ТЕХНІЧНІ НАУКИ

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CONDENSATION THERMOELECTRIC DRYER AS THE BEST WAY OF DRYING FRUIT RAW MATERIALS

Summary. Drying of raw fruits and vegetables is both a thermophysical and technological process, in which the processes of heat and mass transfer are connected in one whole. When drying the prepared raw materials, the structural – mechanical, physico – chemical and other properties of the dried raw materials change. The choice of method and optimal mode of the drying process, the calculation of the design of the dryer and all ancillary equipment, is determined by the properties of the dried material, as well as the technology of its production. As in most processes, the naturalness of dried products and the ecological purity of the technological process come to the fore. Criteria of quality and efficiency of the process are combined into one task – to increase the efficiency of the drying process and the creation of non-energy-intensive heat technologies and equipment for their implementation. This article looks at a comparison of different drying chambers in their structure and principle of operation, which should play a major role in the energy efficiency of the entire drying process. The energy efficiency of the drying process of fruit and vegetable raw materials is achieved by improving the technological equipment and installing energy efficient controls, but we should not forget about the environmental friendliness of the process and the rational use of mechanical and thermal energy in the system. One of the most common processes is convective drying in a chamber or tunnel dryer. Significant increase in energy efficiency of the drying process is possible with the implementation of deep recovery of thermal energy using steam compression or thermoelectric heat pumps. After carrying out a series of laboratory and research works to compare different convection drying systems with thermoelectric heat pump, a diagram reflecting the heat consumption per 1 kg of evaporated moisture for each system was built.

Keywords: drying, raw materials, technological process, efficiency increase, convective drying, thermoelectric heat pump.

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КОНДЕНСАЦІНА ТЕРМОЕЛЕКТРИЧНА СУШАРКА ЯК НАЙКРАЩИЙ СПОСІБ СУШІННЯ ПЛОДООВОЧЕВОЇ СИРОВИНИ

Анотація. Сушіння плодоовочевої сировини – одночасно і теплофізичний і технологічний процес, в якому в одне ціле пов'язані процеси переносу тепла і маси. При сушінні підготовленої сировини змінюються структурно – механічні, фізико – хімічні та інші властивості сировини що сушиться. Вибір методу та оптимального режиму процесу сушіння, розрахунок конструкції сушильної машини та всього допоміжного обладнання, визначається властивостями висушуваного матеріалу, а також технологією його виробництва. Як і в більшості процесів на перший план виступає натуральність сушених продуктів та екологічна чистота технологічного процесу. Критерії якості та економічність процесу поєднуються в одну задачу – підвищення ефективності процесу сушіння та створення неенергоємних теплотехнологій і обладнання для їхньої реалізації. Дана стаття розглядає порівняння різних за своєю структурою та принципом дії сушильних камер, які в свою чергу мають відігравати велику роль в енергоефективності всього процесу сушіння. Одним із найпоширеніших процесів є конвективне сушіння в камерній або тунельній сушарці. Одними із найпоширеніших конструкцій в процесі сушіння плодоовочевої сировини є конвективні камерні сушарки. Основним напрямком покращення системи конвективної камери сушіння є підвищення ефективності та зменшення енергоємності процесу. Значне підвищення енергетичної ефективності процесу сушіння, можливе при здійсненні глибокої рекуперації теплової енергії з використанням парокомпресійних або термоелектричних тепловий насосів. Провівши ряд лабораторних та дослідницьких робіт з порівняння різних систем сушіння конвективним методом з термоелектричним тепловим насосом було побудовано діаграму яка відображає витрати теплоти на 1 кг випареної вологи для кожної системи. Проте створення інноваційного процесу сушіння плодоовочевої сировини за допомогою конденсаційної сушки з термоелектричним тепловим насосом та контактним утилізатором в складі системи, має перевагу в екологічній чистоті технологічного процесу, універсальності сушильного устаткування, модульності й автономності теплових зон, широкому діапазоні продуктивності та отримання побічного продукту.

Ключові слова: сушіння, сировина, технологічний процес, підвищення ефективності, конвективне сушіння, термоелектричний тепловий насос.

Problem statement. Equipment for drying raw fruits and vegetables and any drying equipment based on convective method of drying has a simple device. The units have high specific energy consumption, ranging from 1.6 to 2.5 kWh/kg. However, this method has some disadvantages that lead to irrational use of energy by installations, because the drying of the product in this way is inevitably accompanied by heat loss to heat structures and the environment. Therefore, the problem is to improve the system for further energy efficiency. In this review of the material it is done through the introduction of a new system, comparing it with different ones based on the use of a thermoelectric heat pump and heat recovery with moisture removal through a contact heat exchanger.

