Drying characteristics of heat pump dried shrimp (*Pandalus borealis*) and fish cake

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Abstract: The peeled, headed and whole shrimps (*Pandalus borealis*) as well as the fish cake of 50 mm(diameter)×(7～9) mm(thickness) and 50 mm×(14～18)mm were dried in a heat pump dryer at (−2～0)℃ and 20℃. The results showed that the drying characteristics of shrimp and fish cake were significantly affected by the handling conditions(with shell or without shell, with head or without head) of shrimp and the thickness of fish cake. The peeled shrimp has the shortest drying time and the headed shrimp is dried faster than the whole shrimp both at the drying temperature of (−2～0)℃ and 20℃, and the drying rate of thin fish cake is faster than thick fish cake especially at 20℃. The drying characteristics could be well described by diffusion model ($MR = A\exp(-kt)$). A series of empirical regression equations have been established and these models indicate that increasing the drying temperature from (−2～0)℃ to 20℃ significantly enhanced the drying rate and k-values, and the drying time decreased greatly.

Key words: heat pump drying; drying characteristics; shrimp (*Pandalus borealis*); fish cake; drying model

CLC number: S375;S951.5 **Document code**: A **Article ID**: 1002-6819(2006)09-0189-05

Zhang Guochen, Sigurjón Arason, Sveinn Víkingur árnason. Drying characteristics of heat pump dried shrimp(*Pandalus borealis*) and fish cake[J]. Transactions of the CSAE, 2006,22(9):189−193. **(in English with Chinese abstract)**

1 Introduction

Fish and shrimp represent one major source of protein to human beings in the world. Preservation is an important issue for fish and shrimp because they are easily perishable products. Drying has been proved to be an efficient and cheap method for food preservation. It has been used to preserve fish and shrimp for a long time in most areas of the world. In recent years, the annual world production of dried, unsalted fishery products has been 350000 tons, and the world production of dried fish is 3140000 tons[1].

Heat pump dryers (HPD) have been in widespread commercial use since the 1970s, particularly in the timber and food drying industries[2]. In the application studies of HPD, it has been found that the colour and aroma qualities of dried agricultural products using HPD were better than those when using conventional hot air dryer[3-5]. Heat pump should play a key role in fish and shrimp drying. High quality dried fish and shrimp products can be achieved with this innovative technology due to its low drying temperature and independency with the outdoor air. Also, energy consumption is reduced because of high coefficient of performance of the heat pump and the high thermal efficiency of the dryer when properly designed.

Along with the development of heat pump drying technology, it has become important for establishing empirical thin layer drying models by experimental studies. In the past two decades, many experimental studies on HPD dried agricultural materials have been carried out. Based on the three major models (compressor, evaporator and condenser model), some experimental models have been developed[6-9].

In Scandinavia there is a well established fish drying industry based on the application of heat pump drying technology. The special low temperature and low humidity capabilities of heat pump dryers are significant there. This is possibly the most successful application of heat pump drying[2]. There are two rack cabinet dryers with heat pumping system which is used for cod head drying in Iceland. But until recently few studies on fish and shrimp drying using heat pump dryers have been reported. The objective of this research is to study the drying characteristics of shrimp and fish cake, investigate the effects of heat pump drying on the quality of dried shrimp and fish cake as well as evaluate the application of heat pump in fish and shrimp drying production.

2 Materials and methods

2.1 Equipment

Received date: 2005-10-10 Accepted date: 2006-03-10

This study was supported by UNU Fisheries Training Programme (Iceland)

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Drying experiments of shrimp and fish cake were carried out with a batch type heat pump dryer (designed by IFL and Seafood Bureau of Iceland, produced by Cooltech) in Gullfiskur Company. The heat pump dryer was mainly used for the production of dried haddock fillets and its production duration was seven days. The working temperature of this dryer was divided into two steps in the whole drying process. In the first step, the temperature was kept at −2～0℃ and lasted for four days. The temperature of second step was 20℃ and the duration was approximately three days.

2.2 Shrimp and fish cake

Shrimp (*Pandalus borealis*), commercially quickly frozen on boat with the size of 98～104 counts/kg and frozen peeled shrimp with the size of 538～570 counts/kg were purchased from an export company.

Four different types of shrimp were used in this project, they were frozen peeled shrimp, thawed peeled shrimp, headed shrimp (with the size of 196～200 counts/kg) and whole shrimps. The headed shrimp were obtained by removing the heads of the same shrimp under frozen conditions. All the samples were kept in frozen storage (−18～−20℃) before starting the experiment except thawed peeled shrimp. Thawed samples were obtained by putting frozen peeled shrimp into flowing water of 5℃ at the workshop temperature of 5～8℃ for 30 minutes and then putting them on a grid until no water can drop down.

