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The kinetics of drying fish in the equipped with a heat pump

Summary

The drying process is characterized by the drying speed decreasing due to over drying of the fish upper layer. This is explained by its thickening and increasing resistance of moisture diffusion to the surface.

It has been experimentally established that fish tissues heating in the process of drying to the drying agent temperature lasts from 0,1 to 0,8 hour depending on the fish thickness and this accounts for a comparatively small value of general drying duration.

When the regular mode occurs the drying rate keeps constant in all the points of fish body and it characterizes relative speed of changing moisture content in fish body and depends only on its physical properties, parameters of moisture evaporation process on its surface, form and size of fish. To support this hypothesis we have undertaken the fish drying experiment (parch, roach) in a special drying installation.

According to the research results, carried out in Kaliningrad state technical university (KSTU), a pilot heat pump plant installation (HPDI) for dry and cold smoking of fish has been modernized and service testing.

It has been experimentally confirmed and theoretically validated that fish drying parameters in the pilot heat pump plant are getting self-aligning. The duration of drying process is reduced on average by 20...30% in comparison with conventional plants.

***Key words**: Fish, drying, drying rate, heat pump installation*

Kinetyka suszenia ryb w suszarni wyposażonej w pompę ciepła

Streszczenie

Proces suszenia charakteryzuje się tym, że prędkość suszenia obniża sie z powodu wysychania warstwy zewnętrznej suszonej ryby. Jest to związane ze zwiększaniem się grubości wysuszonej warstwy i zwiększaniem oporu przenikania wilgoci do powierzchni ryby.

Eksperymentalnie ustalono, że ogrzanie tkanki ryb do temperatury powietrza (medium) suszącego trwa od 0,1 do 0,8 godziny, w zależności od grubości ryby, co stanowi niewielką wartość ogólnego czasu suszenia.

Kiedy ustabilizują się warunki procesu suszenia wówczas występować będzie stała szybkość suszenia we wszystkich punktach ciała ryby co charakteryzuje względną szybkość zmian zawartości wilgoci w ciele ryby, która zależy tylko od parametrów procesu, właściwości fizycznych, odparowania wilgoci z powierzchni, kształtu i wymiarów ryby.

Dla udowodnienia tej hipotezy wykonano doświadczenia suszenia ryb (okoń, płoć) w specjalnie zaprojektowanej instalacji suszarniczej.

Zgodnie z wynikami doświadczeń, potwierdzonymi teoretycznie, przeprowadzonymi w Kaliningradzkim Państwowym Uniwersytecie Technicznym (KSTU) pilotowego urządzenia suszarniczego, zmodernizowanego przez zastosowanie pompy ciepła zostały osiągnięte następujące korzyści. W okresie letnim obniżone zostało zużycie energii o 30% a w okresie zimowym o 7% przy jednoczesnym skróceniu czasu procesu suszenia.

***Słowa kluczowe**: ryba, suszenie, szybkość suszenia, instalacja z pompą ciepła*

Entry

Fish drying is a non-stationary and non-reversible process, going on at the alternating (decreasing) speed, so calculation of kinetics process presents considerable difficulty. Fish muscle tissues refer to moist, colloid, capillary-porous bodies and moving forces of removing moisture at low temperature drying of such bodies is a moisture possession gradient. The drying process is characterized by the drying speed decreasing due to over drying of the fish upper layer. This is explained by its thickening and increasing resistance of moisture diffusion to the surface.

The kinetics of the inner mass transference at low temperature fish drying may be described in general case by equation of moisture change speed at anybody point (Ginsburg 1985):

$$\partial U/\partial \tau = \alpha_m \nabla^2 U + \alpha_m \delta \nabla^2 \Theta + k_p/\rho_0 \nabla^2 p \qquad \textbf{(1)}$$

where: U – body moisture content; Θ – temperature drop, p – general pressure of moist air, α_m – diffusion coefficient, δ – relative thermo diffusion coefficient, k_p – molar filtering moisture transference coefficient, p_0 – anhydrous body density, ∇^2 – Laplace operator.

