Moisture Transmission Through Peanut Oil Films

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ABSTRACT

The rate of moisture transfer through a peanut oil film was measured. It was found that the rate can be expressed by the equation:

$$r = \frac{k\, a_1\, (\Delta a)}{t}$$

where r is the rate in g water/cm2/day, a_1 is the higher water activity, Δa is the difference in the water activity across the barrier, t is the film thickness and k is a constant.

This principle was extended to fat-humectant systems where the lower water activity phase is intimately distributed through the fatty medium such as peanut butter and chocolate liquor. Doubling the fat content should increase the film thickness around each particle by 2 and halve the transmission rate as was found experimentally.

Key words: Water permeability, water transmission, water activity, oil films, peanut oil films, peanut butter and chocolate liquor.

It is commonly believed that fats and oils form a good barrier to moisture. How good depends on several factors which will be set forth in this paper.

The importance of this subject is particularly noticeable in the darkening of peanut butter when subjected to solutions, mixtures or gas phases of high water activity, such as is found in combinations of peanut butter and jelly. The mechanism of transfer of moisture through chocolate liquors is similar, and the similarity in these mechanisms will be described. The relationship of film properties and moisture transfer rate will be described first by an appropriate mathematical model. The applications to homogeneous fat-solids emulsions such as peanut butter and chocolate liquors will be shown as an extension of the model.

Previous work in this area has been done by W. Landmann, et al. (1958). Their procedure was essentially the same as ours for studying pure fat films, although the films they studied were crystalline at room temperature. They were concerned primarily with coating fat-moisture transmission, whereas ours was on liquid fat films.

Materials and Methods

Moisture transfer across fat boundaries is caused by the difference in water activity from one side to the other. Water activity is a function of the molarity of the solution (Norrish, 1964). In the case of air-solution equilibrium systems, the water activity is measured by the relative humidity. Therefore, glycerol solutions for which the water actvities, as given by Norrish, were used for the humectant layer in the fat-humectant system, as well as to control the humidity in the air space.

The simple fat-humectant systems were set up in two-inch aluminum foil or rigid aluminum cups. In the first type of system, approximately 5g of glycerol solution of the desired water activity was first poured into the cup, then an accurately measured volume of commercially refined and bleached peanut oil was carefully floated on

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top. The thickness of the oil layer was calculated from the area of the container. These were placed in desiccators in which the water activity of the air was controlled by a glycerol water solution. The experiments were conducted at ambient room temperature (70°-75°F). The desiccators were given at least 24 hours to reach equilibrium before the samples were introduced. Extreme temperature fluctuations were avoided since rapid temperature changes have an effect on the relative humidity (water activity) of the air and will give anomalous results. The sample cups were weighed periodically and the moisture transfer across the fat barrier was calculated from the weight increase of the fat-humectant system in the cups.

The second type of fat-humectant system investigated was food substances having a homogeneous mixture of fat and humectant material, i.e., peanut butter and chocolate. In these food substances, the water activity of the non-fat particles was not precisely measured, but it is known to be very low, between 0.05 and 0.10.

Results and Discussion

SIMPLE SYSTEM

The rates of moisture transmission are found from the slopes of the curves for moisture transmission (change in mass as described above) versus time shown in Figures 1, 2 and 3. The linearity of these curves demonstrates a fundamental finding of this research: that the rate of moisture transmission is, for purposes of generalization, constant with time. Of course, it can be expected that the humectant materias involved in moisture transfer change their water activity as the weight increases. However, the amount of water absorbed in relation to the total solution was small and did not materially affect the water activity. Thus, it is a property of the fat itself that the rate of transfer is constant for each sample.

