Conference Paper

Resource and Energy Efficient Method of Dried Fish Production

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Abstract

The authors of the article propose a method of convective dehydration of fish products, which has an intermittent nature of implementation. The dehydration process consists of the continuous initial phase and following combined periods consisting of phases of drying and relaxation of dehydrated surface layer of the raw material. The necessity of applying relaxation is due to the fact that during the drying process the surface layers that have lost some of the moisture are significantly densified. The size of the capillaries for moisture passing through the surface layers is reduced. Near the surface a layer is formed, which lacks the significant mass of moisture and has low diffusion properties. As a result, the dehydration process of the entire sample slows down. The rational use of relaxation leads to restoring the moisture-conducting properties of the surface layer of fish. The supply of electrical energy to the heating elements is stopped during the relaxation. The minimum circulation rate of the drying agent is maintained in the drying installation. Fresh air with a lower temperature and higher relative humidity than the drying agent is supplied to the drying agent. The conditions in the drying installation restrain external mass transfer and facilitate to the relaxation of the dehydrated surface layer, that is, to the redistribution of moisture in the thickness of the fish. The proposed method of dehydration of fish raw material reduces the cost of electric energy in the production of dried products and provides more rational coolant usage. The final fish products have more attractive appearance due to reduction of tissue deformation as a result of applying the relaxation of dehydrated surface layer.

Keywords: fish dehydration, dehydration rate, moisture diffusion coefficient, moisture gradient

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1. Introduction

During cold drying fish exsiccates during the whole process. Moreover the intensity of moisture loss changes with time [1]. The amount of the reduced moisture depends on a mechanism of moisture and heat transfer within the wet material and mass- and heat transfer of the material surface with the environment [2--4]. The task of this research is to develop the technology which allows intensifying the dehydration process during the decreasing drying rate and to reduce the electricity consumption [5--7]. The drying process retardation in the second dehydration phase occurs due to changes in diffusion properties of the surface layer of fish with respect to micro capillaries size reducing [8]. It is proposed to use the regimes of relaxation in order to recover the diffusion properties of fish tissues. During the relaxation the conditions are created for staged moisture transfer from the central layers, where the dehydration has not appeared yet, to the dehydrated surface layers. As per proposed method the dehydration occurs on every linear element of moisture transfer, then the relaxation of the surface layer. The relaxation of dehydrated surface layers follows the penetration of the sample's inner moisture to the surface. The appearance of the moisture inside the dehydrated area leads to the capillaries unpasting and expanding. During the next linear element of moisture content change, the sample again enters the dehydration process with better conductive properties throughout its volume.

2. Methods and Equipment

2.1. Methods

2.1.1. Part by weight of water defining

Part by weight of water in raw material and in the final product is defined by drying on a Chizhova Eleks-7 device. This method is based on water exudation from the product due to contact with heated plates of the temperature of 125-150 °C of the device. The mass change is then determined by weighing. A 2-3 g sample is placed in pre-dried 15x15 cm paper bags. The sample is dehydrating to a constant weight. The final result is taken as the arithmetic mean value of the results of two parallel determinations; the acceptable differences should not exceed 0.5 %.

2.1.2. Method of experimental kinetics curves tracing

In order to trace the experimental kinetics curves of dehydration it is required to determine the initial part by weight of moisture in fish. During the dehydration process it is necessary to determine the weight loss of the treated object. Needed for experimental kinetics curves of dehydration tracing, moisture content of the fish by dry weight basis $\omega^c{}_i$, (%), at the relevant time of the dehydration process, are determined from the formula:

$$\omega_i^c = \frac{m_i \cdot 100}{m_c - m_I}, \tag{1}$$

where m_I - weight of fish at a certain time, kg;

m_c - weight of dry matter in fish, kg.

In order to determine the weight of dry matter m_c in fish the following formula is used:

$$m_c = m_0 \cdot \left(1 - \frac{\omega_0^o}{100}\right), \tag{2}$$

where m_c - weight of fish at the initial dehydration moment, kg;

ω_0^o - the initial moisture content of fish per its weight, %.

