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The Theory for Predicting the Moisture Distribution of Stored Grains

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ABSTRACT

High moisture content of barley seeds, which were carried to the labolatory within 10 minites after havest, were stored in air tight bottles at constant temperature, and the individual moisture contents of the grains were measured at predecided time intervals.

The theory for predicting the moisture movement between two kinds of different moisture content grains was tried to apply to the prediction of the moisture distribution and the comparison of the predicted values with the observed data showed the good suitability of the theory. The shapes of the moisture distribution predicted from the theory were similar to the observed ones for the tempetature range of 10 to 50°C.

This study will be useful in designing the mix-storage facility or dryer.

Key Word : Barley, Moisture Distribution, Prediction, Plane Sheet Model

INTRODUCTION

The harvesting period of barley and wheat is limited to only two weeks in Japan because there are a few varieties of them and the period overlaps with the rainy season. Moreover, the improvement of combine harvesters has shortened the time for havesting and causes the over-receiption of the harvested crops in the collecting center such as a country elevators.

For this reason, the mix storage method has been proposed as a method of drying the surplus amount of the high moisture wheat beyond the drying facility can handle. Yamashita and Oida(1965), who might be the vangurd of this field, reported the aspects of the moisture transfer between the dry and wet rough rice during the storage and presented its empirical formulae with the storage temperature, moisture difference, effective contact area and storage time. Yamashita et al. (1986) also reported the results of the experiment about wheat as a sequel. Tsai et al.(1987) researched the moisture distribution of some kinds of cereal grains at the riping period, post-havest period, storage period and drying process by using the commercial single grain moisture tester and gave several useful informations. And then Tsai et al.(1988) studied about the characteristics of moisture transfer and quality by mixing of rice.

However, the theory for describing the moisture movement among the stored grains was not still presented until Murata et al.(1989) analyzed the problem.

This study is the application of the theory to the prediction of the moisture distribution of stored barley with time.

MATERIALS AND METHODS

Cereal grains used for this study were "AMAGINIJO" variety of barley, which were harvested at a farm in Fukuoka on 26th of May, 1990 and carried to the labolatory for the tests in about 10 minites so that the moisture distribution of them can be kept at the same state when they were havested. Fig. 1 is a schematic diagram of apparatus used in this study.

45 bottles of air tight glass bins were prepared and 9 bins were used for each temperature condition. After carried to the labolatory, a hundred grains of the materials were immediately put into the glass bin each. These glass bins with a hundred grains of barley were placed in a chamber controlled at a predetermined temperature(10, 20, 30, 40 and 50°C) and tests were started. At every time interval(3, 6, 9, 12, 24, 36, 48, 72 and 96hr), one bin was taken out of the chamber and the indivisual weight of all grains in the bin were measured with the high precision balance (Shimadzu L-180DTP and Mettler PK300MC) which has a 0.1mg of precision at most. After that, the grains were dried at 135°C in an oven for 24hr and the individual moisture content of them were decided.

Since it took about 40 minites to finish measuring the weight of all grains, weight loss might be caused in the grains. Then, the whole weight of grains were measured both before weighing the individual grain and after weighing all the grains in order to correct the weight loss during weighing.

The tests of the temperature condition ranged from 30 to 50°C were conducted in a drying chamber, but the tests for 10 and 20°C were carried out in a refrigerator installed with a heater which was controlled by a power source control device(Chino mini-7). And also a 0.1mm diameter T-type thermo couple(C-C thermo couple) was inserted in a grain to monitor the change of seed temperature. The grain with a thermo couple was put into one of the bins filled with a hundred grains of barley and the seed temperature was recorded.

DISCUSSION

1. The theory for predicting the moisture content of individual grain

The moisture of barley just havested distributed from 9 to 40%, wet basis in this case and its distribution was biassed toward the higher part of the moisture content. When these grains were stored in an air tight bin, the moisture distribution moved toward the lower part of the moisture content at first stage with the shape holded and it became to be a shape like a steep slope mountain. Finally, the moisture movement stoped at the time when the moisture of all the grains reached to each equilibrium moisture content.