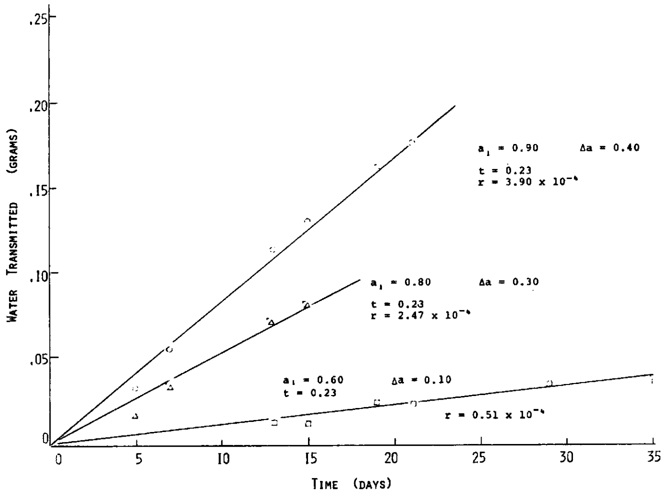

Fig. 1. Water Transmission Through Peanut Oil Films 0.23 cm Thick.

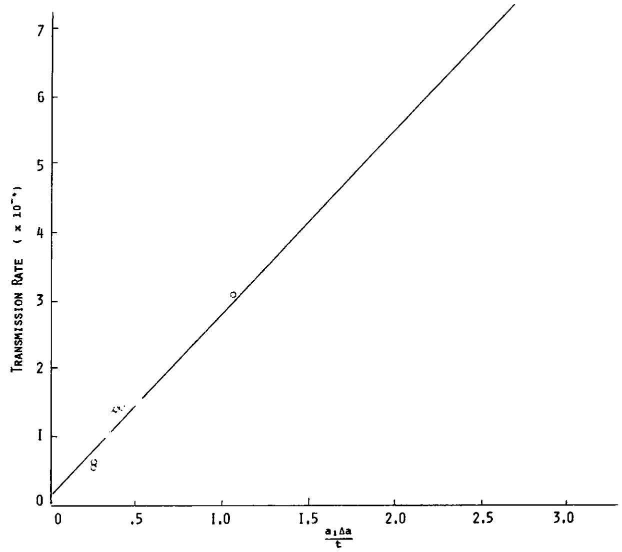

Fig. 2. The Water Transmission Rate as a Function of the Driving Force and Film Thickness.

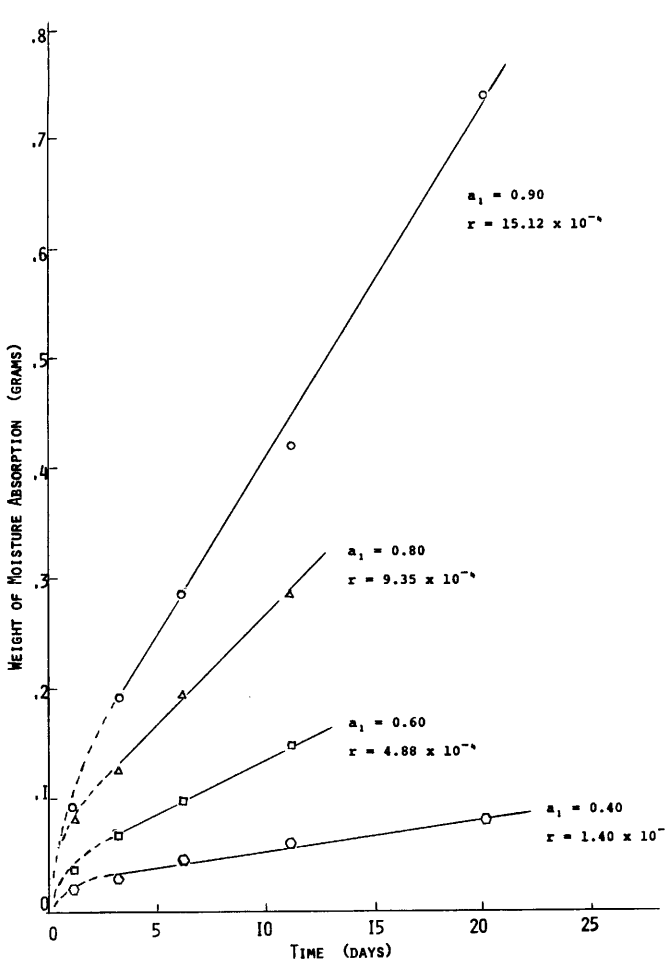

Fig. 3. Water Absorption of Peanut Butter.

