APPLICATION OF HEAT ACCUMULATORS FOR A TWO-STAGE CONVECTIVE VACCUM-PULSE DRYER

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Abstract

The article presents technical approaches to increasing the energy efficiency of initial moisture content of plant material corresponding to the beginning of the drying period of a two-stage convective vacuum-impulse dryer using a preliminary analysis of the temperature regime in the drying plant and the possibility of using heat accumulators based on materials capable of accumulating thermal energy as a result of a phase transition.

The analysis of temperature regimes was carried out using a non-contact method for measuring the temperature field, implemented in a thermal imager. A convective drying unit acts as a source of pre-charging of heat accumulators.

using technical approaches Paraffin with a melting point of 50-70 °C was used as a material capable of accumulating thermal energy in a phase transition to increasing the energy efficiency of initial moisture content of plant material

KeyWords: drying plant, thermal analysis, thermal accumulators, energy saving.

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Introduction

At the present stage of development of the agro-industrial complex, the creation of innovative equipment is required, and first of all, this refers to energy-intensive technologies. Such technologies include the processes of drying plant materials.

The presence of moisture in the plant material during storage leads to the growth of bacteria. Aside from the active ingredients, all fresh agricultural products such as fruits, vegetables and leaves generally contain a high percentage of both bound and unbound water. If the agricultural product is dried without affecting the active nutrients and with the maximum removed moisture, it can be safely stored for a long time. The high moisture content of plant materials must be rapidly reduced to a residual acceptable percentage to prevent any enzymatic reaction and oxidation (Lin , Zhang, Lei, Zhang , Cheng , & Zhu , 2010) . Leaves usually lose up to 85% of their weight on drying (Chen & ,Mujumdar , 2006) In addition, during the drying process, several low-boiling component losses and oxidation changes can occur that affect the nutritional, physical and chemical composition of the dried leaves, but overall drying results in nutrient concentration. Typically, dried leaves have active nutrient levels that are three to four times higher than fresh leaves (Navale, Upasni Supriya, Harpale, & Mohite, 2014) and (Mehta & Joshi , 2010) . Green leaves are high in iron and vitamins such as C and K, lutein, carotenoids, and folic acid (Greens, 2016) . In heat pump drying, cooled and dehumidified air is passed through a condenser cooler to reduce the percentage relative humidity. A heat pump dryer (HPD) dries humid air, heats it and recirculates it through the drying chamber. Thus, the color and its active substances in the leaves remain intact. The HPD is an economical, environmentally friendly, hygienic dryer, and can be operated over a wide low temperature range of heated air, thus providing adequate drying conditions for heat-sensitive materials, making it particularly suitable for leaf drying. Drying technology using heat pumps requires less energy (reduced by 50%), since the system can recover latent heat in a closed loop and it does not depend on atmospheric weather conditions (Babu, Kumaresan, & Antony Aroul Raj, 2018) and (Shinde , Das, & Datta , 2013) . In addition to the technical advantages of heat pump drying technology, the drying speed is limited due to the low temperature, which takes a long time for the drying process. The cost of equipment maintenance is high due to the complex heat supply system (Shinde , Das, & Datta , 2013) Absorption cooling for heat pumps has improved their energy efficiency and increased the intensity of heat exchange processes. In the article (Poomsa, Deejing , & Wiset , 2011). it was noted that drying temperatures and drying environment have a significant effect on the physiological parameters of the dried material when drying with a heat pump.

For drying plant materials, microwave heating is used, which is due to the interaction between the electromagnetic field and the molecules of plant material. The material to be heated is placed between these two electrodes, which are exposed to an electric field that alternates approximately 40,000,000 times per second. When the electric field changes over time, the polar molecules in the material change their position. The resulting friction creates heat energy (heat) throughout the product, and since the water molecule is bipolar in nature, it heats up and evaporates (Marra, Zhang, James, & Lyng, 2009).

At the same time, the presented drying technologies have significant disadvantages, which are associated with the complexity of the equipment and technology used.

