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## Article

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## **DETERMINATION OF HEAT TRANSFER COEFFICIENT IN ADVANCED ROTARY FILM EVAPORATOR**

*The object of research is the process of concentrating fruit and vegetable purees in an improved rotary film evaporator. The existing hardware design of traditional processes for processing fruits and vegetables, as a rule, is not unified enough, inconvenient in operation and is designed for high productivity. Concentration of fruit and vegetable purees occurs mainly in vacuum evaporators of periodic and continuous operation at a temperature of 60–80 °C under vacuum, which allows them to significantly preserve their nutritional value. But the duration of the process remains very significant (in devices of periodic action up to 75–90 minutes). One of the most problematic areas in the concentration of fruit and vegetable raw materials is significant losses of biologically active substances. At the same time, an important indicator of the quality of the process of concentrating pasty fruit and vegetable pastes is the value of the heat transfer coefficient, which characterizes the efficiency of the heat transfer method and the design features of the mixing device, taking into account the thermophysical characteristics of the product. To create conditions for conducting research to determine the heat transfer coefficient, it is necessary to use instrumentation with precise regulation of the necessary technological parameters.*

*To study the heat transfer coefficient when concentrating fruit and vegetable purees, an automatic installation of an improved rotary evaporator was designed. The improvement of the rotary film evaporator (RFE) is carried out due to the lower location of the separating space by installing a screw discharge of the paste and preheating the output puree with secondary steam.*

*The experimental dependences of the heat transfer coefficient on the product flow rate make it possible to determine the rational values of the flow rate of the RFE feedstock at various values of the rotor shaft speed. It is found that the heat transfer coefficient is influenced to a large extent by the product consumption, and the rotor speed acts to a lesser extent, only the relative speed of fluid passage around the developed hinged blade changes. It is found that when the frequency changes from 0.3 to 1.7 s<sup>-1</sup>, an increase in the heat transfer coefficient by 1.45 times is observed, which is explained by a more intensive degree of mixing of the product by the blades.*

**Keywords:** fruit and vegetable raw materials vacuum film evaporator, heat transfer coefficient, articulated blade, secondary steam energy, vegetable paste.

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### **1. Introduction**

In modern conditions of life, concentrated food products from plant materials of organic origin are in increasing demand among consumers. Such products and semi-finished products include jams, confitures, candied fruits, fruit and vegetable purees and pastes, and the like. The nutritional value of processed products of fruits and vegetables primarily depends on the technological regimes and hardware design of the lines for their production [1, 2]. After all, it is fruit and vegetable raw materials that are a rich source of vitamins, anthocyanins, mineral and pectin substances, phytoncides that can increase the immune system [3, 4]. The increased demand for the use of concentrated high-

quality fruit and vegetable products leads to a constant search for the implementation of effective measures to intensify heat and mass transfer equipment and processes for their processing [5, 6]. Further nutritional value and organoleptic characteristics of the final product depend on the implementation of constructive and technological solutions for processing fruit and vegetable raw materials [7].

Traditionally, the process of concentrating fruit and vegetable purees and juices is implemented in vacuum evaporators of periodic and continuous action at a gentle temperature of 60–80 °C under vacuum, which allows them to significantly preserve their nutritional value. But the duration of the process remains very significant (for example, in devices of periodic action up to 75–90 minutes) [8].

Analysis of literature data showed that the use of rotary film evaporators (RFE) for concentrating fruit and vegetable purees has a number of advantages over the traditionally used evaporation equipment:

- significant reduction in the duration of heat treatment;
- higher degree of mixing of the product;
- reduction of overall and weight characteristics;
- possibility of carrying out other processes besides evaporation (drying, rectification, stirring and mixing, chemical transformations, etc.). It should also be noted that RFE have relatively small overall dimensions, which generally contributes to their use in the production of fruit and vegetable pastes near the zone of their growth [9].

An important indicator of the quality of the process of concentrating pasty fruit and vegetable pastes in RFE is the value of the heat transfer coefficient, which characterizes the efficiency of the heat transfer method and the design features of the mixing device, taking into account the thermophysical characteristics of the product. To create conditions for conducting research to determine the heat transfer coefficient, it is necessary to use instrumentation with a clear regulation of the necessary technological parameters (temperature, shaft rotation frequency, product consumption).

Thus, the *object of research* is the process of concentrating fruit and vegetable purees in an improved rotary film evaporator. The *aim of research* is to determine the heat transfer coefficient in the developed installation of the rotary-film apparatus during the concentration of fruit and vegetable pastes.

