

AIR DRYING OF SHRIMP

H. S. Ramaswamy¹, K. V. Lo², and L. M. Staley²

¹Department of Food Science, and ²Department of Bio-Resource Engineering, University of British Columbia, Vancouver, B.C. V6T 1W5.

Received 30 October 1981

Ramaswamy, H. S., K. V. Lo, and L. M. Staley. 1982. Air drying of shrimp. *Can. Agric. Eng.* 24: 123-128.

The drying characteristics of shrimp were investigated in a pilot-scale air dehydration cabinet under through-flow and cross-flow drying conditions at two air velocities and four air temperatures. Flow orientation and temperature were found to be significant factors influencing the drying time. Time-temperature relationships for obtaining a desired moisture content in the final product were developed for a wide range of conditions. The basic dehydration equation was found to be applicable to shrimp drying.

INTRODUCTION

Shrimp (*Peneus indicus*) has long been considered a delicate, highly priced seafood commodity. Freeze-drying has been the obvious choice as a successful preservation method. Shrimp was one of the first foods to be freeze-dried (Kermit 1954) and the process has been commercialized both in the U.S. and Europe (Miner 1965; Nixon 1966). Freeze-dehydration characteristics and various quality aspects of the rehydrated shrimp have been the subjects of a number of investigations (Goldblith et al. 1963; Lusk et al. 1964, 1965; Moorjani and Dani 1968; Moorhouse and Salwin 1970). Sharma and Seltzer (1979) investigated the effects of different phosphates on the quality of the freeze-dried shrimp and found coating the shrimp with Kena powder to impart the most desirable mechanical, sensory and rehydration characteristics. Soo and Sander (1977) applied texture profile analysis to fabricated cooked shrimp patties and developed an objective method for the measurement of texture parameters.

Freeze-drying is an expensive preservation method involving high capital investment and is currently employed for highly priced food materials which are sensitive to heat. Although the method has been in use for shrimp dehydration, it adds significant cost to the already expensive raw material. Where the quality attributes are not critical and some compromise is possible, alternate processing methods have been employed. In the Orient, sun-drying is the most popular method of preservation for the relatively smaller-size shrimp and the dehydrated material has found shelf-space in many Chinatown supermarkets in Canada and the U.S.

The present investigation was initiated in response to interest shown by the seafood industry in the air-dehydration process. Information available on air-dehydration of shrimp is rather scarce. Some

aspects have been described by Venkataraman et al. (1953) and Moorjani and Dani (1968). Most often the published information deals with freeze-dried shrimp.

The objective of the present research was, therefore, to study the drying characteristics of shrimp using a pilot plant air-drier. The variables included were flow-orientation (through-flow and cross-flow air circulation), air velocity, and temperature of drying. The purpose was to develop a wide range of time-temperature relationships for shrimp dehydration.

EXPERIMENTAL

Shrimp, caught in British Columbia, Canada, and obtained from a local dock were used in the study. The material was packed in freezer bags (2 kg/bag) and kept frozen in a -20°C cold-storage room.

Prior to a dehydration run, the material was removed from the freezer and par-

tially thawed in warm water. It was then peeled, washed, blanched in boiling water for 1 min, and cooled in cold running water.

Drying was carried out in a pilot plant cabinet air-drier designed and fabricated in this laboratory. The drying area was divided into three compartments and could be used for through-flow, cross-flow, and pot-hole drying. Steam coils were used for heating the air and a variable-speed fan was used to circulate the air. Airflow rate was controlled by a set of two orifice plates, the lower one fixed and the upper rotatable. Stainless steel perforated trays were used to contain the material for drying. A schematic diagram of the pilot plant cabinet air drier is shown in Fig. 1. The operating characteristics and other pertinent details of the drier, and its use in grain drying have been reported by Bhargava (1970).

