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The use of low-grade heat in dehydration processes of agricultural products

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Abstract. Dehydration is one of the main technological processes in the production of food and pharmaceutical products. Dehydration allows products to extend their shelf life, or is an intermediate step in product manufacturing. An important direction in improving the efficiency of production of agricultural products is to control the consumption of heat and electricity. It has been established that waste heat can be used as a free efficient source of low-potential energy for the drying process. This article discusses the benefits of using a heat pump for the drying processes of agricultural products. Heat pump drying can obtain high quality products at low energy costs. A comparative analysis of the convective drying method using a heat pump with other modern dehydration methods of agricultural products was carried out. It was revealed that convective drying with the use of a heat pump is the most advantageous method of dehydration of agricultural complex products.

1 Introduction

One of the most frequently discussed problems of the past decades is the question of the processes of saving energy resources. The constant cost increase of energy resources leads to look for cheaper and renewable energy sources. A possible solution to this issue is the use of low-grade heat generated during technological processes in many industries, including the agro-industrial complex.

This type of thermal energy is called "waste heat". The energy is not used in any way, but simply dissipates in the atmosphere. The waste heat is called low-potential, since its temperature is slightly higher than the ambient air temperature, but it does not have a sufficient temperature for technological or heat exchange processes. However, it is possible to use this type of heat as the secondary energy source.

One of the well-known methods is the use of heat pumps. It can utilize the low-potential "waste heat" and reuse it for heat exchange processes. [1]

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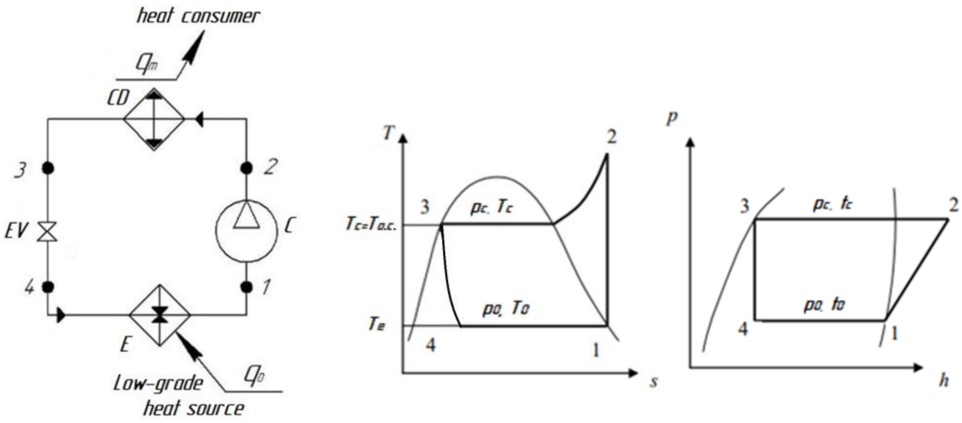
2 Materials and Methods

The operation principle of a heat pump was proposed by William Thomson, known as Lord Kelvin, back in 1852. He offered to use a refrigeration machine to generate heat. The heat pump proposed by Thomson used ambient air as the working fluid. Schematic diagram and image of the heat pump cycle is shown in fig. 1.



a) b) c)

Fig 1. Steam compression heat pump

a) schematic diagram; b) cycle in T-s diagram;

c) cycle in lg p-h diagram;

CD - condenser; C - compressor; E - evaporator; EV - expansion valve

A heat pump is a thermodynamic machine, where heat is converted from a low-potential source, due to the supply of external energy and its work, to the consumer at a higher temperature. The operation principle of a heat pump is identical to refrigeration and air conditioning units. The reverse thermodynamic cycle is used to produce heat. [2]

Despite the high availability of energy resources, the use of heat pumps in combination with the heat from ventilation emissions is extremely promising for enterprises. Advantages of using heat pumps for individual heat supply are:

- lack of extended heating networks;
- reduction of costs for the use of energy resources;
- improvement of the environmental component of production;
- increased safety of heat production compared to gas or solid fuel boilers.