Murata et al.(1989) solved the problem on the moisture migration when the grains with two different moisture content are mixted and reported the suitability of the theory by comparing the observed data with the predicted data. They also suggested the solution can be applied to not only the problem in case of the mixture of two different moisture content of grains but also the one in case of the mixture of n kinds of different moisture content of grains.

The purpose of this study is to prove the suitability of the theory for predicting the moisture distribution when the grains with n kinds of moisture content are mixed. The theory used for predicting the moisture distribution of stored grains in the state of both constant temperature and air tight is as follows.

When two different initial moisture content of grains are mixted, the moisture content contained in these grains must move according to the diffusion theory. Assuming that the moisture of grains diffuses out only from its both ends of grains, the plane sheet model is available as a diffusion model.

Equations (1) and (2) are hold for the higher and lower moisture content of grains respectively.

$$\frac{\partial m_1}{\partial \theta} = D' \frac{\partial^2 m_1}{\partial X^2} \tag{1}$$

$$\frac{\partial m_2}{\partial \theta} = D' \frac{\partial^2 m_2}{\partial X^2} \tag{2}$$

Initial conditions and boundary condtions are given as

I.C. $m_1 = m_{10},\ m_2 = m_{20}$ at $\theta = 0$ (3)

B.C.

$$\frac{\partial m_1}{\partial X} = 0,\ \frac{\partial m_2}{\partial X} = 0, \quad \text{at } X = 0 \tag{4}$$

$$\frac{\partial m_1}{\partial X} = -\alpha(m_1 - m_{1e}), \text{ at } X = 1 \tag{5}$$

$$\frac{\partial m_2}{\partial X} = -\alpha(m_2 - m_{2e}), \text{ at } X = 1 \tag{6}$$

The moisture diffused from the higher moisture content of grains than average inintial moisture content must be absorbed into the lower moisture content of grains because the space air among the grains can not afford to hold enough moisture. This condition is expressed as

$$W_1 \frac{\partial m_1}{\partial X} + W_2 \frac{\partial m_2}{\partial X} = 0, \quad \text{at } X = 1 \tag{7}$$

Defining the total amount of the moisture of grains Y as

$$Y = W_1 m_1 + W_2 m_2 \tag{8}$$

Equations (3) through (6) are simlified as

$$\frac{\partial Y}{\partial \theta} = D' \frac{\partial^2 Y}{\partial X^2} \tag{9}$$

I.C. $Y = W_1 m_{10} + W_2 m_{20}$, at $\theta = 0$ (10)

B.C.

$$\frac{\partial Y}{\partial X} = 0 \quad \text{at } X = 0 \tag{11}$$

$$\frac{\partial Y}{\partial X} = 0 \quad \text{at } X = 1 \tag{12}$$

This problem corresponds to the one printed in p.60 of Crank's book(1975) and the exact solutions for predicting the moisture content of individual grains at any time of θ after putting into an air tight bin are

$$m_1 = (M_{1o} - M_{1e})\sum_{n=1}^{\infty}\frac{2\alpha^2\exp(-\beta_n^2 D'\theta)}{\beta_n^2(\beta_n^2+\alpha^2+\alpha)} + M_{1e} \quad (13)$$

$$m_2 = (M_{2o} - M_{2e})\sum_{n=1}^{\infty}\frac{2\alpha^2\exp(-\beta_n^2 D'\theta)}{\beta_n^2(\beta_n^2+\alpha^2+\alpha)} + M_{2e} \quad (14)$$

where the β_n is the nth positive root of

$$\beta\tan\beta = \alpha \quad (15)$$

The value of D' is obtained by substituting the drying constant K into the following formula.

$$D' = \frac{4K}{\pi^2} \quad (16)$$

where K is the slope of the straight line obtained by fitting the observed data to the following Arrhenius type equation with the least square method (known as a regression analysis in the field of statistics).