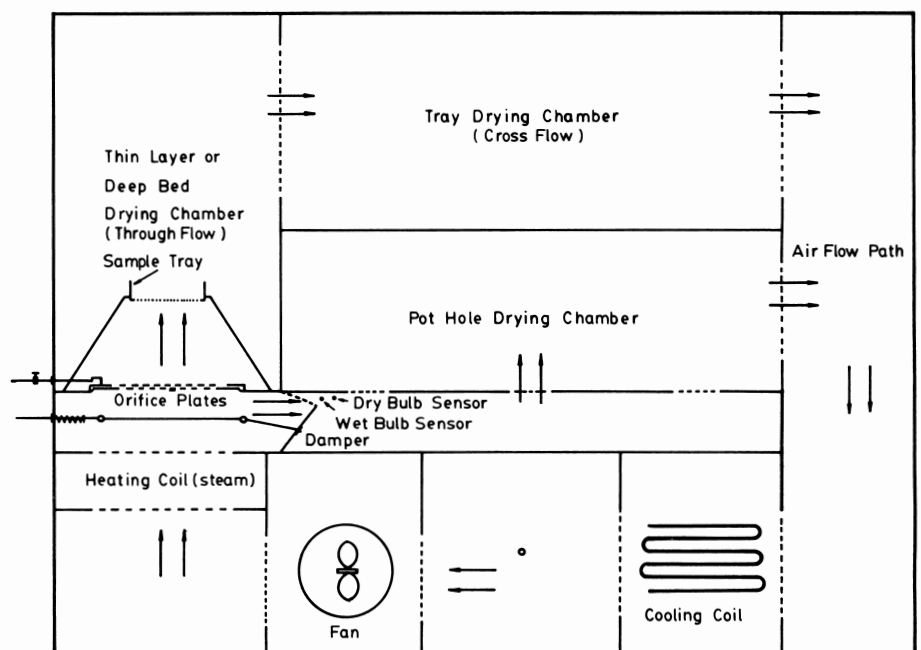


Figure 1. Schematic diagram of the pilot plant cabinet air drier.

TABLE I. DEHYDRATION PARAMETERS FOR SHRIMP

Drying conditions			Parameters		Correlation coefficient r_2
Temperature (°C)	Air velocity (m/sec)	Relative humidity (%)	A	B (h ⁻¹)	
<i>Cross-flow</i>					
71	1.00	5	0.992	0.583	0.996
	1.75	5	0.912	0.636	0.992
62	1.00	6	0.943	0.470	0.992
	1.75	5	0.866	0.487	0.986
53	1.00	6	0.895	0.428	0.992
	1.75	7	0.968	0.410	0.998
43	1.00	8	0.995	0.380	0.995
	1.75	10	0.962	0.377	0.997
<i>Through-flow</i>					
71	1.00	5	0.562	0.599	0.925
	1.75	6	0.571	0.636	0.968
62	1.00	5	0.641	0.672	0.944
53	1.00	6	0.765	0.700	0.984
43	1.00	15	0.718	0.502	0.963

The prepared shrimp were spread uniformly on the perforated stainless steel tray in a single layer and then placed in the appropriate chamber (cross-flow or through-flow air pattern) of the drier. The initial material weight was approximately maintained at 450 g/tray. The tray was taken out, weighed and returned to the drier at several time intervals to monitor the progress of drying. The time intervals were 10 min in the first 0.5 h; 0.5 h in the next 2–3 h, and 1 h, thereafter, up to 8 h. One last measurement was made at the end of 24 h.

Moisture content in fresh shrimp as well as dried shrimp was determined by drying in a vacuum oven at 70°C for 24 h. The relative humidity was measured using a hygroscope (Rotronic AG) and the air velocity by a hot-wire Anemometer (Flow Corporation). Water activity of shrimp samples at different moisture contents was also measured using the hygroscope at 27°C.

RESULTS AND DISCUSSION

The average total weight loss during peeling and blanching was found to be 70% based on fresh ice-free shrimp. The average moisture content of the prepared samples prior to drying was 78.4% wet basis (WB) and average moisture content of the commercial air-dried samples was 20% (WB).

The temperature stability in the drier during the various drying operations was observed to be ±1°C. Ambient air was heated to the desired dry bulb temperature and stabilized overnight before the actual test run. The drying conditions for the different test runs are given in Table I. At temperatures 53°C and above the relative humidity was 6 ± 1%. Stabilization was

difficult to achieve at 43°C and the relative humidity ranged from 8 to 15%.

Effect of Drying Conditions on Moisture Removal

The effect of different drying conditions on moisture removal is presented in Figs. 2–5. The unaccomplished moisture ratio is defined as $W_t = (M_t - M_e)/(M_i - M_e)$, where M_i and M_e are the initial and the equilibrium moisture content of

the sample, respectively, and M_t is the remaining moisture content at time t . All moisture contents are expressed on a dry mass basis (DB).

