Method of Calculating the Parameters of the Process of Reducing Pressure in a Vacuum-Evaporator

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Abstract. In agriculture, the use of humic preparations can increase the productivity, productivity of animals and poultry. The growth rate of consumption of humic preparations in 2021 ... 2025 will be from 1 to 5% per year and the market capacity in Russia will be 1500 tons per reptile. Improvement of equipment for the production of humic preparations is urgent. The physical and mechanical properties of the humic suspension have been determined. In the production of humic preparations, medical centrifuges OS-6MC, a flow-through sedimentation centrifuge and a periodic vacuum evaporator (VVU) were used to increase the concentration of humic suspension. In terms of the energy of germination and germination of spring wheat, a rational method for increasing the concentration of humic suspension by evaporation has been substantiated. We have developed and patented a line with VVU to increase the concentration of humic suspension [21]. At the exhibition Golden Autumn - 2020 (Moscow) “For the production of highly efficient agricultural machinery and the introduction of advanced resource-saving technologies”: Kurgan State Agricultural Academy was awarded a bronze medal and a diploma: "For the development of a line for the production of a humic preparation.” When the time for the VVU to enter the operating mode is the sum of the heating time of the installation to the operating temperature and the time for the pressure drop in the installation from atmospheric to working. A method has been developed for calculating the heating time of the VVU with a tank of 50 liters from the initial installation temperature of 10 °C to the boiler temperature of 85 °C, and of the humic suspension to 60 °C will be 30 minutes at a power source of 12 kW, which is confirmed by experiment. A method for calculating the parameters of the process of lowering the pressure in the VVU has been developed. Dependencies are obtained for studying the relationship between the design and technological parameters of the VVU when the pressure is reduced from atmospheric to working. The time of pressure reduction with a volume of 1 m3 of the vacuum system will be 5 ... 6 minutes, which is confirmed by experiment.
1. **Introduction**
In agriculture, the productivity and productivity of animals and poultry can be increased by using humic preparations [1-9]. The growth rates of the consumption of humic preparations in 2021 ... 2025 will be from 1 to 5% per year and the market capacity in Russia will be 1500 tons per year [10-12].

2. **Timeliness**
The equipment used for the production of humic preparations has a number of disadvantages: it has a negative effect on humic preparations, reducing their quality, is expensive, occupies a large area with low productivity and high labor costs. Improvement of equipment for the production of humic preparations is relevant [13-16].

3. **Setting**
To substantiate the method for increasing the concentration of humic suspension, its physical and mechanical properties were determined: density, kinematic viscosity, dry matter content, sedimentation height, sedimentation rate of particles [17, 18]. The growth energy after evaporation is 7.8% higher than after centrifuges. In the production of humic preparations to increase the concentration of humic suspension, medical centrifuges OS-6MC, a flow-through sedimentation centrifuge and a periodic vacuum evaporator (VVU) were used [19-20]. The germination rate after evaporation is 11.4% higher than after a flow-through precipitation centrifuge and 4.6% higher than after the OS-6MC centrifuge. This can be explained by the fact that in centrifuges under the influence of centrifugal forces, separation factor $\Phi = 6000 ... 7000$, the destruction of molecules of useful substances occurs and the effectiveness of drugs decreases. In terms of the energy of germination and germination, a rational way of increasing the concentration of humic suspension by evaporation has been substantiated. Based on a review of literary sources [21-24] and conducting exploratory experiments, we have developed and patented a line with VVU to increase the concentration of humic suspension [25, 26].
At the exhibition Golden Autumn - 2020 (Moscow) "For the production of highly efficient agricultural machinery and the introduction of advanced resource-saving technologies": Kurgan State Agricultural Academy was awarded a bronze medal and a diploma: "For the development of a line for the production of a humic preparation."

4. **Theoretical research results**
Purpose of the study: to determine the time of the VVU reaching the operating mode at start-up. The VVU scheme of periodic action is shown in Figure 1.

![Diagram of a batch vacuum evaporator](image-url)
1 - boiler for suspension with a water jacket and thermal insulation, 2 and 3 pipelines for supplying the jacket and removing the coolant from the jacket, 4 - drainage branch of the concentrated suspension, 5 - thermometer, 6 - vacuum gauge, 7 - pipeline from the boiler to the steam condenser, 8 - steam condenser, 9 - pipeline from condenser to ejector, 10 - ejector inlet chamber, 11 - working nozzle, 12 - mixing chamber, 13 – diffuser.

Line work. Boiler 1 is filled with slurry and sealed with a lid. The coolant circulates through the jacket of the boiler and pipes 2 and 3. The energy consumption for heating the VVU to the operating temperature is determined by the formula:

\[ W_u = \sum W_i \]  

(1)

where \( W_i \) is the energy consumption for heating the VVU components to the operating temperature, J.