Analysis of recent research and publications. However, it is possible to achieve increased drying efficiency in various ways, starting from material preparation, selection of low-energy drying equipment, intensification of dehydration and establishment of optimal process parameters [1]. Convective chamber dryers are one of the simplest designs for drying various raw materials. They have the following advantages: simplicity of a design and operation; versatility; maintainability, etc. However, the main disadvantages of dryers are: a high percentage of manual labor, high energy consumption of the process, and uneven drying in the chamber. However, given that the amount of manual labor is extremely difficult to change in this process and expensive (this disadvantage is inherent in almost all food processing processes), reducing energy consumption and equalization of temperatures and humidity in the working chambers of convective chamber dryers is one of the main tasks. facing designers and developers of drying equipment [2]. However, conducting a series of experiments with drying raw materials using an electric heater and a heat pump for a chamber dryer, it was found that the method of convective drying in a dryer using a heat pump is the best in terms of efficiency and coefficient [3].

Emphasizing the unresolved parts of the general problem. The main problem today is that this consideration of systems already took place at the expense of drying convection chambers using various electric, vacuum, steam-compression pumps, but the use of thermoelectric heat pumps is a new stage of product drying. Control by feeding energy to the individual elements of Pelte with which the thermoelectric heat pump is composed – were considered very rarely and exclusively not in the food sphere, especially not in the process of convective drying.

Setting objectives. The main purpose of this work is to consider differently structured thermoelectric heat pump drying systems, and to obtain at the end an innovative condensation drying system for fruit and vegetable raw materials using thermoelectric heat pumps, which leads to an energy-efficient drying process with the formation of a by-product – condensate with flavor properties.

Main part. Nowadays, there is a considerable choice of drying equipment. Chamber and belt dryers have proven to be the most effective for vegetables and fruits [4; 5]. The choice of dryer type depends on a number of chemical properties of the material and the design of the dryer. However, in operational terms, chamber dryers are still preferred.

One of the most common methods of drying products today is the convective method of drying, which is based on the heat transfer of the product, which is dried by the energy of the heated drying agent – air or gas-vapor mixture. This method of drying fruit and vegetable raw materials occurs when washing the product with heated air, flue gases, superheated steam and other coolants that have a temperature higher than the temperature of the material, resulting in a drying process. In this method of drying due to the combined product of thermal energy is the evaporation of moisture in the product, and the removal of moisture vapor is carried out by a drying agent.

The process of convective drying with increased energy efficiency, possible in the implementation of deep recovery of thermal energy due to steam compression or thermoelectric heat pumps. The advantage of using thermoelectric heat pump (THP) (see Figure 1) is the ability to implement the process with the temperature of the drying agent to a temperature of 100-120°C without additional electric heater and ease of implementation of process equipment (no freon pipes, evaporator, condenser, compressor and etc.). The main control body of the THP is a series of Peltier elements connected in series, which heat the radiators from which the drying temperature of the required temperature is blown off, and the current is regulated by means of a PWM regulator.

(The Peltier element is a thermoelectric converter, the principle of which is based on the Peltier effect – the emergence of temperature differences in the flow of electric current).

Considering the process of drying fruits and vegetables using a thermoelectric heat pump (THP) instead of steam compression heat pump, was gradually considered the implementation of three main systems of convective drying of fruits and vegetables: 1 – "Open" scheme of drying raw materials. air-to-air"; 2 – Closed condensing drying scheme using two THP "air-to-air"; 3 – Closed condensing drying scheme using THP "air-air" and contact heat exchanger with THP "air-water".

The first open system is shown in Figure 2, which shows a parameterized scheme of the technological process of drying raw materials using as a drying agent heated by THP air from the environment and the block diagram of its model as a control object. Improving the energy efficiency of the process is achieved through the use of THP "air-to-air" through which the partial recovery of thermal energy of the spent drying agent.

System description: the process of convective drying takes place with the help of thermoelectric heat pump THP, where in its hot circuit by means of a centrifugal fan the drying agent from the environment is fed (drawn in) and heated to the required set temperature at the chamber inlet. The hot drying agent passes through the pre-prepared raw materials (washed and cut according to technological parameters) passes through the trays, which have a mesh surface, heats the product, reducing its moisture content and goes to the exit of the chamber. After that, the spent drying agent at the outlet of the dryer chamber goes to the cold circuit of the THP where, knowing its heat, it is cooled and expelled into the atmosphere.

