

EXAMINATION CONCERNING MODELING DISSOLVING PROCESS IN VACUUM PAN SALT

Tomoyuki Kamoshida , Masami Hasegawa

Research Institute of Salt and Sea Water Science, The Salt Industry Center of Japan, 13-20, Sakawa 4-chome, Odawara-shi Kanagawa 256-0816, Japan

Key Words :Simulation model, Dissolving process, Vacuum pan salt

1. Introduction

After the salt monopoly institution in Japan was abolished in 1997, many kinds of edible salt have been circulated to the market. These products are difference in their particle size and shape due to their manufacturing method. Therefore the difference is expected to be caused in usability when cooking and food processing. Especially, in cooking or food processing, salt is usually dissolved prior to use. In such case, dissolving rate must be considered, because the rate will be changed according to the particle size and shape.

In this paper, we studied the simulation model of dissolving process, based on Hixson et al's dissolving equation¹⁾, of cubic salt crystals (Vacuum pan salt). Moreover, using obtained model in this study, we estimated dissolving rate of commercially available salts and evaluated the practicability.

2. Experiments

2.1 Samples

Vacuum pan salts were carefully washed by ethanol to remove bittern adhered on the crystals, and then dried. The samples were classified by sieving to the range of 0.15 to 2.00mm. On the other hand, commercially available salts which have a specific particle size distribution (as divided by normal distribution) shown in Table 1 were prepared.

In this study, the sieves that used were provided in Japanese Industrial Standard (JIS)²⁾.

2.2 Experimental method

Experimental procedure, including apparatus and operational conditions, was carried out by means of To et al's method³⁾. 2000ml of purified water was introduced to 3000ml sized beaker equipped with temperature control unit and double wing stirrer whose length was 11.5cm. The water was maintained constantly at 293K and stirred by 300rpm. Then 20g of sample was added into the beaker, its electrical conductivity was measured every 0.1 second. Obtained analogue data was converted to digital one to store personal computer. Measurement was repeated 5 times in every sample, and the electrical conductivity was converted to its solution concentration(C). Then we calculated an average of C as observed values.

3. Result and Discussion

3.1 Simulation Model

Hixson et al proposed; when solution concentration C_t during dissolving process is much smaller than saturated concentration C_s (Sink condition; $C_t / C_s < 0.1$), the reduction weight of particles having uniform size according to elapsed time can be described by the equation(1)¹⁾.

$$M_0^{1/3} - M_t^{1/3} = \frac{2KC_s M_0^{1/3}}{\rho D f} t \quad (1)$$

t ; time(sec), K ; dissolving rate coefficient(cm sec^{-1}), D ; particle size(cm)
 C_s ; saturated concentration(g cm^{-3}), M_0 ;
 initial sample weight(g), M_t ; residual of
 sample weight(g), ρ ; density of sodium
 chloride(g cm^{-3}), f ; shape coefficient(-).

As both sides of equation (1) are divided by $M_0^{1/3}$, equation (2) is obtained. Change of sample weight during dissolving process will be linear.

$$\left(\frac{M_t}{M_0}\right)^{1/3} = 1 - \left(\frac{2KC_s}{\rho f}\right)\left(\frac{t}{D}\right) \quad (2)$$

Then, the mesh size of using sieve is defined D_i , and one of smaller mesh size is defined D_{i-1} . Average shape coefficient between D_i

and D_{i-1} is defined f_{iav} . The weight change w_{0i} between D_i and D_{i-1} is described by equation (3).

$$w_{0i}^{1/3} - w_{ti}^{1/3} = \frac{2KC_s w_{0i}^{1/3}}{\rho D_i f_{iav}} t \quad (3)$$

w_{ti} ; residual sample weight between meshes(g).

As both sides of equation (3) are divided by w_{0i} , equation (4) is obtained.

$$\left(\frac{w_{ti}}{w_{0i}}\right)^{1/3} = 1 - \left(\frac{2KC_s}{\rho f_{iav}}\right)\left(\frac{t}{D_i}\right) \quad (4)$$

Using equation (5), w_{ti} is converted to concentration change c_{ti} when w_{0i} is dissolved.

