EFFECT OF OPERATING CONDITIONS ON ATMOSPHERIC FREEZE DRIED COD FISH

[1]Eikevik, T.M., [1]Strømmen, I., [1]Alves-Filho, O., [2]Hemmingsen, A.K.T.

[1]Norwegian University of Science and Technology, [2]SINTEF Energy Research
Kolbjorn Hejes vei 1D, NO-7465 Trondheim, Norway
e-mail: trygve.m.eikevik@ntnu.no

ABSTRACT

This paper describes the advantages of heat pump atmospheric freeze drying and the effect of the operating conditions on the dried cod fish properties and characteristics. Measurements were made to obtain data on drying kinetics and to determine relevant property parameters such as water activity, rehydration, density, colour and level of non-denatured protein content.

According to the extraction analysis the non-denatured protein content of the dried fish rises inversely with the drying temperature and thus atmospheric freeze dried samples had higher non-denatured protein fraction than dried runs at positive temperatures. DSC analysis indicated that non-denatured protein concentration is directly proportional to initial moisture content and consistently the frozen material used for the drying tests had lower protein fraction than fresh fish.

The cod fish samples dried at atmospheric freeze drying conditions (-8, -4 and -1^{o}C) present brighter colour, lower density and higher rehydration ability compared to samples dried at positive temperatures.

Sorption measurements were made and used to plot the equilibrium moisture content versus water activity. The graph show a trend to a sigma type sorption isotherm, which is well described by a four-parameter equation.

Combinations of atmospheric freeze drying and drying at temperatures above the freezing point gives better quality of the products. The capacity decreases for the plant running at temperatures lower than initial freezing point. This paper gives an equation to calculate the energy used and effective SMER for a combined drying mode.

Keywords: atmospheric freeze drying, cod fish, quality parameters, energy, sorption, heat pump, denatured protein

INTRODUCTION

In the modern society the focus on instant products are increasing. The processing parameters will highly influence the quality, environmental and energy aspects. The society expresses a desire for better products and for more efficient and environmentally friendly processes. Drying is a preservation method that has been used over thousands of years. To make a drying potential the air has to have low relative humidity at the inlet of the dryer. Normally this has been done by heating the air (hot air dryers). It is also possible to make drying potential by dehumidifying the air before drying and heat the air to a given temperature. This can be done by help of a refrigeration unit (heat pump). This gives possibilities to dry at ambient temperatures and also at temperatures below the initial freezing point of the product (atmospheric freeze drying) (Strømmen et al., 2005). Therefore, R&D addressing such topics is technically important and socially necessary. During drying moisture content is reduced until a safe level in which there is a minimum spoilage caused by microorganisms, enzymes and other agents.

When properly designed a heat pump system is the most efficient way to make drying conditions with low temperatures and low relative humidities, as required in atmospheric freeze drying. Heat pump dryers heat sensitive materials can be dried at temperatures from -20ºC to +80ºC. Heat and mass transfer is increased in a low temperature heat pump dryer by using fluidized bed mode which promotes better contact between suspended particles and air.

The cod fish is a source of protein with low fat content and the main fishing period in Norway is concentrated in a relatively short time period from January to April. Then, drying would be a logistic alternative to supply dried fish around year by lowering the moisture and water activity of the raw material. Usually, atmospheric freeze drying of fish minimizes fatty acid oxidation and reduces protein denaturation (Alves-Filho, 2004).

The main objective of this work is to determine the effects of heat pump fluidized bed drying conditions on cod fish properties in a range of temperatures and temperature programs from -8^{o}C to +10ºC. Measurements were done by sampling and analysis of relevant quality parameters.

MATERIALS AND METHODS

Raw material and sample preparation

The raw material for the experiments was frozen Norwegian cod fish in the forms of slabs (mass 100gr, dimensions: 6.3cm with, 7.5cm long and 2cm thick). The slabs were maintained frozen (-20^{o}C) until being cutted in pieces of 5 x 5 x 5mm. The sample preparation was made in a freezing room at -20^{o}C temperature to avoid melting.

