AIDIC *Conference Series*, Vol. 9, 2009
Editor Sauro Pierucci
DOI: 10.3303/ACOS0909021

ISBN 978-88-95608-10-5 ISSN 2036-5969

QUANTITATIVE EVALUATION OF THE DESIGN PARAMETERS REQUESTED IN A BEEF AND PORK DRYING OPERATION

Yasuyuki Konishi[a] , Masayoshi Kobayashi[b]

[a]Hokkaido Industrial Technology Center, Japan
[b]Advanced Technology Institute of Northern Resources, Japan

For the design parameters requested in the drying operations of beef (produced in Australia, B_A, and Hokkaido, B_H) and pork (produced in Hokkaido, P_H), five design parameters, effective moisture diffusivity (*De*, m^2/s), activation energy of *De* (E_D, kJ/mol), correlation time (τ_C, s) determined by a proton NMR technique, lipid ratio (*LR*, %), and hardness (N_P, Newton/m^2), were quantitatively evaluated as a function of a variety of the water species retained in the beef- and pork-meat tissues. All five parameters, without regard for the geographic origin of the beef and pork, demonstrated a critical value of moisture content (c*W*, %-d.b.) which was strongly related to a critical value of τ_C (cτ_C). They were evaluated as c*W* = 130%-d.b. and cτ_C = 1.0×10^{-8}s. At the two values, the five design parameters showed a drastic dynamism indicating two different water species in the tissues of the beef and pork as water species-A_1 (at $\tau_C = 0.1\sim0.8\times10^{-8}$s < c$\tau_C$) and water species-$A_2$ (at $\tau_C = 1.0 \sim 10\times10^{-8}$s > c$\tau_C$). The water species-$A_1$ was characterized as a weakly restricted water species indicating almost identical values of *De*, E_D, *LR*, and N_P without depending on the value of τ_C. A_2 was demonstrated as a strongly restricted water species indicating characteristic behavior depending on each of the five design parameters. The pre-exponential factors, δD_0's, for the *De'*s of the beef and pork were evaluated in the range of $1.3 \sim 4.0\times10^{-7}$ for species-A_1 and less than 9×10^{-8} m^2/s for species-A_2. Regarding the influence of *LR* on *De*, species-A_1 gave an identical value of *De*, whereas *De* for species-A_2 decreased with increasing the amount of *LR*.
The five parameters proposed could be effectively used to design the drying products of B_A, B_H, and P_H, and the water species-A_1 and -A_2 retained in the three meats were clearly distinguished by visualizing them as a function of τ_C.

NOMENCLATURE

B_A	*beef meat produced in Australia* (--)
B_H	*beef meat produced in Hokkaido, Japan* (--)
$C\tau_C$	*critical value of correlation time of water proton* (s)
D	*moisture diffusion coefficient* (m^2/h)
D_0	*frequency factor of D* (m^2/h)
De	*effective moisture diffusion coefficient* (m^2/h)
De^0	*pre-exponential factor of effective moisture diffusivity* (m^2/h)
E_D	*activation energy of moisture diffusivity* (kJ/mol)
I	*nuclear spin quantum number of water proton* (= 0.5) (--)
L_a	*half distance of a-axis of the rectangular sample* (m)
L_b	*half distance of b-axis of the rectangular sample* (m)
L_c	*half distance of c-axis of the rectangular sample* (m)
LR	*Lipid ratio for the meat* (%)
N_P	*Hardness of meat products* (Newton/m^2)
P_H	*pork meat produced in Hokkaido, Japan* (--)
R	*gas constant* (=8.314J/K·mol)

Please cite this article as: Konishi Y. and Kobayashi M., (2009), Quantitative evaluation of the design-parameters requested in a beef and pork drying operation, AIDIC Conference Series, 09, 177-186 DOI: 10.3303/ACOS0909021

r	*proton-proton distance of water molecule* (= 0.16 nm)
T_2	*spin-spin relaxation time of water proton* (s)
T_D	*drying temperature* (°C)
t	*drying time* (h)
W	*moisture content at the drying time t* (%-d.b.)
W_0	*initial moisture content at the time of PUP operated* (%-d.b.)
W_D	*initial moisture content of drying flesh sample* (%-d.b.)
We	*equilibrium moisture content* (%-d.b.)

