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Technical paper

Hot-Air Drying Model for Udon Noodles

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Experimental drying curves of udon noodles in an air temperature (dry bulb) range of 15 to 65°C and a relative humidity range of 60 to 80% were evaluated to develop an appropriate mathematical model to predict the moisture content of udon noodles at any time during the air-drying process. Three simple mathematical equations were used to try to fit these curves, and it was found that Page's equation had the best fittings for the experimental drying data by doing comparative analysis of the coefficients of determination and standard deviations. Page's equation was finally selected to describe the drying curves of these noodles and the dependency of the drying parameters (e.g., slope and intercept) on air temperature and relative humidity was investigated. A generalized model based on Page's equation with drying parameter *K* (function of air temperature and relative humidity) and n (constant) provided a suitable description of hot-air drying behavior of udon noodles.

Keywords: udon noodles, mathematical model, drying curve, hot-air

Dry udon noodles are a very important part of the food industry in Japan and there are many producers of these noodles. Because of temperature differences, noodles from different areas have special flavor and demand special drying conditions (temperature and relative humidity). When a manufacturing company designs and develops an udon noodle-drying device, it must meet the demand of the particular dry noodle producer. This requires that certain reliable data about the drying characteristics of noodles. However, there is little information about noodle drying methods (Asano, 1981; Isobe, 1995), and there is also no systematic and detailed study of air-drying characteristics of noodles.

The objectives of this research were therefore, to investigate the drying characteristics of udon noodles hung on a bar under different air conditions and to develop an appropriate mathematical model which could be used to predict noodle moisture content at any time during the drying process.

Experimental Apparatus and Procedures

Drying apparatus A schematic diagram of the experimental noodle drying apparatus used in the present research is shown in Fig. 1. It consists of an air conditioning system and a noodle-drying chamber. The air conditioning system delivers desired air to the chamber which remains at a predetermined air temperature and relative humidity. The chamber was insulated with 50-mm thickness of expanded polystyrene to minimize the effect of heat loss to the surroundings. A door was provided in the chamber which allowed insertion or removal of the sample. The hook base, on which twelve pieces of udon noodle bars could be hung, was suspended from the middle of chamber ceiling. The hook base could be turned at low velocity. Two propeller fans were installed on the ceiling to send a uniform current of air to sample noodles, leaving a current of air of about 1.8 m/s surrounding the drying noodles. Since this is the appropriate air velocity for considering the strength of a wet noodle, we decided not to examine air velocity as a variable here.

Drying test procedures Noodle samples were made of wheat flour (made by Nishin Flour Milling Company, Tokyo) and salt water (Baume degree of salt water is 10) at a ratio of five to two. Before the start of each drying run, about 3 kg of noodle samples (2 mm thickness) were made with an initial moisture content of about 50% (dry basis). A small quantity of this sample was used to measure the initial moisture content by an infrared moisture-measuring instrument (developed by Kett Japan, Model FD-600). The rest of the sample was placed in the drying chamber and hung on a bar suspended on the hook base, and the drying test began. Fifteen minutes later, a small quantity of noodle sample being dried was taken from the chamber and its moisture content and dimensions, e.g., thickness were immediately measured. This same operation was repeated after 30 min, 45 min, 1 h, 1.5 h, two h, two point five h, three h, four h, five h, six h, seven h, eight h, nine h, ten h, twenty-two h, twenty-four h and twenty-six h.

Drying model selection For practical use in the future (to simulate the drying curve and to design a drying procedure), some simple empirical drying equations were selected, which had been successfully used in thin-layer drying of agricultural crops.

The first drying model is the exponential equation,

$$\mathrm{MR}=(M-M_e)/(M_0-M_e)=\exp(-At), \qquad (1)$$

where M is moisture content (% dry weight basis), M_e is equilibrium moisture content (% dry weight basis), M_0 is initial moisture content (% dry weight basis), t is time (h), A is drying parameter.