2.1.3. Temperature and relative humidity of the drying agent

The temperature and relative humidity of the drying agent recording inside the drying installation is implemented by universal eight-channel micro processing control device OVEN TRM148, installed in the automatic control system unit. Temperature and relative humidity detectors DVT-03M are connected to the measuring device TRM148 via analog input module MVA8 through RS 485 interface.

The temperature and relative humidity of the drying agent could be considered as a single dimensionless parameter – operating severity X_p. Temperature increase and moisture decrease intensify the dehydration process. The operating severity is determined by the formula:

$$X_p = \bar{t}\left(1 - \frac{\overline{\varphi}}{100}\right), \tag{3}$$

where $\bar{t}$ --average temperature of the drying agent, $^{\circ}C$;

$\overline{\varphi}$ - average relative humidity of the drying agent, %.

2.1.4. The drying agent motion speed

The motion speed of the drying agent is measured by the anemometer with external paddles UNI-Trend UT363S.

2.1.5. Electricity consumption

Single-phase electricity supply meters 1F NEVA with discrete output have been used for consumed electrical energy record for fish dehydration by the proposed and traditional (without applying relaxation of dehydrated surface layer) methods. The meters have been connected to the analog input module OVEN MVA8 [9].

2.2. Equipment

2.2.1. Experimental drying installation

The drying installation has four independent drying cells. Every cell is equipped with electricity supply meter, temperature and relative humidity detectors, tubular element and duct work with control valves for the drying agent circulation. Figure 1 shows the diagram of the experimental installation.

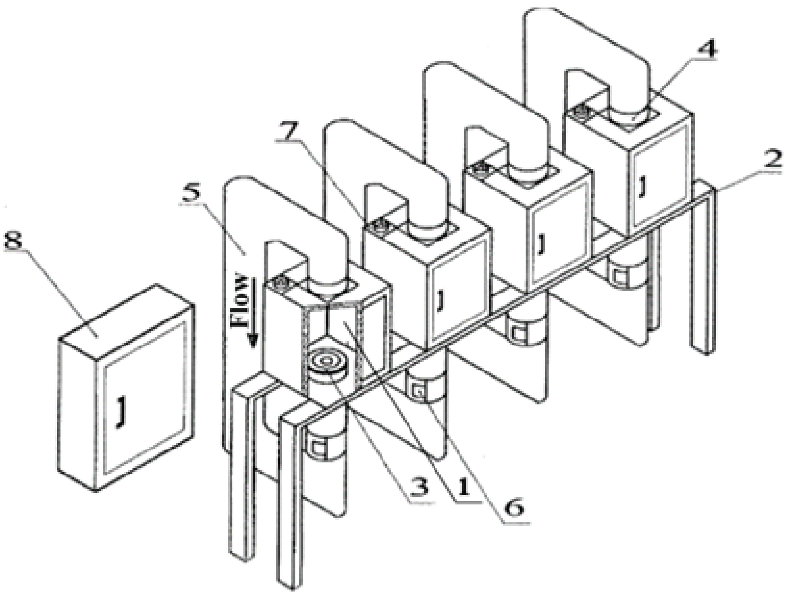

Figure 1: Experimental drying installation: 1 -- independent drying cell; 2 -- frame of the drying installation; 3 - cross flow fan; 4 -- vacuum fan; 5 -- flue of coolant circulation; 6 -- heating unit; 7 -- coolant ejection fan; 8 -- automatic control system unit.

2.3. Object

The study object is frozen blue whiting. The fish has been frozen, rinsed, split to back, then salted away by brining to the salt content of 2.0-2.5 %. The samples with similar dimensional and mass characteristics are chosen for dehydration.