One of the ways for solving the energy saving problems, ecological safety and technological processes intensiveness in the food industry is the use of heat pumps for production of both heat and heat and cold.

For the purpose of finding out the advantage of using the heat pump the research of drying fish by air prepared by conventional method and the air prepared in the heat pump operating on a closed-circuit cycle of feeding air into the drying plant has been carried out.

Experiments results and their discussion

It has been experimentally established that fish tissues heating in the process of drying to the drying agent temperature lasts from 0,1 to 0,8 hour depending on the fish thickness and this accounts for a comparatively small value of general drying duration (fig. 1).

During that time the temperature levels off and keeps constant at different points throughout the fish thickness, i.e. temperature gradient tends to zero.

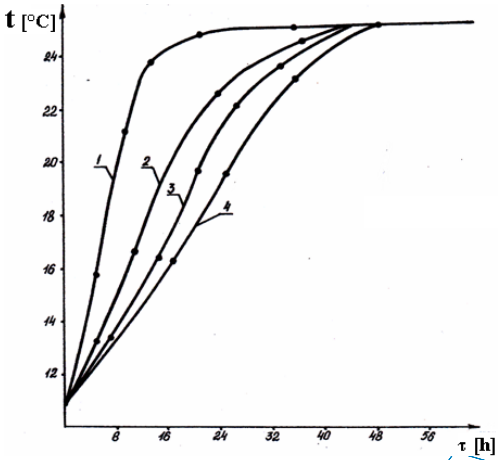

Fig. 1. The dependence of temperature in a fish body on the time of drying: 1 – on the surface of fish; 2, 3 – in a fish body; 4 – in the centre of fish body.

Rys. 1. Zależność temperatury w ciele ryb od czasu suszenia: 1 – na powierzchni ryby; 2, 3 – wewnątrz ryby; 4 – w centrum ryby.

It is known that mass transference reaches considerable values under the general pressure of moist air at the temperature of product close to 100°C. At such a temperature alongside with the pressure increasing due to specific volume rising of moisture in pores and capillaries we observe intensive vapor creation throughout the whole moist body volume, which is characteristic to such processes as frying, drying by means of high frequency electric current and others. Since the process of fish drying takes place at temperatures not higher than 35°C the influence of no relaxing pressure gradient is not of considerable value and it may be neglected.

So, mass transference at dry curing and cold smoking of fish may be described by the first equation component (2):

$$\partial U/\partial \tau = \alpha_m \nabla^2 U \qquad (2)$$

Equation solution is known from the heat transference theory. It is obvious that just like in heat transference the regular mode occurs in the process of drying at a certain moment, which is defined by the drying rate:

$$\partial U/\partial \tau = -m = const \qquad (3)$$

When the regular mode occurs the drying rate keeps constant in all the points of fish body and it characterizes relative speed of changing moisture content in fish body and depends only on its physical properties, parameters of moisture evaporation process on its surface, form and size, of fish.

If we experimentally determine the change of moisture content of fish thought time, then drying rate at regular mode can by defined by equation:

$$(\lg U_1 - \lg U_2)/(\tau_1 - \tau_2) = a_m = const \qquad (4)$$

Drying curves are demonstrated at fig 2.