The effect of different drying temperatures on moisture removal during cross-flow dehydration of shrimp is shown in Fig. 2. Higher drying temperatures produced steeper drying curves indicating faster removal of moisture. The trend was similar for the two air velocities.

The effect of air velocity on moisture removal during the cross-flow dehydration at different temperatures is illustrated in Fig. 3. Differences between the two air velocities in terms of moisture removal were greater at higher drying temperatures and at intermediate times (1.5–2.5 h). The difference was usually negligible beyond a drying time of 6 h.

The effect of temperature on moisture removal during the through-flow drying of shrimp at air velocity of 1.00 m/sec is illustrated in Fig. 4. The trend was similar; however, the difference in moisture removal at different temperatures was smaller compared to the cross-flow dehydration. It was observed that variation in air velocity between 1.00 and 1.75 m/sec had little effect on the moisture removal at any of the temperatures employed for through-flow dehydration.

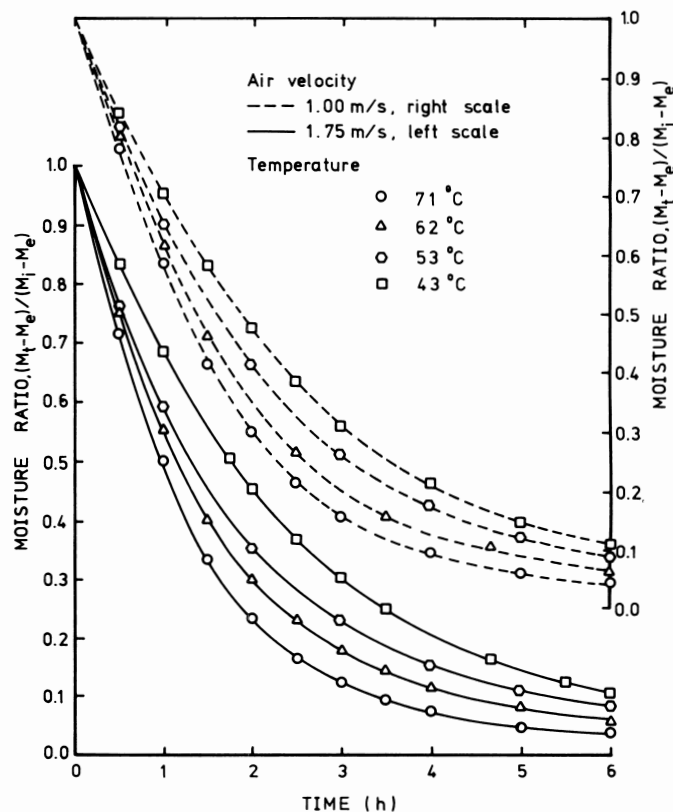


Figure 2. Effect of drying temperature on moisture removal during the cross-flow dehydration of shrimp at two air velocities.

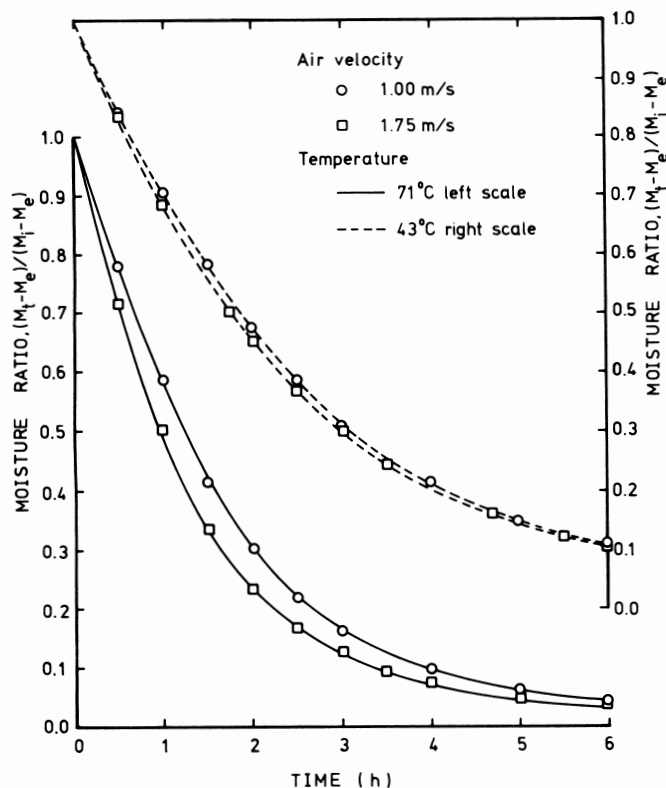


Figure 3. Effect of air velocity on moisture removal during the cross-flow dehydration of shrimp at different drying temperatures.

