Energy efficient systems and regimes at fish products drying processes

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Abstract. When designing modern technologies and modes of food raw material processing, it is necessary to use technological systems allowing to make products safe for the consumer and with minimal labor and energy costs. Modern processing complexes need methods of raw material processing are essential to reduce the cost of production and improve the efficiency of technological equipment. To increase the productivity of technological lines and the level of development of a modern enterprise, an integrated approach to improving processes and equipment is required, provided that the finished products are of high quality. Scientific and design developments of the authors associated with the improvement of the efficiency of technological equipment are aimed at solving the following technical and operational tasks: improving the efficient and economical use of resources; enhancing the quality, uniformity and environmental safety of products; increasing the productivity of the processes and reducing their complexity. The design of the equipment is based on providing the efficient processing modes, identified on the basis of the laws of the processes under study. The technology of dried fish snacks production with heat pump using was developed. The designed original unit for effective mechanical processing of minced fish is utilized in technology.

1. Introduction
Heat pumps using natural low-potential energy sources are energy efficient and environmentally friendly for facilities that consume heat for the process [1, 2, 3]. The heat of soil, air or water can be considered as a low-potential source of energy [4, 5, 6]. The geographical location of the Kola region, where technological processing of aquatic bioresources is carried out, is favorable for the effective use of heat pumps. Due to warm Atlantic waters in the coldest period of the year, the water temperature of the Kola Bay does not fall below 3 °C above zero. In summer water surface layer with the thickness of 5 to 8 meters can warm up to plus 12 °C.

The objective of the study is to increase the energy efficiency of mass transfer in the process of fish structured products dehydration when the products change their internal properties under the influence of a drying agent. The tasks are to find out the regularities of the mechanisms of monitoring the internal properties of objects, to identify the general laws of kinetics of dehydration in the process of drying; to study the effect of chemical composition, geometric dimensions of the bodies, regime parameters of the drying agent on the process of drying; to create resource-saving technological equipment using heat pumps.

2. Development and creation of resource-and energy-efficient structured fish products drying technology
The researches were carried out on the basis of the research laboratory of the Department of processing and refrigeration equipment of the Murmansk state technical university. A series of studies were conducted to identify the patterns of dehydration of minced fish products of different size and mass, species and chemical composition in terms of changing rigidity of heat treatment. We have determined how these parameters affect the duration of the drying process.

\[
\tau = \psi(\omega_0, \frac{S}{m}, t, \varphi, v)
\]  

where \(\omega_0\) - initial moisture of product on its dry weight, %; 
\(\frac{S}{m}\) - specific product surface, m\(^2\)/kg; 
\(t\) - temperature of drying agent, °C; 
\(\varphi\) - relative humidity of drying agent, %; 
\(v\) - circulation rate of drying agent, m/s.

Heat and humidity characteristics \(t\) and \(\varphi\) were combined by a common parameter \(x_r\), representing the rigidity of the heat treatment regime [4].

\[
x_r = t \left(1 - \frac{1}{\varphi}\right)
\]  

The researches were carried out according to the method described below. The samples of minced fish were pre-weighed, specific product surface was measured, it was laid on carriers, which, in turn, were placed in the drying chamber. The experiments were divided into series, in each one the parameter influencing the process was altered in the range studied, and the rest parameters were maintained at the constant level.

During the experiments, the temperature ranged from 40 to 60 °C, the relative humidity of the drying agent ranged from 35 to 44 %. The air circulation rate was changed from 3 to 5 m/s. At specified time’s periods humidity losses were determined. The initial moisture of the objects of study ranged from 56 to 81 % (mackerel, sea bass, cod).

Figure 1 and 2 shows the experimental curves of convective drying of minced mackerel and sea bass with an initial moisture content of 54 and 73%, respectively.
The drying curves show that the rate of material dehydration increases as well as rising of regime rigidity. It is advisable to conduct intensification of the process at reasonable power consumption [7, 8]. The energy consumption of the drying chamber in the mode of using only heater, as well as in the drying regimes with using of a heat pump are analyzed. Graphs of the energy consumption for the drying process of raw materials in the conditions of operation of the experimental drying plant on heaters and with the heat pump using is shown in figure 3.
The studies were carried out using the experimental drying chamber designed by the authors. Currently, installation work is underway to equip the unit with a heat pump, which in its output characteristics can provide energy efficient operation of the chamber in soft semi-hot drying regimes at any external air parameters. The scheme of the experimental chamber for food materials drying is shown in figure 4.

![Diagram of the experimental plant for drying food materials](image)

Figure 4. Scheme of the experimental plant for drying food materials

We have proposed rational regimes of fish products processing in conditions of semi-hot drying, depending on the initial moisture content and fat content of fish should be implemented with the heat treatment rigidity in the range of $x, = 30-44$.

