Effect of drying air temperature on heat pump fluidized bed drying of cod fish

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Introduction

The cod fish is a source of protein with low fat content. In 2003 the cod catches in Norway reached 217462 tons [1] for the fishing period that concentrated from December to April. Drying permits to stabilize the raw material and to guarantee dry fish supply around year. Research about optimal drying process is necessary as to address high quality of dried product and to avoid degradation of the main components during processing [2]. Low air drying temperatures reduce lipid oxidation in fish processing and improve significantly the quality of the final product. Furthermore, low temperature enhances other properties of the dried fish, such as color and rehydration ability [3]. Heat pump dryers have a wide interval of process temperature (-20 to 100 °C), which is suitable for processing heat sensitive materials at atmospheric freeze conditions. Additionally, the heat pump is the most energy efficient way to supply heating and cooling during drying [4]. The main disadvantage of stationary atmospheric freeze drying is low throughput. However, this process may be improved by using fluidized bed that promotes excellent contact between suspended particles and air, with subsequent higher rates of heat and mass transfer.

The main objective of this work is to determine the temperature effect on heat pump fluidized bed drying of cod fish using temperatures below and above the fish freezing point.

Materials and Methods

Heat pump fluidized bed dryer

A sketch of the heat pump fluidized bed dryer used in the experiments is shown in the Figure 1. The dryer main constituents are the drying chamber, cyclone and blower and the heat pump components are the compressor, evaporator, condensers and valves. The drying chamber outlet air is dehumidified and cooled in evaporator and heated in the condenser to reach the desired drying chamber inlet air temperature. The cylindrical drying chamber was made of methacrylate with a 0.25 m diameter and a 0.6 m height. All the drying circuit in contact with the surroundings was thermally insulated.

The different process variables logged using a data acquisition unit (Fluke hydra) were: inlet air velocity (m/s), relative humidity (%) and temperature (°C). Also the outlet air temperature and relative humidity were recorded.

Sample preparation

The material for the experiments was frozen Norwegian cod fish, previously pressed and manufactured in slabs (mass 100 g, dimensions: 6.3 cm width, 7.5 cm long and 2 cm thick). The slabs were maintained frozen (-20 °C) until being cut in cubes (0.5 cm side) using an electric stainless-steel saw. The cubes were cut in a cold-room at 0 °C temperature, which avoids melting and makes cutting easier.

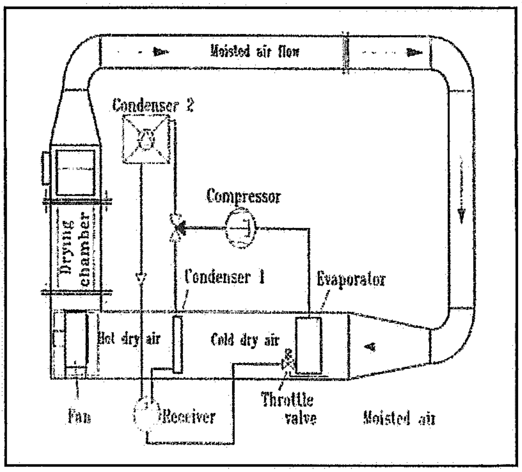

Figure 1. Sketch of the heat pump fluidized bed dryer.

Drying conditions

Drying experiments were carried out at freeze drying conditions (-10 and -5 °C) and low or medium air drying temperatures (0, 15 and 30 °C). The air velocity was kept between 1.5 and 2.5 m/s and controlled to maintain fluidization.

A sample load of 2.2 g cm^{-2} was used in the experiments, which correspond to a bed volume of 2 L. The bulk density of the bed was 500 g/L.

Experimental measurements

Drying kinetics were determined taking samples at regular period of times and measuring moisture content using an infrared drying balance (Precisa HA300).

Modeling

Drying kinetics were modeled using theoretical and empirical models.

The diffusion model for cubes [5] is expressed by:

$$W(t)=W_e+(W_c-W_e)\cdot\left(\sum_{n=0}^{\infty}\frac{8}{(2n+1)^2\pi^2}\exp\left(\frac{-D_e(2n+1)^2\pi^2 t}{4L^2}\right)\right)^3$$

The Weibull model [6] is:

$$W(t)=W_e+(W_c-W_e)\cdot\exp\left(-\left(\frac{t}{\beta}\right)^{\alpha}\right)$$

The moisture effective diffusivity (D_e) and the parameters of Weibull model (α and β) were determined using an optimization method. The variance (VAR, %) was determined to indicate the goodness of the fit.