Greek letters

ε	*porosity of the meat tissue* (--)
π	*the ratio of the circumference of a circle to its diameter*(=3.14)
γ	*gyromagnetic ratio of proton* (=2.675×10^{8} rad·T^{-1}·s^{-1})
$\hbar$	*modified Plank's constant* (=6.63×10^{-34} J·s)
ω_0	*resonance frequency* (=3.14×10^{9} s^{-1})
τ_C	*correlation time of water proton* (s)
χ	*labyrinth factor of the meat tissue* (--)
δ	*diffusibility* (=ε/χ)

1. INTRODUCTION

To design commercial food products, as has been described by various authors, a large number of parameters, such as the taste, nutrition, flavor, and color, should be taken into account. For the quantitative evaluation of the design parameters of food products, the physical and physicochemical identification of the chosen parameters should be carried out (Belton *et al.*, 2003). Regarding dry food products, in particular, the water species retained in the food tissues is one of the most important components imparting taste to foods. The water species is strongly related to the structure of food tissues accompanied by dynamic variation resulting from the dehydration process of foods in air or under forced drying conditions. The water species, therefore, assume diverse states in the physicochemical structure of foods influenced by the drying conditions. For the design of food products, the dynamic states of the water species must be clarified. Figure 1 is a schematic of a typical dehydration curve for beef and pork; the products are widely distributed on the curve depending on the moisture content. As demonstrated in previous studies (Konishi *et al.*, 2008(a) and 2008(b)), two different water species, species-A_1

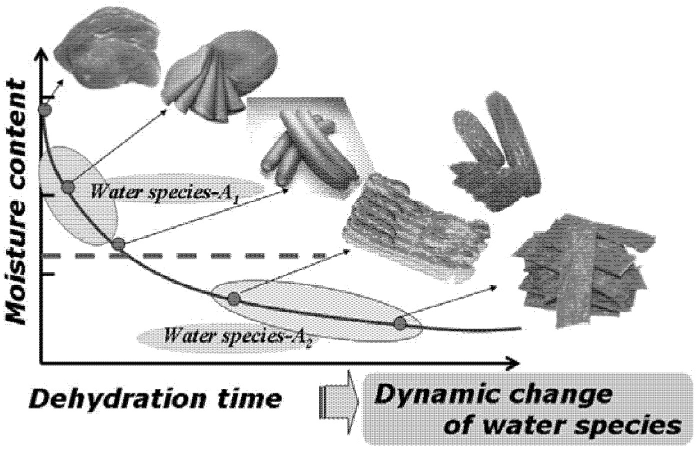

Figure 1. Dynamic change of the water species retained in the meat-products derived from the dehydration.

and -A_2, could exist in squid muscle tissue, depending on the specified moisture content, as distinguished in Fig. 1. Fig.1 illustrates the two water species producing characteristic meat-food products resulted from their moisture contents. The two water species must be carefully identified by using a variety of foods and quantitative design parameters. To this end, five design parameters, the hardness (N_P, Newton/m^2), amount of lipid (LR, g/g), correlation time of water species (τ_C, s) derived from the proton NMR method, effective diffusivity of water species (De, m^2/s), and activation energy of moisture diffusivity De (E_D, kJ/mol), were selected. Konishi *et al.* (2003) demonstrated that the dehydration dynamism of squid was strongly influenced by the multifunctional water species retained in the squid muscle. In fact, it was reconfirmed that this characteristic water species strongly influenced the five parameters, De (Konishi *et al.*, 2001(a), 2001(b)), E_D (Konishi *et al.*, 1999), N_P (Konishi *et al.*, 2008(b)), LR (Konishi *et al.*, 2008(b)), and τ_C (Konishi *et al.*, 2008(b)). Ruiz-Cabrera *et al.* (2004) demonstrated that the content of lipid in pork meat contributed to the reduction of De.

The objectives of this study are (1) to characterize the five design parameters responding to the quantitative evaluation of food quality; (2) to demonstrate a critical point distinguishing the two water species and exhibiting a drastic change influenced by the five design parameters; and (3) to clearly discriminate the five design parameters among the beef produced in Hokkaido (B_H) and Australia (B_A) and the pork produced in Hokkaido (P_H) in the course of a drying operation of the three meats.

2. EXPERIMENTAL

Two beef meats (produced in Australia, B_A and Hokkaido, B_H; 50mm square and 8±1.0mm in thickness) and a pork meat (produced in Hokkaido, P_H; 50mm square and 6±1.0mm in thickness) were used as a sample. The B_A, B_H and P_H had the initial moisture content of 230~280%-d.b.(dry base, W_D). The moisture content of the samples in the course of drying operation was evaluated as a dry base, W_0 (%-d.b.). The sample placed in a stainless steel net tray (4 meshes) that was mechanically hung from a strain gage transducer in the dryer. The sample weight was continuously recorded by the output of strain-gage transducer using a data-logger. Drying temperatures (T_D) of 40, 50, 60, 70 and 80°C were chosen. In the present experimental drying conditions, it was reconfirmed that the drying operations for the beefs and pork were within a falling-rate period.