The current experiments on dehydration of minced fish products of different initial moisture confirmed the expediency of drying the raw material with high fat content in soft modes of semi-hot drying. When processing raw materials with low fat content it is advisable to increase the heat treatment rigidity to the upper recommended limits for the heat- and mass transfer processes intensification.

Deviation from the recommended heat treatment rigidity for raw materials with high fat content can lead to faults. Dried, sintered surface of the product can result if the deviation is above the recommended heat treatment rigidity. At the deviation below the recommended rigidity, the soft mode of semi-hot drying converts into the hard mode of cold drying. This significantly inhibits the internal diffusion of moisture and leads to the technological faults typical for raw materials with high fat content [9, 10].

The study of kinetics of dehydration of fish raw materials of different types in semi-hot drying showed the possibility of effective reduction of energy consumption for the process using heat pumps.
To improve the energy efficiency of the drying chamber, a heat pump of «water-air» type was constructed (figure 5).

Figure 5. Heat pump for convective drying of products
The unit operates on a spiral refrigeration compressor with a cooling capacity of 4.5 kW. Boiling point is 5 °C, condensing is 50 °C, superheat is 10 °C and subcooling is 0 °C. The system works on the ozone friendly refrigerant R407C [11]. It is being adapted for continuous operation in the conditions equivalent to the use of low-grade heat non-freezing Kola Bay. It is planned to develop recommendations for the modernization of drying chambers of industrial facilities involved in the fish raw materials drying on the Kola coast. The introduction of heat pump systems of the required capacity and optimal drying modes into the technological lines will significantly improve the energy efficiency of the technological equipment of coastal fish processing enterprises.

As an industrial implementation of the obtained patterns, we have developed a resource and energy saving technology of the production of dried fish products (fish chips) made of lean and fatty fish species. To increase the flavoring qualities and biological value of finished goods the technology of fish chips production assumes the use of the natural crushed dried plant components from berries, herbs and seaweeds of the Kola region.

The preliminary analysis of the designs of the machines available showed that uniform distribution requires relative long mixing. This leads to the increase of the product temperature, reduces the quality, in particular, its appearance and consistency [12 - 16]. Moreover, the value of the product is reduced when introducing ready-made crushed additives of long shelf life. We solved the problem of reducing the complexity of mechanical processing of the product and the uniform distribution of the introduced food products.

The results of the system analysis of the available designs of mechanical equipment for grinding and mixing allowed to develop the design of the unit, which makes it possible to grind the dried components into powder and evenly distribute them in the mass of minced fish [6]. The design of the unit for grinding of dry components and mixing them in viscous food products is shown in figure 6.

![Figure 6](image_url)

**Figure 6** - Design of the unit for grinding and mixing of products:
1 - electric motor; 2 - reducer; 3 - loading hopper grinder; 4 - sieve; 5 - spring shock absorbers;
The required amount of dry filler is fed into the loading hopper of the shredder, where it is ground into powder with knives and enters the sieve through the outlet pipe. Due to the vibration received by the spring-loaded sieve from the shredder, the crushed vegetable additives are distributed on the surface of the viscous product, and by means of a stirrer are mixed evenly, without clots. At the end of the process, the agitator is disconnected from the clutch, and the bowl is overturned for unloading.

After the effective completion of the mechanical process the formation of fish mincemeat, fish products loading on the pallets and drying at optimally high energy efficient modes take place. Further, according to the technological scheme, the finished product is formed, packed and sent to the consumer. Thus, we achieve an environmentally safe natural fish product of high quality.

3. Conclusion

At increasing the energy resources costs, the use of outdated energy-intensive technologies is becoming technically complex and economically impractical. Therefore, the developed modern technological systems must meet the requirements of product quality as well as save energy resources.

The approach proposed allows to optimize the process in time and energy costs for its implementation. The study of kinetics of dehydration of fish of the structured product of various types by semi-hot drying showed the reduction of energy costs for the processes of heat treatment by dehydration in soft regimes of semi-hot drying to 15-25% compared to the traditionally used high-temperature drying, as well as an additional opportunity to reduce the energy consumption of the process up to 50% by means of heat pump systems.

The authors developed a mathematical model of kinetics of dehydration of formed fish products under the influence of a drying agent in the temperature range from 40 to 80 ° C in semi-hot drying processes. A method of setting the optimal regimes of heat treatment of the product by drying in industrial conditions is being designed.

The production technology for dried formed fish products (chips and snacks) using resource-efficient regimes of dehydration of raw materials is developed. The machine-hardware support of the production scheme for manufacture of dried formed products from fish minced meat with flavoring components using the reliable resource-energy efficient equipment for heat-mass transfer and mechanical processes is offered:

- heat pump installation «water-air» for the process of convective dehydration (drying) of products with an adaptive automatic system of process parameters control was developed and constructed.
- the design of the unit dried plant components grinding and their effective uniform mixing in the volume of viscous food products (minced fish) was engineered.

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