# The Prediction of Rice Taste Value for the Post-drying Paddy

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**Abstract:** The heat and mass transfer regular inside rice is described with the evaporation front theory when the rice is dried, and the problems are solved with the finite element method. Considered the results, the variable process of the rice taste was simulated during drying. It is verified that the experiment value corresponds to the predicting value. The results in this paper can be applied to analyze and predict the rice taste value under different drying technology parameters. [Nature and Science, 2004,2(2):83-85]

**Key words:** evaporation front theory; taste value; rice

## 1 Introduction

Drying is an important process for the rice post-harvest treatment. In the course of drying, the activity constituent, such as amylose, protein, etc, within the rice is apt to deteriorate (Zheng, 1999). If the moisture diffuses quickly inside the rice, the cell membrane is destroyed. Those changes destroy the rice taste, and so the viscosity and flavor decreases, hardness increases, which lead to the cooked rice decreasing the characteristics flavor and taste.

In this paper, the change regularity is analyzed when the paddy is dried, and the taste value is predicted for the post-drying rice. The rice taste is an important index that indicates rice quality of taste, and the taste value is measured with taste analyzer meter (Japan, ATAKA-10A), which establish the base on determining the reasonable drying technology of the rice, and harmonize the relations between the dryer productivity and drying quality post-drying of the paddy.

## 2 Models of the Rice Taste Value Established

Bruce (1992), Courtoris (1995), Pan yongkang (1998) researched wheat and corn product quality change regularity after dried, which is analyzed in this paper. On the basis of the research, a result was obtained that change regularity of the rice taste accord with the one step kinetic equation.

$$-\frac{ds}{dt} = kS \quad (1)$$

On above equation, S is the taste value of the rice, t is the time of drying process, and k is the kinetic constant.

Equation ( 1 ) is handled with integral calculus, and obtain the result,

$$S=S_0e^{-kt} \quad (2)$$

$S_0$ is the initial taste value.

The drying temperature is a key factor that influences the rice taste quality. The effect factor $k$ can be determined by following formula.

$$k=k_0\exp(-\frac{E}{RT}) \quad (3)$$

$k_0$ is the frequency factor that indicates comprehensive coefficient which can express the internal constituents collide for the temperature is enhanced and chemical reactions occur. E is activity energy of constituent reaction, and T is absolute temperature of the heat air. R is the general gas constant. R=8.314 kJ/(mol.K).

Frequency factor $K_0$ is related to moisture, and it can be expressed with the following formula.

$$k_0=exp(z_1+z_2M) \quad (4)$$

$z_1$, $z_2$ are the property constants, for paddy, $z_1$=119.5, $z_2$=14.1.

Combined the equation (3), (4), and (2), the following equation were obtained.

$$S = S_0 \exp\left\{-\exp\left[\left(-\frac{E}{RT} + z_1 + z_2 M\right)t\right]\right\} \quad (5)$$

The formula 5 shows that the change regularity of the rice taste is related to the drying temperature, moisture and duration during drying. In order to analyze deeply the change regularity of the rice taste during drying, it is necessary to establish the mass and heat transfer model to calculate the temperature and moisture value at certain time during paddy drying process.

## 3 The Model of the Mass and Heat Transfer During Drying

Paddy is character of porous glue material, whose inter moisture is non-continuous. In the same direction, moisture diffused velocity is smaller than the velocity of evaporating during drying. Therefore, it assumes that there exists a moving front interface of evaporating, which is defined wet area from the center to the evaporating front interface (EFI). In the wet area, moisture diffuses with the liquid state, then evaporates and turns into gas at EFI. It is defined dry area from the EFI to the rice surface. In dry area, moisture diffuses with the gas state. The EFI moves from surface to the inside rice with the drying proceed.

Coupling function between temperature and moisture should be considered, when mass and heat transfer is studied in wet area. Rice is simplified a cylinder whose radius is r, and the distance to the EFI is s (as Figure 1 showing).