MATHEMATICAL MODEL

Table 1 is the data collected relating water activity, film thickness, and moisture transfer rate for the peanut oil system. Intuitive ideas about how such a system should behave, particularly the exponential nature of the rate with increasing water activity, together with the model proposed by Landmann, et al. (1960), led us to investigate by stepwise regression analysis the following rate model:

$$r = k_0 + k_1 a_1 + k_2 \Delta a + k_3 a_1 (\Delta a) + k_4 t + \frac{k_5}{t} + k_6 \frac{a_1 (\Delta a)}{t}$$

where r is the rate (g water/cm^2/day), a_1 is the higher water activity (relative humidity), Δa is the difference in water activity across the barrier, t is the thickness of the film in cm, and $k_0 \ldots k_6$ are the constants to be generated by the regression program. The analysis indicated that the following equation was sufficient to account for 97% (R^2) of the variation in the data:

$$r = k \frac{a_1 \ (\Delta a)}{t}$$

The k in this equation turns out to be 2.72 x 10^{-4}g water/cm^2/day. Figure 4 shows the relationship between r and a_1 (Δa)/t where the slope of the curve is k and the intercept, 0.13 x 10 $^{-4}$, is insignificant and may not be real when compared to the variability of the experimental data.

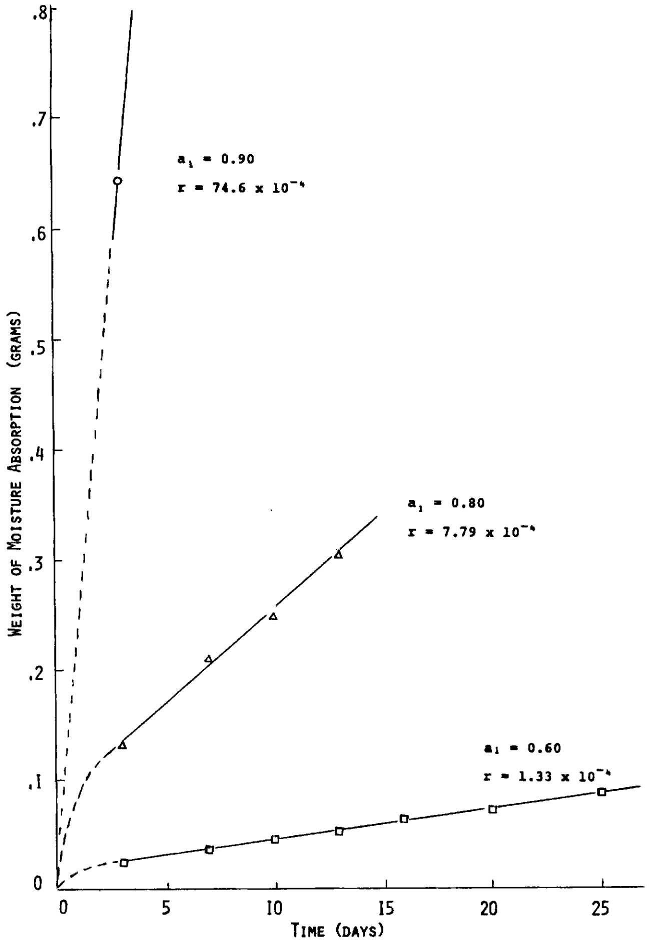

Fig. 4. Water Absorption of Chocolate Liquor.

FOOD SYSTEMS

The significance of this finding can be extended to food systems where water absorption is a problem, such as peanut butter in combination with sweet spreads (jelly). Another example is chocolate in candy or baked goods. Although it might be possible to estimate the oil film thickness of such a system from the oil content and the surface area of the internal solid phase (assuming spherical particles of uniform size) the effort was considered superficial to the design or intent of this work. We feel, however, that a comparison of the homogeneous system to the pure layer system is valuable in demonstrating the mechanism.