Studies show that high temperature has a significant effect on the properties of the dried material (C. han EWC, Lim , Wong , Lim , Tan , & Lianto , 2009) and (Dehghannya, Pourahmad, Ghanbarzadeh, & Ghaffari, 2019). However, the retention of both of these components was highest at moderate temperatures (60 ˚ C). Low temperature (50 ˚ C) and high temperature (80 ˚ C) affect retention due to longer drying times and higher temperatures, respectively. Therefore, a moderate temperature (60 ˚ C) may be the limiting temperature for hot air drying of leaves (eg Coleus), and the greatest losses were observed at 80 ˚ C (Dwivedy , Rayaguru , & Sahoo , 2012). Drying in a microwave oven at the appropriate power level can retain the maximum amount of beneficial properties for the material to be dried. At the same time, a significant disadvantage of microwave drying is the presence of a plasma discharge, which causes the surface of the dried product to burn, and the effect of "exploding" the raw material upon accelerated heating in a microwave field. The intensity of the microwave drying can be increased by using a vacuum. In this case, rapid heating deeper into the product is combined, increasing the pressure gradient of the water vapor and a lower evaporation temperature of the water.

The use of progressive two-stage convective vacuum impulse drying (DCVIS) dominates over other types of drying (Rodionov Y. V., 2011). The use of DCVIS excludes the formation of agglomerates of plant material in the first period and allows you to preserve nutrients in the second period of drying, allowing you to significantly reduce the process time and energy consumption through the use of energy-saving two-stage liquid ring vacuum pump (LHV) (Rodionov , Vorobiev , Maksimov, Popov, & Sviridov, 2009). and, consequently, the price of the finished product, to preserve the useful qualities of the dried plant material (Rodionov et al, 2012). The use of a two-stage LHV is also due to its operational safety, environmental friendliness of work (working area without lubrication), high efficiency and the ability to pump out all types of gases and vapors. Depending on the size and shape of cutting of the dried plant materials, the two-stage KVIS unit is manufactured in two versions:

1. Combinations of a convective swirl dryer and a KVIS cabinet (fig. 1) for small materials with a regular spherical shape.

2. Combinations of a convective tray dryer and a KVIS cabinet for other arbitrary shapes (Fig. 2).

However, the main disadvantage of DKVIS is the unevenness of moisture removal from the material along the trays in a vacuum cabinet, significant energy losses in the first (convective) stage, long warm-up or reaching the operating mode.

RESEARCH OBJECTIVE: Increasing the uniformity of material heating in a vacuum cabinet using thermal accumulators based on phase transition materials.

METHODOLOGY AND MATERIALS:

For research, a drying unit was developed, which is shown in Figure 1. The unit included the following elements: 1 - a convective swirling bed dryer (first stage of drying); 2 - KVIS cabinet (second stage of drying); 3 - two-stage ZhVN with sequential switching on of stages; 4 - one-stage LHVN with an adjustable discharge window; 5 - chiller for cooling the working fluid; 6 - water pump; 7 - tank for working fluid recirculation; 8 - piping system with regulation and control devices.

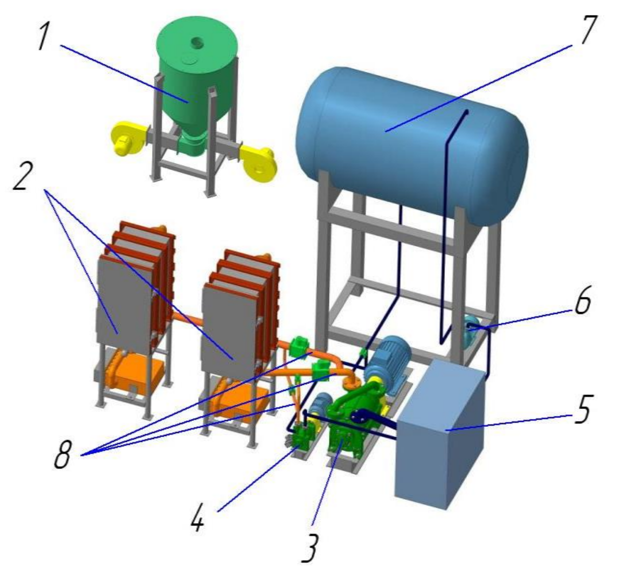

Figure: 1 - Combined dryer for small materials of regular spherical shape.

Figure 2 shows a drying complex, which has: 1 - convective tray dryer (first stage of drying); 2 - KVIS cabinet (second stage of drying).