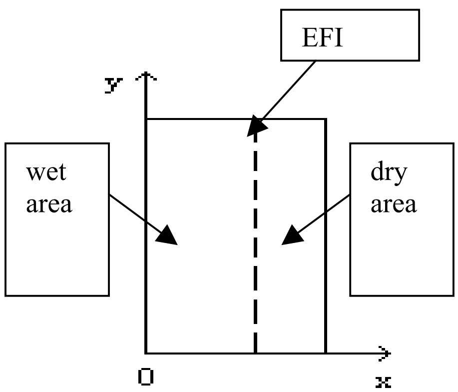


**Figure 1 Simplifying paddy as cylinder**

### 3.1 Dry area (r-s≤x≤r)

In dry area, moisture is equal to the equilibrium moisture which is in accordance with conditions of drying and rice only has heat transmitting without moisture gradient. The function of the heat transmitting is list as following.

$$M_i=M_e \tag{6}$$

$$\rho_q c_q \frac{\partial T_1}{\partial t} = div(k_q \nabla T_1) \tag{7}$$

$\rho_q$ is the density of the dry area, $\rho_q$=550 kg/m$^3$. The $c_q$ is the heat coefficient of the rice, $c_q$ =0.9214+0.545M. $k_q$ is the heat conduction coefficient of the rice, $k_q$ =0.1+0.011$M$. T is the temperature of the dry area. t indicates the dry duration. $M$ is the moisture content of the paddy (%, w.b).

### 3.2 Wet area (0≤x≤r-s )

During drying, moisture and thermal is transmitted simultaneously internal of the wet area, which is descrybed with luikov system equation.

$$\rho_q c_q \frac{\partial T_1}{\partial t} = div[k_q + \varepsilon L k_m \nabla M_2] \tag{8}$$

$$\rho_q \frac{\partial M_2}{\partial t} = div[k_m \delta \nabla T_2 + k_m \nabla M_2] \tag{9}$$

where, L is the vaporization potential thermal, *L=1000(1+2.566exp((−20.176M)(2505-2.836)).*

δ is the sort coefficient that describes coupling function between moisture and thermal, δ=0.015.

ε is the evaporating coefficient of internal moisture, ε=0.7.

$k_m=a_m \rho_q c_m$ ; The m represents quantity.

Initial condition: At the initial stage of the drying, the temperature and the moisture of the paddy is well distributed.

$$T(x,0)=T_0 \tag{10}$$

$$M(x,0)=M_0 \tag{11}$$

Boundary condition: it is assumes the temperature on the rice surface maintains constant Tr.

$$T_1(0,t)=T_r \tag{12}$$

There is same the temperature and moisture at the interface between the wet and dry area.

$$T_1(s,t)=T_2(s,t)=T_v \tag{13}$$

$$M_1(s,t)=M_2(s,t)=M_e \tag{14}$$

The moisture and thermal balance equation at the EFI was listed.

$$k_1 \frac{\partial T_1(s,t)}{\partial t} - k_2 \frac{\partial T_2(s,t)}{\partial t} = (1-\varepsilon) M(s,t) \rho_2 L \frac{ds(t)}{dt} \tag{15}$$

$$\frac{\partial M_2(s,t)}{\partial t} + \delta \frac{\partial T_2(s,t)}{\partial t} = 0 \cdot \tag{16}$$

### 3.3 Solving the equation with finite element method

The Crank-Nicolson method was used to solve equation (6).

$$( k_q[k] + \rho_q c_q \frac{2[N]}{\Delta t})\{T\}_{i+1} = (k_q[K] - \rho_q c_q \frac{2[N]}{\Delta t})\{T\}_i \tag{17}$$

the solution of the equation (8) and (9) was obtained under the same method.

$$\left(\frac{2C[N]}{\Delta t} - [K]\right)\{T_2\}_{i+1} = \left(\frac{2C[N]}{\Delta t} + [K]\right)\{T_2\}_i + B[K](\{M_2\}_i + \{M_2\}_{i+1}) \tag{18}$$

$$\left(\frac{2F[N]}{\Delta t} - E[K]\right)\{M_2\}_{i+1} = \left(\frac{2F[N]}{\Delta t} + E[K]\right)\{M_2\}_i + [K](\{T_2\}_i + \{T_2\}_{i+1}) \tag{19}$$

In order to ensure equations (18) and (19) to stabilize without conditions, the reasonable time step Δt was determined to avoid the oscillating solution.

$$\Delta t \le -\frac{2}{\lambda_{\max}} \tag{20}$$

The $\lambda_{\max}$ is the maximum characteristics value of the matrix [N] and [K].

The equation (17) and (18) was combined to solve, the value of the $\{M\}_{i+1}$ and $\{T\}_{i+1}$ were obtained. The value of the temperature $T_i$ and moisture $M_i$ at certain time t can be obtained on the basis of the hypothesis that the temperature and the moisture of the paddy is well distributed at the initial stage of the drying. Therefore, all distributes value of the temperature and moisture field can be calculated at one space and time.

