E3S Web of Conferences **461**, 01059 (2023) https://doi.org/10.1051/e3sconf/202346101059
RSES 2023

Control of modes of energy-saving vibro-drying devices

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Abstract. This paper proposes a method for optimizing the drying process of pectin hydrolyzate in the vibrofluidized bed of inert material, which allows to determine the values of the parameters of the regime at which the drying process continues with minimal costs for thermal and heat. It is based on the experimentally obtained relationship between the specific productivity of the drying equipment and the following parameters of the drying process: air movement speed in the drying chamber, initial air temperature, specific load depending on the drying area, gas distribution network , the initial concentration of dry matter. A complex criterion for the optimization of the vibrofluidized drying process has been developed, its minimization allows to increase the efficiency of the drying process. Restrictions on the ranges of changing the parameters of the drying process have been developed.

1 Introduction

The technological process of pectin production is energy-intensive and environmentally unsafe. Such a process traditionally includes the stages of washing apple pomace, extracting pectin by acid hydrolysis, separating the solid fraction, followed by treatment with ethyl alcohol, and drying [1]. In industrial conditions, large volumes of ethyl alcohol are required, as well as significant energy costs for its regeneration. One of the promising directions of the technological process of pectin production is the drying of the hydrolyzate directly before its precipitation with ethyl alcohol.

A promising direction for the modernization of the technological process of pectin production is the use of an intensive method of drying pectin hydrolyzate in a vibrating fluidized bed of inert granules [2]. Carrying out the drying process in a vibrofluidized layer of an inert material is associated with increased costs for thermal and electrical energy. In this regard, the urgent task is to find the optimal values of the regime parameters of the pectin hydrolyzate drying process in a vibrofluidized bed, which minimize the reduced costs, including the cost of steam and the cost of electricity. At the same time, in the optimization process, it is necessary to take into account a number of restrictions on the regime parameters of drying, due to the specifics of the technological process [3–6].

The purpose of the studies carried out in this work was to develop a methodology for optimizing the process of drying pectin hydrolyzate in a vibrofluidized bed, based on the criterion of minimizing the reduced costs for energy carriers. The proposed method is based on the dependence obtained experimentally, which determines the restrictions on changing the regime parameters of the drying process. The developed technique made it possible to determine the values of the regime parameters of the drying process, at which the minimum energy costs are achieved.

2 Methodology and research results

The limiting productivity of the vibrofluidized bed drying plant depends significantly on the parameters of the pectin hydrolyzate, including its initial concentration in terms of dry matter, and changes with varying temperature and air velocity in the drying chamber [3, 4]. Also, an important factor affecting the performance of the installation is its specific load. In order to identify the relationship connecting the listed mode parameters of the drying process, an experimental drying installation was developed, which includes the following elements (Fig. 1): drying chamber 1, fan 2, eccentric vibration drive 3, heater 4. The vibration drive provides vertical oscillatory movements of the drying chamber. Cubic fluoroplastic granules are placed on the gas distribution grate of the drying chamber. The fluidization of these granules is ensured both by fluctuations in the gas distribution grid and by supplying hot air to the drying chamber. Temperature control and regulation is carried out by an electronic potentiometer complete with a fast-response thermocouple. Before the product is fed into the drying chamber, it is preheated using a heat exchanger 6. From the container 8, the pectin hydrolyzate is pumped by a pump 7 into a pneumatic nozzle spraying the hydrolyzate in a layer of granules. The air consumption for spraying in all experiments was 11 m3/h. The product is deposited on the surface

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of the inert granules, forming a thin film. To reduce the viscosity of the product, before it was fed into the layer of inert material, it was preliminarily heated in heat exchanger 6 with hot water coming from a thermostat. After drying, the product loses its connection with the inert granules and moves with the air into the cyclone 5, which ensures the separation of the dried product from the air stream.