For the effective discrimination of the water species in the beef and pork meats, a nuclear magnetic resonance (NMR) technique was used to measure the ^{1}H-NMR spectra and a spin-spin relaxation time (T_2) of water protons. The beef and pork meat samples cut into 2×2×10mm pieces were inserted into an NMR sample tube (4mm in inner diameter and 180mm in length). ^{1}H-NMR spectra were obtained using a JEOL A-500 FT-NMR spectrometer operating at 500MHz for protons. The observed frequency width was 20 kHz. The 90° pulse width was 12.5 μs, and the number of pulse repetitions was 8. The proton chemical shifts were measured by using a slight amount of water containing deuterium oxide as an external reference. All the NMR measurements were performed at 23.5±0.5°C. The spin-spin relaxation times, T_2, were obtained by the spin locking_method.

The value of T_2 obtained is related to the correlation time (τ_C) by using *Eq.*(1):

$$\frac{1}{T_2}=\frac{\gamma^4\cdot\hbar^2\cdot I(I+1)}{5r^6}\left(3\tau_c+\frac{5\tau_c}{1+\omega_0^{\,2}\cdot\tau_c^{\,2}}+\frac{2\tau_c}{1+4\omega_0^{\,2}\cdot\tau_c^{\,2}}\right) \tag{1}$$

where T_2 is the spin-spin relaxation time of the water proton (s), γ is the gyromagnetic ratio of a proton (= 2.675×10^8 rad·T^{-1}·s^{-1}), $\hbar$ is the modified Plank's constant (6.63×10^{-34} J·s), I is a nuclear-spin quantum number of a water proton (= 0.5), r is the proton-proton distance of a water molecule (0.16 nm), ω_0 is the resonance frequency of NMR (= 3.14×10^9 s^{-1}), and τ_C is the correlation time of a water proton (s). Using this equation, τ_C values at any given T_2 can be evaluated.

The hardness of the meat samples was measured by using a creep tester equipped with a V-shaped plunger of 30 mm in width and 1 mm in thickness to press a 60% of a meat size of 2~8×10×50 mm evaluating the value of N/m^2. The lipid ratio was evaluated by using a calibration curve which was determined by the NMR method using the proportion change of the meat-lipid mixture, similar to the Nagy and Kormendy's report (2003).

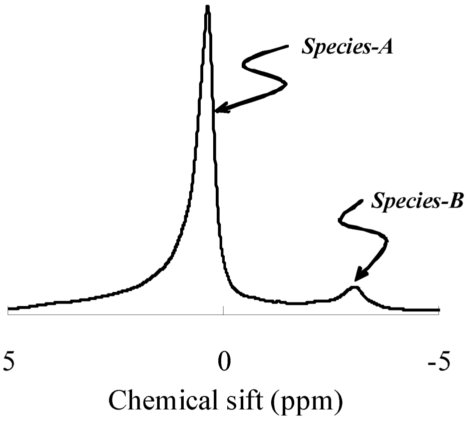

Figure 2. Typical example of ^{1}H-NMR spectrum for the B_H (W_0=82%-d.b.)

3. RESULTS AND DISCUSSION

3.1. Dynamic Evaluation of the Water Species Characterizing the Quality of Beef and Pork by Using Proton NMR Spectroscopy

As has been demonstrated by many researchers (Miwa *et al.*, 2003; Lechert, 1981; Barara *et al.*, 1999; Labbé *et al.*, 2002), water species in solid materials are classified diversely with variously restricted strengths on the basis of physicochemical data, such as physisorbed-, chemisorbed-, frozen-, unfrozen- (Fasina, 2005; Muir, 1984), bound- (Sadikoglu *et al.*, 1998; Podorozhko, 2000), free-, strongly restricted-, and weakly restricted-water. In a previous study (Konishi *et al.*, 2001), two types of water species were distinguished in a fish paste sausage from the viewpoint of chemical engineering. One was a strongly restricted water species characterized by lower effective moisture diffusivity, *De*, and the other was a weakly restricted water species with higher *De*. The two water species were divided at a specified moisture content indicating the dynamism of multifunctional water species derived from the dehydration of food tissues. In the present study, our attention is focused on a more

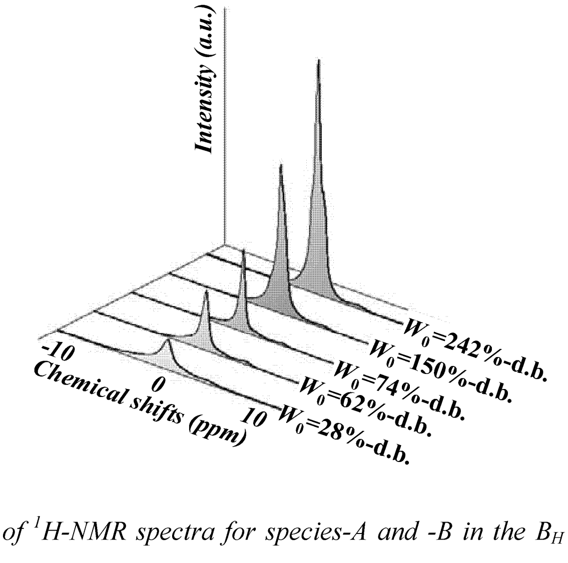

Figure 3. Dynamic behavior of ^{1}H-NMR spectra for species-A and -B in the B_H in the course of a drying operation.

direct identification of the multifunctional water species retained in the beef and pork tissues by using the ^{1}H-NMR method.