Ross and White (1972) utilized equation (1) to study differences in drying characteristics of white and yellow corn. This equation was also used by Westerman *et al.* (1973) to study rela-

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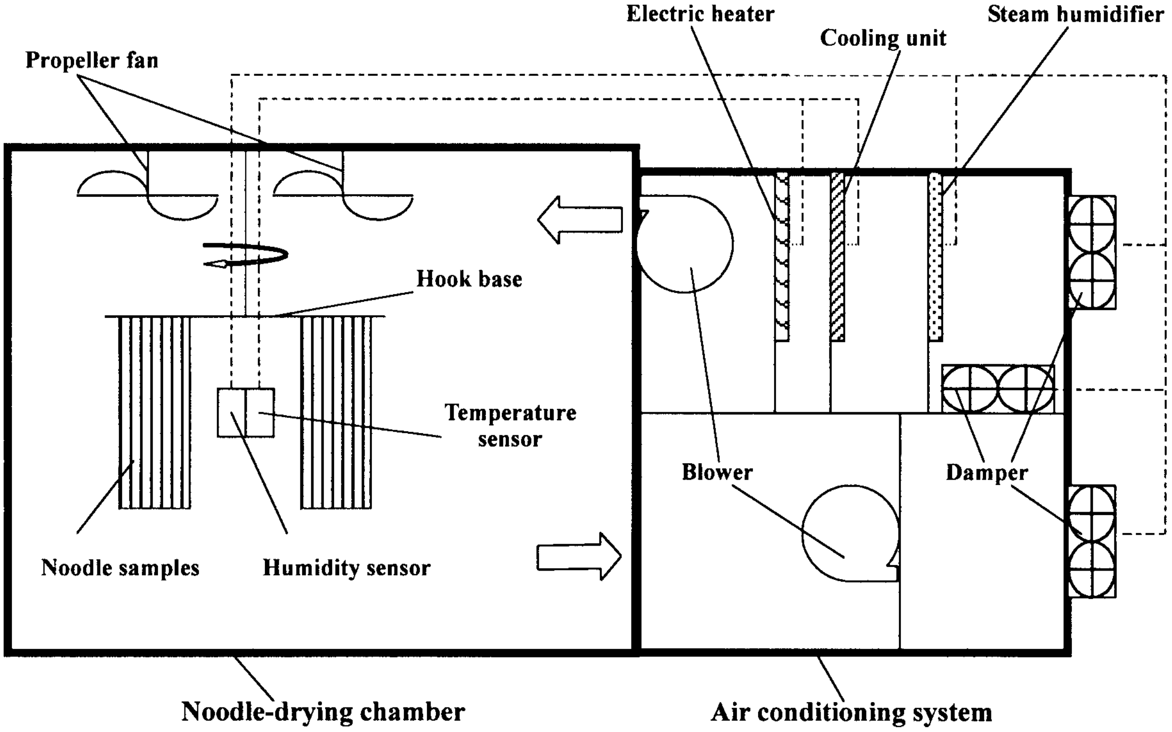

Fig. 1. Schematic diagram of experimental noodle drying apparatus.

tive humidity effects on high temperature drying of corn, and White *et al.* (1981) used the equation to study the drying characteristics of popcorn.

The second drying model is a modification of the first equation,

$$\mathrm{MR}=B\exp(-Ct), \qquad (2)$$

where B and C are drying parameters.

Equation (2) was used by Kameoka (1988) to study drying characteristics of rough rice on thin layer. This equation was also used by Taharazako *et al.* (1992) to discuss the drying characteristics of buckwheat.

The third drying model is Page's equation,

$$\mathrm{MR}=\exp(-Kt^{n}), \qquad (3)$$

Where K and n are drying parameters.

Equation (3) was employed by White *et al.* (1973) to study the effect of ambient dew-point variation on thin-layer drying characteristics of white-shelled corn. Overhults *et al.* (1973) used this model to describe thin-layer drying of soybeans and the equation was also used by Pathak *et al.* (1991), and Tagawa *et al.* (1996) in their thin-layer drying studies.

Results and Discussion

Drying curves and dynamic equilibrium moisture contents The experimental drying curve data of udon noodles at an air temperature of 20°C and relative humidity of 70% are shown in Fig. 2. The moisture content decreased rapidly during the first drying period and then leveled off thereafter to reach a constant value. All experimental runs showed also the same tendency and indicated nearly the same values at the 22 h point, and at the 24 and 26 h. The moisture content of the noodles at 24 h was regarded as the dynamic equilibrium moisture content. The concept of dynamic equilibrium moisture content, M_{de} was also used in the selected drying model, because no other information on equilibrium moisture content of dry udon was found.