The average temperature and moisture of the rice quality were simplified as following.

$$\overline{T} = \frac{\sum_{e=1}^{n} \frac{\pi A^{(e)}}{6}[(2r_i + r_j + r_m)T_i + (r_i + 2r_j + r_m)T_j + (r_i + r_j + 2r_m)T_m]}{\sum_{e=1}^{n} \frac{2\pi}{3} A^{(e)}(r_i + r_j + r_m)} \tag{21}$$

$$\overline{M} = \frac{\sum_{e=1}^{n} \frac{\pi A^{(e)}}{6}[(2r_i + r_j + r_m)M_i + (r_i + 2r_j + r_m)M_j + (r_i + r_j + 2r_m)M_m]}{\sum_{e=1}^{n} \frac{2\pi}{3} A^{(e)}(r_i + r_j + r_m)} \tag{22}$$

The soft ware turbo C 2.0 was applied to solve the equations (5), (17), (18) and (19). The process include following step.

(1) Inputting the size of the rice and the information of the triangle three nodes element.

(2) Inputting the initial moisture of the rice.

(3) Inputting the information of the boundary conditions and the system of the time different.

(4) Setup drying duration t.

(5) Calculating the parameters value of the rice property and heated air.

(6) On the basis of the equations (17), (18), and (19), the sub procedures, which are subject to the distribution moisture and temperature inside paddy, were used to calculate the value of the moisture and temperature at each node.

(7) Setup the circulation times N =N+1 and return the step 5.

(8) If the information of the each nodes was obtained, the solve process is over and all data was output.

(9) The data from step (8) was entered into the equations (21) and (22) to calculate the value of the average moister and temperature.

(10) The value of the average moister and temperature were entered into the equation 5, the taste value of the post-drying rice was obtained.

## 4 Verified Experiment

To verify the validity of the equation (5), an experiment was conducted. The initial rice moisture is 21.5% (wet basis). The original rice taste value is $S_0$ 72.5%. Drying temperature is the 40℃. The curve in the Figure 2 suggests the results that the truth value accord with the theory value, and the equation (5) can be applied to predicate the taste value of the post-drying rice.

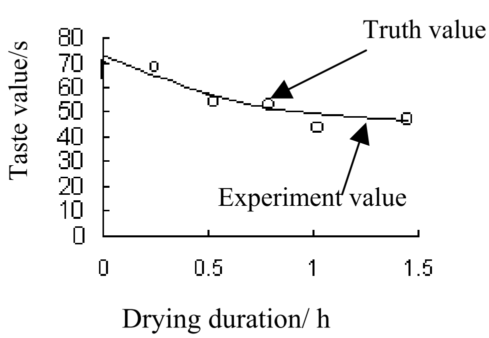


**Fig. 2 Post-drying rice taste value theory and truth value**

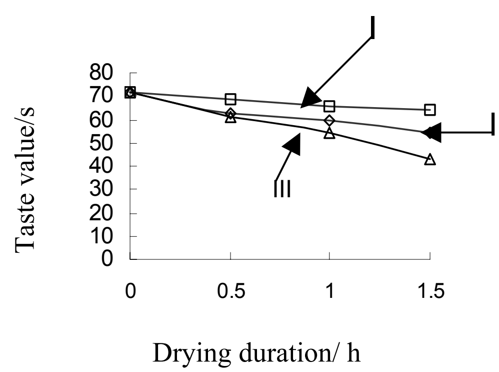


**Fig. 3 Rice taste value of different paddy drying technology**

To ensure the quality of the post-drying rice and to decrease crack, the equation (5) was used to predict the change rate of the rice taste at different parameters and technology of the rice drying. Either Two stages or multi-stages drying technology often was applied to dry the rice. However, the paddy is characteristic of high thermal-sensitive grain, which is apt to degradation during drying. The higher is the initial paddy moisture; the lower is the temperature, which lead to the taste inferior.

Figure 3 describes the variable rate of the rice taste under different two stages drying technology on basis of the equation (5). Analyzed three drying technologies, the variable rate of the rice taste is the smallest if the drying temperature combination is successively 40□+60□(□) and the biggest of the variable rate of the rice taste is the drying temperature combination 60□+40□(□). The drying temperature combination 50□+50□ (□), which lead to the rice, taste variable lie to the middle degree.

## 5 Conclusion

In this thesis, the mathematical model that can predict the variable taste rate of the post-drying paddy is developed, which can be applied to determine the reasonable drying technology process and parameters.

A conclusion was put forwarded that the rice taste variable rate is the smallest under the condition of the drying temperature from low to high among the drying technologies, which are developed in this thesis.

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