Figure 2 is an illustration of a typical example for the ^{1}H-NMR spectrum of the beef with W_0 = 82%-d.b. Two peaks are clearly evident, called species-A and -B, each of which has a different ppm value, 0.35 and -3.16 ppm, respectively. Our interest is focused on the characterization of the two species based on the dynamic behavior of each species in the course of a drying operation. Figure 3 is an illustration of the dynamic behavior of the ^{1}H-NMR spectra for species-A and -B in the course of the drying operation. The peak height of species-A was drastically decreased with decreasing W_0, whereas species-B indicated no change independently of the degree of dehydration. Based on this evidence and additional experimental data (the exact agreement of the NMR spectrum of beef meat lipid with the species-B), it could be concluded that species-A is a water species and species-B, a lipid.

3-2. Discrimination of the Dehydration Curves for the B_A, B_H and P_H

τ_C can be evaluated at any moisture content during the dehydration operation by using *Eq.* (1) and Fig. 3. Figure 4 shows the dehydration response curves of the three meats, B_A, B_H, and P_H, obtained under a continuous drying operation at W_0 = 270%-d.b. and T_D = 50°C, even exhibiting τ_C as a function of W_0 (designated as the τ_C-W_0 curve). The drying time should progress from the right-hand to the left-hand side of the horizontal axis in Fig. 4. The three experimental τ_C-W_0 curves strongly demonstrate two different regions (designated as regions-I and -II) divided at W_0=130%-d.b. In region I (W_0 >130%-d.b.), the three τ_C-W_0 curves give an identical value of τ_C, τ_C =1.0(±0.3) $\times 10^{-8}$ s, independently of the W_0-value. In this region, the water species has lower restriction strength because of the lower τ_C, named as species-A_1. In region II (W_0 <130%-d.b.), the τ_C-W_0 curve gives a steep increase of τ_C with decreasing W_0. In this region, the water species has strongly restricted strength because of the higher τ_C, called species-A_2. This evidence clearly demonstrates that water species-A dynamically changes from water species-A_1 to -A_2 depending on the progress of dehydration. On the three τ_C-W_0 curves in Fig. 4, it is clearly evident that all the B_A, B_H, and P_H produced in the two geographic areas commonly agree with one identical curve. This unclear discrimination of the three τ_C-W_0 curves shows how difficult it is to use them as design tools for characterizing the three meat products.

Overcoming this obstacle of distinguishing the three curves will require a new method for visualizing the design parameters. To meet this need, the moisture diffusivity (*De*) must be identified. As was reported in the previous section, the dehydration operation is limited in a falling rate period. In this period, the *De* can be evaluated by using *Eq.* (2) (Jason, 1958):

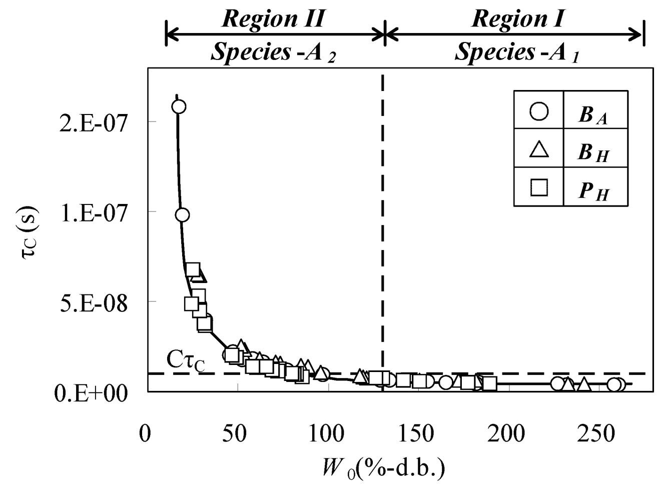

Figure 4. τ_C *as a function of* W_0 *for* B_A, B_H, *and* P_H.