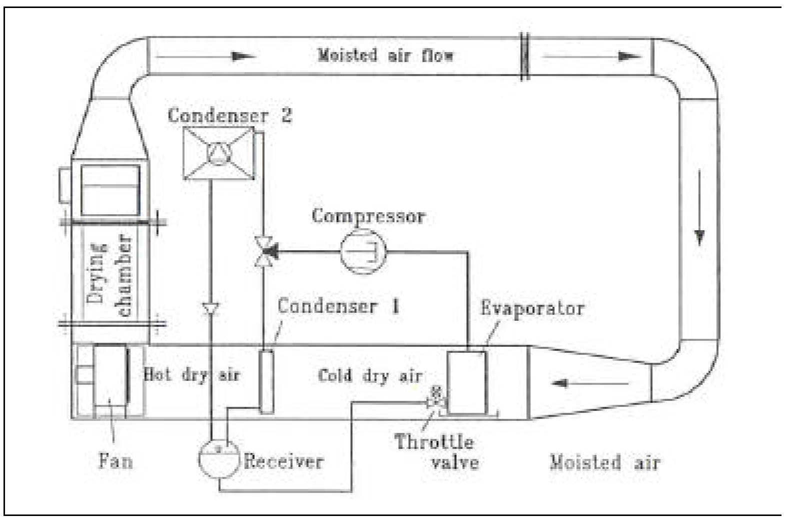

Figure 1 Layout of the fluid bed heat pump dryer

Heat pump fluidized bed dryer

The heat pump fluidized bed dryer used in the experiments is shown in Figure 1. The dryer has a drying chamber and blower, and the main components of the heat pump are the compressor, evaporator, condensers and valves. The drying air is recirculated in order to enhance the energy efficiency of the process. Thus the drying chamber outlet air is dehumidified and cooled in the evaporator and heated in the condenser to reach the desired drying conditions at the inlet of the drying chamber. The air temperature is controlled by the heat pump three-way valve by redirecting refrigerant flow partly into condenser 1 and 2. The cylindrical drying chamber was made of methacrylate with a 0.25 m diameter and a 0.5 m height. All the drying circuit in contact with the surroundings was thermally insulated.

The different process variables were logged using a data acquisition unit (Fluke hydra) continuous recording, monitoring and display of inlet air velocity (m/s), relative humidity (%) and temperature (ºC). Also the outlet air temperature and relative humidity were recorded.

The relative humidity at inlet of the dryer is given by the heat pump capacity. As shown in the Mollier diagram in Figure 2 the drying process has an optimum when the energy consumption is as low as possible. This is given by the sizing of the heat pump compressor and the evaporator (air cooler). The evaporator cools the air from point b) to point c). Point d) indicates the average surface temperature of the cooler. If the compressor is sized to large then point a) will move to the left in the Mollier diagram. The air will achieve a lower relative humidity and give a quicker drying. On the other hand the energy consumption for the compressor will increase and the SMER will decrease for the process. It is of importance that the heat pump is properly designed for actual running conditions for the product.

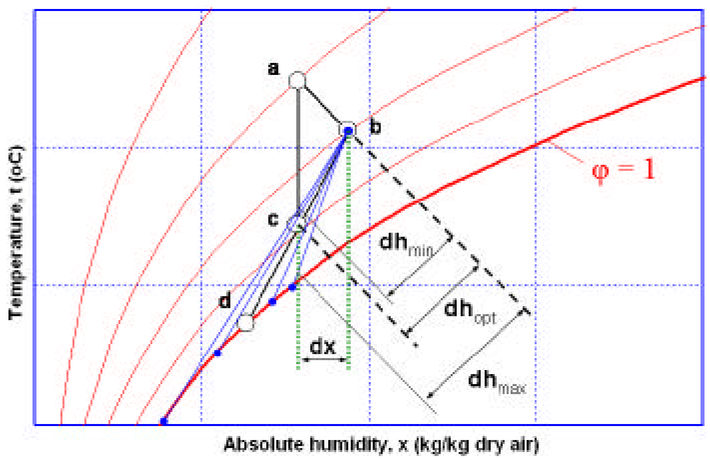

Figure 2 Mollier diagram for the drying process

Drying conditions

The temperature programs used in the experiments are as follows:
+10°C, +5°C, +1°C, -1°C, -4°C and -8°C. Some of the tests had a final drying at +20°C. The change between low and high temperature was not done at the same water content in all the experiments. In general the change in drying temperature was done at a water content lower then 50%.

RESULTS

The quality of atmospheric freeze dried cod is affected by the drying conditions, especially the drying air temperature. The drying time (capacity), bulk density, re-hydration ability and color for cod cubes are affected by different temperatures and residence times at temperatures below the material freezing point. The result of the experiments is shown in Figure 3 to 9. In Figure 3 the drying curves for two of the experiments are given. Drying at -10°C only the drying time will be in the order of 300 minutes. If the temperature is lowered to -8°C the water content is still about 60% after approx. 300 minutes. In this experiment the temperature in the inlet of the drying chamber was increased to +20°C after 360 minutes. The total drying time was then 550 minutes.