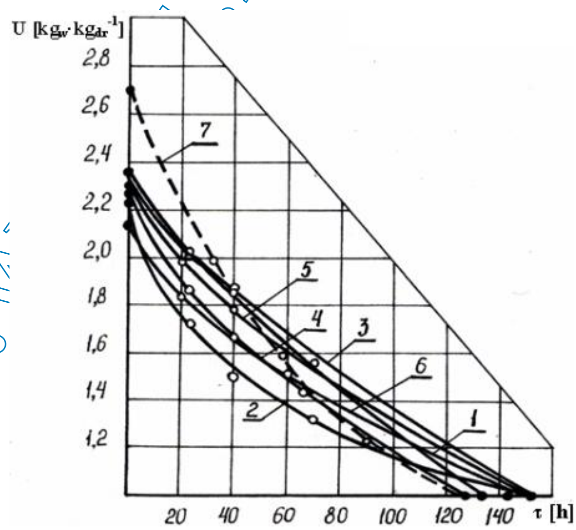

Fig. 2. Fish moisture change in the drying process for different values of relative humidity air - φ.: 1 – perch (φ = 50%); 2 – perch (φ = 70%); 3 – roach (φ = 50%); 4 – roach (φ = 70%); 5 – safrefish (φ = 50%); 6 – safrefish (φ = 70%); 7 – perch in HPDI.

Rys. 2. Zmiany wilgotności ryby w czasie suszenia dla różnych wartości wilgotności względnej powietrza: 1 – okoń (φ = 50%); 2 – okoń (φ = 70%); 3 – płoć (φ = 50%); 4 – płoć (φ = 70%); 5 – ciosa - Pelecus cultratus (φ = 50%); 6 – ciosa - Pelecus cultratus (φ = 70%); 7 – okoń w HPDI.

To support this hypothesis we have undertaken the fish drying experiment (bass, roach) in a special drying installation. It allowed to maintain constant air parameters (temperature, moisture and speed). Fish drying was carried out at $t°$ 20°C, relative air moisture 50% and 70% and speed 1,5m·s^{-1} , in a range from initial moisture to 50% of corresponding standard moisture of dried and cured fish product. Simultaneously were done fish drying experiments also in a heat pump drying installation (HPDI).

At the basis of experimental data the drying rate was calculated. Dependence of different fish drying on time is presented on fig. 3.

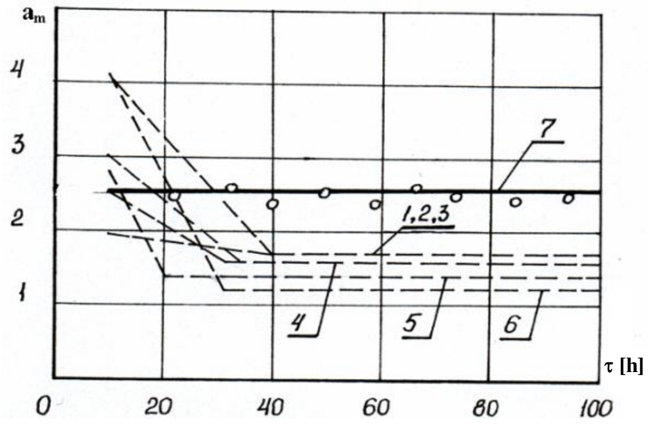

Fig. 3. Dependence of drying rate on time: 1 – perch 50%; 2 – perch 70%, 3 – roach 50%; 4 – roach 70%; 5 – safrefish 50%; 6 – safrefish 70%; 7 – perch in HPDI.

Rys. 3. Zależność szybkości suszenia od czasu dla różnych wartości wilgotności względnej powietrza: 1 – okoń 50%; 2 – okoń 70%; 3 – płoć 50%; 4 – płoć 70%; 5 – ciosa - Pelecus cultratus 50%; 6 – ciosa - Pelecus cultratus 70%; 7 – okoń w HPDI.

As it is seen from fig. 3 the drying rate at fixed air parameters gradually slows down and in 20 – 40 hours the regular mode comes.

The regular mode in HPDI comes at the very beginning of the process and keeps on during the whole drying process.

The experiment demonstrate that self setting of air parameters in HPDI keep regular mode of fish drying process due to gradual temperature rise and relative air moisture drop at slowing down the speed of moisture removal from the product. It cuts considerably the time of the process.