Fish cake was made from small fresh fish meat by using an extruder. After being extruded, the fish cakes were frozen and stored in frozen storage (−20℃). The fish cake used in this project was in cylinder shape and with a diameter of about 50 mm. Before the drying experiment, the fish cakes were cut into pieces manually under semi-thawed condition and then it was divided into two groups. One was thin group with the thickness of 7～9 mm, the other group had the thickness of 14～18 mm.

2.3 Methods

In this project, the experiments of the first group of samples were started in the first stage of the drying cycle at −2～0℃ and the second group of samples were put into the dryer when the drying temperature increased to 20℃. In every experiment, approximately 300～400 g samples were put on a small grid (30 cm×30 cm) and some other samples(about 3～4 kg) were put on a large grid(100 cm×120 cm). All the samples were spread in single layer both on small and large grids. During the experiments, the small grids were taken out at regular intervals(2 hours at −2～0℃ or 1 h at 20℃), quickly weighed with a digital balance (an accuracy of ±0.5 g) and then returned to the dryer at once. At the time of measuring the weight change, about 50 g samples were taken from large grids and put into plastic bags and sealed well as fast as possible. The initial moisture content of the samples was determined by drying in an oven at 102℃ to 105℃ for four hours. The moisture content changes were calculated according to the initial moisture content and the weight change of the samples. The finial moisture content was 15%～18%(w. b.). The temperature and relative humidity(RH) in the heat pump dryer were determined and recorded automatically by HOBO U12 Temp/RH Data Logger at every five minutes. The air flow rate in heat pump dryer was measured with an anemometer(type: testo 452).

Moisture content was determined according to the method ISO 6496(ISO1990). About 5 g of samples was weighted accurately(±1 mg) in a pre-weighted clean and dry metal dish with a lid. The sample was heated in a heating oven at 102℃ to 105℃ for four hours. The lid was then placed on top of the dish with lid cooled in a desiccator and then weighted. The moisture content of the sample corresponded to the weight loss observed and results were given as percentage of the weight of dried material(w. b.).

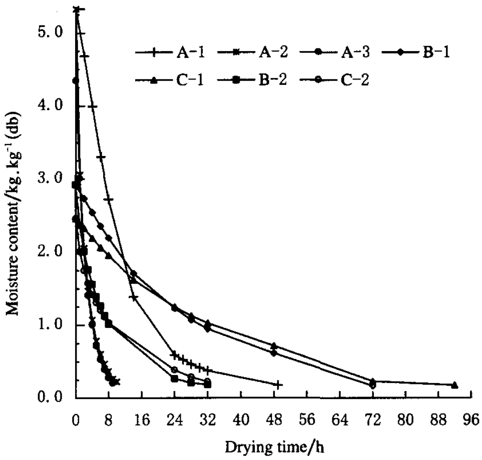
3 Results and discussion

3.1 Drying curves of shrimp and fish cake

The initial moisture contents of frozen peeled shrimp, thawed peeled shrimp, frozen headed shrimp, frozen whole shrimp and frozen fish cake were 84.2%, 74.5%, 71.1% and 81.4%, respectively. The air speed in the heat pump dryer was fixed in the range of 1.8～2.2 m/s. The relative humidity(RH) varied among 40%～60% depending on the drying temperature. The drying curves of shrimp and thick fish cake at different drying temperatures are shown in Fig. 1 and Fig. 2.

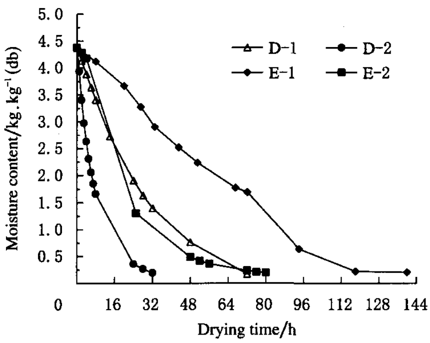
The drying of peeled shrimp at 20℃ was much faster than that at −2～0℃. It took only nine and ten hours to dry thawed peeled shrimp and frozen peeled shrimp to a final moisture content of 0.21 and 0.23 (kg water/kg dry solid) at 20℃ respectively. Whereas the drying of frozen peeled shrimp at −2～0℃ required 48 hours. The same trends are presented in the drying of other samples. For example, the drying of headed shrimp and whole shrimp at 20℃ required nearly the same drying time of 32 hours, but 72 and 92 hours were needed relatively to dry the same samples at −2～0℃; The drying of thin fish cake required

32 hours at 20℃, compared with 68 hours at −2～0℃.