Currently, the cost of using heat pumps is much more economical than electric heating and is comparable to the cost of gas heating [3].

Table 1. Thermodynamic characteristics of refrigerants

Working substance	Chemical formula	Marking	Critical temperature °C	Boiling point °C at 0.1 MPa pressure	Condensation pressure MPa, at condensation temperature = 90°C
Trifluoromonochloromethane	CF3Br	R13B1	67.50	-58.70	6.20
Azeotropic mixture R22	-	R502	90.00	-45.60	4.35
Difluoromonochloromethane	CHF2Cl	R22	96.13	-40.84	4.60
Ammonia	NH3	R717	132.40	-33.35	5.20
Difluoromonochloroethane	H3C2F2Cl	R142	136.50	-9.25	1.76
1, 1, 1, 2- tetrafluoroethane	CF3CFH2	R134	102.00	-26.00	3.30
Difluorochlorobromomethane	CF2ClBr	R12B1	155.00	-5.00	1.40
Difluorodichloromethane	CF2ClCHFCl	R123	182.00	29.00	0.62
Tetrachlorofluoroethane T	CHClFCF3	R124	122.50	-13.19	1.80
R22/R152/R124	33/15/52	R401C	111.00	-28.00	3.00
Monofluorodichloromethane	CFHCl2	R21	178.50	8.90	1.10
Propane	C3H8	R290	96.80	-42.17	4.00

The operation principle of a heat pump is based on the reverse thermodynamic cycle. The refrigerant, known as the working medium, is a key element in a heat pump operation. It tends to evaporate at sufficiently low temperature at atmospheric pressure. The pressure created by the refrigerant being compressed should not be too high, as it can damage the equipment. The refrigerant must be harmless to humans, non-explosive, and it must be chemical resistant and inert towards metal and lubricants. The most common refrigerants are listed below. [4]

Today, the number of used refrigerants is growing every day. The choice of working fluid is a compromise solution.

The absorption and release of heat by the refrigerant occurs during its periodic transition from a gas state to a liquid one, and vice versa.

The working cycle of a heat pump begins with the compression of the gaseous working medium in the compressor and the increase of its temperature due to compression. After that, the working medium gives off its heat inside the condenser, where the working medium is liquefied and the circulating water is heated. After that, the working medium enters through the expansion valve, where there is a sharp decrease in the residual pressure and the transition to the gaseous state of the working medium. After the expansion valve, the working medium enters the evaporator, where the working medium "boils" at a low pressure. Inside the evaporator, heat is also taken in by the working medium from a low-potential source. After the evaporator, the refrigerant enters the compressor, and the cycle repeats. [5]

The main advantage of a heat pump usage for heat transfer processes is the transformation of 1 kW of electrical energy spent on the operation of the compressor into 2.5-5.5 kW of thermal energy transferred to the consumer.

The heat pump efficiency is measured by the ratio of the heat transferred from the consumer to the energy expended on the operation of the pump. This value is called the coefficient of performance, or the coefficient of transformation.

The value of the transformation coefficient depends on the following factors:

• temperature difference between source and consumer of heat (the greater the difference, the lower the coefficient)

• thermodynamic properties of the refrigerant

• technical perfection of heat pump design.

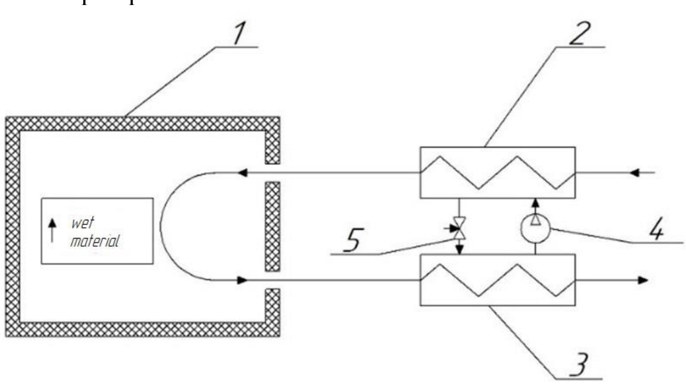
Depending on these factors, the actual value of the transformation coefficient can vary from 2.5 to 5.5 [6].