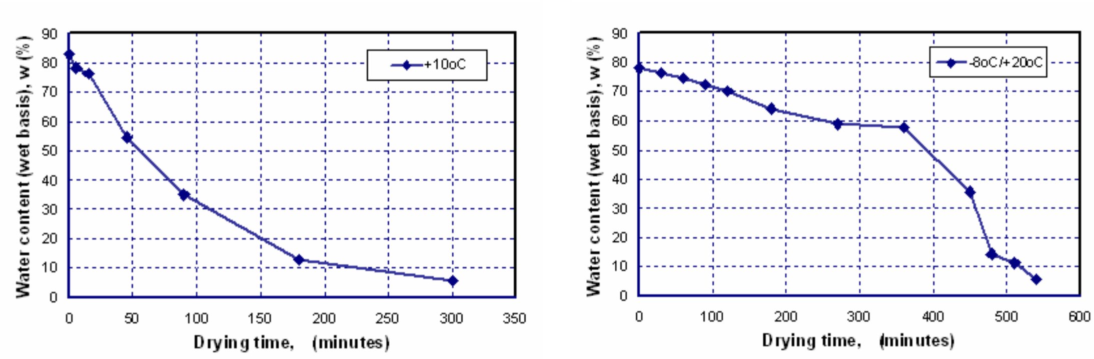

Figure 3 Drying curves for the cod pieces with drying temperature at +10°C and with start temperature program at -8°C and final drying at +20°C

In Figure 4 the experimental sorption data are plotted as a function of water activity. In the figure there is also plotted the GAB adsorption model fitted to the experimental data. The GAB model is given in equation (1).

$$W = \frac{W_m * K * C * a_w}{(1 - C * a_w) * [1 + (K - 1) * C * a_w]} \qquad (1)$$

The parameters for the GAB model is determined by help of the solver in an excel spreadsheet. The standard deviation for the experiments in the GAB model is 44.3 and the constants are; C= 2.19, K= 0.99999 and W_m= 0.114. As shown in Figure 4 the GAB model do not fit the experimental data well at water activity of 0.8 to 0.9.

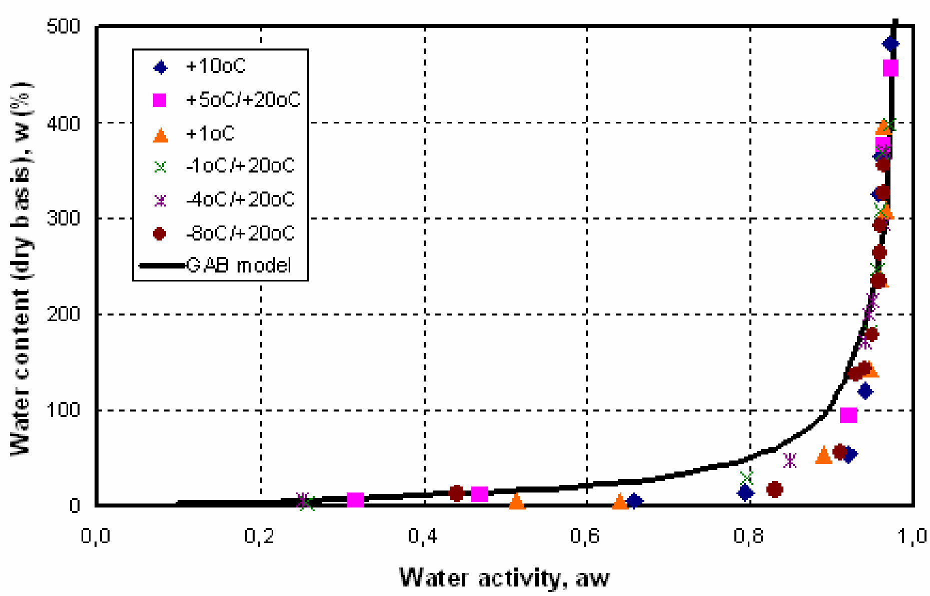

Figure 4 : Sorption isotherm for cod pieces dried at different temperature programs

In Figure 5 the bulk density is plotted for the different drying programs. As shown in the figure the bulk density is decreasing with the drying temperature. The bulk density at -8°C is less then half of the bulk density at +10^{o}C. The temperature program make is possible to design the drying process to a requested bulk density for the product.