$$K = d\cdot\exp(-\frac{f}{T}) \quad (17)$$

Moreover, the value of the equilibrium moisture content Me in Equations(13) and (14) of each grain is calculated from

$$M_{1e} = M_0 + \frac{1}{2}\triangle M \quad (18)$$

$$M_{2e} = M_0 - \frac{1}{2}\triangle M \quad (19)$$

$\triangle M$ is also estimated from the follwing formula on the hysteresis between sorption and desorption isotherm which has been more improved than that reported in the previous study.

$$\triangle M = \frac{(3.371 - 0.08081t)(M_0 - M_0)}{H} \quad (20)$$

2. The suitability of the estimated values based on the theory for the observed data

Figures 2 through 6 show the change of standard deviation of moisture distribution in each temperature condition. The symbol ○s in these figures are the observed standard deviations and also ●s are the predicted ones from the moisture migration theory mentioned above ations agree well with the observed ones. Seeing these figures, the moisture distribution of grains gets to be more smoothly converged with the seed temperature going up.

Figures 7 through 11 show both the observed moisture distribution and thepredicted data from the theory in each seed temperature condition. Since the predicting the change of the moisture distribution in first stage of moisture migration is important in terms of the practical use, these figures are all at the time within 10hr after mixing. This is mainly because the moisture moves actively with this time period as shown in the figures. In all the figures, the shapes of the bserved moisture distribution as shown in these figures. This shows that the theory proposed in this study is effective for predicting the moisture distribution after mixing.

CONCLUSIONS

The barley seeds, which had almost the same moisture distribution as they had been in the field, were stored in bins at the constant temperature and its moisture distributions were measured at a time interval. As the result of applying the Murata's theory on the moisture migration to this problem, the predicted shapes of the moisture distribution of stored grains were similar to the observed ones and the validity of applying the theory to this problem was proved. The core formulae are equations (13) through (20) as shown in the previous section.

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SYMBOLS

D' = diffusion coefficient per unit length, [1/hr]

d = constant depending upon the variety of cereal grains, [1/hr]

f = constant depending upon the variety of cereal grains, [K]

H = correcting factor, [%, dry basis]

M = moisture content of a cereal grain[%, dry basis]

$\triangle M$ = moisture content difference between equilibrium moisture content of sorption and desorption[%, dry basis]

$\bar{M}$ = average moisture content of grains stored in an air tight bin, [%, dry bais]

T = absolute temperature, [K]

t = temperature, [°C]

α = no dimensional mass transfer coefficient corresponds to the Biot number in heat transfer phenomena, [-]

θ = time, [s]

SUBSCIPTION

e = equilibrium

0 = initial

1 = higher moisture content

2 = lower moisture content

REFERENCES

1)CRANK, J. 1975. The Mathematics of Diffusion (2nd Edition). Oxford University Press. 60-61.

2)JIN, Z., R. YAMASHITA and K. GOTO. 1990. Study on the Grain Storage Drying. J. of JSAM. 52(6):87-93.

3)MURATA, S., A. TAGAWA, T. KAWANO and S. ISHIBASHI. 1989. Simulation of Moisture Transfer among Cereal Grains. J. of JSAM. 51(4):57-61.

4)TSAI, C. L., R. YAMASHITA and K. GOTO. 1987. Moisture Distribution of Cereal Grain in Post-Harvest Processing. J. of JSAM. 49(6):599-604.

5)TSAI, C. L., R. YAMASHITA and K. GOTO. 1988. Characteristics of Moisture Transfer and Quality by Mixing of Rice. J. of JSAM. 50(3):117-121.

6)YAMASHITA, R. and A. OIDA. 1965. Moisture Transfer of Rough Rice. J. of JSAM. 27(4):261-265.

7)YAMASHITA, R., C. L. TSAI, Z. JIN and K. GOTO. 1986. KOKUMOTSU NO SUIBUN-IDOTOKUSEI NIKANSURU KENKYU ("Study on the Moisture Transfer of Cereal Grains" in English). J. of Kansai Branch of JSAM. Vol. 59:27-30.