The main control parameters for regulating this process are the regulation of the drying agent (F air) in the system using the AC frequency (f) on the fan, and the temperature of the drying agent at the inlet to the chamber (T outlet air). regulates the current of the heat pump THP "air-to-air". The

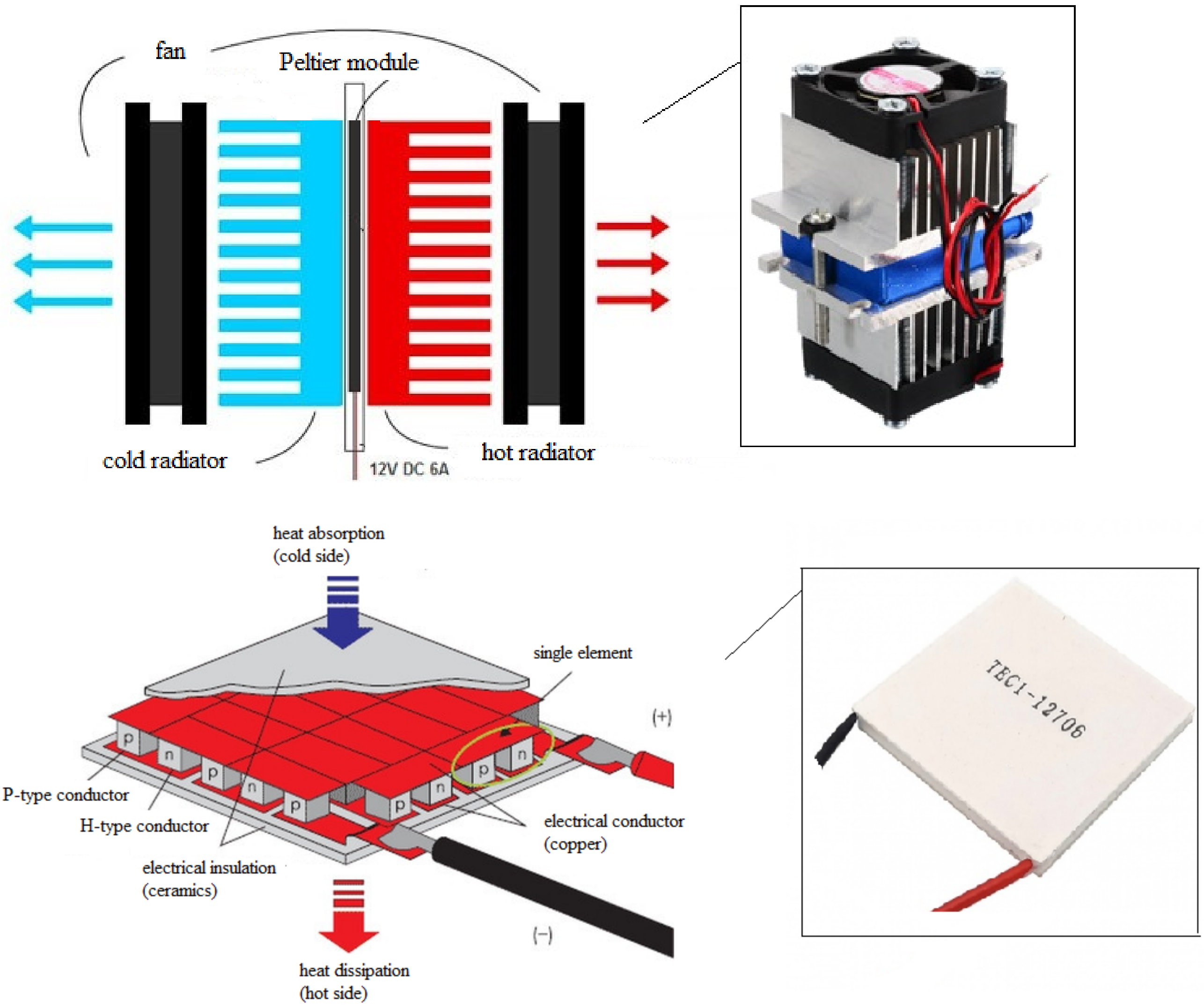

Figure. 1. Schematic diagram of the construction of thermoelectric heat pump THP and the main control body

main factor of uncontrolled disturbance is the relative humidity of the environment (M ambient), which directly affects the relative humidity at the entrance to the dryer chamber (M outlet air).

Depending on the drying range and the type of loaded raw material, the air flow rates in the system can vary in the range from 1 m/s to 3 m/s. Regarding the temperature of the hot drying agent after THP, this parameter maintains the required temperature (70-90˚C) at the inlet to the dryer chamber, while the parameter M outlet air strongly depends on environmental parameters such as: temperature T ambient (range depending on 0 to 40 ˚C) and relative humidity M ambient (range depending on 20 to 90%).

The advantage of such a system is the simplicity of implementation of technological equipment, the need for minimal costs to automate the process. The disadvantages of this system are the high drying temperature ranges and the influence of ambient air parameters.

The second closed-type system is shown in Figure 3, which presents a parmetrized scheme of the technological process of condensation drying using two thermoelectric heat pumps THP "air-to-air"; and the block diagram of its model as a control object. The use of two heat pumps in this scheme allows you to form a drying agent with a given temperature and humidity at the entrance to the drying chamber.

