Application of HP in the atmospheric freeze drying unit

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Abstract. Method of increasing the energy efficiency of atmospheric freeze drying due to the use of a heat pump unit (HPU) in a circuit are considered in this article. The use of HPU in the composition of the drying unit allows to more fully use the heat of superheated steam and the heat of condensation in the process of freeze-drying at atmospheric pressure. This increases the energy efficiency during operation.

1. Introduction
The undeniable advantages of the freeze-drying method for dehydrating frozen food have been confirmed by numerous studies in the food, chemical and pharmaceutical industries. In spite of this, a number of drawbacks impede the wider use of this type of units: high energy intensity and material consumption of the units, low intensity of the process, the impracticability of continuous quality control of the product, and the impossibility of obtaining particles with a given structure and properties.

There is a method for increasing the energy efficiency of a vacuum sublimation unit using a heat pump unit (HPU) in a circuit. A schematic diagram of such a technical solution is presented in figure 1.

Figure 1. Schematic diagram of the use of a heat pump in a freeze dryer. 1 - compressor with electric drive; 2 - sublimator (refrigerant condenser); 3 - condenser (refrigerant evaporator); 4 - intermediate heat exchanger; 5 - vacuum pump.
Due to the analysis of the research results of various authors on the use of TNU in sublimation drying plants, it became possible to develop the schematic solution for the sublimation dehydration of a stationary layer of moisture-containing product at atmospheric pressure.

2. Device design and operating principle.
We have developed a plant for drying materials, attempting to ensure the continuous operation of a closed system for circulating a gaseous drying medium at all stages of drying.

2.1. Device design
The unit is a sublimation chamber operating at atmospheric pressure, combined in a closed system with two blocks for preparing the gaseous drying medium. It includes two evaporators, two heat exchangers for transferring heat of superheated refrigerant vapor to air, as well as a heat pump condenser installed in the drying section and fans.

A feature of this unit is the transfer of heat from the refrigerant gas superheated in the heater to the air, which is then fed to the frozen product for freeze-drying. The heat pump evaporator is located in front of the heater along the drying agent (air). And the heat from the condenser located in the final drying unit is used for final processing to achieve the desired final moisture content of the product. Further, figures 2, 3 show the unit diagram.

Figure 2. Block diagram of the developed unit, top view
1 - drying chamber; 2 - drained material; 3 - part of the condenser of the refrigerating machine; 4 - low-temperature evaporator; 5 - air heater; 6 - sublimated product; 7 - air heater; 8 - low-temperature evaporator; 9 - heat insulated casing; 10 - block drying; 11 - blinds.
The arrows in figures 2 and 3 show the air circulation pattern in the closed system of the sublimation chamber. The block drying has an air-permeable casing to ensure the operation of the condenser of the heat pump and the drying of the sublimated material.

2.2. Operating principle

The principle of the unit operation has the following basic steps:

• wet material is placed in the sublimation chamber and frozen;
• air cooled with a low-temperature evaporator heats and dries in the air heater, then through the blinds it is fed into the sublimation chamber to the frozen product;
• frozen moisture from the product is sublimated;
• the product is moved to the block for drying, where the desired final moisture content of the product is reached at the required positive temperature using a chiller condenser; the heated air passing through the sublimation chamber, sublimates moisture from the frozen product, increasing its humidity;
• the humidified air enters the low-temperature evaporator, where the frozen out moisture deposits, forming a layer of frost;
• after a certain time, the blinds are closed and the first evaporator defrosts, at the same time drying is performed using a second evaporator with an air heater;
• after sublimation, the product is sent to the drying block, where at positive temperatures it is dried to specified humidity; and in the drying block, the air flow from the inlet passes through the condenser of the refrigerating machine, being heated to specified temperature and directed to the exhaust unit.
Thus, the unit continuously realizes the process of atmospheric freeze-drying and heat drying of the wet product.

3. Intercomparison
We compared specific energy costs for implementing the process in a vacuum freeze drying unit (VFD) and in an atmospheric freeze drying unit (AFD) without the use of HPU and HPU.

For comparison, VFD (PRC, “Kemolo”), AFD, (RF, Moscow, FSBEI HE "NRU" MPEI ") and ASSA with HPU dryer (RF, Moscow, FSBEI HE" National Research University "MPEI") were selected. The object of the study was meat (animal protein). The obtained values of the compared characteristics are summarized in table 1.

| Specifications | VFD | AFD | AFD+HP |
|----------------|-----|-----|--------|
| Workpiece size | Slices (10 mm thick) | Slices (4 mm thick, 50 mm long) | Slices (4 mm thick, 50 mm long) |
| Drying time, h | 22 | 5 | 5 |
| Unit costs, kW*h / kg | 3.78 | 2.1 | 1.745 |

After analyzing the obtained results, we can conclude that the use of HPU allows reducing the specific electricity consumption in AFD + HPU more than 2 times, as compared with ARIA, and by 17% compared with AFD without HPU. This solves the problem of heat recovery from the compressor of the refrigerating machine. So, heat utilized (former thermal pollutant) is now used in the process cycle to dry the product (material) after the freeze-drying unit.

Conclusion
The use of HPU in the structure of the drying unit allows more fully using the heat of superheated steam and the heat of condensation in the process of freeze-drying at atmospheric pressure. This increases the energy efficiency during operation. Sublimation drying units of the proposed design at atmospheric pressure have no analogues in the Russian Federation (and in other countries). In addition, the introduction of HPU into the technological cycle of the AFD allows expanding the range of application of such devices through the follow-on development of the market of heat pump units in the Russian Federation.

References
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