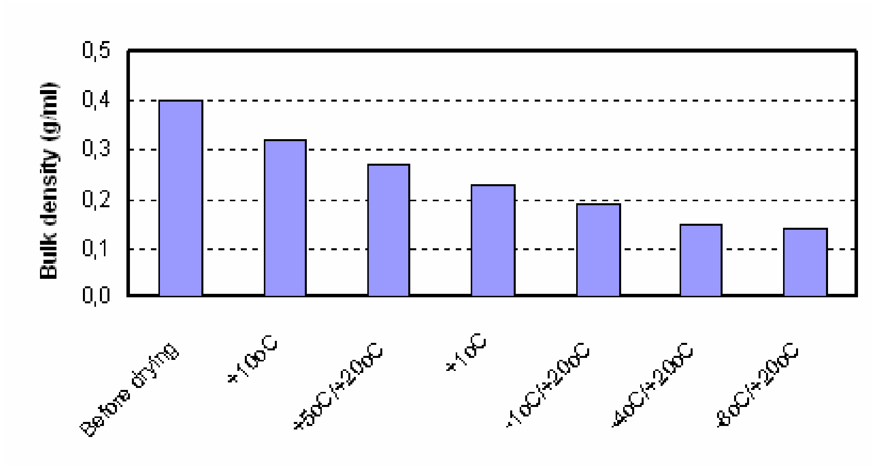

Figure 5: Bulk density of cod pieces dried at different temperature programs

The rehydration of the cod pieces followed a standard procedure. One gram of the product was put into 50 ml boiling water and stirred. Rest water was removed and water content was measured. The calculation of the rehydration ability is given by equation (2):

$$R_a = \frac{m_w}{m_{ts}} * 100\% \qquad (2)$$

The ability to absorb water and the absorption time after drying is highly dependent of the drying temperature program. After only 60 seconds the product dried at -8^{o}C has absorbed most of the initial water content.