Results and Discussion

Drying kinetics of cod fish at different temperatures are plotted in Figure 1. The material initial moisture content was 4.52±0.31 kg water (kg dry matter)$^{-1}$. It seems that the falling rate period is the predominant element in the drying kinetics of cod fish. It showed usual trend for similar products where the drying rate increases with temperature.

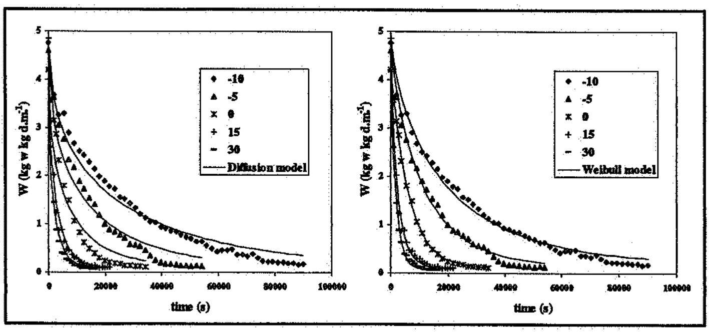

Figure 1. Drying kinetics of cod fish and modeling.

The parameters of the models and the variance were obtained and are listed in Table 1. The Weibull model fitted better drying kinetics than the diffusion model as suggested in Figure 1 and Table 1). Hypothesis assumed to solve diffusion model, such as non shrinkage or constant moisture effective diffusivity, do not suit the cod fish behavior during drying. Therefore, better description of drying kinetics requires new hypothesis. However, these should be closer to reality, which would add more complexity to mathematical solution of the model. But, the values obtained for effective moisture diffusivity are within the typical range of foodstuffs.

	Diffusion model		Weibull model		
T (°C)	D_e(10^{-11} m^2 s^{-1})	VAR (%)	β (10^3 s)	α	VAR (%)
-10	2.3	97.5	19.0	0.77	98.7
-5	4.0	95.9	11.4	0.88	99.3
0	7.5	93.8	6.2	1.00	99.9
15	21.8	98.2	2.0	0.82	99.5
30	28.1	97.5	1.7	0.94	99.7

Table 1. Parameters estimated and explained variance with the modeling.

Actually, the kinetic parameters of the models, D_e and β, follow the Arrhenius relationship with temperature, allowing the activation energy (Ea, kJ mol^{-1}) to be identified. When the ln (De) or ln (1/B) is plotted against 1/T a liner relation is usually found and the E_a can be calculated from the slope. Using the parameters estimated from the experiments this relationship is plotted in Figure 2.

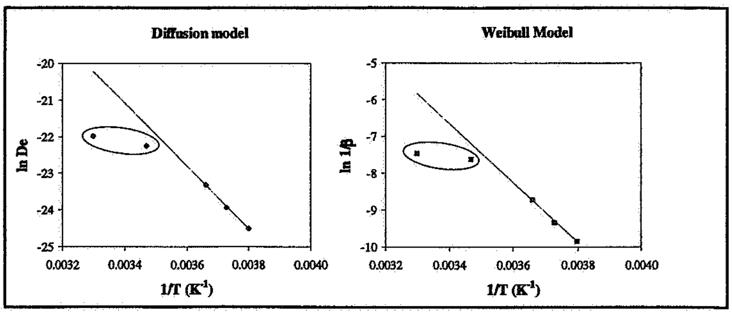

Figure 2. Temperature effect on kinetic parameters.

An evidence linear relationship was not found for the kinetic parameters identified in the modeling. The values for 15 and 30 °C depart from the linearity established by the other values. These differences are explained by the fact that not only water was in different states (liquid or partially frozen) but also the structures of the products are different. This suggests that the data below freezing and data above freezing should not be analyzed together for such a purpose.

If activation energy is calculated using all the data the plots obtained (diffusion model 42.2 kJ mol^{-1}; Weibull model 40.8 kJ mol^{-1}) are smaller than if determined using only the three low temperatures (diffusion model 71.2 kJ mol^{-1}; Weibull model 67.0 kJ mol^{-1}). Obviously, the energy necessary to dry the cod fish cubes at low temperature is larger than when drying is done at higher temperatures. This may be explained by the higher energy necessary to change the water state from freezing to vapor than from liquid to vapor.

Conclusion

Tests to study the temperature effect on drying kinetics of cod fish were carried out in a temperature range below and above freezing point (-10 to 30 °C). It showed usual trend of foodstuffs in which drying rate increases with temperature. Kinetic drying parameters, D_e and β, were estimated using an optimization method.

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