So equation (6) is obtained.

$$w_{0i} = w_{ti} + c_{ti} V \quad (5)$$

V ; solution volume(cm^3).

$$c_{ti} = \frac{w_{0i}}{V} \left[1 - \left\{ 1 - \left(\frac{2KC_s}{\rho D_i f_{iav}} \right) t \right\}^3 \right] \quad (6)$$

On the other hand, as the relationship between C_{ti} and the Integrated value of change in concentration C_t when the sample is dissolving is expressed by equation (7), C_t

during dissolving process of sample having a normal distribution can be described by equation (8).

$$C_t = \sum_{i=1}^n c_{ti} \quad (7)$$

$$C_t = \sum_{i=1}^n \frac{w_{0i}}{V} \left[1 - \left\{ 1 - \left(\frac{2KC_s}{\rho D_i f_{iav}} \right) t \right\}^3 \right] \quad (8)$$

3.2 Evaluation of Simulation Model

Figures 1 and 2 show observed results and predictions from equation (8) of the commercially available salts shown in table 1

during their dissolving process. The dissolving rate coefficient is used a value of $1.05 \times 10^{-2} \text{ cm} \cdot \text{sec}^{-1}$ obtained by To et al's³⁾.

Table 1 Particle size distribution of the commercially available salts

No.	Average size D_{av} (mm)	Standard deviation σ (mm)
1	0.332	0.093
2	0.648	0.232

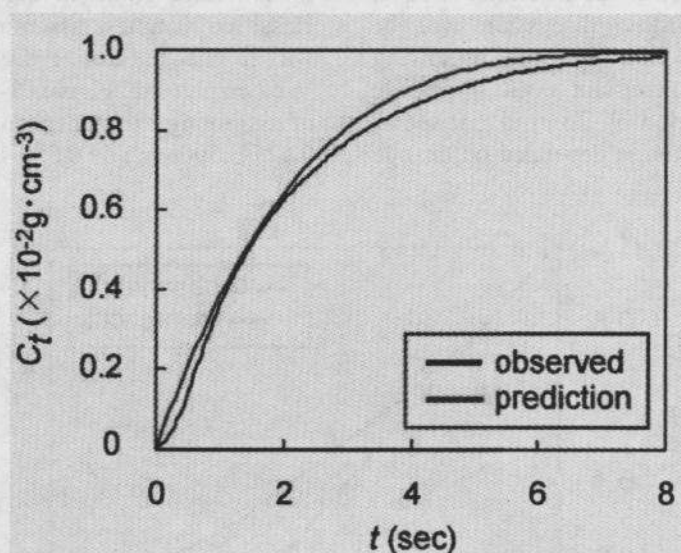


Figure 1 Comparison prediction value from equation (8) with observed one (commercially available salt No.1)

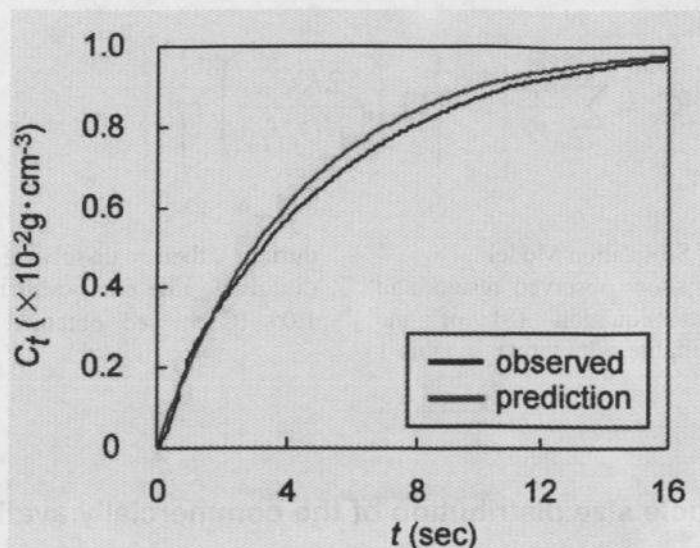


Figure 2 Comparison prediction value from equation (8) with observed one (commercially available salt No.2)

By using equation (8), the difference of dissolving property on particle sizes can be easily predictive. However, there are little bit difference between the observed and the prediction in the stage of the latter area of dissolving. So, further discussion will be necessary. Considering that the dissolving rate coefficient is constant even if particle size changes reported by To et al¹⁾, it seems that this phenomenon is depended on change of shape coefficient f_{iav} when dissolving.