System description: The convective drying process takes place in a closed circulation circuit with forced drainage of the drying agent, which occurs due to cooling of the waste drying agent by cooling the heat pump circuit thermoelectric air-to-air-heat pump. In order for the condensation process to take place, the cooled dryer needs to be cooled by thermoelectric air-to-air heat pump pump 2, which acts as an after-cooler to the dew point. The cooled drying agent then passes through the thermoelectric air-to-air heat pump hot circuit, where it is heated to the required temperature level at the input to the drying chamber. Drying modes are optimal for temperature and humidity, are set and supported automatically. The main regulatory body can be the thermoelectric heat pump THP of the cooler, and more precisely the change of the current intensity on it and the regulation of the air flow in the dryer system. The main control parameters for regulating this process are the flow control of the drying agent

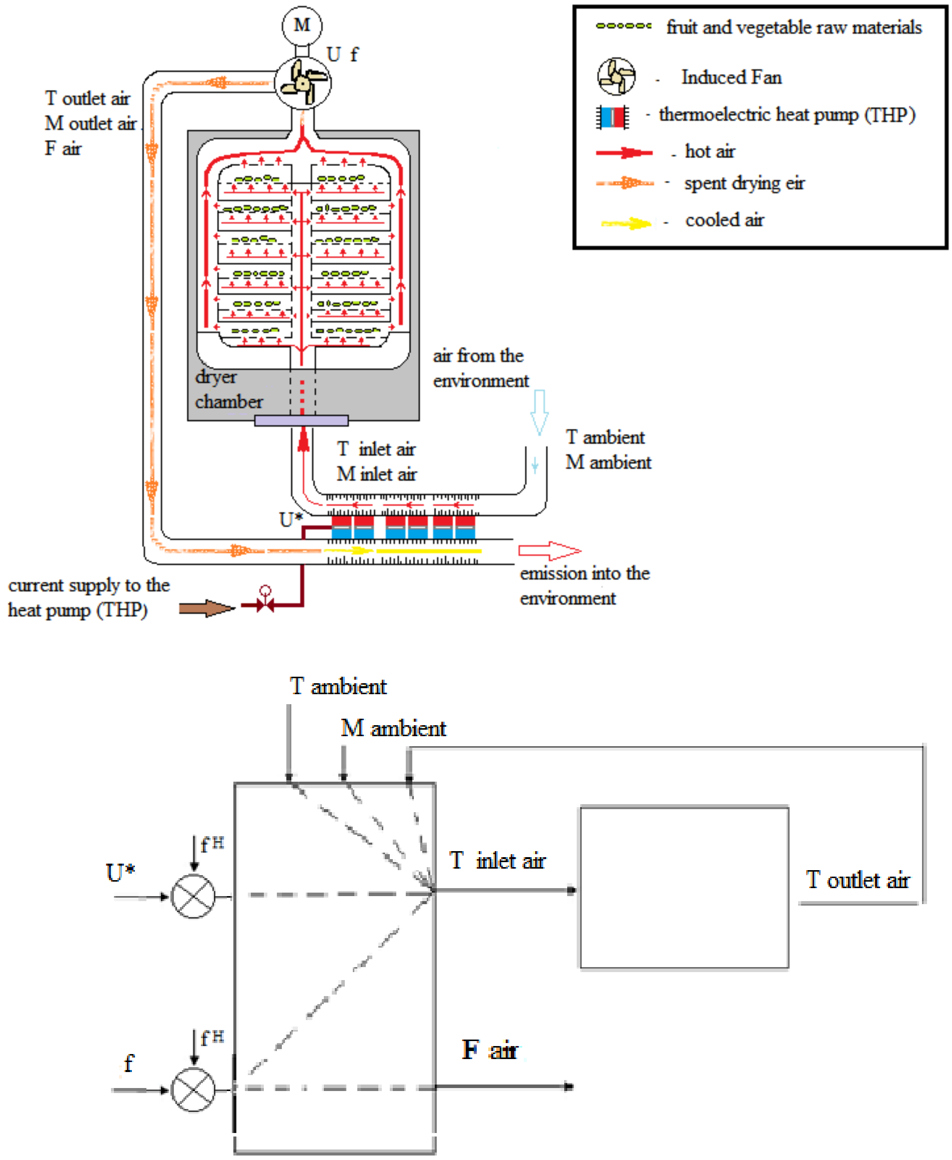

Figure 2. Parmetrized scheme of technological process of drying "open" type using THP "air-to-air" and block diagram of its model

Where: f – fan speed control; U * – control of THP supply current; T inlet air – temperature of the drying agent at the inlet to the dryer chamber; M inlet air – relative humidity at the entrance to the dryer chamber; F air – air flow in the system; T outlet air – the temperature of the spent drying agent; M outlet air – the relative moisture of the spent drying agent; T ambient – ambient air temperature; M ambient – the relative humidity of the environment.