A−1: frozen peeled shrimp, −2～0℃;
A−2: frozen peeled shrimp, 20℃;
A−3: thawed peeled shrimp, 20℃;
B−1: frozen headed shrimp, −2～0℃;
B−2: frozen headed shrimp, 20℃;
C−1: frozen whole shrimp, −2～0℃;
C−2: frozen whole shrimp, 20℃;

Fig. 1　Drying curves of shrimp



D−1: frozen thin fish cake(7～9 mm), −2～0℃;
D−2: frozen thin fish cake (7～9 mm), 20℃;
E−1: frozen thick fish cake(14～18 mm), −2～0℃;
E−2: frozen thick fish cake(14～18 mm), 20℃

Fig. 2　Drying curves of fish cake

For the drying of shrimp, it was found that the shell of the shrimp acted as a barrier to the moisture diffusion out of the shrimp[10]. The results of this study show that the moisture content during the drying processes was significantly affected by the condition(with shell or without shell, with head or without head) of the shrimp. Among the three different kinds of shrimp (peeled, headed and whole shrimp), the peeled shrimp has the shortest drying time and the headed shrimp is dried faster than whole shrimp both at the drying temperature of −2～0℃ and 20℃. Similarly, drying time was also considerably affected by slice thickness of fish cake. The thin fish cake(7～9 mm) is dried faster than thick fish cake (14～19 mm), and this effect is more noticeable at high temperature (the drying time reduced 32 hours and 64 hours at −2～0℃ and 20℃ respectively).

3.2　Modeling of drying kinetics of shrimp and fish cake

It has been generally accepted that removal rate of moisture from salted fish during the falling rate period was governed by the transfer of water by diffusion[11−13]. The thin layer drying equation according to Fick's second law of diffusion has been widely used to estimate the drying time during the falling drying rate periods. Thus, drying rate can be expressed by the following equations (Diffusion model):

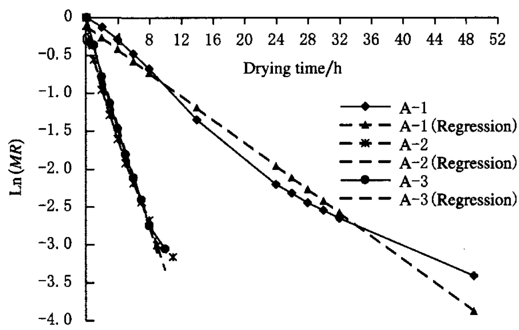
$$MR = \frac{M_t - M_{eq}}{M_0 - M_{eq}} = A\exp(-kt) \qquad (1)$$

Where　MR —— water content ratio; M_t —— the water content in drying time t, kg/kg (dry basis); M_0 —— the initial water content, kg/kg (dry basis); M_{eq} —— the equilibrium water content, kg/kg (dry basis); A ——constant; k ——drying rate constant (h −1).

Model (1) could be transformed into following form:

$$\mathrm{Ln}(MR) = \mathrm{Ln}A - kt \qquad (2)$$

When the experimental data were plotted based on Equation (2), Fig. 3, 4 and 5 were obtained. A serious of regressions had been carried out, all the values of constant A, constant k and R^2 of the drying models were obtained(Table 1).

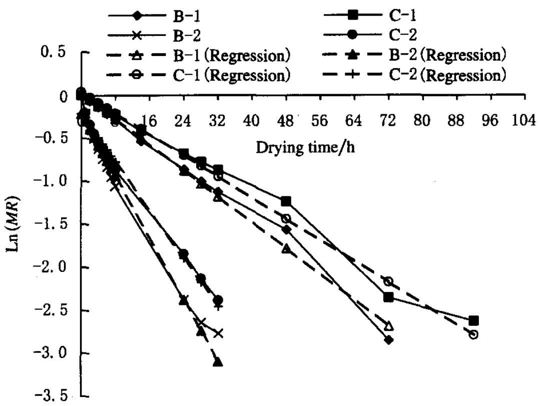


A−1: frozen, −2～0℃; A−2: frozen, 20℃;
A−3: thawed, 20℃

Fig. 3　Relationship curves of Ln (MR) — Drying time of peeled shrimp under different treatments

