comparable to a food product. This very general consideration must modify any conclusions based on model-system behavior about food-system behavior.

EXPERIMENTAL

The first of two studies conducted in an attempt to simulate conditions in jars of sweet, fresh cucumber pickles involved placing water and 50% sucrose syrup solutions in layers in 16-oz glass jars. The layers consisted of the following fractions of syrup by volume in the containers: 0 (all water), ¼, ½, ¾, and 1 (all syrup). There were 5 different arrangements in all. In the ¼, ½, and ¾ layered systems, the syrup was first measured into the jar then the rest of the jar was filled with water by pouring it carefully on the syrup to avoid appreciable mixing. The initial temperature of water and syrup was 77° C.

For the second study, about 350 g of plastic spears, made by cutting solid 2-in diameter, 4-in long phenolic rods lengthwise into 6 equal wedges, were put in the jars; these plastic wedges are about the size and shape of fresh cucumber spears. The jars were filled as before with the 5 layered arrangements of syrup and water. The total volume of syrup and water necessary to fill the jar was about 7 oz. The only resemblance of the system to an actual cucumber pack is that of the product shape.

Both the jars with and those without plastic spears were heated by submerging them in an agitated water bath maintained at 180° F. Copper-constantan thermocouples in plastic rods were inserted through a pressure fitting in the jar cap and temperatures were measured and recorded by a 12-point (1 min cycle) temperature recording potentiometer. The thermocouples were located along the central axis of the jars at 1.3, 3.8, 6.3, and 8.8 cm from the jar bottom; that is, in the center of each quarter of the jar. Only one thermocouple at a time was placed in any one jar. Temperature records were obtained at 4 points for each of the 5 layering configurations.

Time-temperature plots of the experimental data were made on semilogarithmic coordinate paper and the heating rate, f_h, and lag factor, j, as defined by Ball *(1)*, were determined.

RESULTS AND DISCUSSION

Figures 1 and 2 give the average lag factor and heating rate at the 4 positions in the 5 layered arrangements for the systems without plastic spears. Table 1 gives the results of an analysis of variance of these data. There is no obviously discernible pattern to the effect of the layers on the lag factor although the few values that are quite far from the over-all mean ($\bar{j} = 1.23$) are in the region just under the boundary between the water and syrup. The lag factor averages for all-water and all-syrup packs are lower than the averages for the other 3 configurations. These same general observations apply to the heating rate averages. The average heating rate for the all-syrup pack, f_h, (10.1 min) is just higher than that for all-water, 8.8 min, (not significantly different) and both are lower than the averages for the other 3 configurations (all-water is significantly different from the other 3 configurations). In the mixed layerings the slowest heating point (largest f_h) is in the region just under the boundary layer between the 2 liquids. The largest f_h appears in the configuration with ¼

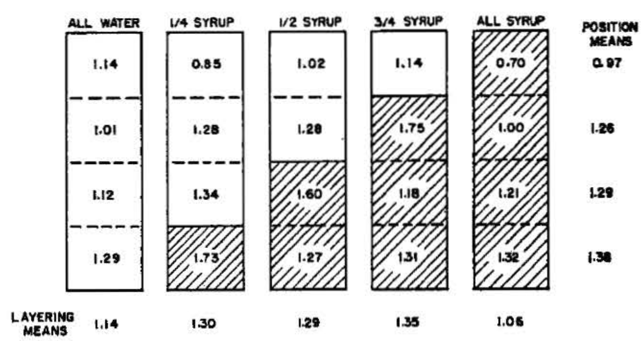

Figure 1. Average lag factors, j, in water-syrup (50% sucrose) model systems.

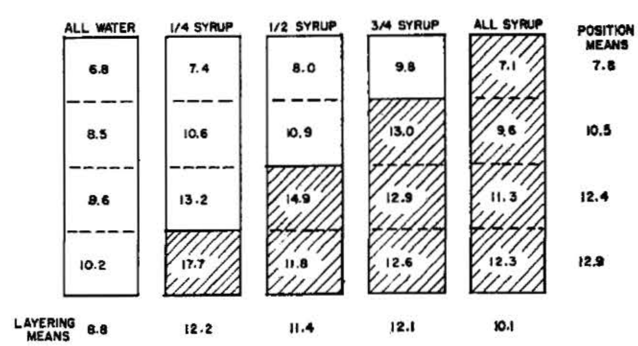

Figure 2. Average heating rates, f_h min, in water-syrup (50% sucrose) model systems.

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[b] Presented before the Nineteenth Annual Meeting of the Institute of Food Technologists, Philadelphia, Pennsylvania, May 19, 1959.