Reduction of drying time in HPDI can be accounted for by self-alignment of air parameters in the drying process. Within the heat pump when it is used in the system of preparation of recycling air of drying plant, the heat Q_k is fed to air within the heat pump condenser, the heat Q_0 in the air cooler is removed and power N of compressor for heating air is spent. Some of the heat ΔQ is lost to the environment. There is exchange of "explicit" heat Q_{ex} fed by warm air with the temperature t_a to the product with the temperature t_p and "implicit" heat Q_{im} releasing by the product to the air with the vapoured moisture between air and moist product surface which are equal to:

$$Q_{ex} = \alpha(t_a - t_b)F \qquad (5)$$

$$Q_{im} = r_t \beta_p (p_p - p_a)F = r_t u \qquad (6)$$

where: α – heat removal ratio, [Wt·m^{-2}·°K^{-1})]; F - heat mass exchange surface, [m^2]; r_t – heat of water steaming at product surface temperature t_p, [J·kg^{-1}]; β_p – steaming ratio, [kg·(s^{-1}·m^{-2}·Pa^{-1})]; p_p and p_a – partial pressure of saturated water steam over the product surface in the air, [Pa]; u - drying speed, [kg·s^{-1}], equal to:

$$u = \beta_p (p_p - p_a)F \qquad (7)$$

Thus, the heat balance of drying plant with the heat pump has the image:

$$N = Q_K - Q_0 = \Delta Q + \alpha(t_a - t_b)F - r_t u \qquad (8)$$

The left part of equation (8) according to the heat balance of heat pump plant presents power spent for driving compressor N, which depends on the kind of coolant, thermodynamic cycle of heat pump plant operation, compressor type and other factors and amounts approximately to (0,2....0,3) Q_0.

Then, expression (8) takes the form:

$$(0{,}2....0{,}3)\ Q_0 = \Delta Q + \alpha(t_a - t_b)F - r_t u \qquad (9)$$

Expression (9) reflects the fact of self-alignment of air parameters in the drying plant with the heat pump.

As it is shown in the paper (Suslov et al. 2007), the temperature rise of the surface product (t_p), takes place during the product drying surface process and it becomes practically equal to the temperature of air and reduction of moisture steaming speed (u), which brings about, as it follows from the heat balance (8) to the change of heat load on heat pump – Q_0.

It is known from the theory of refrigeration machines and heat pumps, that while reduction Q_0, pressure ratio p_c/p_0 increases and hence power for pressing coolant steam and feeding temperature, and heat Q_{ex} fed to the product also increases. The process of removing moisture from the product is getting more intensive at that, i.e. arises process preventing reduction of dry speed (u).

According to the research, carried out in Kaliningrad State Technical University (KSTU) the pilot plant H10-ИВЦ-1-03 for fish cold smoking of periodic operation has been service-tested at the commercial fishing form "Truzhenic morja" of Kaliningrad region. The series refrigeration plant MBT20 was used as a heat pump. Electric engine power is 10 kW. The plant testing was carried out in different seasons. The energy consumption during the summer times reduced by 30%, the technological process duration for fish cold smoking reduced by 25%, due to the gradual temperature increase of air and decrease of its moisture contents in the process of drying. Energy consumption in winter was reduced by 3 times and the time technological process was reduced by 7%.

Results

1. The regular mode in HPDI comes at the very beginning of the process and keeps on during the whole drying process.
2. The experiment demonstrate that self setting of air parameters in HPDI keep regular mode of fish drying process due to gradual temperature rise and relative air moisture drop at slowing down the speed of moisture removal from the product. It cuts considerably the time of the process.

3. Self alignment of air parameters in the drying installation with the heat pump was theoretically found.
4. A pilot heat pump drying installation for dry and cold smoking of fish has been produced.
5. During the service-testing of pilot heat pump drying installation in the summer time the energy consumption was reduced by 30%, the time of technological process was reduced by 25%. In winter season electric energy consumption was reduced by 3 times and duration of product preparation was reduced by 7%.

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