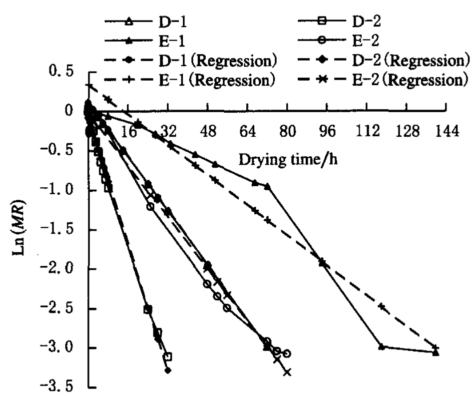
According to the regression analyses, the drying of shrimp and fish cake has the linear relationships between the natural logarithm MR with the drying time. The drying characteristics of heat pump dried shrimp and fish cake could be well described by diffusion model. From table 1 people can see, almost all the coefficients of correlation (R^2) of these regression equations were in the range of 0.970～0.998 (except E－1, 0.9376). So these regression equations (except E－1) are applicable for the prediction of drying rate of shrimp and fish cake under heat pump drying.

The former studies show that an increase of drying air temperature can lead to the increasing of drying rate constant (k) in the drying of many biological materials[14-16]. The results of this study also demonstrated that increasing the drying temperature from －2～0℃ to 20℃ significantly enhanced the drying rate and k-values (Table 1).



B－1: headed shrimp, －2～0℃; B－2: headed shrimp, 20℃;
C－1: whole shrimp, －2～0℃; C－2: whole shrimp, 20℃

Fig. 4 Relationship curves of Ln (MR) — Drying time of frozen headed shrimp and whole shrimp at different drying temperatures



D－1: thin fish cake (7～9 mm), －2～0℃;
D－2: thin fish cake (7～9 mm), 20℃;
E－1: thick fish cake (14～18 mm), －2～0℃;
E－2: thick fish cake (14～18 mm), 20℃

Fig. 5 Relationship curves of Ln (MR) — Drying time of frozen fish cake at different drying temperatures

Table 1 Values of constant A, constant k and R^2 of the drying models

Samples *	A	k	R^2
A－1	0.8954	0.07679	0.9703
A－2	0.7643	0.30	0.9855
A－3	0.9314	0.336	0.998
B－1	1.0297	0.03771	0.9887
B－2	0.7846	0.08486	0.9836
C－1	1.0200	0.02964	0.9882
C－2	0.8021	0.06898	0.9864
D－1	1.1139	0.04294	0.9821
D－2	0.9005	0.09718	0.9955
E－1	1.4095	0.0239	0.9376
E－2	0.963	0.04093	0.0985

* The meanings of A－1, A－2, A－3, B－1, B－2, C－1, C－2, D－1, D－2, E－1 and E－2 were the same with that in Fig. 1 and Fig. 2.

4 Conclusions

The results showed that the drying characteristics of shrimp and fish cake were significantly affected by handling conditions (with shell or without shell, with head or without head) of the shrimp and the thickness of fish cake. Comparing different types of shrimp samples, the peeled shrimp has the shortest drying time, and the headed shrimp dried faster than whole shrimp is both at the drying temperature of －2～0℃ and 20℃. Similarly, the drying of thin fish cake is faster than thick fish cake, especially at 20℃. The drying time of all the heat pump dried shrimp and fish cake decreased greatly as drying temperature increased from －2～0℃ to 20℃.

The drying characteristics of shrimp and fish cake at －2～0℃ or 20℃ in heat pump dryer show that the drying characteristics could be well described by diffusion model ($MR = A\exp(-kt)$). A series of empirical regression equations have been established and they were found to be applicable for the prediction of drying rate of shrimp and fish cake. These models also indicated that increasing the drying temperature from －2～0℃ to 20℃ significantly enhanced the drying rate and k values.

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热泵干燥北极虾和鱼块的干燥特性研究

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摘　要：利用热泵干燥机,分别在－2～0℃和 20℃两种温度下对北极虾整虾、去头北极虾、去壳北极虾和尺寸分别为 50 mm(直径)×(7～9)mm(厚度)和 50 mm×(14～18) mm 的鱼块进行了干燥研究。结果显示,虾的状态(有壳或无壳、有头或无头)和鱼块的厚度对其干燥特性有着显著影响。无论干燥温度为－2～0℃还是 20℃,去壳虾所需干燥时间均最少,去头虾的干燥速度均大于整虾；薄鱼块的干燥速度在 20℃显著大于厚鱼块的干燥速度。扩散模型 $MR = A\exp(-kt)$ 可以很好地描述热泵干燥北极虾和鱼块的干燥特性,根据试验结果建立的一系列统计回归模型显示,当热泵干燥温度由－2～0℃增加到 20℃时,干燥速度和 K 值显著增加,干燥时间明显减小。

关键词：热泵干燥；干燥特性；北极虾 (*Pandalus borealis*)；鱼块；干燥模型