3.3 Consideration of Shape Change

From the result of 3.2 section, we studied that shape change factor was introduced to the model, based on dissolving experiment of the classified samples, assuming that the shape will be changed during dissolving process of Vacuum pan salt. Figures 3-5 show the results of dissolving experiment for 0.150-0.250mm, 0.425-0.500mm and 0.850-1.00mm particles.

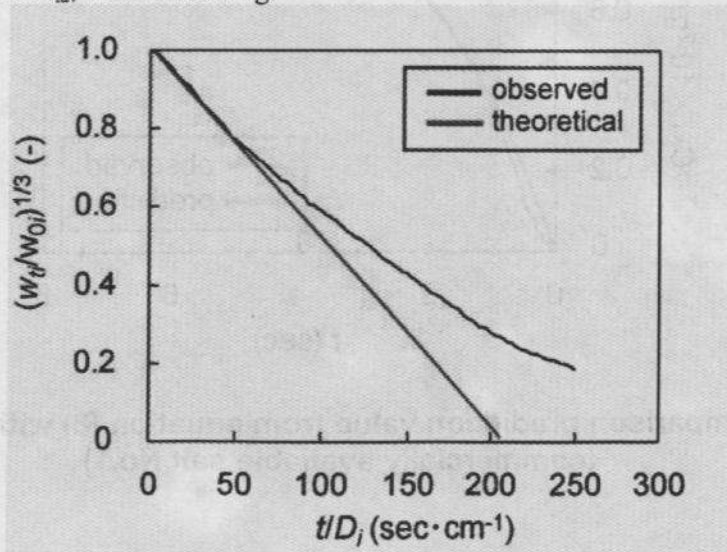


Figure 3 Comparison theoretical value, which is relationship between t/D_i calculated by equation (4) and $(w_t/w_0)^{1/3}$, with observed one (0.150-0.250mm particle)

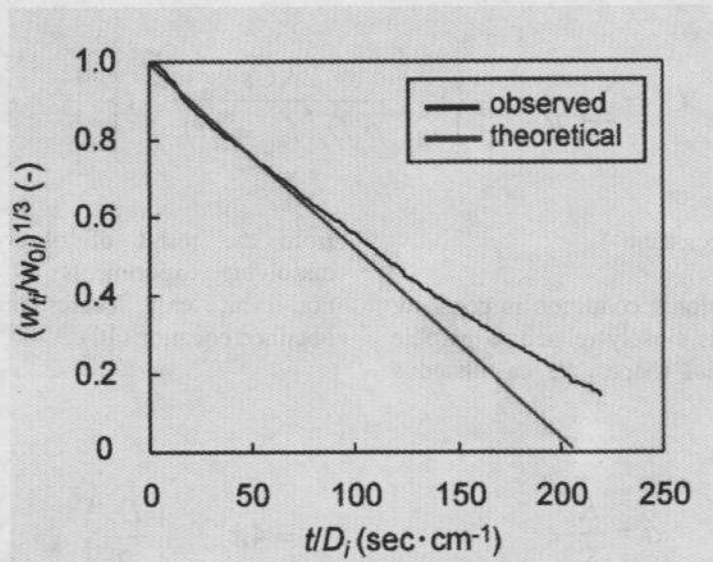


Figure 4 Comparison theoretical value, which is relationship between t/D_i calculated by equation (4) and $(w_t/w_{0i})^{1/3}$, with observed one (0.425-0.500mm particle)