3. Results

3.1. Dehydration method description

Depending on a fish type, the dehydration is conducted at the drying agent temperature (air) from 18 to 33 °C, relative humidity from 30 to 60 % and motion rate from 2 to 3 m/s. In order to intensify drying during the first 10 -- 15 minutes the dehydration of the raw material is conducted at the temperature of the main process and the drying agent motion rate from 3 to 4 m/s until the sample weight loss is from 3 to 4 %. Then the motion rate of the drying agent is maintained from 2 to 3 m/s during the dehydration process. The recirculation of the drying agent is maintained in the cell during the process of predrying and dehydration process. The amount of circulating coolant in the installation should be from three to times the supplied amount of fresh air for mixing.

According to the proposed method the dehydration process (Figure 2) consists of continuous initial phase of dehydration T_n and combined periods T_1, T_2,..., T_i. The duration of continuous initial phase τ_{Tn} is from 3 to 8 hours.

The reference point for applying the combined periods could serve the second critical point K_2 , which appears on the dehydration kinetics curve due to bonding energies of moisture with the material increase, which is expressed in the significant decelerating of dehydration rate. The critical points on the dehydration kinetics curve appear when the period of moisture removal with the lower bonding energy with the material stops, and the moisture removal with the higher bonding energy begins. The second critical point occurs in the zone of removal of micro capillary moisture from fish. As the dehydration proceeds the micro capillaries decrease in size [7], therefore, the bonding energy of water decreases in the micro capillaries. After the critical point K_2 the moisture removal slows down. The second critical point K_2 corresponds to the moisture per dry matter ${\omega_{K2}}^c$ on the dehydration kinetics curve. The value of ${\omega_{K2}}^c$ is determined by the formula [7]:

$$\omega^c_{K2} = 0.784\omega^c_0 + 2, \tag{4}$$

where ${\omega^c}_0$ - the initial moisture of fish per dry matter, %;

The duration of the continuous initial dehydration phase τ_{Tn} could be found from the experimental dehydration kinetics curve by projecting K_2 point on horizontal axis. Such value could be increased up to 4 hours.

The duration of continuous initial dehydration phase τ_{Tn}, hours, could be calculated as per the formula:

$$\tau_{Tn} = \tau_2 + K_{rel}, \tag{5}$$

where τ_2 -- the duration of dehydration from the beginning of the process to the point K_2, hours;

K_{rel} -- empirically determined coefficient, the K_{rel} value is chosen in the range from 0 to 4 hours. The maximal values of K_{rel} are chosen at the initial technological regimes of dehydration try-out.

After the continuous initial phase T_n the whole process is divided into similar time periods -- combined periods of dehydration T_1, T_2,..., T_i. T_1 -- the first period, T_2 -- the second period, T_i -- the final period. The duration of the combined period T is in a range of 2-6 hours. For small-sized fish and fillets the value T is expected to be from 2 to 4 hours, for big-sized fish -- from 4 to 6 hours. Every combined period consists of the drying phase T_{O1}, T_{O2},..., T_{Oi} and dehydrated surface layer relaxation T_{R1}, T_{R2},..., T_{Ri}. The duration of the relaxation phase of the first period T_{R1} is from 5 to 10 % of the duration of the combined period T. The duration of the relaxation phase of the final period T_{Ri} is from 20 to 40 % of the duration of the combined period T. The gradual increase of the relaxation phase duration from T_{R1} to T_{Ri} occurs according to the linear dependency. Figure 2 shows the gradual increase of the relaxation phase and decrease of the dehydration phase in the combined period. The gradual increase of the relaxation phase in course of time of the dehydration process relates to significant moisture losses from the surface layer of fish and lowering its moisture-conducting properties [3]. More time is required to restore the moisture-conducting properties of the surface layer as the dehydration proceeds. That is why the duration of the relaxation phase decreases. During the relaxation heating elements are switched off, in the installation the coolant motion rate is maintained from 0.2 to 0.5 m/s. Air of lower temperature (by the value from 3 to 10 °C lower than the air in the drying cell) and higher relative humidity than the drying agent (by the value from10 to 30 % higher than in the drying cell) is supplied to the drying installation. Fresh air is used for this purpose. The coolant motion rate in the cell is maintained from 0.5 to 1 m/s. During the relaxation the amount of the circulated drying agent in the installation should be 1.5 -- 2.5 times higher than the amount of fresh air supplied for mixing. During the relaxation the temperature of the circulated coolant in the cell gradually declines on the value from 3 to 8 °C.