3 Results and Discussions

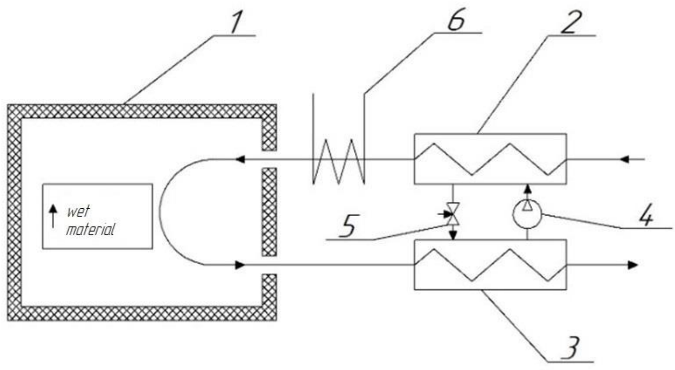
3.1 The usage of heat pumps in the drying process

One of the most common drying methods is the convective heat drying. The essence of the method is the passage of pre-heated dried air through the product layer. Dry air mixes with excess moisture formed on the surface of the drying product, after which the vapor air mixture is removed from the drying chamber, and the process starts again. The dry heated air is used as a drying agent; in some cases, dry steam or flue gases are used [7].

The main disadvantage of this method is the discharge of waste heat into the atmosphere. A waste low-grade heat can be reused for the drying process by supplementing the system with a heat pump.



a)



b)

Fig 2. Schematic diagrams of convective installations with a heat recovery unit

a) with the addition of a heat pump; b) with the addition of a heat pump and additional heater

1 - drying chamber; 2 - condenser; 3 - evaporator; 4 - compressor; 5 - expansion valve; 6 - heater.

Fig. 2 (a) shows the diagram of a convective dryer with a heat pump; Fig. 2 (b) shows the diagram with a heat pump and an additional heater to further increase the temperature inside the drying chamber. It is known that the efficiency of a heat pump decreases with the decrease in the relative humidity of the outgoing air, and the use of a heat pump can become inefficient at a relative humidity of less than 30%. This is due to a decrease in the proportion of the heat of water vaporizing in the heat carrier, which reduces the temperature of the refrigerant at the moment of boiling in the evaporator, which results in a decrease in the constant temperature inside the evaporator, leading to a decrease in the transformation coefficient. In this case, a convective drying system with a heat pump with air bypass (Fig. 3) is used, where part of the heat carrier passes through the bypass to the condenser. The use of this drying scheme with a heat pump helps to reduce the required amount of heat necessary to heat the coolant.