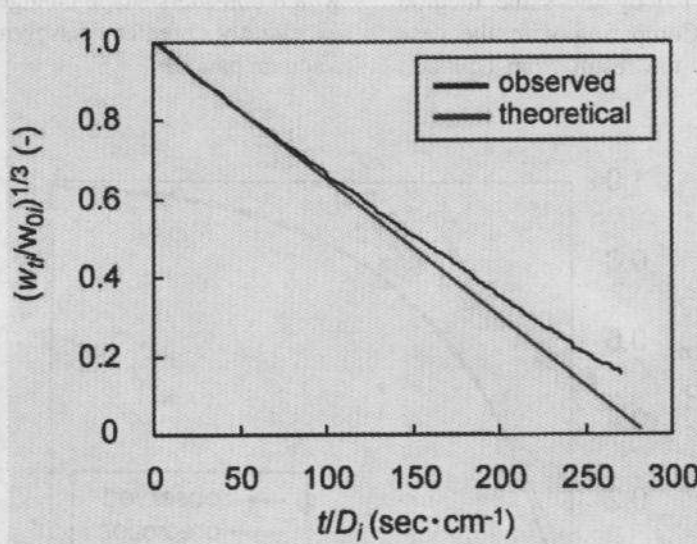


Figure 5 Comparison theoretical value, which is relationship between t/D_i calculated by equation (4) and $(w_t/w_{0i})^{1/3}$, with observed one (0.850-1.000mm particle)

In equation (4), the relationship between t/D_i and $(w_t/w_{0i})^{1/3}$ can be described by linear, when the shape coefficients are constant. The reason why the slopes are different on the data of Figures 3-5 is that the initial shape coefficients are different each other depending on their particle sizes. Especially, as a shape of 0.850-1.00mm particle shown in Fig.5 is almost spherical, the slope becomes

smaller than one of smaller particle. So we think that dissolving rate of smaller particle becomes low, because the initial shape, cubic, becomes gradually spherical during dissolving. So, as we assume that the shape will be changed during dissolving, the correction term that the shape coefficient changes as time elapsed is introduced to equation (8). So, equation (9) is obtained.

$$C_t = \sum_{i=1}^n \frac{w_{0i}}{V} \left[1 - \left\{ 1 - \left(\frac{2KC_s}{\rho D_i (f_{iav} + at)} \right) t \right\}^3 \right] \quad (9)$$

a ; experimental constant(-).

In case of operational condition is constant, we think that a is closely related to particle size and its initial shape. We calculated a

from the result of observed data from dissolving experiments by means of the non-linear least squares method and then obtained equation (10).

$$a = \frac{K^2}{S_{pi}} \quad S_{pi} = 4\pi f_{iav} \left(\frac{D_i}{2} \right)^2 \quad (10)$$

3.4 Evaluation of the Model considering Shape Change

Figures 6 and 7 show the validated result of equation (9) and (10) by the same method described in 3.2. Comparing with the case using equation (8), the result from equation

(9) and (10) predicts properly the observed one even in the latter stage of dissolving. From these results, this simulation model which considers shape change of particle can excellently predict dissolving process of Vacuum pan salt.

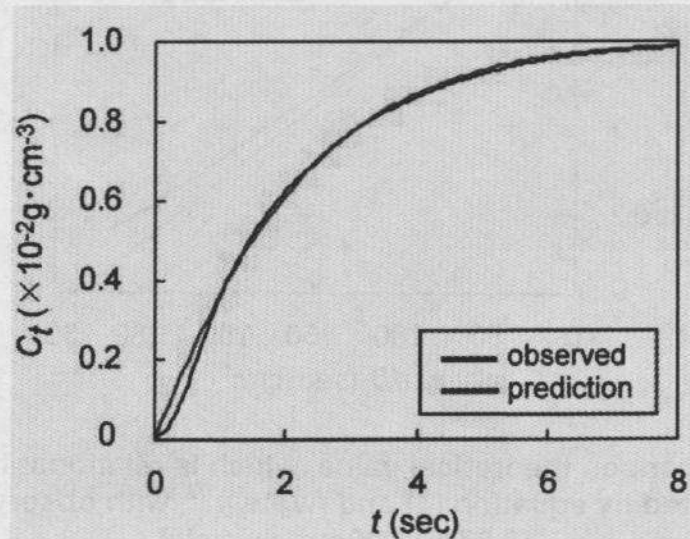


Figure 6 Comparison prediction value from equation (9) with observed one (commercially available salt No.1)