3.2. Example of the method implementation

The air-cured back of blue whiting production. The raw material (frozen whole blue whiting) is cured with general operations (preparation): defrosting, rinsing, splitting to back, rinsing and sorting, salting away by brining, rinsing, threading of fish to the bars,

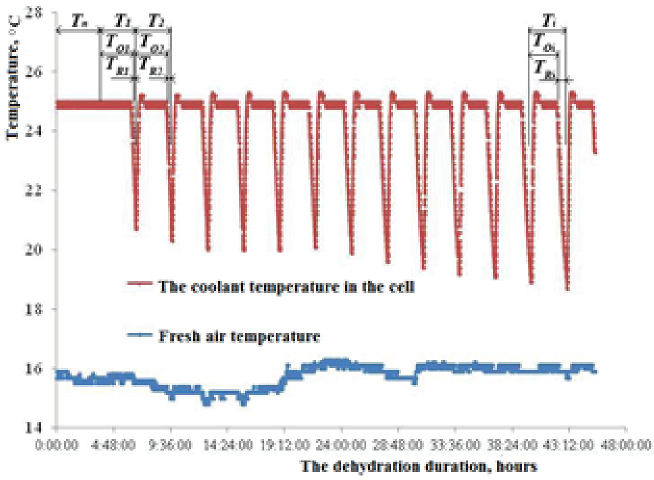

Figure 2: Temperature change of coolant in the cell during the dehydration of fish with the proposed method.

draining, arrangement of the bars with fish on the stand of bars. The stands of bars with fish are then placed to the drying installation. The initial moisture content of fish per dry matter is 400 %, specific surface area of fish (the relation of surface area of fish to its weight) is 0.19 m^2/kg. The relaxation phase of the first combined period is T_{R1} = 10 %. The relaxation phase of the final combined period is T_{R14}= 30 %. The parameters of fresh air for mixing with the used coolant are: $t_{f.a.}$ is from 15 to 16 °C, and relative humidity $\varphi_{f.a.}$ is from 39 to 44 %.

Predrying regime. The settings to the predrying process are: the coolant temperature t_p = 25 °C, the coolant motion rate v_p = 4 m/s, predrying duration τ_p = 10 min, the amount of circulated coolant in the installation is three times higher than the amount of fresh air supplied for mixing.

Continuous initial phase T_p. The settings include parameters T_n: the coolant temperature t_{Tn} = 25 °C, coolant motion rate v_{Tn} = 2.5 m/s, duration τ_{Tn} = 3 hours (τ_2 = 2.9 hours, K_{rel} = 0.1), the amount of circulated coolant in the installation is four times higher than the amount of fresh air supplied for mixing.

After the initial phase T_n ends the dehydration process is divided into combined periods T. In this example the amount of combined periods equals n_T = 14, The duration of each combined period of dehydration τ_T = 3 hours.

The first combined period T_1.

The dehydration phase T_{O1} of the first combined period T_1: the coolant temperature t_{TO1} = 25 °C, the coolant motion rate v_{TO1}= 2.5 m/s, duration τ_{To1} = 162 min (90 % of the duration T_1), the amount of circulated coolant in the installation is four times higher than the amount of fresh air supplied for mixing. The relaxation phase T_{R1} of the first combined period T_1, T_{R1} = 10 % of τ_T. During the relaxation heating elements are switched off. The parameters of the relaxation phase T_{R1}: the temperature of the coolant in the beginning of relaxation equals the temperature of the coolant during the dehydration phase $t_{TR1\ beg}$ = 25 °C, the coolant temperature in the end of relaxation $t_{TR1\ end}$ = 20.7 °C, the average coolant temperature of the relaxation phase $t_{TR1\ av}$ = 22.9 °C, the coolant motion rate v_{TR1}= 0.5 m/s, duration $\tau\ _{TR1}$ = 18 min (10 % of the duration T_1), the amount of circulated coolant in the installation is two times higher than the amount of fresh air supplied for mixing.