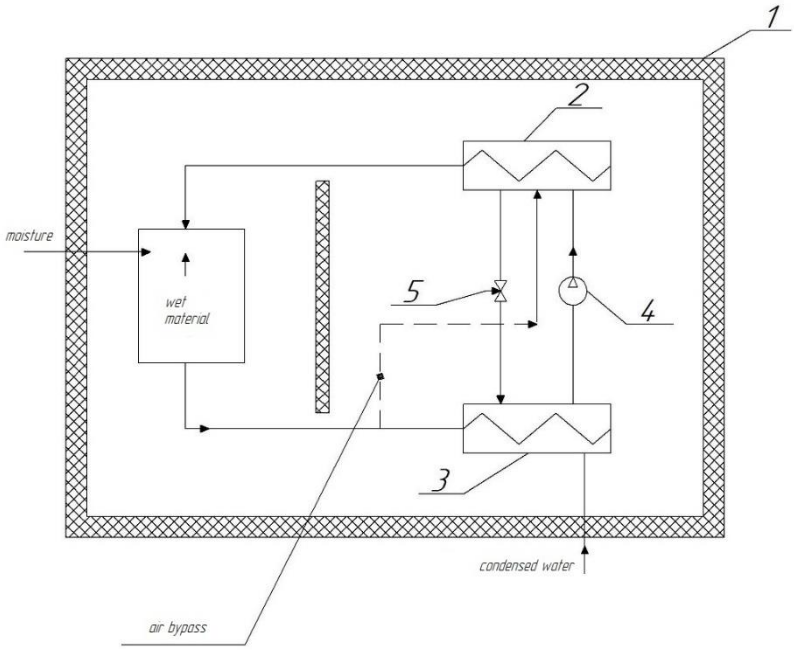


Fig 3. Schematic diagram of a convective drying plant with a heat recovery unit with an air bypass

1 - drying chamber; 2 - condenser; 3 - evaporator; 4 - compressor; 5 - expansion valve.

The use of convective heat transfer is not the only method of moisture removal. In addition to convective drying, such types of dehydration as vacuum, infrared, inductive, natural, sublimation, combined are used. Further we analyze each type.

3.2 Conductive drying

The principle of this drying method is the direct contact of the product with the heating elements of the installation (drums, belts, etc.). In this type of drying, air is used only to carry away the vaporous water from the drying chamber. Due to the design features of the working parts of the apparatus, this type of drying is used for dehydration of pasty products and purees. The main disadvantage of this type of dryer is the uneven heating of the product layer, since heat exchange between the working part of the apparatus and the product occurs due to the heat transfer process, the inner layer of the product is heated first. In this regard, the following processes occur: protein coagulation, thermal decomposition of sugars and color change. It can also be noted that during conductive drying, the generated heat is not utilized [8].

3.3 Vacuum drying

The principle of vacuum drying operation is the thermal evaporation of free moisture from the surface of the material at low pressure. The boiling water temperature depends on the pressure inside the system: it becomes lower with decreasing pressure [9].

This drying method can obtain high quality products due to the tightness of the system. This drying method can save up to 90% of the product nutrients. However, the system is expensive to purchase and maintain.

3.4 Freeze drying

This type of drying has a similar operation principle with vacuum drying. A distinctive feature of this method is the sublimation process, in which free moisture evaporates from frozen raw materials, bypassing the process of moisture transition into a liquid. The sublimation process takes place under vacuum pressure and low temperature, the sublimation process is also called “cold drying”. The output is a high-quality product with a high degree of recovery, up to 95% of useful substances are preserved in the products. Despite the effectiveness of the method, it is energy-intensive, and this type of equipment requires expensive maintenance by qualified personnel [10].

3.5 Infrared drying

This method appeared quite recently and resembles the convective drying method. During this drying process, heat is transferred from the source of infrared radiation to the product. It is claimed that infrared rays penetrate deep into the product and act on the free moisture inside the product layer. This drying method is highly effective, since after infrared drying, about 90% of useful substances remain in the products. Among the disadvantages, one can note the cost of equipment and the novelty of the method. [11]

3.6 Combined drying

A combined type of drying is a combination of several types of dryers. This type of drying can be used to obtain the best result, since the method will incorporate the best aspects of the above methods. However, the disadvantages of all methods will also affect the performance of the drying process. [12]

3.7 Natural drying

It is the most “time-tested” way to dry food. The drying process takes place with the help of solar radiation: the material is laid out, hung in the open sun and left to dry completely. The method has the highest energy efficiency, since only clear sky and warm climate are needed for this method. However, with all the advantages, the drying process takes longer time, and the material is not protected from bacterial infection.

4 Conclusion

Today there are many methods for drying agricultural products. In this paper, the most common methods were analyzed, with the comparative description of each method. The method of convective drying using a heat pump can be considered as most promising. The use of the secondary low-grade heat can reduce energy costs for the drying process to a minimum. Products become more accessible.

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