(F air) in the system by means of the variable voltage frequency (f) on the fan, and the temperature of the drying agent at the entrance to the chamber (T inlet air) the current of the thermoelectric air-to-air heat pump is regulated by the regulation (U1).

Depending on the drying range and the type of raw material loaded, the system's air flow can vary from 1m/s to 2 m/s. Regarding the temperature of the hot drying agent after air-to-air heat pump, this parameter maintains the required temperature (40-70 °C) at the input to the drying chamber. With respect to the AC voltage frequency (f ") on the fan that extracts heat from the air-to-air heat pump pump 2 cooling circuit, it became (const). The current of the air-to-air heat pump 2 to the cooler is regulated by the regulation (U2), changing the temperature of the cooled drying agent at the input of the hot air-to-air heat pump.

The advantage of such a system is the ease of implementation of technological equipment, the need for minimum costs for automation of the process, and the value of the specific energy consumption to remove moisture from the material due to the utilization of heat of the waste heat carrier in 1,5... 2 times compared to the previous system. The disadvantage of this system is a small performance (up to 40 kg/day depending on the product). The maximum temperature of the hot drying agent t = 60°C, and the specific consumption of electricity for the evaporation of moisture is 0,4...0,7 kW h/l. An example of such a system using partial recovery steam compression heat pumps was considered before [6].

The third system is the closed-type system depicted in Figure 4, where the parmetrized circuit of the condensing drying process using THP "air-air"