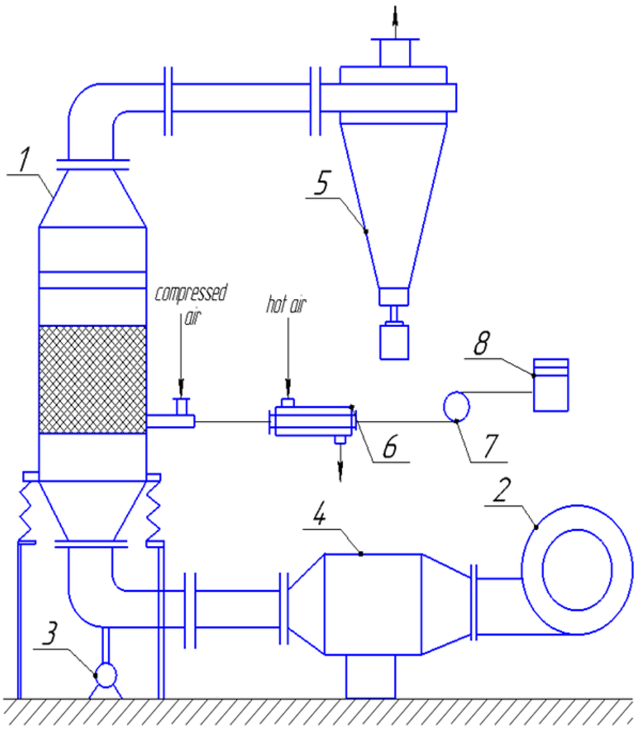

Fig . 1. Scheme of the experimental drying plant

In the course of a preliminary experimental study, it was shown that the process of drying pectin hydrolyzate in a vibrofluidized bed proceeds continuously. With an increase in the product flow rate, the nonuniformity of the boiling of the fluidized bed increases and sticky granules are observed, while the surface of the granules is not completely covered with the product. Therefore, to increase productivity, a vibrating gas distribution grate was used, which makes it possible to break agglomerates of granules. In the experiments performed , the vertical vibration frequency was 7.5 Hz, the amplitude was 8 mm. Drying was started with a low productivity with a further stepwise increase in the supply of pectin hydrolyzate with an interval of 30 minutes.

In the course of the experiments, the following regime parameters of the drying process acted as factors: air velocity in the drying chamber v , m/s, initial air temperature t 1, oC , specific load G , kg, related to the area of the gas distribution grid Fp , m2, initial dry matter concentration C, %. Accordingly, when conducting experiments, an orthogonal plan of the four listed factors, varied at four levels, was used. The plan is built on the basis of two ordered and two Latin squares of size 4 x 4 [4, 5]. Based on the results of these experiments, an empirical relationship was obtained between the performance of the installation and the controlled process variables

$$U_p = 1{,}47 \cdot 10^{-7}(1{,}15G_p - 0{,}23)(0{,}38v - 0{,}026)(1{,}9t_1 - 41{,}63)(-3{,}12C_1 + 210{,}8) \quad (1)$$

where U_p=U/F_p , U is the ultimate performance of the plant, kg/h; F_p is the area of the gas distribution grid, m2; Gp = G / F_p ,

G is the specific load, kg; v is the speed of air movement, m/s; t_1 - initial air temperature, ^{o}C ; C_1 - initial concentration for dry matter, %.

The obtained dependence (1), as well as the recommendations outlined in [6, 7], allow us to formalize the following two indicators of the efficiency of the pectin hydrolyzate drying process in a vibrofluidized bed.

The first indicator is the reduced cost of thermal energy consumed by the vibrofluidized bed installation:

$$J_1 = 3600 P_s C_a \rho_a \times \frac{(100-W_2-C_1)(t_1-t_0)}{U_p \eta_k r_s} \to min; \quad (2)$$

where $P_s$is the cost of steam, rub./kg; C_a- specific heat capacity of air, kJ/(kg/K); ρ_a- air density at the entrance to the drying chamber, kg/m ^{3} ; W_2- humidity of dry product, %; t_0- ambient temperature, ^{0} C; η_k- efficiency of the heater; r_s- specific heat of phase transformation of steam, kJ/kg.

The second indicator is the reduced cost of electricity consumed by the vibrofluidized bed installation:

$$J_2 = P_e v(100 - W_2 - C_1)(G_p g - \Delta p)/U_p \eta_p r_d \quad (3)$$

where $P_e$is the cost of electricity, sum ./kW*h; g - free fall acceleration, m/s ^{2}; Δp- resistance of the air path of the dryer, Pa; η_p- fan efficiency; r_d- the same electric motor.

3 Research results

In accordance with the scalar convolution method [8, 9], we combine (2) and (3) into the following complex criterion for optimizing the drying process in a vibrofluidized bed:

$$J = J_1 + J_2 \to min \quad (4)$$

Thus, taking into account (4), the problem of optimizing the drying process in a vibrofluidized bed is reduced to finding the values of the regime parameters included in formula (1), which provide a minimum cost for thermal and electrical energy, with a maximum specific productivity per unit area of the gas distribution grid [10-19].