Table 1. Data of simple peanut oil - humectant system.

Test	a_1	a_2	Δa	t (cm)	(g water/cm^2/day)
1	.90	.50	.40	.230	3.90 x 10^{-4}
2	.80	.50	.30	.230	2.47 x 10^{-4}
3	.60	.50	.10	.230	0.51 x 10^{-4}
4	.80	.60	.20	.323	1.53 x 10^{-4}
5	.40	.20	.20	.323	0.68 x 10^{-4}
6	.80	.60	.20	.415	1.47 x 10^{-4}
7	.80	.60	.20	.507	1.06 x 10^{-4}
8	.91	.54	.37	.138	7.10 x 10^{-4}
9	.91	.54	.37	.322	3.17 x 10^{-4}
10	.91	.54	.37	.552	1.94 x 10^{-4}
11	.91	.54	.37	.782	1.47 x 10^{-4}
12	.91	.54	.37	.922	1.35 x 10^{-4}

Unlike the pure layer system, the homogeneous (peanut butter and chocolate liquor) systems show a short period of very high moisture absorption before the constant rate sets in (Figure 3 and 4). The difference is explained by the lack of continuity of the fat barrier in the homogeneous system. There is humectant material near the surface of the system that absorbs moisture rapidly. Soon a gradient with a little fat layer protection of the material is established, that promotes a in the material is established, that promotes a steady rate of water absorption. Thus, the substance behaves like many small fat layer systems piled on each other: the driving force of the moisture through the material is the difference in moisture content of infinitesimal layers of humectant separated by infinitesimal layers of fat, through the system. A moving boundary can be observed in the peanut butter as moisture is absorbed since a moisture content in excess of 6% darkens the material, which further confirms this mechanism.

The model of the homogeneous system can be checked in two ways. A comparison of the graphs for the two kinds of systems (Figures 3 and 4) reveals that the relationship between the rate and the humidity outside of the system for the food products is very similar to the relationship between the humidity difference and the rate for the pure layer system in Figure 1. This lends support to the moving boundary model. Furthermore, we would expect that doubling the thickness of the tiny fat layers such as we postulated would reduce by half the moisture transfer rate. An examination of the data in Table 2 shows that this is exactly what happens.

Table 2. Rate of water absorption for peanut butter and peanut butter with added peanut oil.

RELATIVE HUMIDITY	RATE OF MOISTURE ABSORPTION (g water/cm^2/day) Peanut Butter (a)	Peanut Butter + 50% PN Oil (b)	RATIO a/b
90%	15.12 x 10^{-4}	8.32 x 10^{-4}	1.82
80%	9.35 x 10^{-4}	4.93 x 10^{-4}	1.90
70%	5.48 x 10^{-4}	2.76 x 10^{-4}	1.99
60%	4.88 x 10^{-4}	2.27 x 10^{-4}	2.15

Conclusion

This study has developed a mathematical expression to relate the physical properties of an oil film and water activity of a material on either side of the film to the rate of moisture transmission through the film (equation 2). This equation differs from Landmann's *et al.* (1960), in that it has a multiplier of the higher of the two water activities. This must be added to support our data and to account for the role of the water content of the fatty substance in the mechanism.

It is further proposed that this equation could adequately depict the moisture transfer through other oil films, although the constant, k, may vary. Further extension of this work could develop a relationship between k and the composition of the fat layer, i.e., saturation, fatty acid chain length, and even alcohol radicals such as those found in mono- and diglycerides.

There are practical implications of this study for the food industry. The application to peanut butter and chocolate liquor was pointed out but there are many other areas, particularly in the confection and bakery areas, where moisture control is important and applications of such studies could be beneficial.

Bibliography

1. Landmann, W., N. V. Lovegren and R. O. Feuge. 1960 Permeability of Some Fat Products. **J. Am Oil Chem Soc. 37, 1.**
2. Norrish, R. S. 1964. Equilibrium Relative Humidity of Confectionery Syrups — A Nomogram. **Confectionery Production 30** (October).