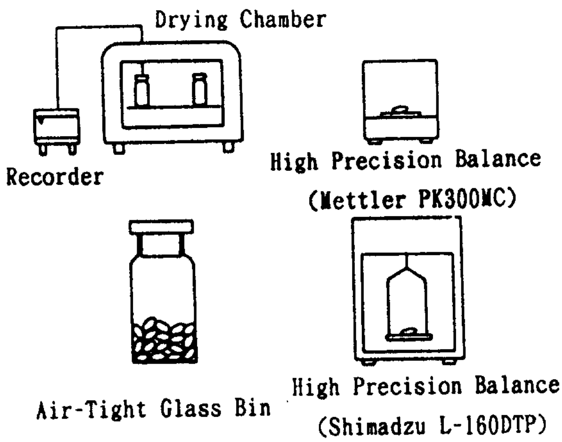

Fig. 1　Schematic diagram of the apparatus

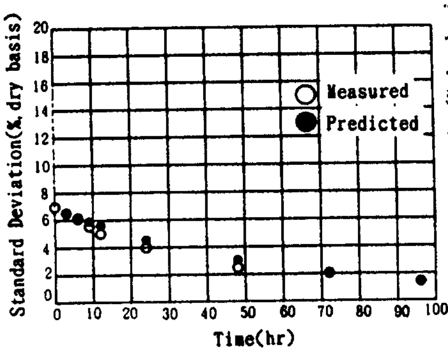

Fig. 2　Plot of standard deviation against time (10°C)

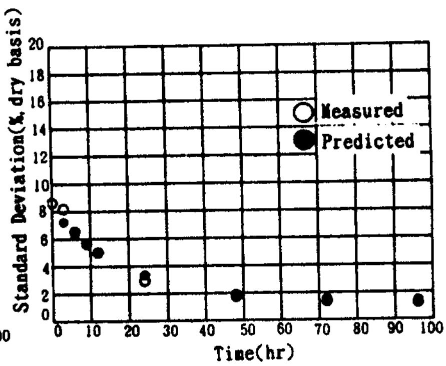

Fig. 4　Plot of standard deviation against time (30°C)

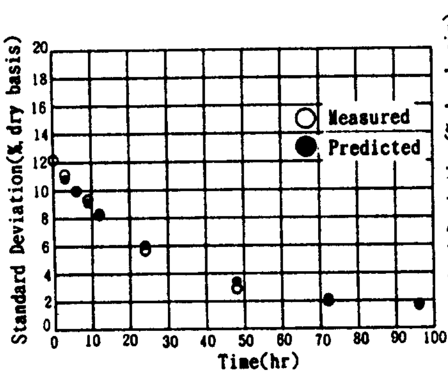

Fig. 3　Plot of standard deviation against time (20°C)

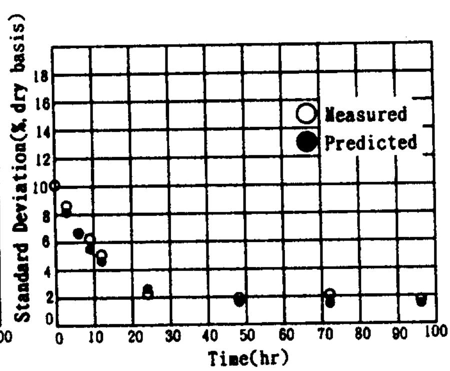

Fig. 5　Plot of standard deviation against time (40°C)

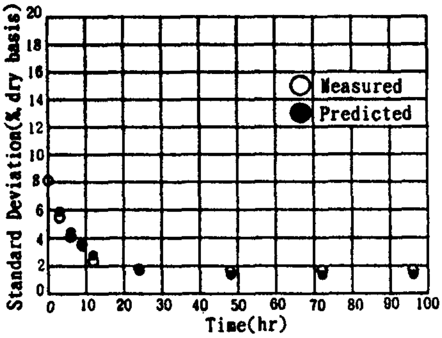

Fig. 6 Plot of standard deviation against time (50°C)