Through-flow and cross-flow dehydration at two temperatures for a given air velocity (1.00 m/sec) are compared in Fig. 5. The differences were significant, particularly in the time region of 0.5–2.5 h. In through-flow drying the moisture ratio

was brought down to 0.5 in less than 0.5 h, but in cross-flow drying it required 1–2 h. This can be easily ascribed to a better contact of the whole bulk of hot air with the material during through-flow drying, while in cross-flow dehydration, only a

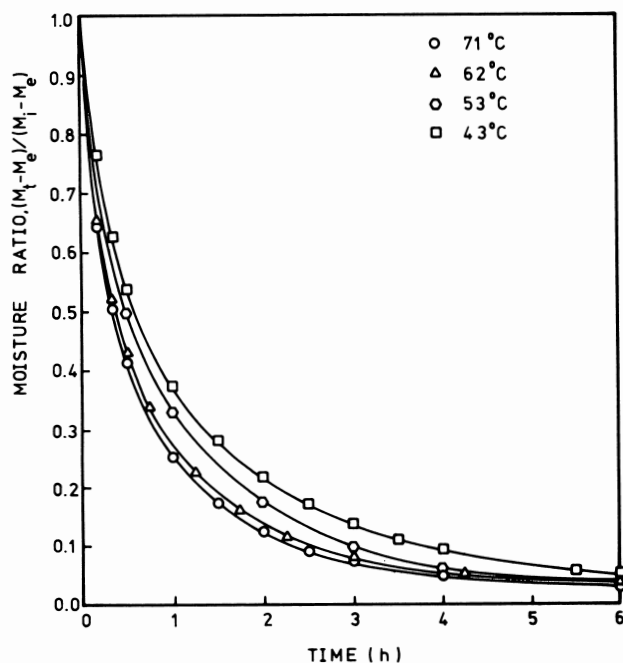


Figure 4. Effect of temperature on moisture removal during the through-flow dehydration of shrimp (air velocity, 1.00 m/sec).

fraction of the hot air makes contact with the material.

Time to Achieve a Given “Dryness”

Although Figs. 2–5 show the effects of temperature, velocity and mode of the medium flow on the moisture removal, they cannot be directly used to find out, under the different conditions, the time required to achieve a given “dryness” (the desired moisture content) in the final product (M_t). To obtain this information the following must be known: (1) initial moisture content (M_i) of the material; (2) the desired degree of “dryness”; and (3) the equilibrium moisture content (M_e) of the sample.

The average initial moisture content of all the shrimp samples used in the study (78.4% WB and 363.4% DB), and the average moisture content of the commercial air-dried samples (20% WB and 25% DB) were taken as the basis for the initial and target moisture contents. The average equilibrium moisture contents achieved at the different temperatures (at the end of 24 h) were taken as the basis for obtaining M_e . A relationship between the equilibrium moisture content (M_e) and the drying temperature is shown in Fig. 6. The air-flow rate or flow orientation had little effect on the resulting equilibrium moisture content at a given temperature. Hence, the different values at a given temperature were averaged out and this value was plotted.

Using the above three parameters, the unaccomplished moisture ratio, $W_i = (M_i - M_e) / (M_i - M_e)$ can be calculated and Figs. 2–5 can then be used to determine the drying time required. Time-temperature relationships for such a process under different conditions are given in Fig. 7. The results generally indicated slight increases in drying times at lower air velocity at a given temperature for cross flow drying. Similar observations were observed by Bhargava (1970) for grain drying at temperatures above 15.5°C. At 43°C cross-flow drying, the drying times at the two air velocities were almost equal. The slightly higher relative humidity existing at the higher air velocity might be a reason for the reduced differences between the two drying times.