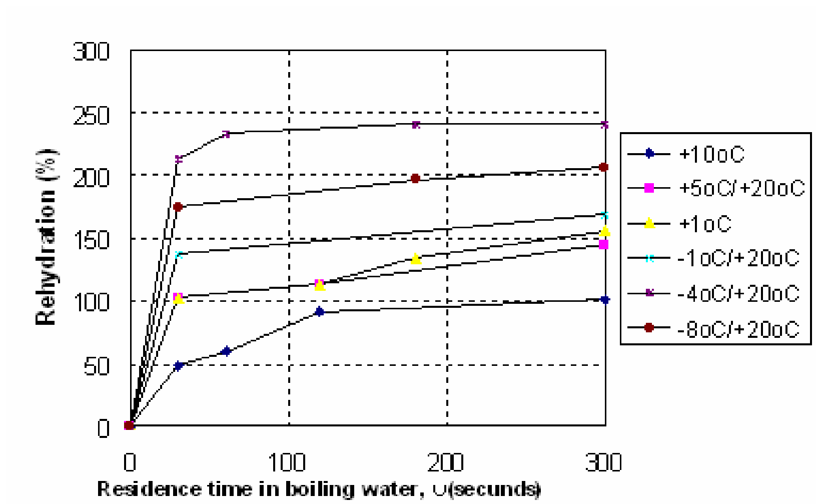

Figure 6: Rehydration of cod pieces dried at different temperature programs

Figure 7: Pictures of cod pieces dried at +10^{o}C and -8^{o}C

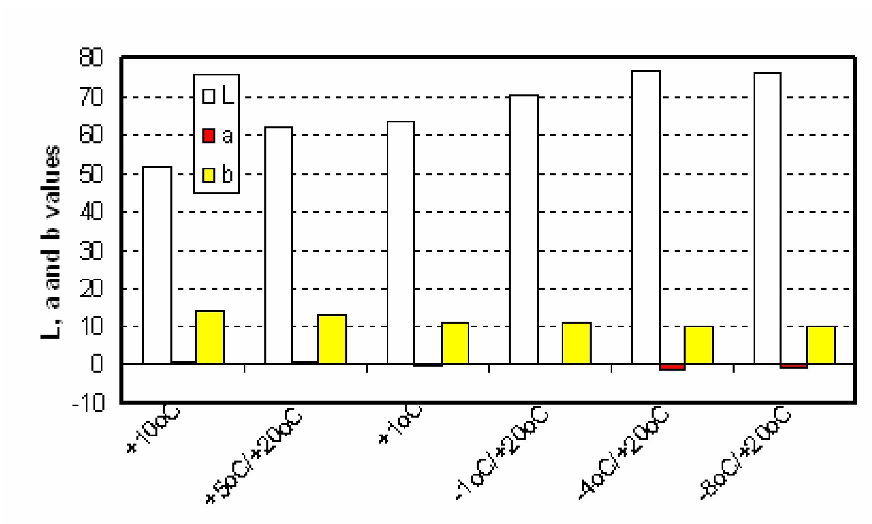

Figure 8: Colour measurements of the cod pieces dried at different temperature programs

The colour measurements were done with a X-Rite®948 instrument. As show in Figure 7 and 8 the colour of the cod pieces are influenced by the temperature program. The white component is increasing and the yellow component is decreasing with lowering drying temperature. This is clearly seen from the pictures in figure 7 showing cod pieces dried at +10^{o}C and -8^{o}C.

The protein denaturation was measured for the cod pieces after drying. The results are shown in Figure 9. The indication from the measurements is that the denaturation of proteins is decreasing by lowering the drying temperatures. These measurements have to be followed up with measurements on rehydrated samples. The analyses are done with a DSC.

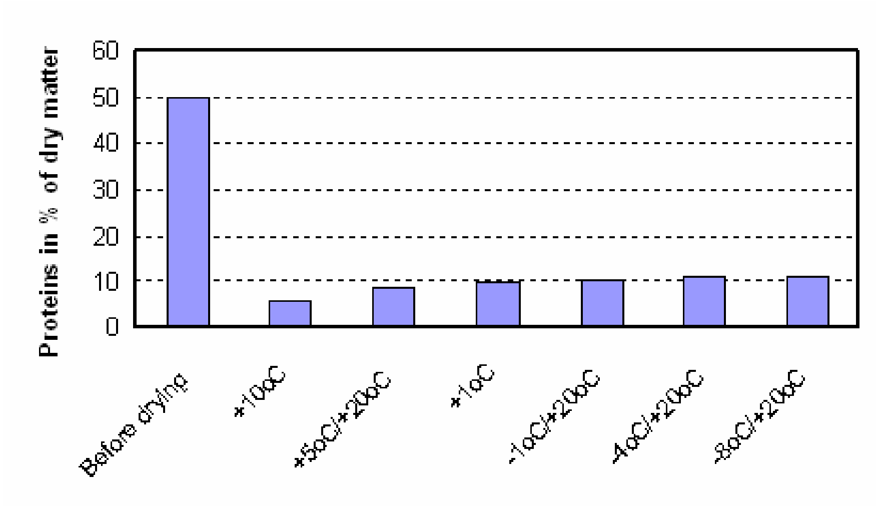

Figure 9: Protein denaturation of cod pieces at different drying programs

Design of heat pump drying in combined temperature modes

Heat pump drying allows operation in combined modes using air temperature below and above the material freezing point. To achieve as high SMER as possible an industrial fluidized bed heat pump dryer should be designed according to the following “rules”:

- Drying operation with optimum bed height to attain a higher relative humidity at the dryer outlet
- Stable fluidization due to the sorption characteristics of the material being dried
- Continuous, not batch operation, due to the lowering of capacity and efficiency during a batch process
- As high inlet temperature in the dryer as possible, due to improved thermal efficiency and capacity
- As low refrigeration capacity as possible, as long as the desired production is achieved (over-sizing increases dh/dx and reduces SMER)
- The choice of evaporating and condensing g temperature of the heat pump should be the combination giving the best combination of COP and dh/dx (an optimum might exist).

The energy consumption in an a continuous heat pump drying operated in a combined drying mode at temperatures at $-5^{o}C$ in the first stages and at $30^{o}C$ at the second stage. The SMER is calculated modifying Equation (3) as follows:

$$SMER = \frac{COP_{LT}}{\left(\frac{dh}{dx}\right)_{LT}} * \frac{t_{LT}}{t_{tot}} + \frac{COP_{HT}}{\left(\frac{dh}{dx}\right)_{HT}} * \frac{t_{HT}}{t_{tot}} \qquad (3)$$

$$COP = \frac{Q_o}{W} \qquad (4)$$

The conditions above are given in Table 1 and the process state points can be easily drawn the moist-air Mollier diagram.