When minimizing the optimization criterion (4) , the following restrictions are imposed on the ranges of change of the regime parameters of the drying process in the vibrofluidized bed t_1, v, G_p and C_1:

air temperature at the inlet to the drying chamber

$$t_{1min} \leq t_{1max} \leq t_{1max} \quad (5)$$

where t_{1min}- 100 °C; t_{1max}- 120 °C - minimum and maximum air temperatures at the inlet to the drying chamber, the values of which are selected according to the conditions given in [2, 19-23];

air velocity in vibrofluidized bed apparatus

$$v_{min} \leq v \leq v_{max} \quad (6)$$

where v_{min}- 4.0 m/s; v_{max}- 5.5 m/s – minimum and maximum air velocities in the apparatus of the vibrofluidized bed, the values are selected according to the data of [2, 20];

– specific load of inert material granules

$$G_{p\,min} \leq G_p \leq G_{p\,max} \quad (7)$$

Where$G_{p\,min}$ - 140 kg / m ^{2} ;$G_{p\,max}$ - 170 kg/m ^{2} - minimum and maximum specific loads of cubic fluoroplastic granules with a fin size of 4 mm;

– dry matter concentration

$$C_{1\,min} \leq C_1 \leq C_{1\,max} \quad (8)$$

Where$C_{1\,min}$ - 5%; $C_{1\,max}$- 15% - minimum and maximum concentrations for dry matter according to [7].

Additionally, a limitation is introduced on the final moisture content of the dry product W_2

$$W_{2\,min} \leq W_2 \leq W_{2\,max} \quad (9)$$

where $W_{2\,max}$- 9%;$W_{2\,min}$ - 5% - the minimum and maximum allowable dry product moisture content according to technological conditions.

Also, according to technological conditions, the temperature of the product during drying should not exceed 75. Considering that the temperature of the product during drying in a fluidized bed practically coincides with the temperature of the exhaust air, the condition t_2 - $t_{2\,d\,occurs}$, where $t_{2\,d}$ = 75 °C. In this case, the exhaust air temperature t_2 is related to the air temperature at the inlet to the drying chamber t_1 by the heat balance equation. In this equation, it is permissible to neglect the heat costs for heating the hydrolyzate because of their smallness in comparison with the costs for moisture evaporation. The equation for such a heat balance has the form

$$U_p = 3600 K_p \rho_a C_a v (t_1 - t_2)/r \quad (10)$$

Where K_p - heat loss coefficient; r is the specific heat of vaporization.

The value of the specific heat of evaporation is determined by the formula

$$r = r_0 + C_s t_2 - C_w \theta + \Delta r \quad (11)$$

where $C_w$is the specific heat capacity of water, kJ/(kgK); θ– product temperature, K; C_s– specific heat capacity of steam, kJ/(k*K); Δ r is the specific heat of overcoming the bond between moisture and material, kJ/kg; r_0= 2500 kJ/kg.

Table 1. Optimal values of regime parameters of the drying process

Mode parameter	Optimal value mode parameter
Air velocity in the drying chamber v , m/s	5.5
Specific load of inert material granules G / F_p, kg/m ^{2}	170
The initial concentration of pectin on dry matter C_1,%	5
Exhaust air temperature t_2, ^{0}C	74.76

Thus, the problem of optimizing the mode of the drying process in a vibrofluidized bed is reduced to minimizing the quality criterion (4) under constraints (5)–(10). The problem posed was solved numerically by the method of sequential quadratic programming [10, 11, 19] using the MATLAB software package. Fig. 2 shows the analysis of the drying process to obtain pectin based on the experiments.

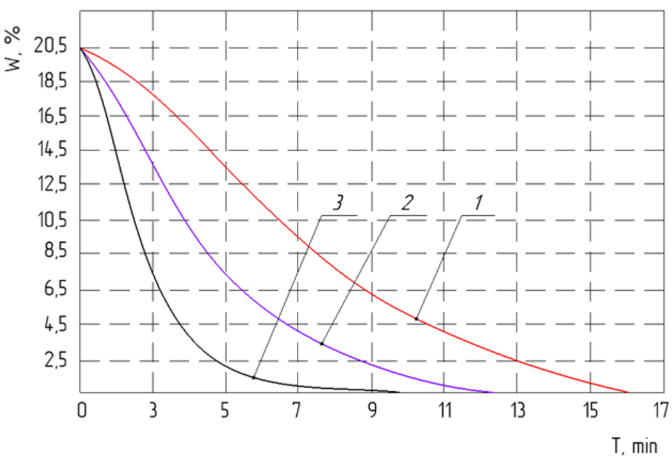

Fig. 2. Kinetic characteristics of the drying process in a vibrofluidized bed apparatus at a drying agent temperature of 60 °C(1), 70 °C(2), 80 °C(3).

 https://doi.org/10.1051/e3sconf/202346101059

Based on the results of solving the optimization problem, the values of regime parameters of the drying process were obtained (Table 1), at which the complex criterion (4) reaches a minimum.

4 Conclusion

A technique for optimizing the process of drying pectin hydrolyzate in a vibrofluidized layer of an inert material is proposed, which makes it possible to reduce the energy intensity of this process. An experimental dependence has been obtained that determines the restrictions on changing the regime parameters of the drying process. The optimization of the drying process based on the minimization of the complex criterion of reduced energy costs has been carried out. On the basis of the proposed method, the values of the regime parameters of the drying process are determined, at which the costs of thermal and electrical energy can be minimized.

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