Then the following combined periods T_2 - T_{13} are implemented with parameters different in duration of dehydration phases, relaxation, and the coolant temperature in the cell in the end of relaxation.

Parameters of the final combined period of dehydration T_{14}.

The dehydration phase T_{O14} of the combined period T_{14}: the coolant temperature t_{TO14}= 25 °C, the coolant motion rate v_{TO14}= 2.5 m/s, duration τ_{TO14} = 126 min (70 % of the duration T_{14}), the amount of circulated coolant in the installation is four times higher than the amount of fresh air supplied for mixing. The relaxation phase T_{R14} of the combined period T_{14}, T_{R14} = 30 % of τ_T During the relaxation heating elements are switched off. The parameters of the relaxation phase T_{R14}: the temperature of the coolant in the beginning of relaxation equals the temperature of the coolant during the dehydration phase $t_{TR14\ beg}$ = 25 °C, the coolant temperature in the end of relaxation $t_{TR14\ end}$ = 18.6 °C, the average coolant temperature of the relaxation phase $t_{TR14\ av}$ = 21,8 °C, the coolant motion rate v_{TR14}= 0.5 m/s, duration $\tau\ _{TR14}$ = 54 min (30 % of the duration T_{14}), the amount of circulated coolant in the installation is two times higher than the amount of fresh air supplied for mixing.

Figure 3 shows the parameters of the dehydration phases and relaxation of the combined periods T_1 - T_{14} of the example 1.

Figure 4 shows the dehydration curves for the continuous process and for the proposed method. The duration of dehydration is 45 hours. The dehydration rates of these processes are approximately identical. However, according to the proposed method of dehydration the total duration of the phases of relaxation is 7.8 hours. During this period of time there is no electricity supply to tubular elements. The fans of installation work in the economy mode, maintaining the flow rate in the cell 0.5 m/s. According to this method the electricity consumption is 15 % less in comparison with the continuous process. For the regime with the initial relaxation phase T_{R1} = 10 % and final relaxation phase T_{R13} = 40 % (the other technological parameters are identical to the ones described in the example) the electricity consumption is 17.5 % less in comparison