$$\frac{W - We}{W_D - We} = \left(\frac{8}{\pi^2}\right)^3 \cdot exp\left(\frac{\pi^2 \cdot De \cdot t}{4} \cdot \left(L_a^{\ 2} + L_b^{\ 2} + L_c^{\ 2}\right)\right) \qquad (2)$$

where W is the moisture content at the drying time t (%-d.b.), We is the equilibrium moisture content (%-d.b.), W_D is the initial moisture content of the drying flesh sample (%-d.b.), t is the drying time (s), and L_a, L_b, and L_c are one-half the distance of the rectangular sample (m). Figure 5 represents the effective diffusivity of water species as a function of the moisture content. As seen from the three curves obtained, even though the data were scattered, the dynamism of De for the three curves of B_A, B_H, and P_H again demonstrated two regions (I and II) divided at W_0=130%-d.b., indicating an identical De independently of W_0 at the region-I and a gradual decrease of De at region-II with decreasing W_0. It is easy to discriminate the De's for the three meats.

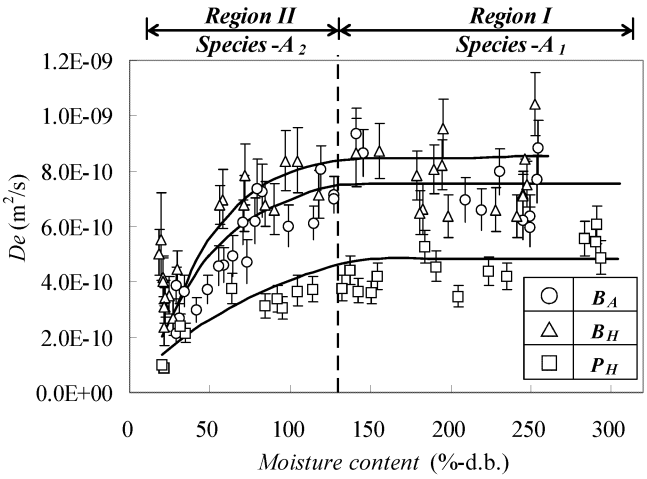

Figure 5 Effective moisture diffusivity of B_A, B_H , and P_H as a function of moisture content (T_D=50°C).

For a clearer discrimination between regions-I and -II, the De can be re-expressed as a function of τ_C instead of W_0 by using Fig. 4. Figure 6 represents the dynamism of De as a function of τ_C. From the three De-τ_C curves obtained, species-A_1 and -A_2 can be more clearly discriminated than the curves in Fig. 5. Focusing on the boundary between regions-I and -II, a critical value of τ_C =1.0 × 10^{-8} s, which corresponds to W=130%-d.b., designated as $c\tau_C$, becomes evident. The $c\tau_C$ will be examined further in the next section.

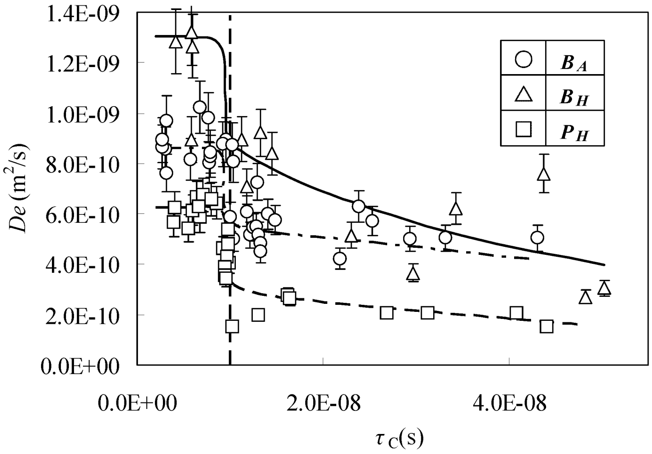

Figure 6. Comparing behavior of De between B_A, B_H and P_H as a function of τ_C at 70 °C.

The activation energy (E_D) of the *De* can be evaluated using a simple Arrhenius-type relationship, *Eq.* (3):

$$De = De^0 \cdot exp\left[\frac{-E_D}{R\cdot(T_D+273)}\right] \tag{3}$$

where De^0 is the pre-exponential factor (m^2/s), R is the gas constant (=8.314J/K·mol), and T_D is the drying temperature (K). The Arrhenius plots of *De*-values obtained at T_D = 50~70°C evaluated E_D's for beef and pork. Figure 7 shows the E_D's as a function of τ_C for B_A, B_H, and P_H. The three curves of E_D to be divided again into two regions at $c\tau_C = 1.0\times10^{-8}$ s as regions-I ($\tau_C < 1.0\times10^{-8}$ s) and –II ($\tau_C > 1.0\times10^{-8}$ s) are easily recognized. In region-I, the E_D's of the three curves fall on 17±2 kJ/mol independently of both τ_C and the kind of meat, indicating that water species-A_1 has similar mobile energy in the three meat tissues. In region-II, the E_D's for the three meats steeply decreased to reach 7.8 for B_A, 5.5 for B_H, and 1.2 kJ/mol for P_H with increasing τ_C, indicating that water species-A_2 has different mobile energy depending on the kind of meat. This different behavior observed in the two regions strongly suggests that water species-A_1 and -A_2 should have different moisture diffusion mechanisms in the three meat tissues and that the mechanism is drastically changed at the $c\tau_C$ because of a physicochemical change of the three meat tissues due to dehydration. This evidence will be discussed in a later section of this paper.