## 2. Methods of research

To study the heat transfer coefficient when concentrating organic fruit and vegetable purees, an automatic installation of an improved rotary evaporator was designed. The improvement of the rotary film evaporator (RFE) was carried out due to the lower location of the separation space, the establishment of a screw discharge of concentrated organic fruit and vegetable paste and the preheating of the output puree with secondary steam.

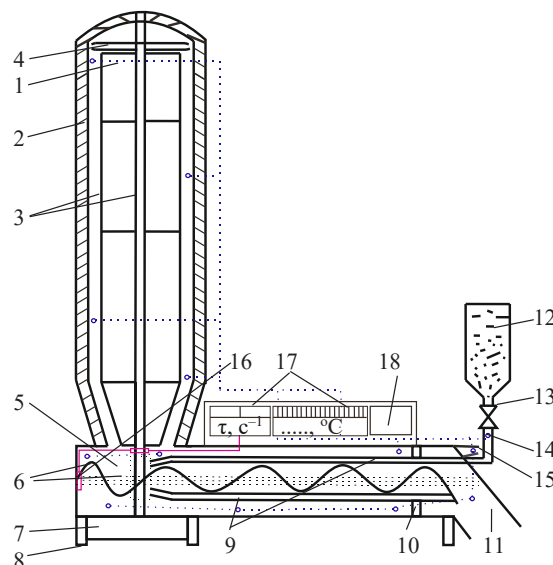
RFE 1, where the rotor 3 is installed along the axis of the body, on which the articulated shovels are fixed (Fig. 1). The rotor is driven from the engine compartment 7, and the apparatus is mounted on racks 8. Externally, the casing is heated by a flexible film resistive electric heater of the radiating type with heat insulating alyufom (FFREHRT, Ukraine) 2. The power of the heaters and the rotor motor is measured using a measuring set 17 and a microcontroller 18 (Atmega-16PI, Ukraine).

The vacuum in the inner space of the apparatus is created by a vacuum pump, which is connected to the condensate outlet pipe 15. The flow rate of raw materials is controlled by the volumetric method and is regulated by means of the valve 13.

The temperature of the working surface of the apparatus, of the prototype at the inlet and outlet, of the secondary steam is measured by thermocouples 14 and regulated by a microcontroller 18. The rotational speed of the rotor and auger shaft is stabilized and regulated by the installed frequency sensors 16 on the display panel of the microcontroller.

Fruit and vegetable puree comes from the tank of the initial product 12 with simultaneous measurement of the

flow rate and passing through the coil blower 9 is preheated by the energy of the secondary steam and enters through the inner shaft of the film-forming device 4. Then it jumps up with a rotor with cutting blades 3, forming a film flow and moving it to the separating space 5 where the secondary steam is separated from the concentrated paste volume. The resulting paste goes to the unloading auger 6 and is removed from the RFE for further processing through the concentrate unloading pipe 11. Secondary steam from the separating space 5 is forcibly removed by the exhaust fans 10 for subsequent technological needs.



**Fig. 1.** Diagram of the experimental setup of a rotary-film evaporator (RFE) for studying the heat transfer process:  
1 – RFE model; 2 – flexible film resistive heater of emitting type with heat insulating alyufom (FFREHRT); 3 – rotor with shearing blades;  
4 – film-forming device; 5 – separating space; 6 – unloading auger;  
7 – engine compartment; 8 – racks; 9 – coil blower of incoming puree;  
10 – exhaust fans; 11 – branch pipe for unloading the concentrate;  
12 – initial product tank; 13 – volumetric flow meter;  
14 – thermocouples; 15 – secondary air outlet branch pipe;  
16 – frequency meters; 17 – measuring set K-505 (Ukraine);  
18 – ATmega8-16PI microcontroller

The determination of the heat transfer coefficient was carried out by experimentally establishing the average temperature of the prototype  $\bar{t}_p$ , namely the temperature at the moment of film formation and the release of the concentrate using the appropriate thermocouples:  $\bar{t}_p = (t_{p-v} + t_{p-r})/2$ . Also, the wall temperature  $\bar{t}_{wp}$  from the product side was determined as the temperature electric heater FFREHRT  $\bar{t}_{wt}$  (set on the control panel) and wall temperature difference  $\Delta t_w: t_{w-p} = t_{w-t} - \Delta t_w$ .