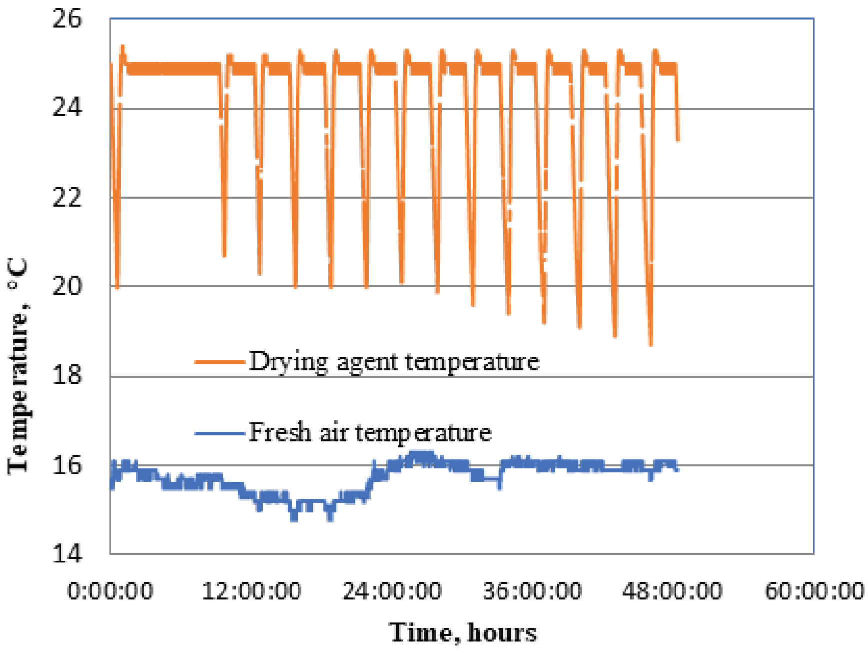

Figure 3: Coolant temperature change in the cell during the blue whiting dehydration.

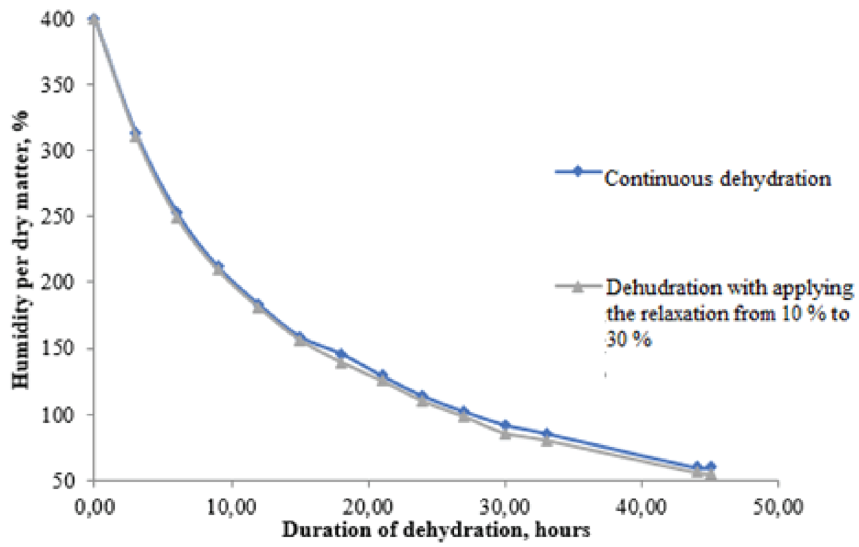

Figure 4: Kinetics curves of dehydration of the back of blue whiting for continuous process and with applying the relaxation.

with the continuous process. Figure 5 shows the final product after the continuous dehydration process and after applying the combined periods.

a b

Figure 5: Final product without applying the relaxation (a), after applying the relaxation of the surface layer (b).

4. Discussion

The dehydration rate of the analyzed methods is approximately the same. However, according to the proposed method of dehydration the total duration of the phases of relaxation is 7.8 hours. During this period of time there is no electricity supply to tubular elements. The fans of installation work in the economy mode, maintaining the flow rate in the cell 0.5 m/s. According to this method the electricity consumption is 15 % less in comparison with the continuous process. For the regime with the initial relaxation phase T_{R1} = 10 % and final relaxation phase T_{R13} = 40 % (the other technological parameters are identical to the ones described in the example 1) the electricity consumption is 17.5 % less in comparison with the continuous process. After applying the relaxation regimes, the final product has more attractive appearance. Fish tissue deformations due to dehydration are feebly marked. Therefore, the regimes of dehydration with phases of relaxation of moisture in fish allow decreasing the electricity consumption by saving the resources of the drying installation, as well as to increase the quality (the appearance) of the final product.

5. Conclusion

The proposed method of dehydration allows decreasing the electricity consumption during the production of dried fish by 10 -- 15 % in comparison with the traditional method of dehydration (without applying the regimes of relaxation of the surface layers) without increasing the duration of the whole process. This method allows more rational use of the coolant. After applying the proposed technology, the final product has more attractive appearance due to decreasing the phenomenon of fish tissue deformation as a result of relaxation applying. This method does not require the significant technical changes in the traditional technological process.

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Conflict of Interest

The authors have no conflict of interest to declare.

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