TABLE 1

Analysis of variance of heating characteristics of model system

	Degrees of freedom	Lag factor, j	Heating rate, f_h
		Mean square	Mean square
Layerings	4	0.183	25.8*
Positions	3	0.482	80.1**
Interaction	12	0.144*	7.6**
Error	35	0.018	0.48

* Significant at the 5% level.
** Significant at the 1% level.

syrup; the lag factor corresponding to this point is the second largest. It seems probable that convection takes place to some extent within each liquid layer, but there is no exchange of liquid across the boundary, except, of course, for a small amount being transferred by diffusion.

Figures 3 and 4 give the average heating characteristics for the model systems containing plastic

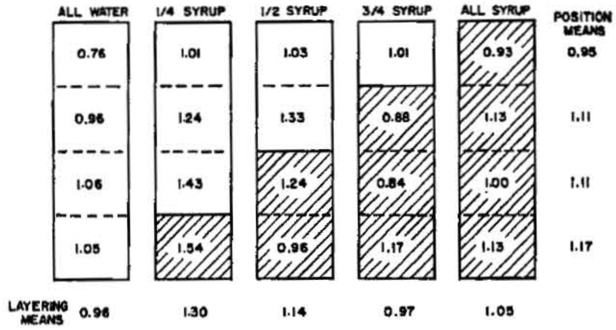

Figure 3. Average lag factors, j, in water-syrup (50% sucrose) model systems with plastic spears.

spears.[c] In these tests no effort was made to replicate all possible positions and all layerings so that the averages are calculated from 2 to 9 individual values. No statistical analysis was made of these latter results. The same general statements can be made about the location of the slowest heating points and the location of the largest lag factors. As before, all-water and all-syrup configurations heat, throughout the jar, faster than any of the other three configurations. For any particular configuration having two liquids the slowest heating point is in the region just below the boundary between the two liquids. The most striking difference between the systems with the plastic spears and the systems without them are the several extremely large f_h values. Why the presence of the spears should give rise to such slow rates of heating in some parts of the jars is not easily explained. The fact cannot be entirely explained by the increase in surface area that might be expected to retard liquid flow, because the all-water and all-syrup configurations with plastic spears heat just as fast, if not faster, as the same configurations without the spears.

[c] As a matter of interest, the heating rate at the slowest heating point in a jar of sweet, fresh cucumber pickles is about 40 min.

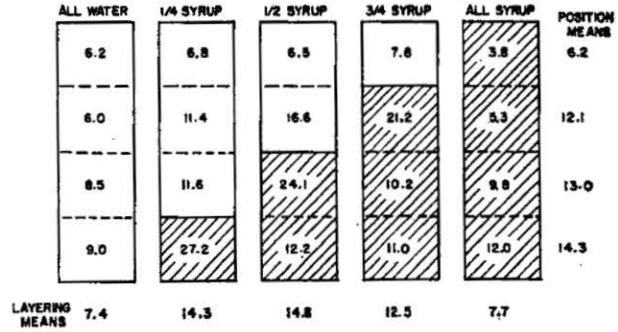

Figure 4. Average heating rates, f_h min, in water-syrup (50% sucrose) model systems with plastic spears.

SUMMARY AND CONCLUSIONS

Two model systems with built-in stratification that restricted convection to selected regions of a jar were examined to determine the effect of stratification on the heating characteristics throughout the jar. Heating rates, f_h, and lag factors, j, are presented for both model systems at four points in the 16-oz jars for each of five different layered arrangements.

When there were two liquids of different density in a jar the heating rates, f_h, were affected depending on the particular arrangement, the position in the jar, and whether the plastic spears were used. For example, in the layered system with plastic spears in which the layered arrangement was half-water and half-syrup, there existed large temperature differences in the syrup section that would normally lead to convection. Ten minutes after this jar had been in the 180° F water bath, a difference in temperature of 35° F existed between points only 2.5 cm apart; the colder point was above the warmer point, and this temperature inversion persisted throughout the heating period.

In general, the slowest heating points were found in the regions just under the boundary between the water and the syrup. Heating rates were more affected than lag factors. In both systems studied (with and without plastic spears) the all-water pack was the fastest heating (over-all jar average), but the all-syrup pack heated nearly as fast. The data suggest that the syrup alone is not responsible for the slow heating regions observed in some of the arrangements.

The resemblance of these model systems to food systems is remote, to be sure, for a number of obvious reasons, principal among them the fact that no liquid exchange takes place between "product" and covering liquor; the fact that the sucrose concentration gradient remains essentially constant throughout the heating period; and the fact that these concentration gradients are present at the beginning of heating and are larger than those found in food systems. Nevertheless, the authors believe that these results are suggestive of the changes in heating characteristics that are brought about by product-induced density gradients, and the density gradients produced by any external cause, such as the addition of dry sugar.

Acknowledgment

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