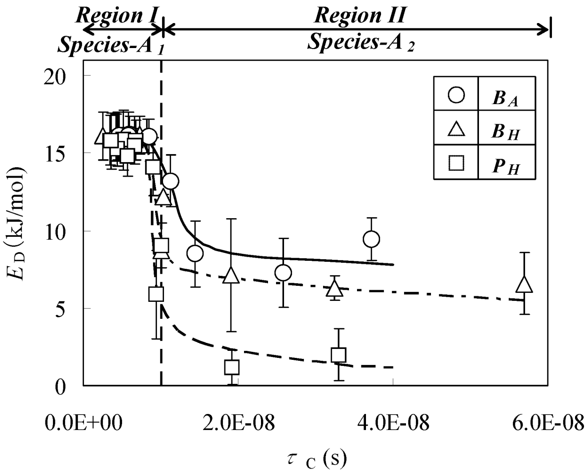

Figure 7. Comparing behavior of E_D between B_A, B_H, and P_H as a function of τ_C at 50~70 ℃.

3-3. Physicochemical Discrimination of B_A, B_H, and P_H due to the *LR* and N_P as the Design Parameters

Our focus is on the clear discrimination of the design parameters for B_A, B_H, and P_H during their drying processes. Figure 8 shows *De* as a function of *LR*. Comparing the characteristics of the three curves, the increase of the *LR*-value for the B_A, B_H, and P_H commonly contributes to a decrease of *De*, which is similar to the result obtained by Ruiz-Cabrera *et al.* (2004). Comparing the absolute values of *De* among the three meats, the *De*-value of P_H may be approximately 0.6 times of B_H. With these results, desirable meat products can be designed. Since the P_H has a low *De*-value accompanied with a lower lipid ratio, the quality of pork meat products can be maintained for a long period of time because its dehydration rate is lower than those of B_A and B_H. In addition, using the three *De*-*LR* curves, it is easy to choose the best meat among B_A, B_H, and P_H on the basis of the *De*-*LR* curves in Fig. 8. The P_H should be determined because of the difficulty of dehydration in air, which indicates an advantage for longer storage times to keep good quality of the meat.

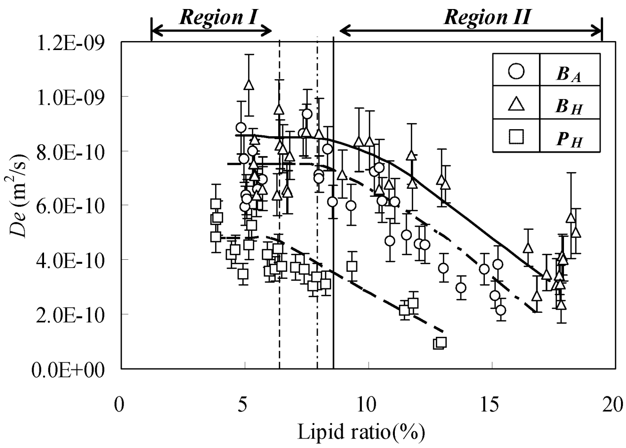

Figure 8. Comparing behavior of De as a function of lipid ratio between B_A, B_H, and P_H at 60 ℃.

For the actual design of meat products, the hardness (N_P) is an important parameter. Figure 9 represents the N_P as a function of τ_C. The two regions, regions-I and -II, divided at the cτ_C=1.0×10^{-8} s are easily recognized again. In region-I, the N_P gives an identical value of $0.8(\pm0.7)\times10^5$ N/m^2 independently of the kind of meat. In region-II, the increase of τ_C commonly contributes to the steep increase of N_P for the three types of meat. The cτ_C should be identified to design desired meat products because, at the cτ_C, a drastic change of N_P takes place. The physical meaning of this drastic change will be discussed in the next section.