Table 1 : Process conditions for the heat pump drying in combined drying mode

Air and heat pump loops	**LT**	**HT**
Air inlet drying temperature	-5 ^oC	30 ^oC
Air inlet relative humidity	40%	40%
Air outlet relative humidity	80%	80%
Surface temperature of air cooler	t_{dp} - 5^{o}C	t_{dp} - 5^{o}C
Heat pump evaporating temperature	air cooler surface temperature – 2^{o}C	air cooler surface temperature – 2^{o}C
Heat pump condensing temperature	air inlet drying temperature + 5^{o}C	air inlet drying temperature + 5^{o}C
Heat pump refrigerant	NH_3	NH_3

The calculations are plotted in the Figures 7 and 8, which indicate that drying at -5^{o}C for 10 hours results in lower bulk density, higher rehydration ability and energy consumption 7.5 times higher than drying at 30^{o}C only.

The SMER for the combined drying mode with 10 hours at -5^{o}C reduces the SMER to 67% compared with drying at 30^{o}C.

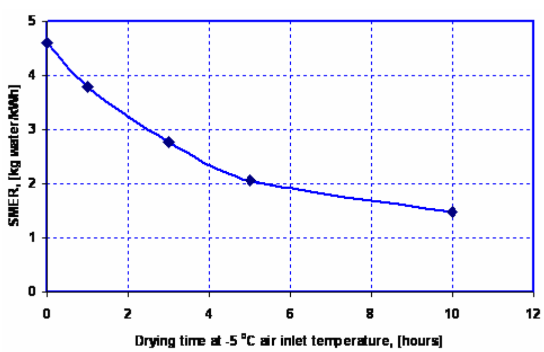

Figure 10: SMER for dried pieces of cod with increasing drying time at low temperature

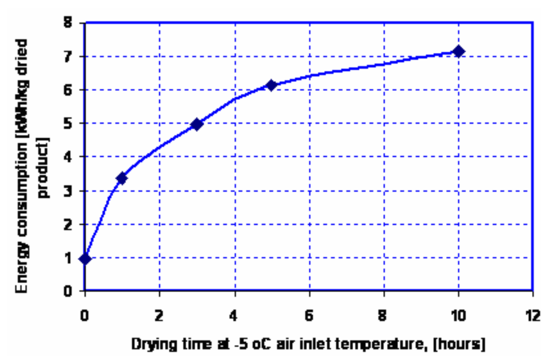

Figure 11: Dryer energy consumption per kg dried cod pieces with increasing time at low temperature

CONCLUSIONS

Atmospheric freeze drying with heat pump is a new alternative for producing high quality dried food products with low density, high rehydration ability and light colour. By controlling drying conditions these properties can be adjusted to the qualities market is requesting. Compared to vacuum freeze drying the atmospheric freeze drying is considerably cheaper and this drying process is now industrialized in Hungary for drying sweet corn and green peas.

In this paper cod pieces are dried at combined drying mode (low and high temperatures) showing improved rehydration ability and colour. Energy consumption and the SMER are highly influenced by drying time at low temperatures. An example shows drying at initial temperature of -5^{o}C and final temperature at +20^{o}C. With an initial drying time period of 10 hours at –5^{o}C the SMER will be reduced with 67 % compared to drying at 30^{o}C only. The energy consumption will be 7.5 times higher compared to drying at 30^{o}C only.

NOTATIONS

W	water content, dry basis	
W_m	monolayer water content	
K	constant	
C	constant	
a_w	water activity	
R_a	rehydration ability	(%)
m_w	water content in product after rehydration	(gr)
m_{ts}	dry matter of the product	(gr)
SMER	specific Moisture Extraction Ratio	(kg water/kWh)
LT	low temperature drying	
HT	high temperature drying	
dh	enthalpy difference for the air	(kJ/kg dry air)
dx	difference in humidity for the drying air	(kg water/kg dry air)
Q_o	refrigeration capacity	(kW)
W	energy consumption (compressor and fan)	(kW)
COP_{LT}	coefficient of performance for the low temperature drying heat pump	(-)
COP_{HT}	coefficient of performance for the high temperature drying heat pump	(-)
t_{dp}	air dew point temperature	(^oC)
τ_{LT}	drying time at low temperature	(hours)
τ_{HT}	drying time at high temperature	(hours)
τ_{tot}	total drying time	(hours)

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