The energy consumption for heating the VVU components to the operating temperature is determined by the formula:

\[ W_i = c_i \cdot m_i \cdot (t_{2i} - t_{1i}) \]  

(2)

where \( c_i \) is the heat capacity of the substance, J / (kg · K);
\( m_i \) is the mass of the substance, kg;
\( t_{2i} \) - final temperature, ºC;
\( t_{1i} \) - initial temperature, ºC.

The heating time of the installation to operating temperature is determined by the formula

\[ T_u = \frac{W_u}{N} \]  

(3)

where \( N \) is the power of the energy source, kW.

When the suspension is heated to 60 ºC, water is supplied to the working nozzle 11 of the ejector. In this case, a coolant is continuously circulating through the jacket, and the pressure in the boiler decreases from atmospheric to operating 26 ... 20 kPa. From the volume of the boiler above the surface of the suspension, steam condenser 8, pipelines 7 and 9, air is removed by an ejector, which operates in the water-air mode.

The initial data for the calculation. \( W_a \) - total volume of air in the evaporator boiler above the humic suspension, steam condenser, condensate collector and pipelines connecting them, m³; \( P_{at} \) – atmospheric pressure, Pa; \( P_p \) – water pressure in front of the working nozzle, Pa; \( P_n \) – pressure of injected air, Pa; \( \rho_n \) – initial density of air, kg/m³; \( P_c \) – pressure after the ejector, Pa; \( P_{sat} \) – saturated vapor pressure, Pa; \( t_p \) – working water temperature, ºC; \( t_n \) – temperature of the injected air, ºC; \( G_n \) – mass flow rate of injected air, kg/h.

When starting the installation, the pressure in the boiler must be reduced from atmospheric \( P_{at} = 100 \) kPa to working \( P_n = 20 \) kPa. The pressure reduction range is divided into sections of 10 kPa: \( P_{n1} = 100000 \) kPa; \( P_{n2} = 90,000 \) kPa; \( P_{n3} = 80,000 \) kPa; \( P_{n4} = 70,000 \) kPa; \( P_{n5} = 60,000 \) kPa; \( P_{n6} = 50,000 \) kPa; \( P_{n7} = 40,000 \) kPa; \( P_{n8} = 30000 \) kPa; \( P_{n9} = 20,000 \) kPa. We solve the problem by the numerical method of rectangles, considering the decrease in pressure every 10 kPa. Accepted assumption – we do not take into account the pressure loss in the pipeline from the boiler to the condenser. The time of pressure decrease on the i-th section of the pressure scale is determined by the formula:

\[ T_{ji} = \frac{V_{ni}}{V_{ni}} \]  

(4)

where \( i = 0...8 \);
\( V_{ni} \) – volume of vapor is pumped to i-th portion of the pressure scale, m³;
\[ V_{wi} = \frac{\Delta M_i \cdot R_e \cdot (273 + t_p)}{P_{wi} - P_{tp}} \]  

(5)

The density of air in the boiler in each section is determined by the formula:

\[ \rho_{si} = \frac{\rho_s \cdot P_{ni}}{P_{n0}} \]  

(6)

The mass of air in the system is determined by the formula:

\[ M_{wi} = W_w \cdot \rho_{xi} \]  

(7)

The mass \( \Delta M_i \), kg of air evacuated from the system at a pressure drop of 10 kPa is determined by the formula:

\[ \Delta M_i = M_{wi} - M_{wi+1} \]  

(8)

where \( i = 0 \ldots 7 \);

The decrease in air density with a decrease in pressure of 10 kPa is determined by the formula:

\[ \Delta \rho_i = \rho_{si} - \rho_{si+1} \]  

(9)

The volume of evacuated air at a pressure drop of 10 kPa is determined by the formula:

\[ W_{yi} = \frac{\Delta M_i}{\rho_{si}} \]  

(10)

To improve the visibility of the graphs with the calculation results, we introduce the \( P_y \) value:

\[ P_{yi} = P_{ni+1} \]  

(11)

The pressure drop that ensures the flow of water from the working nozzle is determined by the formula:

\[ \Delta P_{pi} = P_p - P_{ni} \]  

(12)

The pressure difference after the ejector and in the boiler is determined by the formula:

\[ \Delta P_{ci} = P_c - P_{ni} \]  

(13)

The maximum volumetric coefficient of injection in the operating mode at a pressure in the boiler of 20 kPa in each section is determined by the formula:

\[ U_{bi} = 0.85 \cdot \sqrt[3]{\frac{\Delta P_{pi}}{\Delta P_{ci}}} \cdot I \]  

(14)