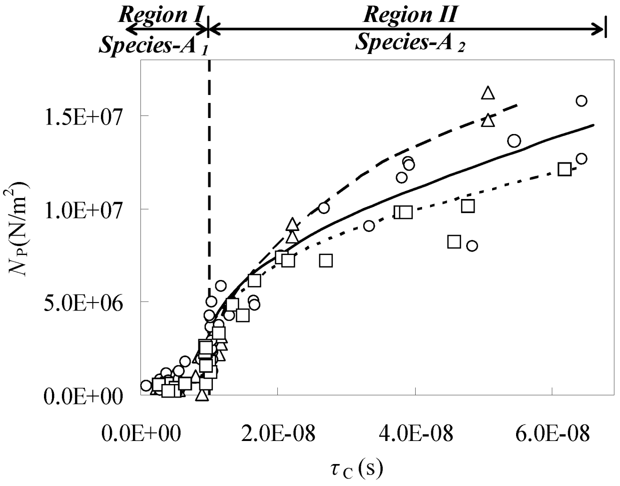

Figure 9. Comparing behavior of N_P as a function of τ_C between B_A, B_H and P_H at 50 ℃.

3-4. Physicochemical Identification of cτ_C as the Design Parameter Recognized by the Pre-exponential Factor of *De*

Regarding the physical meaning of the cτ_C, it is an important consideration to design the three meat products. As is well known, the effective moisture diffusivity, *De*, is expressed by *Eq.* (4):

$$De=\left(\frac{\varepsilon}{\chi}\right)\cdot D=\delta\cdot D_0\cdot exp\left[\frac{-E_{\mathrm{D}}}{R\cdot(T_{\mathrm{D}}+273)}\right] \tag{4}$$

where ε is the porosity of the meat tissue (--), χ is the labyrinth factor of the meat tissue (--), D is the moisture diffusion coefficient (m^2/h), δ is the diffusibility ($=\varepsilon/\chi$), and D_0 is the frequency factor of D (m^2/h).

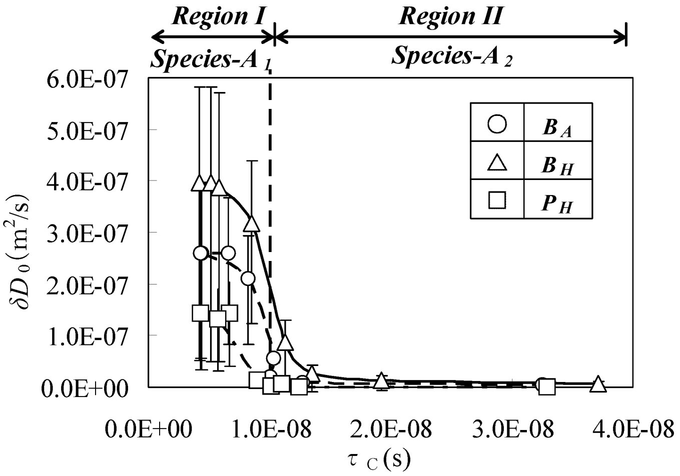

Figure 10. Comparing behavior of the pre-exponential factor between B_A, B_H, and P_H at 50 ℃ as a function of τ_C.

Taking the E_D-τ_C curves presented in Fig. 7 into account (see Eq. (4)), the pre-exponential factor, δD_0, can reasonably be evaluated as shown in Fig. 10. It is clear that the pre-exponential factor is drastically changed at the cτ_C. In region-II, it is clear that the drastic reduction of the δD_0 value strongly contributes to (1) the reduction of De in Fig. 6, (2) the steep reduction of E_D in Fig. 7, and (3) the steep growth of N_P in Fig. 9. The three reasons indicate a dynamic variation of the frequency factor of D (D_0), the porosity (ε), and the labyrinth factor (χ) due to the progress of the dehydration process, which are effectively derived from the dynamic change in the restriction strength of multifunctional water molecules. This is the reason that the cτ_C appeared. Based on these quantitative evaluations for the design parameters presented above, the values of D_0, ε, and χ need to be controlled for the design of commercially requested meat products.

4. CONCLUSIONS

In the course of the drying operation of the three meat products, the quality of the meats was drastically changed because of the dehydration operation, which strongly influenced on the composition dynamism of the multifunctional water species as water species-A_1 and -A_2. The two water species were clearly characterized by the specified design parameters, as shown in the three items below.

(1) For the quantitative evaluation of the meat products requested, three meats, B_A, B_H, and P_H, and five design parameters, De, E_D, N_P, LR, and τ_C as a function of the two water species, were chosen.
(2) In the drying process of the three meats, a specified moisture content (=130%-d.b.) characterized by the cτ_C ($=1.0\times10^{-8}$s) was demonstrated as a critical value for the design parameters, distinguishing the two water species-A_1 and -A_2.
(3) The cτ_C was characterized by the physicochemical features resulting from the biological tissue change of beef and pork meats, such as the frequency factor, porosity and labyrinth factor dynamically derived in the course of the dehydration process.

5. ACKNOWLEDGEMENTS

This work was financially supported by the Cooperation of Innovation Technology and Advanced Research in Evolution Area (City Area) from the Japanese Ministry of Education, Culture, Sports, Science, and Technology.