Through-flow drying showed 60–70% reduction in drying times as compared to the cross-flow drying. In cross-flow drying, the drying times were about 88, 75 and 60% at 53, 62 and 71°C, respectively, compared with drying at 43°C, suggesting substantial reduction in drying times at higher temperatures. The comparative values for through-flow drying

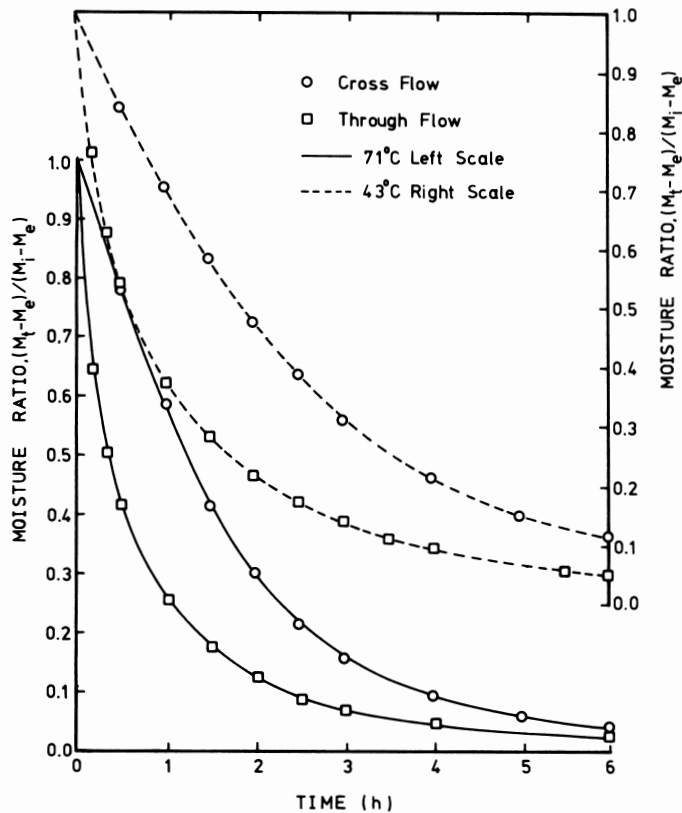


Figure 5. Comparison of moisture removal during through-flow and cross-flow dehydration of shrimp at two temperatures.

were 74, 68 and 65%, respectively, showing no significant reduction in drying time beyond a temperature of 62°C.

Theoretical Approach

Successful application of heat transfer models to mass transfer during diffusion-controlled air-dehydration has been reported by a number of researchers (Sherwood 1929, 1931; Jason 1958; Fish 1958; Charm 1978; Heldman and Singh 1981).

The basic general equation can be represented as

$$W = A_0 \exp(-B_0 t) + A_1 \exp(-B_1 t) + \dots \quad (1)$$

where W is the moisture ratio at time t , and A_0, B_0, A_1, B_1 are constants depending on the product characteristics and drying conditions. When the drying time, t , is sufficiently long, the infinite summation series converges rapidly and Eq.

1 can be approximated by the first term of the series. Thus, the general form may be written as:

$$W = A \exp(-Bt) \quad (2)$$

By linear regression analysis of the experimental data in the form $\ln(W)$ vs. t , values of A and B were calculated for each experimental condition (Table I). Significantly high linear correlations ($r^2 = 0.944-0.998$) between the parameters indicated that Eq. 2 can be used to describe the dehydration behavior. Using the regression parameters (Table I), and the conditions discussed earlier for the desired "dryness," drying times were predicted for the different experimental conditions and compared with the experimental values. The results indicated that the drying times from the two methods were comparable and the mean error in using the regression parameters for drying time prediction was less than 4% as compared with the experimental value. This demonstrates that the conditions for the desired dryness are covered by the linear portion of the semi-logarithmic relationship described by Eq. 2.

A fairly linear portion of the relationship between water activity and equilibrium moisture content at 27°C is shown in Fig. 8. A number of models are available in published literature on moisture sorption isotherms (Karel 1975) and sorption behavior at different temperatures (Pfoest et al. 1976). Using similar relationships at different temperatures, the regression parameters A and B could probably be related to the operating conditions of the dryer, such as temperature, humidity and velocity of the air, and product characteristics such as shape, size and monolayer moisture. The parameter B is a function of the mass diffusivity, the characteristic dimension, and the surface resistance to mass transfer. The characteristic dimension of shrimp varies during the process of drying, making any further theoretical consideration extremely complicated. However, experimental correlation of the results should be fairly useful.

Effect of water activity on the quality and stability of foods has been well recognized (Karel 1975). The water activity range of 0.70-0.75 is generally considered the lower limit for the growth of most food spoilage microorganisms. In the present investigations, the water activity at 27°C of samples at moisture contents below 30% DB, was found to be less than 0.80 (Table II). The level of "dryness," which was based on moisture content of commercial samples, has been set at a moisture content of 20% WB or 25% DB.