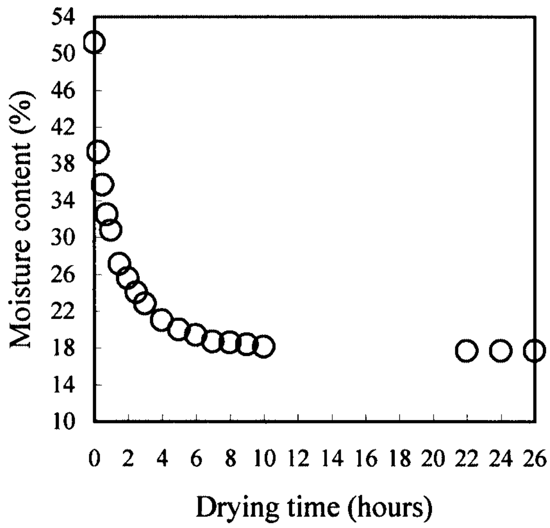

Fig. 2. Moisture content vs. drying time at air temperature of 20°C and relative humidity of 70%.

Comparison of the models Since it was not necessary to estimate M_e from the drying data, the models (equations 1,2 and 3) were transformed to linear equation forms. Model 1 was transformed to: $\ln\mathrm{MR}=-At$; Model 2 was transformed to: $\ln\mathrm{MR}=\ln B-Ct$; and Model 3 was transformed to: $\ln(-\ln\mathrm{MR})=\ln K+n\ln t$. These linear regression equations were fitted to the drying curves from the experimental data for 11 experimental runs under conditions of different air temperature and relative humidity of 70% using the least squares method. The analysis regression results are shown in Figs. 3 and 4. The coefficients of determination for equation (2) were higher than those for equation (1), but standard deviations for equation (2) were larger than those for equation (1). Equation (3) had the highest coefficients of determination and the lowest standard deviations among the three models. According to Akaike's theory, the Akaike information criterion (AIC, Akaike, 1976; Tanaka, 1995) could be used to select the most appropriate model. We selected equation (3) as the drying model by taking the minimum AIC values.

Drying parameters K and n of Page's equation After selection of equation (3) as the drying model, the drying parameters K and n were obtained under very good regression with a high coefficient of determination. These values were analyzed to determine if they were related to drying air temperature and relative humidity.

Figure 5 is a plot of the drying parameter K against drying air temperature (T) and relative humidity (RH). We easily observed that parameter K linearly increased when the air temperature increased and relative humidity decreased. Little interaction between air temperature and relative humidity was observed. We therefore presented the K value as a function of air temperature and relative humidity in a simple linear equation: $K=A+BT+CRH$. As the result of calculation, the regression equation $K=1.6675+0.0214T-0.0187RH$ was obtained with an R^2 value of 0.98. A t-test on the individual coefficients indicated that they were all significantly different from zero at the 99 percent level.

Figure 6 is plot of drying parameter n against drying air temperature and relative humidity. As is evident, the values of n were scattered and no trend was observed as a function of air temperature. And although the mean of n at each relative humidity level

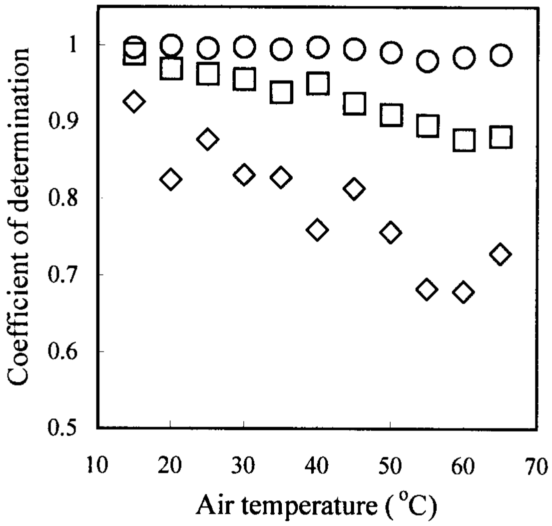

Fig. 3 Comparison of the coefficients of determination for three equations. ○: Equation (3), □: Equation (2), ◇: Equation (1).