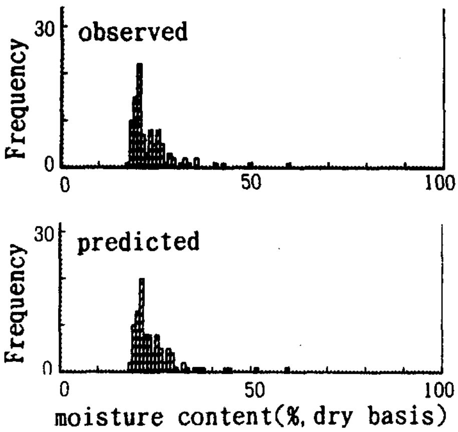

Fig. 7 Comparison of the predicted moisture distribution with the observed (10°C, 3hrs after stored)

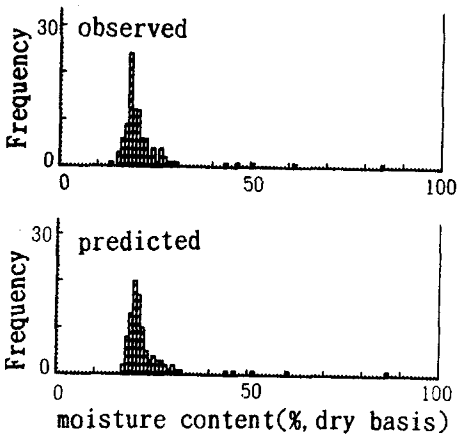

Fig. 8 Comparison of the predicted moisture distribution with the observed (20°C, 9hrs after stored)

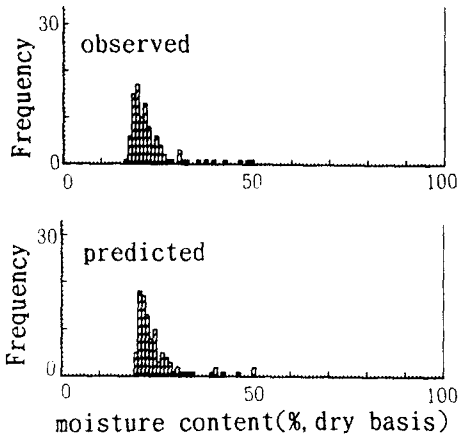

Fig. 9 Comparison of the predicted moisture distribution with the observed (30°C, 9hrs after stored)

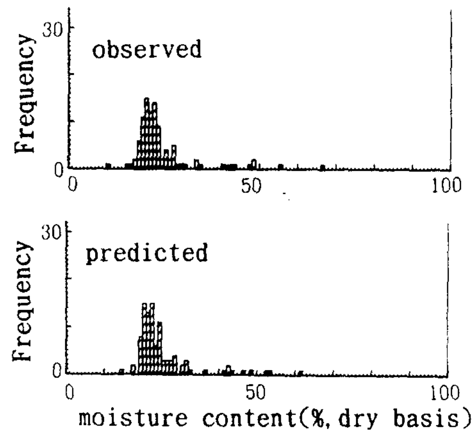

Fig. 10 Comparison of the predicted moisture distribution with the observed (40°C, 3hrs after stored)

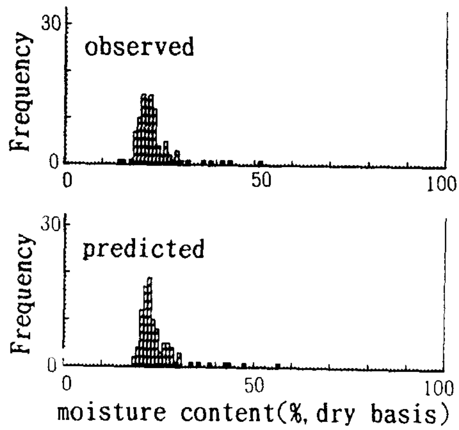

Fig. 11 Comparison of the predicted moisture distribution with the observed (50°C, 3hrs after stored)