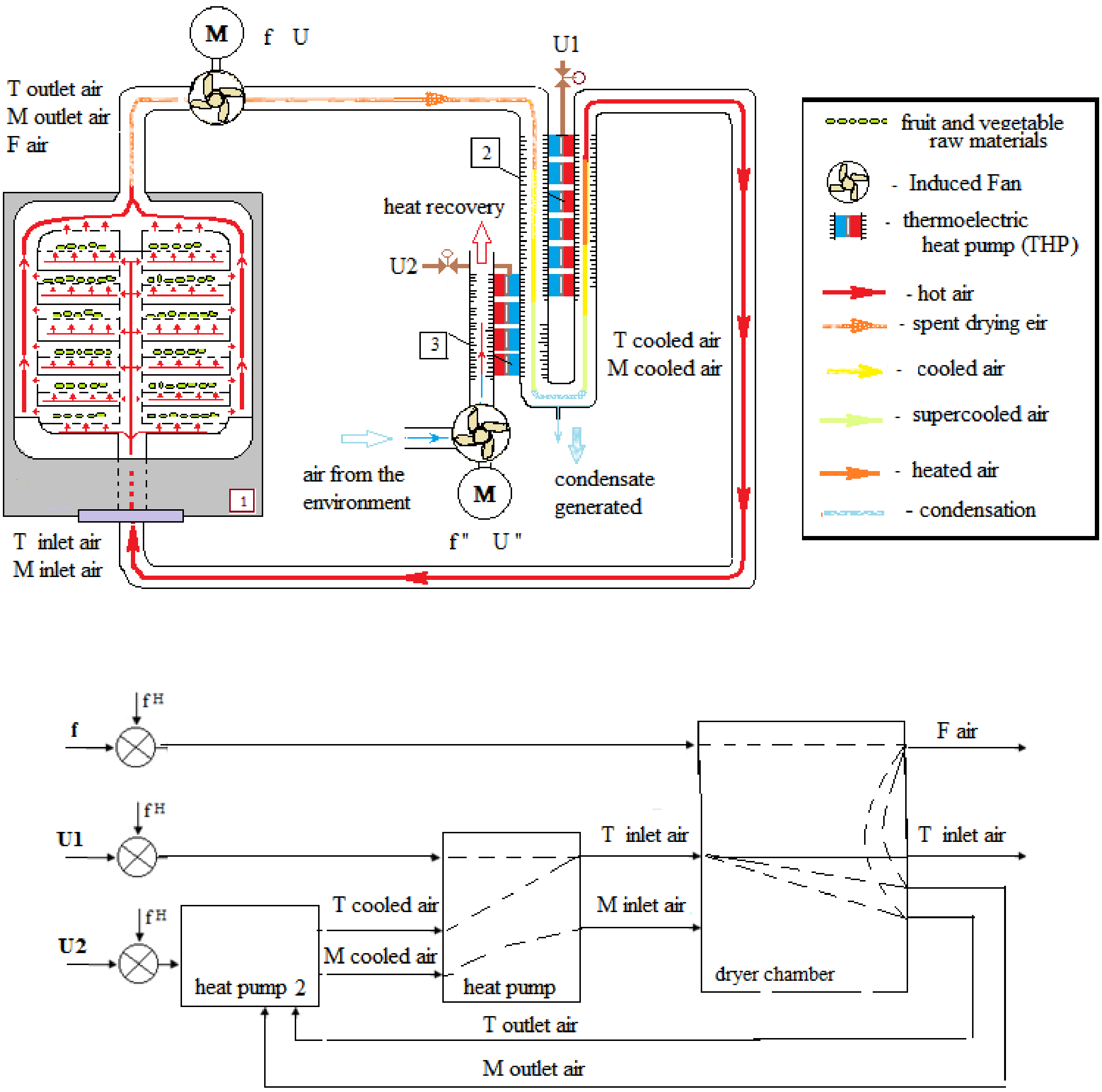

Figure 3. Parmetrized scheme of technological process of drying "closed" type with the use of two THP "air-air" and block diagram of its model

1 – drying chamber; 2 – thermoelectric heat pump "air -air"; 3 – thermoelectric heat pump2 "air –air"

Where: U* – mains voltage; f – control of fan speed; U1 – control of thermoelectric heat pump air-air; U2 – control of thermoelectric heat pump 2 air-to-air; T inlet air – temperature of the drying agent at the inlet to the dryer chamber; M inlet air – relative humidity at the entrance to the dryer chamber; F air – air flow in the system; T outlet air – the temperature of the spent drying agent; M outlet air – the relative moisture of the spent drying agent; M cooled air – relative humidity of the cooled drying agent at the inlet to the thermoelectric heat pump air-air; T cooled water – water temperature at the inlet to the thermoelectric heat pump air-air.

and contact heat exchanger with THP "air-water" and the block diagram of its model as a control object. The use of two heat pumps and a contact heat energy reclaimer makes it possible to form a drying agent with a preset temperature and humidity, as well as to achieve greater energy efficiency and to obtain a by-product (condensate) – saturated with nutritious and valuable compounds.

The periodic drying process removes valuable aromatic compounds (alcohols, essential oils, aldehydes, etc.) when removing moisture from the prepared raw material. For the collection of aromatic compounds, the dryer includes a condensation device that extracts aromatic substances and water from the spent drying agent. Contact heat exchanger allows for a closed cycle drying process.

More detailed information on the system, its main control parameters and transition channel characteristics and identification results have been pre-reviewed and described in more detail [7]. The main regulators in this process of drying raw fruits and vegetables are the position of the regulating U2 current supply body to the thermoelectric heat pump air-to-air, and the process of supercooling the drying agent in the heat exchanger is the position of the regulating U1 supply body to the thermoelectric heat pump-to-water. As with all convective chambers, the air flow rate in the F air system depends on the drying mode and the type of loaded raw material, the air flow rates in the system can vary in the range from 1 m/s to 2.5 m/s. Regarding the parameters to which the regulation is imposed,