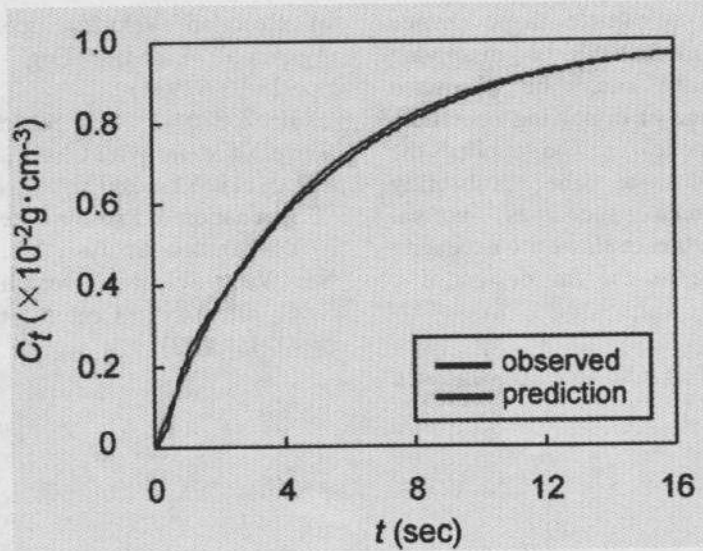


Figure 7 Comparison prediction value from equation (9) with observed one (commercially available salt No.2)

3.5 Dissolving Model of Sample obeyed by Probability Distribution

In general, it is known that particle size distribution of the product relates well to a probability distribution equation⁴⁾. In this section, we studied a new simulation model

of dissolving process of the sample with particle size distribution.

If the size distribution of sample is depended on normal probability distribution, its distribution can be described by equation (11).

$$F(D_i) = \frac{1}{\sqrt{2\pi}} \exp\left\{-\frac{u_i^2}{2}\right\} \quad u_i = \frac{D_i - D_{av}}{\sigma} \quad (11)$$

$F(D_i)$; probability(-), D_{av} ; average size(cm),
 σ ; standard deviation (cm),
 u_i ; standard variable (-)

As the sample weight between meshes w_{0i} is expressed by the product of initial sample weight M_0 and the probability of particle size ($F(D_i) - F(D_{i-1})$), equation (12) is obtained.

$$w_{0i} = M_0 \left\{ \int_{-\infty}^{D_i} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{u_i^2}{2}\right) du_i - \int_{-\infty}^{D_{i-1}} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{u_i^2}{2}\right) du_i \right\} \quad (12)$$

By the above procedure, dissolving process of Vacuum pan salt which obeys the normal probability distribution can be predictive, using the data of average diameter and standard deviation instead of one of the sieving method, by which w_{0i} obtained from equation (12) introduces to equation (9).

4. Conclusion

In this study, we studied a new simulation

model for dissolving process of Vacuum pan salt. Hixson et al's equation which was examined about the particles of uniform size was tried to convert into a simulation model for particles having a size distribution. In this model, the reduction weight change of the particles within each various ranges of particle size is simulated, the dissolving process of the entire sample is presumed by integrating those reduction weights. In

addition, a term of particle shape change introduces to the model, the dissolving process successfully could be presumed against elapsed time of dissolving operation. Moreover, this model can be applied the particles according to the probability distribution formula such as normal probability distribution et al, we are expecting that it is possible to use for design of a vacuum pan salt.

References

- 1) A. W. Hixson, J. H. Crowell, "Dependence

of Reaction Velocity upon Surface and Agitation", Ind. Eng. Chem., 23, pp.923-931(1931)

- 2) JIS Z 8801-1, "Test Sieves - Part 1 : Test Sieves of Metal Wire Cloth", (2000)

Tomoyuki Kamoshida, Masami Hasegawa, "Examination of Particle Size

- 3) Distribution Analysis Methods" Papers of Sea Water Science Research Laboratory the Salt Industry Center of Japan, 4, pp.41-45(2002)