The authors wish to thank Associate Professor Koichi Miura, Kitami Institute of Technology, for their effective assistance with the proton NMR analysis.

6. REFERENCES

Barara, G., Matteo, P. Di, Lamanna, R., Limone, G., Osséo L. Sesti and Vittoria, V., 1999, Water-Polysaccharides Interaction During Apples Drying Process. *Macromol. Symp.*, 138, 237-243.

Belton, P.S., Gil, A.M., Webb, G.A., Rutledge, D., Eds., 2003, Magnetic Resonance in Food Science-Latest Developments, *The Royal Society of Chemistry, Cambridge*.

Donald Muir, D., 1984, Reviews of the Progress of Dairy Science:Frozen Concentrated Milk, *J. Dairy Research*, 51, 649-664.

Fasina,O.O., 2005, Thermophysical Properties of Sweetpotato Puree at Freezing and Refrigeration Temperatures, Intnl. *J.Food Properties*, 8, 151-160.

Jason, A.C., 1958, A Study of Evaporation and Diffusion Processes in the Drying of Fish Muscle. *In Fundamental Aspects of Dehydration of Food Stuffs*, ed. Society of Chemical Industry. McMillan, London, 103-134.

Konishi, Y., Horiuchi, J. and Kobayashi, M., 1999, M. Optimal Design of a Poultice up Process Operation in Food Drying Process Developed for Keeping Good Quality of Foods. *Proceeding of EURO FOOD CHEM X*, Vol.3, 744-751.

Konishi, Y., Horiuchi, J., and Kobayashi, M., 2001(a), Dynamic Evaluation of the Dehydration Response Curves of Foods Characterized by a Poultice-up Process Using a Fish-paste Sausage-I. Determination of the Mechanisms for Moisture Transfer, *Drying Technology*, 19(7), 1253-1269.

Konishi, Y., Horiuchi, J., and Kobayashi, M., 2001(b), Dynamic Evaluation of the Dehydration Response Curves of Foods Characterized by a Poultice-up Process Using a Fish-paste Sausage-II.A New Tank Model for a Computer Simulation, *Drying Technology*, 19(7), 1271-1285.

Konishi, Y., Miura, K. and Kobayashi, M., 2003, Drying Efficiency Design Using Multifunctional Dynamics of Water Molecules in Foods-H-NMR Analysis of a Fish Paste Sausage and Squid, *AIDIC Conference series,* vol.6, 183-190.

Konishi, Y., Kobayashi, M., and Miura, K., 2008(a), Characterization of Water Species Revealed in the Drying Operation of Squid by Using Water Proton NMR Analysis, *Proceedings of the 10th International Chemical and Biological Engineering Conference-CHEMPOR 2008.*

Konishi, Y., Kobayashi, M., Matsuda, H., and Miura, K., 2008(b), Dehydration Dynamism of Beef and Pork, *Proceedings of the 40th Annual meeting of the Chemical Engineering of Japan*, D307.

Labbé, N., Jéso, B. De, Lartigue, J-C., Daudé, G., Pétraud, M. and Ratier, M., 2002, Moisture Content and Extractive Materials in Maritime Pine Wood by Low Field ^{1}H NMR., *Holzforschung,* 56, 25-31.

Lechert, H. T., 1981, Water Binding on Starch (NMR Studies on Native and Gelatinized Starch)., *In Water Activity: Influences on Food Quality,* ed. L.B.Rockland and G.F.Stewart, Academic Press, New York. pp223-245

Miwa, Y., Tanaka, T., Oshiyama, H. and Mochizuki, A., 2003, Study on Structure of Water in Poly (2-methoxyethylacrylate) (PMEA) and Poly (2-hydroxyethylmethacrylate) (PHEMA) by 2H Solid-State NMR., *Journal of Japanese Society for Biomaterials*, 21-2, 143-148.

Nagy, E. and Kormendy, L., 2003, Determination of Fat Content in Meat by Pulsed Nuclear Magnetic Resonance (NMR) Technique, *Acta Alimentaia*, 32, 289-294.

Podorozhko,E.A., Kurskaya,E.A.,Kulakova,V.K., Lozinsky,V.I., 2000, Cryotropic Structureing of Aqueous of Fibrous Collagen:Influence of the Initial pH Values, *Food Hydrocolloids*, 14, 111-120.

Ruiz-Cabrera, M.A., Gou, P., Foucat, L., Renou, J.P. and Daudin, J.D., 2004, Water Transfer Analysis in Pork Meat Supported by NMR Imaging, *Meat Science*, 67, 169-178.

Sadikoglu, H., Liapis,A.I., Crosser, O.K., 1998, Optimal Control of the Primary and Secondary Drying Stages of Bulk Solution Freeze Drying in Trays, *Drying Technology*, 16, 399-431.