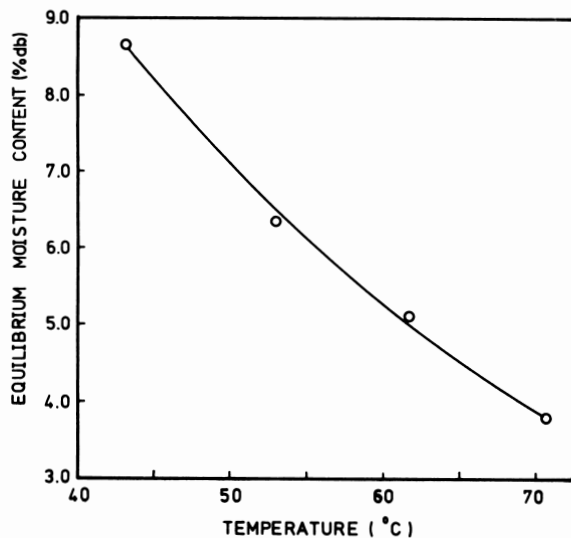


Figure 6. Equilibrium moisture-temperature relationship for shrimp dehydration.

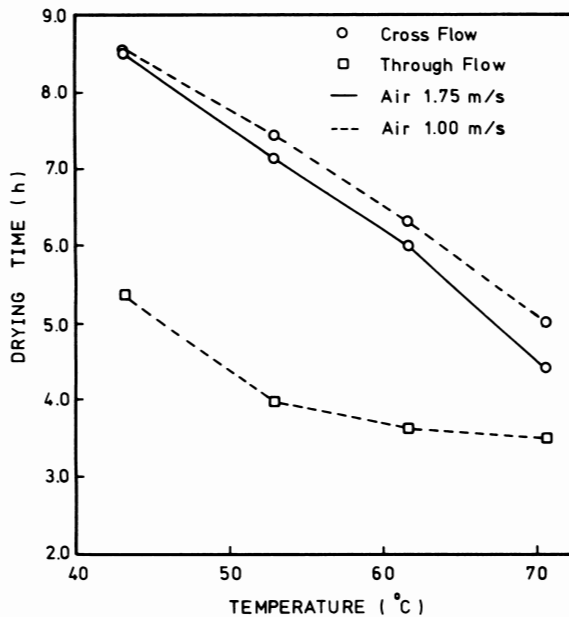


Figure 7. Time-temperature relationships for shrimp dehydration.

The product can, therefore, be considered not potentially favorable for the growth of spoilage microorganisms during storage at room temperatures.

CONCLUSIONS

This study has shown significant differences in drying times for shrimp by through-flow and cross-flow dehydration. Variations in air velocity between 1.00 and 1.75 m/sec did not result in appreciable differences in drying time. Tempera-

ture was found to be a significant factor in cross-flow dehydration of shrimp; higher temperatures resulted in shorter drying times. With through-flow drying, temperatures higher than 62°C did not have significant influence on drying time. A wide range of time-temperature relationships were obtained for shrimp dehydration.

The basic exponential diffusion drying equation was found to be applicable to shrimp dehydration. Dehydration param-

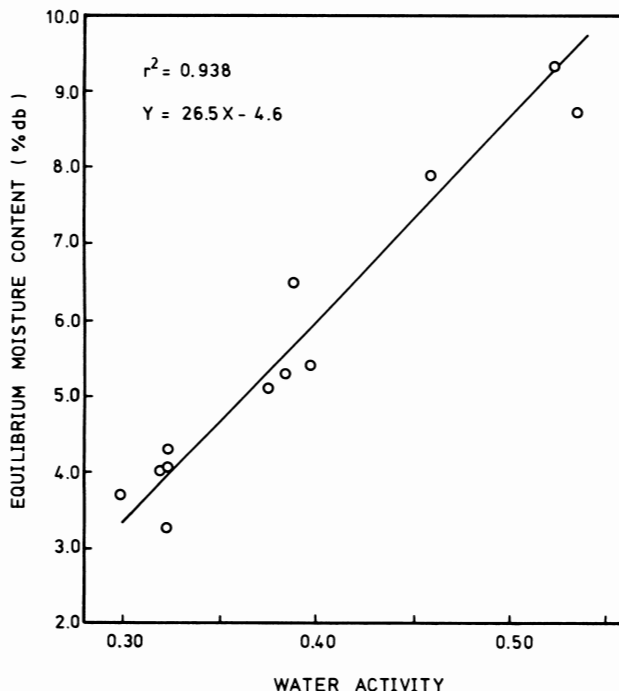


Figure 8. Equilibrium moisture-water activity relationship for shrimp at 27°C.