The flow rate of working water from the nozzle is determined by the formula:
\[ \omega_{pi} = \psi \cdot \sqrt{\frac{2 \cdot \Delta P_{pi}}{\rho}} \]  

(15)

The volumetric flow rate of working water is determined by the formula:

\[ V_{pi} = \omega_{pi} \cdot f_{pi} \]  

(16)

The volumetric flow rate of the vapor-air mixture is determined by the formula:

\[ V_{ni} = U_{0i} \cdot V_{pi} \cdot 3600 \]  

(17)

After substituting formulas (2 ... 14) into formula (1), we obtain the dependence for determining the time of pressure decrease in each section:

\[ T_{xi} = \frac{W_{ai} \cdot \rho_{n} \cdot (P_{ni} - P_{ni+1}) \cdot R_{ao} \cdot (273 + t_{p})}{(0.85 \cdot \sqrt{\frac{P_{p} - P_{ni}}{P_{c} - P_{ni}}} - 1) \cdot f_{pi} \cdot \sqrt{\frac{2 \cdot (P_{p} - P_{ni})}{P_{ni} - P_{np}}}} \]  

(18)

When the unit starts up, the pressure in the boiler decreases from atmospheric to working in time:

\[ T_{ao} = \sum_{i=0}^{n} T_{xi} \]  

(19)

The relationship between the area \( f_{pi} \) and the diameter \( d_{pi} \) of the working nozzle of a water-air ejector, \( G_{n} \) - mass flow rate of injected air, \( \text{kg/h} \); \( P_{p} \) - water pressure in front of the working nozzle, \( \text{Pa} \); \( P_{ni} \) - pressure of injected air, \( \text{Pa} \); \( \rho \) - density of working water, \( \text{kg/m}^3 \); \( P_{c} \) - pressure after the ejector, \( \text{Pa} \); \( P_{np} \) - saturated vapor pressure, \( \text{Pa} \); \( t_{p} \) - working water temperature, \( \degree \text{C} \); \( t_{ni} \) is the temperature of the injected air, \( \degree \text{C} \) and the time of pressure decrease \( T_{x} \), we study using formulas (15) and (17) obtained on the basis of [27]:

\[ f_{pi} = \frac{G_{ao} \cdot R_{ao} \cdot (273 + t_{p})}{3600 \cdot (P_{n} - P_{np}) \left(0.85 \cdot \sqrt{\frac{P_{p} - P_{n}}{P_{c} - P_{n}}} - 1\right) \left(\frac{\rho}{2 \cdot (P_{p} - P_{n})}\right)} \]  

(20)

5. Results

The results of calculations using these formulas were compared with the experimental results [27, p. 233, fig. 7.17c] Figure 2.
**Figure 2.** Dependence of the steady-state pressure in the evaporator boiler on the flow rate of injected air $G_n$, kg/h with a working nozzle diameter of 11 mm and water pressure in front of the nozzle 400 kPa, after an ejector of 100 kPa.

It can be seen from the graph that at the injected air flow rate $G_n = 2$ kg/h, the calculated pressure value in the evaporator boiler is $P_h = 22$ kPa; experimental - $P_s = 20$ kPa. The discrepancy between the calculated and experimental values is 10%. The results of calculations by formulas (15) and (16) of the time for decreasing the pressure in the boiler from 100 to 20 kPa from the diameter of the working nozzle $d_r$, mm, and the pressure after the ejector $P_c$, kPa are presented in Figure 3.

**Figure 3.** The dependence of the time of pressure reduction in the boiler $T$, s, from 100 to 20 kPa, calculated by formulas (15) and (16) from the diameter of the working nozzle $d_r$, mm, and pressure after the ejector $P_c$, kPa with a volume of vacuum system 1 m$^3$. 
It can be seen from the graph that the time for decreasing the pressure with a volume of 1 m3 of the vacuum system will be 5 ... 6 minutes. At start-up, the time for the installation to reach the operating mode is the sum of the heating time of the installation to the operating temperature and the time for the pressure to drop in the installation from atmospheric to working.

6. Conclusions
1. A method for calculating the time of the vacuum evaporator plant reaching the operating mode at start-up has been developed. The heating time of the installation with a tank of 50 liters from the initial temperature of the installation of 10 °C to the boiler temperature of 85 °C, and of the humic suspension to 60 °C will be 30 minutes at a power source of 12 kW, which coincides with the results of the experiment.
2. A method for calculating the parameters of the process of lowering the pressure in a vacuum evaporator to increase the concentration of the suspension has been developed. Dependencies have been obtained to study the relationship between the design and technological parameters of the vacuum evaporator when the pressure drops from atmospheric to operating pressure. The time of pressure reduction with a volume of 1 m3 of the vacuum system will be 5 ... 6 minutes, which coincides with the results of the experiment.

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