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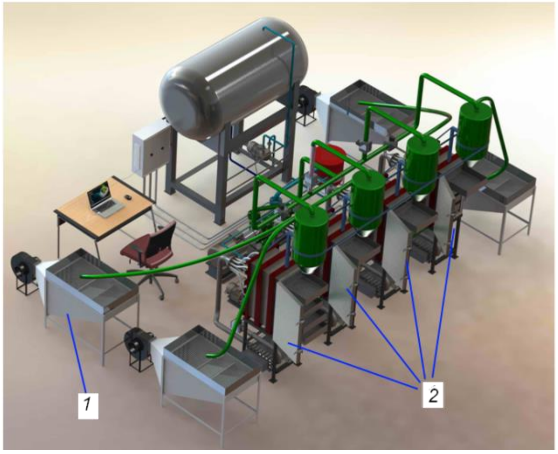

Figure: 2 - Combined dryer for other arbitrary forms of plant materials.

The experimental installation for convective vacuum-impulse drying (Fig. 3) consists of a drying cabinet 1 based on a two-stage liquid ring vacuum pump 2, which is driven by an electric motor 3, heating elements 4, shut-off valves 5, 6, 7, thermocouples 8 and 9, a vacuum gauge 10. The material to be dried is placed on trays inside the cabinet.

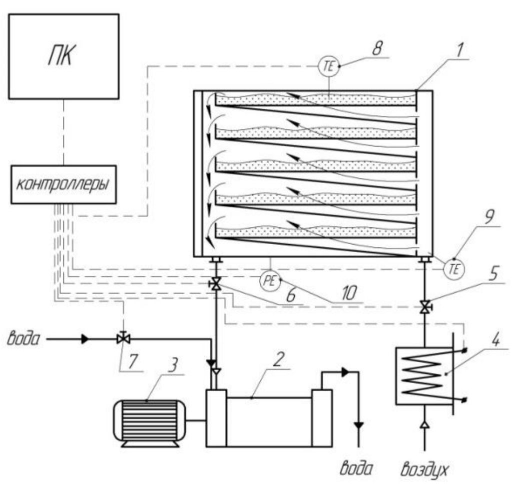

Figure: 3 - Experimental setup for convective vacuum-impulse drying.

As a drying agent, atmospheric air is used, which is heated by heating elements 4. Vacuum valves 5 and 6 are installed at the inlet and outlet of the drying cabinet, respectively. To control the water supply to the vacuum pump, valve 7 is used. Temperature control of the drying agent entering the cabinet, as well as of the material to be dried, is carried out by thermocouples 9 and 8. The change in the mass of the dried product is recorded using a balance with a measurement limit of 1 to 2000g.

All control and measuring devices have an analog or digital output to the software and hardware complex (PTC). The PTC is a set of microprocessor controllers, a device for communication with an object and an operator display panel. For registration, automatic control and signaling of the main parameters of the convection plant, industrial controllers "ICPCON" and I-7000 series input-output modules of the "ICPDAS" company are used. These devices are modular and can operate at ambient temperatures from -25 to + 65 ˚C.

To study the distribution of the temperature field on the surface of the heat exchange equipment, a non-contact method of measuring the temperature field was used. The device in which the presented method is implemented is a thermal imager. During the research, the following equipment was used: Testo 871-1 thermal imager.

Research results and their analysis

Figure 4 shows the curves of the KVI drying kinetics.

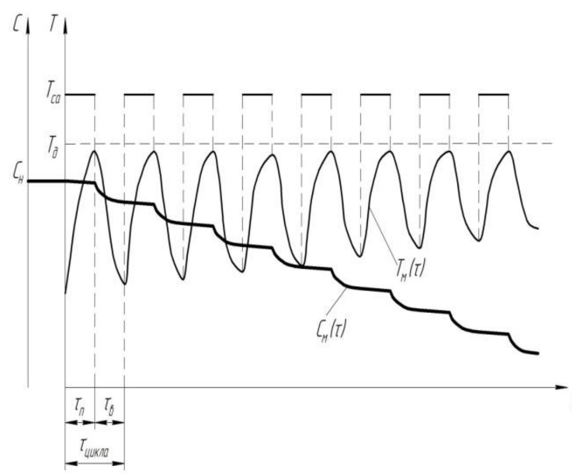

Figure 4 - KVI curves of plant material drying

$C_н$ - initial moisture content of plant material corresponding to the beginning of the second drying period,%; T_{ca} - temperature of the drying agent), K; $T_Д$ - temperature of denaturation of plant material, K; τ_n - the time of heating plant material by convection, ; $\tau_в$ - time of evacuation of plant material, c; $\tau_{цикла}$ - duration of one cycle, c, $C(\tau)$ - curve of drying of vegetable raw materials, $T(\tau)$ - curve of heating of vegetable raw materials

Figure 5 shows a thermogram of the coolant supply system to the drying oven. In fig. 6 Drying oven thermogram.