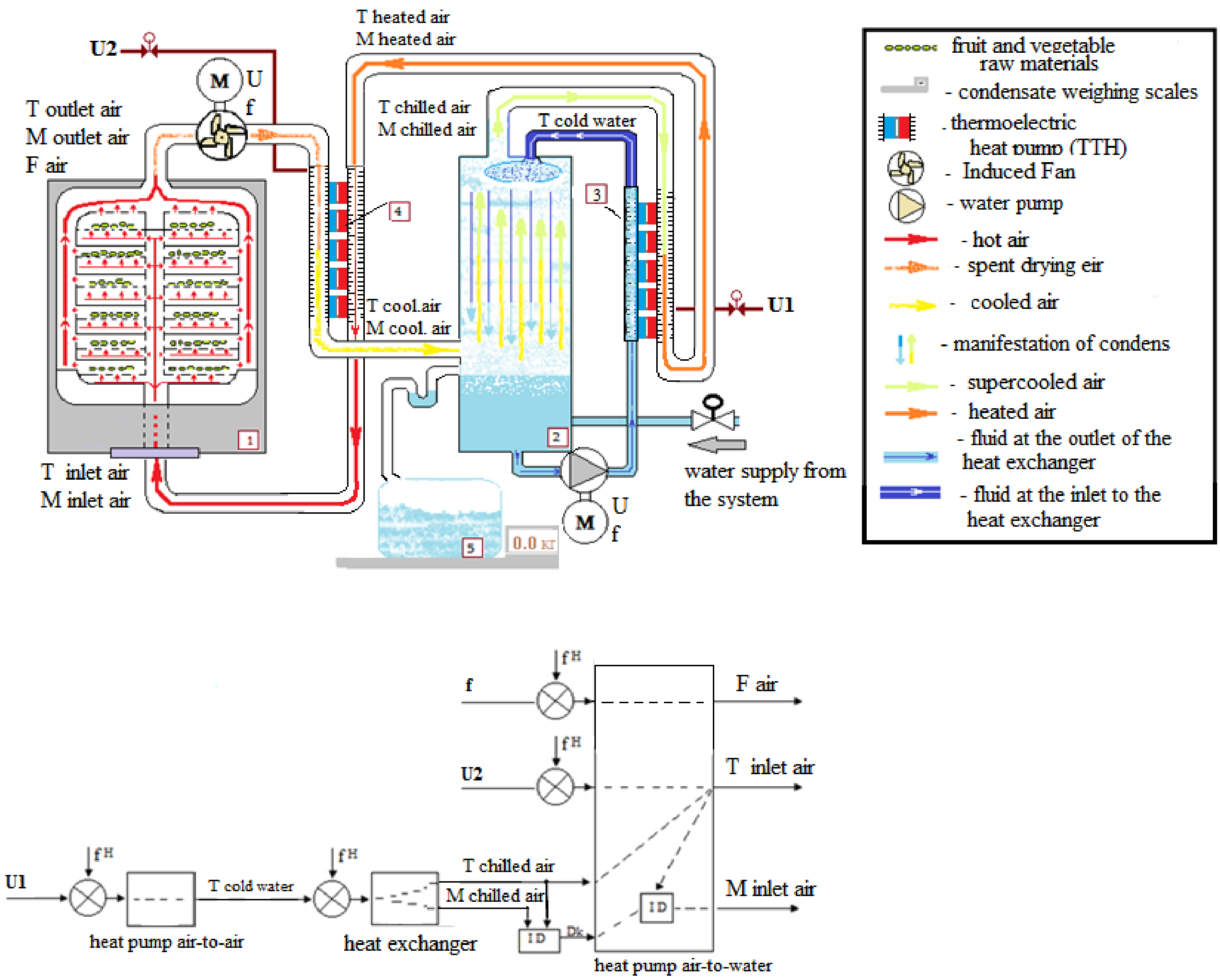

Figure 4. Parmetrized scheme of technological process of drying "closed" type with the use of two THP "air-air" and contact heat recovery with THP "air-water" and block diagram of its model

Where: U – mains voltage; f – control of fan speed; U1 – control of thermoelectric heat pump air-to-water; U2 – control of thermoelectric heat pump air-to-air; T outlet air – the temperature of the spent drying agent; M outlet air – relative humidity of the spent drying agent; T inlet air – temperature of the drying agent at the inlet to the dryer chamber; M inlet air – relative humidity of the drying agent at the entrance to the dryer chamber; M cooled air – relative humidity of the cooled drying agent at the inlet to the heat exchanger; F air – drying agent costs in the system; T cooled water – water temperature at the inlet to the heat exchanger; M chilled air – relative humidity of the supercooled drying agent (≈100%) at the outlet of the heat exchanger; T chilled air – the temperature of the supercooled drying agent at the outlet of the heat exchanger; M heated air – relative humidity at the outlet of the thermoelectric heat pump air-to-water; T heated air – the temperature of the heated drying agent at the outlet of the thermoelectric heat pump air-to-water; fn – uncontrolled perturbations; Dk – absolute moisture content; ID – moisture conversion unit.

the temperature of the drying agent at the inlet to the dryer chamber (T inlet air) and the relative humidity of the drying agent at the inlet to the dryer chamber (T inlet air).

By changing the temperature of the drying agent at the outlet of the heat exchanger, it is possible to change the relative humidity of the air at the inlet to the drying chamber, or the condensate flow rate. The use of a heat exchanger in comparison with the previous system allows to control the process of condensation of vapors of the spent drying agent as effectively as possible, and gives 100% confidence that all moisture was removed due to the counter supply of water vapor. Next, Figures 5 and 6 show the dependences of the temperature of the cooled drying agent at the outlet of the heat exchanger and the thermal power of the heat exchanger, respectively, of water flow through the heat exchanger at constant water temperatures at the inlet of the heat exchanger (1-20 °C, 2-25 °C).

Considering this system right now, we can draw some conclusions compared to previous types of systems. The use of two heat pumps in the implementation of technological processes of condensation drying of raw fruits and vegetables allows you to quickly control the temperature, moisture content and consumption of the drying agent for the implementation of complex multi-stage processes.

According to our calculations, the heat consumption per 1 kg of evaporated moisture during drying previously considered convective dryers and convective dryers with recovery, not inferior to the process of condensing drying of raw fruits and vegetables using thermoelectric heat pumps (Figure 7).