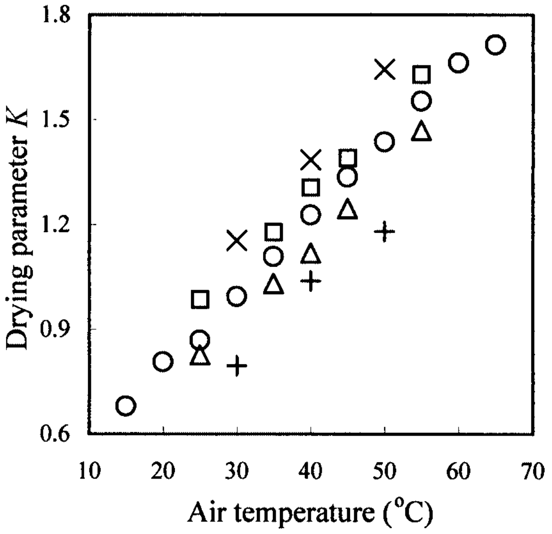

Fig. 5. Plot of drying parameter K against air temperature. ×: Relative humidity of 60%, □: Relative humidity of 65%, ○: Relative humidity of 70%, △: Relative humidity of 75%, +: Relative humidity of 80%.

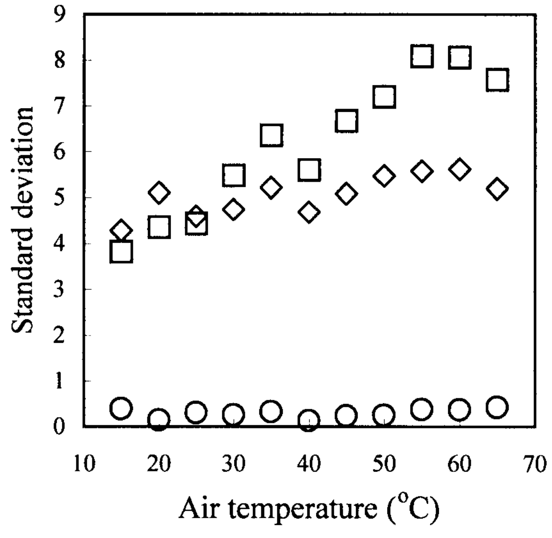

Fig. 4. Comparison of the standard deviations for three equations. ○: Equation (3), □: Equation (2), ◇: Equation (1).

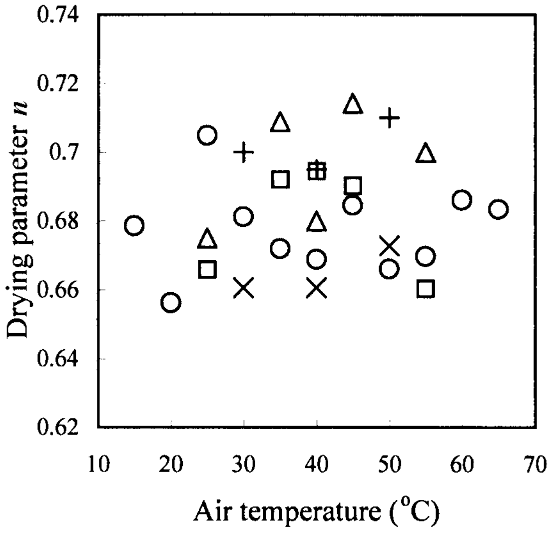

Fig. 6. Plot of drying parameter n against air temperature. ×: Relative humidity of 60%, □: Relative humidity of 65%, ○: Relative humidity of 70%, △: Relative humidity of 75%, +: Relative humidity of 80%.

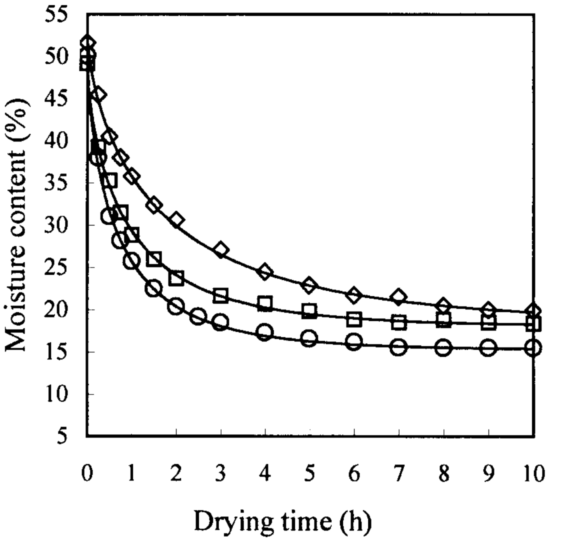

Fig. 7. Observed and predicted moisture contents of udon noodles for three different air conditions. ◇: Observed contents for air condition of 15°C and relative humidity of 70%, □: for air condition of 35°C and relative humidity of 75%, ○: for air condition of 35°C and relative humidity of 65%, —: Predicted moisture contents for the three air conditions.

increased with the increase of relative humidity, we could not confirm differences in the n value using a statistical mathematics technique, especially in the sections from relative humidity of 65% to 75%. We therefore decided to represent n by a constant value taken at the mean of n-values at the relative humidity of 70%. The n-value of 0.685 was obtained.