TABLE II. WATER ACTIVITY OF SHRIMP AS AFFECTED BY MOISTURE CONTENT AT 27°C

Moisture content (% wb)	Water activity
78.4	0.961
68.2	0.943
52.8	0.923
42.1	0.911
34.3	0.878
31.1	0.862
23.5	0.790
20.5	0.750
16.3	0.682
13.5	0.637
8.5	0.504

eters for the various drying conditions were computed. Further experiments are needed to relate A , B and M_e to the known processing parameters such as temperature and humidity of the air, and product characteristics such as moisture content, shape and size.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support provided by the Fathom Farms Ltd., Vancouver, B.C.

REFERENCES

- BHARGAVA, V. K. 1970. Drying of wheat grain in thin layers. M.S. Thesis. Department of Agricultural Engineering, University of British Columbia, Vancouver, B.C.
- CHARM, S. E. 1978. The fundamentals of food engineering. 3rd ed. AVI Publ. Co., Westport, Conn.
- FISH, B. P. 1958. Diffusion and thermodynamics of water in potato starch gel. *In* Fundamental aspects of dehydration of foodstuffs. MacMillan Co., New York.
- GOLDBLITH, S. A., M. KAREL, and G. LUSK. 1963. The role of food science and technology in the freeze dehydration of foods. *Food Technol.* 17: 139.
- HELDMAN, D. R. and R. P. SINGH. 1981. Food process engineering. 2nd ed. AVI. Publ. Co., Westport, Conn.
- JASON, A. C. 1958. A study of evaporation and diffusion processes in the drying of fish muscle. *In* Fundamental aspects of dehydration of foodstuffs. MacMillan Co., New York.
- KAREL, M. 1975. Water activity and food preservation. *In* Principles of food science. Part II. Physical principles of food preservation. O. R. Fennema, ed. Ch. 8. Marcel Dekker Inc., New York.
- KERMIT, B. 1954. Freeze drying attitudes. U.S. Dep. Agric. Economic Research Service. November.
- LUSK, G., M. KAREL, and S. A. GOLDBLITH. 1964. Astacene pigment loss occurring in freeze-dried shrimp and salmon during storage. *Food Technol.* 18: 157.
- LUSK, G., M. KAREL and S. A. GOLDBLITH. 1965. Effects of some processing

- parameters on the rates of freeze-drying of shrimp. *Food Technol.* 19: 620.
- MINER, S. M. 1965. Freeze-drying. *ASHRAE J.* 7: 92.
- MOORHOUSE, B. R. and H. SALWIN. 1970. Decomposition in foods. Effect of freeze-drying and cooking on shrimp quality. *J. Assoc. Off. Anal. Chem.* 53 (5): 899.
- MOORJANI, M. N. and N. P. DANI. 1968. Textural and reconstititional properties of freeze-dried shrimp. *Food Technol.* 22: 886.
- NIXON, G. M. 1966. A preliminary report on freeze-drying study with particular reference to the freeze-drying of shrimp. Occasional paper 67/4. (Cited by Moorjani and Dani (1968)).
- PFOST, D. L., S. G. MAURER, D. S. CHUNG, and G. A. MILLIKEN. 1976. Summarizing and reporting equilibrium moisture data for grains. ASAE Paper No. 76-3520.
- SHARMA, S. C. and E. SELTZER. 1979. Effect of phosphates on the physico-chemical characteristics of freeze-dried shrimp. *J. Food Sci.* 44: 177.
- SHERWOOD, T. K. 1929. Drying of solids. *I. Ind. Eng. Chem.* 21: 12.
- SHERWOOD, T. K. 1931. Application of theoretical diffusion equations to drying of solids. *Trans. Am. Inst. Chem. Eng.* 27: 190.
- SOO, H. M. and E. H. SANDER. 1977. Prediction of sensory response to textural parameters of breaded shrimp shapes using instron texture profile analysis. *J. Food Sci.* 42: 163.
- VENKATARAMAN, R., A. SREENIVASAN, and A. G. VASAVAN. 1953. Drying and preservation of prawns. *J. Sci. Ind. Res.* 12A: 473.