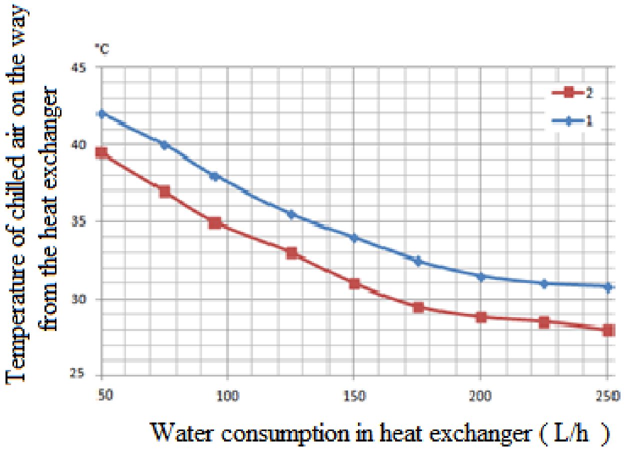

Figure 5. The dependence of the temperature of the cooled drying agent at the outlet of the heat exchanger according to the flow of water in it

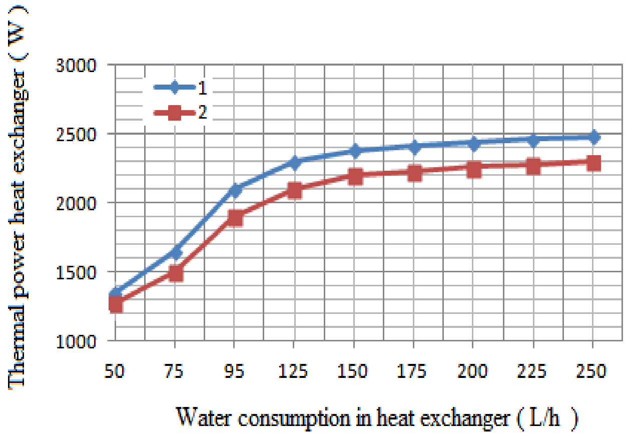

Figure 6. Dependence of thermal power on water consumption in heat exchanger

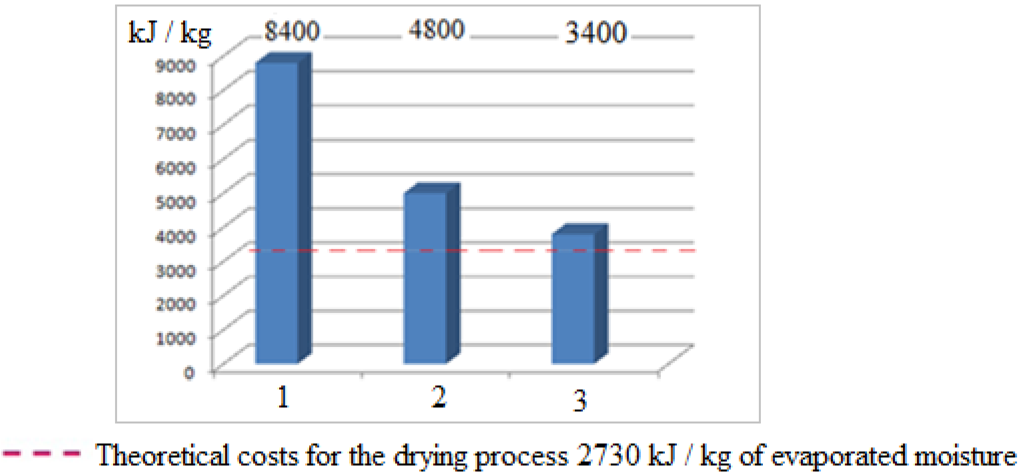

Figure 7. Comparative analysis of heat consumption per 1 kg of evaporated moisture in comparison with three different systems

1 – Conventional convective drying process with thermoelectric propeller pump; 2 – Convective drying process by means of recuperation and two thermoelectric heat pumps; 3 – Condensing drying process using a contact heat recovery unit and two thermoelectric heat pumps "air-water" and "air-air".

Conclusions. The use of two heat pumps in the implementation of technological processes of condensation drying of raw fruits and vegetables allows you to quickly control the temperature, moisture content and consumption of the drying agent for the implementation of complex multi-stage processes.

Creation of innovative process of drying of fruit and vegetable raw materials by means of condensing drying with thermoelectric heat pumps "air-water" and "air-air" consists in ecological purity of technological process, universality of drying equipment, modularity and autonomy of thermal zones, wide range of productivity and by-product.

The main advantages are: high quality of the dried product, low heat consumption per 1 kg of evaporated moisture 3400 kJ, control of heat and moisture drying modes, reliability and ease of maintenance. With increasing demands on the regimes and quality of dried products and cost-effectiveness of production, technology, methods of managing the kinetics of wet exchange, the latest dryers are constantly in need of improvement and updating of modern software process control for their energy efficiency in the future.

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