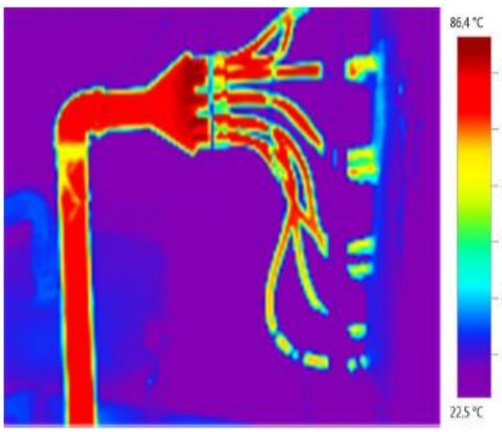

Figure: 5 thermogram of the heating agent supply system to the drying oven

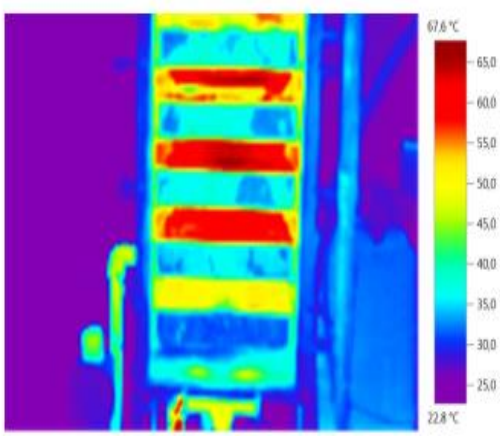

Figure: 6 Drying oven thermogram

In fig. 7 shows the distribution of the temperature field over the cross section of the trays in the drying installation (all in the cabinet 4 trays - P1 (upper tray), P2, P3, P4). In KVIS the trays are arranged in a row one after another from top to bottom.

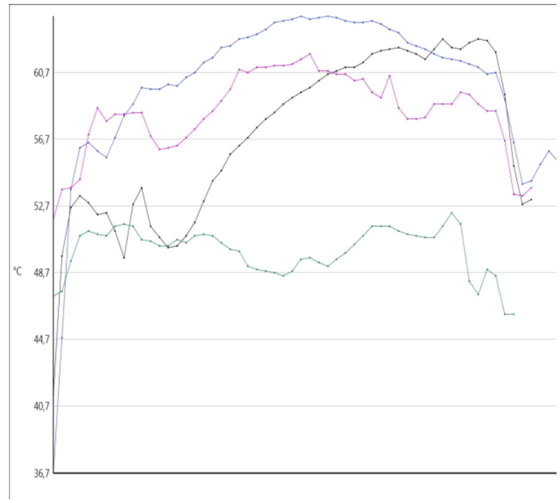

Figure: 7. Thermogram of trays in the KVIS drying cabinet

From the analysis of the temperature field, it follows that there is a clear uneven distribution of the temperature regime, which is a consequence of the operation of the supplied heat flow. The temperature difference between the individual shelves reaches 16 ℃. The lowest temperature is typical for tray 4 (P4). Largest for 2 (P2) trays.

The tray has the shape shown in Figure 8.

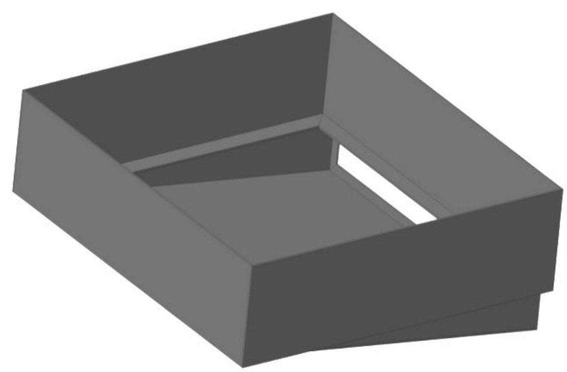

Figure 8 - Tray for a vacuum cabinet for convective vacuum impulse drying

From this, it can be concluded that by placing pre-charged TA (heat accumulators) before drying in KVIS, it is possible to reduce the unevenness of the temperature field along the trays and reduce the time to enter the KVIS drying mode.

It is rational to organize the TA charge in the convective drying mode by installing heat accumulators on the body of the convective dryer. In fig. 9 shows the temperature field of a convective dryer. In fig. 10 shows a histogram of the temperature field distribution on the surface of the convective dryer.