Simulation of drying curve of udon noodle To check the results obtained in the above investigation, the regression equations on drying parameter K and n were inserted in equation (3) and drying curves calculated for three different drying air conditions. Figure 7 shows a comparison between calculation moisture contents and those obtained experimentally: the moisture predicted was in good agreement with that observed. These results showed the usefulness of the drying parameters K and n of Page's equation obtained from the above calculations and the applicability of this equation to describing the drying behavior of udon noodles as an appropriate mathematical model.

Discussion

In this study, udon noodle-drying characteristics were examined and an appropriate mathematical model was proposed. The result was limited to the noodle sample condition described here, although the most typical noodle sample was used.

An initial moisture content of about 50% (dry basis) was adopted in this study as used by most noodles producers. This was because noodle-falling occurred during noodle drying when the initial moisture content was lower and noodle-extending was occurred when the content was higher.

The applicability of the empirical regression equation obtained here to different noodle materials was tested in additional experiments on noodle samples with less salt and of thinner thickness. It was found that Page's equation also fitted well to these drying curves although it was simultaneously observed that the drying rate was more rapid and the characteristic coefficient k value was larger. To apply the empirical regression equation to other noodles with various kinds of materials, therefore, an abundance of data from more experiments with different kinds of materials is needed.

Conclusions

Page's equation well describes the hot-air drying behavior of udon noodles and is an appropriate mathematical model.

There are significant effects of drying air temperature and relative humidity upon the drying rate. A generalized model based on this equation with drying parameter K (function of air temperature and relative humidity) and n (constant) provided a good description of the hot-air drying behavior of udon noodles under the sample conditions used in this research.

References

Asano, R. (1981). Drying equipment of noodles. *Food Sci, spring extra publish*, 56–59 (in Japanese).

Akaike, H. (1976). What about information criterion AIC. *Suuri Kagaku*, **153**, 5–11 (in Japanese).

Isobe, K. (1995). Utilization of air conditioning facility by dry noodle producers. Yearbook of the Noodle Industry, 220–226 (in Japanese).

Kameoka, T. (1988). Thin layer drying characteristics of rough rice. *Nippon Nougyo Kikai Gakkaishi*, **50**, 57–65 (in Japanese).

Overhults, D.D., White, G.M., Hamilton, H.E. and Ross, I.J. (1973). Drying soybeans with heated air. *Trans. Am. Soc. Agric. Eng.*, **16**, 112–113.

Pathak, P.K., Agrawal, Y.C. and Singh, B.P.N. (1991). Thin layer drying model for Rapeseed. *Trans. Am. Soc. Agric. Eng.*, **34**, 2505–2508.

Ross, I.J. and White, G.M. (1972). Thin layer drying characteristics of white corn. *Trans. Am. Soc. Agric. Eng.*, **15**, 175–179.

Tagawa, A., Kitamura, Y. and Murata, S. (1996). Thin layer drying characteristics of Adzuki beans. *Trans. Am. Soc. Agric. Eng.*, **39**, 605–609.

Taharazako, S., Morita, K. and Wei, C.L. (1992). Drying of buckwheat and estimation of its quality. *Nippon Nougyo Kikai Gakkaishi*, **54**, 51–56 (in Japanese).

Tanaka, U. (1995). "Statistical Analysis Handbook." Kyoritu Publishing Company, Tokyo (in Japanese).

Westerman, P.W., White, G.M. and Ross, I.J. (1973). Relative humidity effect on the high temperature drying of shelled corn. *Trans. Am. Soc. Agric. Eng.*, **16**, 175–179.

White, G.M., Ross, I.J. and Westerman, P.W. (1973). Drying rate and quality of white shelled corn as influenced by dew-point temperature. *Trans. Am. Soc. Agric. Eng.*, **16**, 118–120.

White, G.M., Ross, I.J. and White, G.M. (1981). Fully-exposed drying of popcorn. *Trans. Am. Soc. Agric. Eng.*, **24**, 466–468, 475.