The obtained research parameters of the temperatures of the process and the flow rate of the product are the initial parameters for determining the heat received by the product and the heat transfer coefficient according to the standard calculation methods of evaporation equipment [10], in particular:

- the heat received by the product:

$$Q_h = Gc(t_{p-r} - t_{p-in}) + rG_{cond} \quad (1)$$

where  $G$  – mass flow rate of the product, kg/s;  $G_{cond}$  – mass flow rate of condensate, kg/s;  $c$  – specific heat capacity of the product, J/(kg·K);  $r$  – latent heat of vaporization, J/kg;

– coefficient of heat transfer from the working surface to the product:

$$\bar{\alpha} = \frac{Q_h}{\pi D L \Delta t_h}, \quad (2)$$

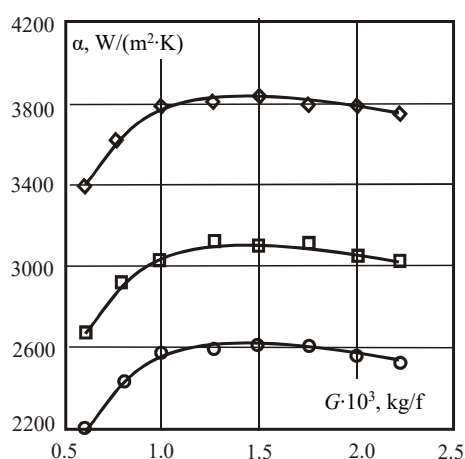
where  $D$  – inner diameter of the working chamber, m;  $L$  – height of the concentration body, m;  $\Delta t_h$  – temperature head, K.

The relative error of research measurements of temperature parameters and mass flow rates of the product and condensate is 2–3 %.

For the research, let's use a multicomponent puree of apples, Jerusalem artichoke and dogwood. Previous studies of various percentages of samples from the selected raw materials in terms of structural, mechanical, physico-chemical and organoleptic indicators revealed a composition with the following content: apples – 65 %; Jerusalem artichoke – 25 %; dogwood – 10 %. For the static probability, all studies on the RFE experimental setup were repeated five times.

### 3. Research results and discussion

The results of the study of the heat transfer characteristics of the RFE depending on the product flow rate and the rotor speed are shown in Fig. 2.



**Fig. 2.** Dependence of the heat transfer coefficient on the product consumption for the developed articulated blade:  
○ –  $n=0.3 \text{ s}^{-1}$ ; □ –  $n=0.7 \text{ s}^{-1}$ ; ◇ –  $n=1.7 \text{ s}^{-1}$

It is found that the heat transfer coefficient significantly depends on the consumption of fruit and vegetable puree and, when the highest value is reached, begins a downward trend (Fig. 2).

This character of the curves is explained by the fact that the edges of the blade actually mix mainly the surface layers of the raw material, and the near-wall layers practically flow down the surface, which leads to a decrease in the heat transfer coefficient. Namely, with increased values of the consumption of puree in front of the leading edge of the blade, a nasal wave with a significant amount of it is formed. The puree is in the nasal wave, partially not in contact with the heating surface, which leads to a decrease in the evaporation process. The puree is thus in contact with the top for less time due to its awakening. The heating interval for mashed potatoes at

high costs increases, which leads to a decrease in the heat transfer coefficient.

It should be noted that the heat transfer coefficient increases to a certain value and, for example, for a rotation frequency of  $1.7 \text{ s}^{-1}$  is  $3845 \text{ W/(m}^2\cdot\text{K)}$ , after which its decrease is observed. The increase in the intensity of heat exchange stops when the maximum value of the product flow rate is reached, which corresponds to the optimal operating mode of the RFE.

One of the limitations of the research is the complexity of stabilizing the rotor speed with cutting blades, depending on the change in the consumption of raw materials supplied for concentration and affects the final heat transfer coefficient. RFE is recommended to be used within the pressure range of 12–15 kPa and the rotor speed with cutting blades from  $0.3$  to  $1.7 \text{ s}^{-1}$ , providing an intensive degree of mixing of the product with blades with a rational heat transfer coefficient.

Further development of research can be aimed at determining changes in color formation depending on the heat exchange modes of concentration, as one of the quality indicators of the resulting concentrates.

### 4. Conclusions

An improved RFE unit has been developed, which allows to determine the heat and mass transfer characteristics of the process of concentrating fruit and vegetable purees to a dry matter content of 30 %. The experimental dependences of the heat transfer coefficient on the product flow rate make it possible to determine the rational values of the flow rate of the RFE feedstock at various values of the rotor shaft speed. It was found that the heat transfer coefficient is influenced to a large extent by the product consumption, and the rotor speed acts to a lesser extent, only the relative speed of fluid passage around the developed hinged blade changes. It was found that when the frequency changes from  $0.3$  to  $1.7 \text{ s}^{-1}$ , an increase in the heat transfer coefficient by 1.45 times is observed, which is explained by a more intensive degree of mixing of the product by the blades.

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