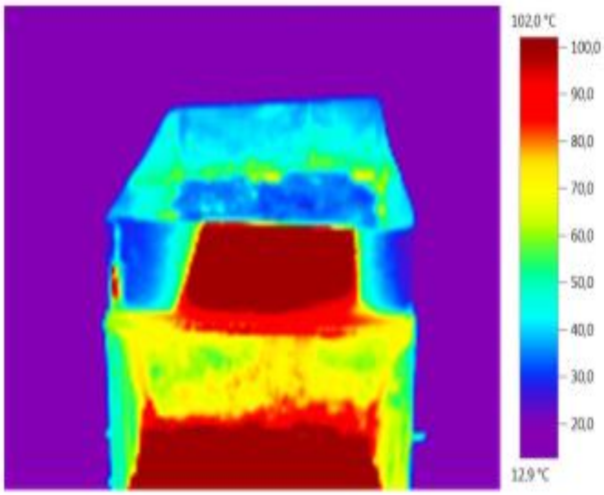

Fig. 9 Temperature field of a convective dryer

In fig. 11 shows the temperature regime of the material being dried in the convective drying mode.

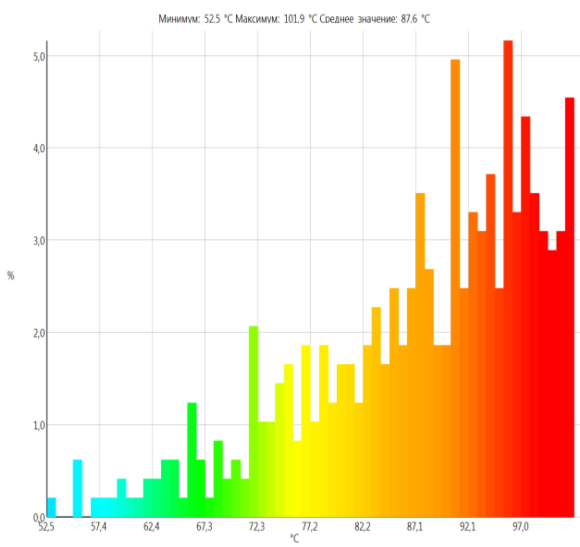

Figure: 10 Histogram of the temperature field distribution on the surface of the KVIS dryer

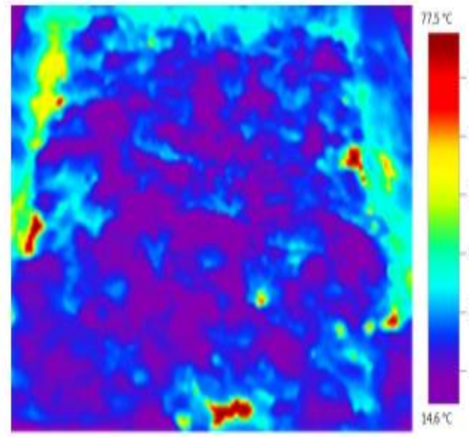

Fig. 11 Temperature field of the material in a convection dryer

Based on the temperature regime of the convection dryer, it can be concluded that the most suitable material that can be used as a heat storage material is paraffin with a phase transition in the range of 50-60 ° C. To form a TA on its basis, a cassette TA design was developed (Fig. 12), which is based on the use of a cellular structure in which paraffin is placed. The reverse side of the TA, which faces the external environment, is thermally insulated. TA is designed to be placed on the walls of the KVIS and the walls of the trays, which provides a normal convective flow of the coolant in the inner space of the drying chamber.

Fig. 12 External view of a cassette heat accumulator

CONCLUSION

An increase in the energy efficiency of KVIS can be achieved in the case of using a TA based on materials that store thermal energy in a phase transition.

The preliminary charge of TA in the convective drying mode allows the accumulation of thermal energy for the drying mode in the cabinet at reduced pressure. This will ensure faster heating of the cabinet and reduce the uneven distribution of the temperature field in the cabinet. The material for TA must have a phase transition in the range of 50-70 ℃, which allows it to be adapted for a drying cabinet and to ensure the accumulation of thermal energy during periods of convective drying, not only in contact with the elements of the convective drying unit, but also from the outgoing heat fluxes of the drying air. The use of TA allows you to create a uniform temperature regime in a vacuum cabinet, which will reduce the drying time due to the absence of the need to reheat the shelves with a low temperature.

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