Methodology for assessing the energy efficiency of separating methods for wax raw materials

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Abstract. The methodology for assessing the energy efficiency of operating actions during the separation of organic contaminants of wax has been developed. Promising methods of separation of media with complex types of bonds are proposed. The dependences characterizing the energy efficiency of separating methods for the wax raw materials have been determined. Mathematical models are obtained in the form of quadratic polynomials characterizing the influence of design parameters on energy characteristics. The influence of the design parameters of the device and the technological properties of the exposed materials in the form of wax raw materials on the values of active and reactive power has been proved. It has been established that the most rational measure for increasing the energy characteristics of devices for separating wax raw materials is to optimize their design and technological parameters.

1. Introduction
Ensuring the country's food security requires an increase in production capacity, which poses the problem of finding optimal technical solutions that provide the maximum technological effect with minimum energy costs. Energy-efficient mechanization of beekeeping is an important part of solving this problem. Development of technical means that minimize wax losses associated with the presence of a large number of organic contaminants in it is relevant for science and technology. Operational impacts associated with the separation of complex media with physicochemical bonds are one of the most energy-consuming; accordingly, the optimization of their parameters, ensuring the minimum energy costs while meeting the requirements of regulatory documents, is an inevitable stage in assessing energy efficiency.

The purpose of the study is to assess the energy efficiency of separating methods for wax raw materials.

2. Materials and methods
The assessment of the energy efficiency of methods of operating influences and devices that implement them is of a complex nature. On the one hand, the assessment of energy efficiency is reduced to the determination of the specific energy consumption per unit of time per unit of finished product, taking into account the qualitative restrictions regulating its properties, on the other hand, to the determination of the influence of the design parameters of the device on the energy characteristics.

The nominal energy costs of a device that implements one or another type of operation in general can be estimated by the following components:

\[ N_{\text{nom}} = N_1 + N_2 + N_3 + \ldots + N_n, \]  

(1)

where

- \( N_1 \) – unit cost of resources required to perform an operation with the required technological effect, kWh;
- \( N_2 \) – unit costs of resources required to drive the working bodies of technological systems, kWh;
- \( N_3 \) – unit costs of resources required for supplying technological material to the corresponding device, kWh;
- \( N_n \) – unit costs of resources required for additional technological operations, kWh.

Let us consider the elements of each of the components of the energy efficiency complex:

\[ N_1 = f \left( \frac{1}{T} \int_0^T p_1 dt, \int_0^T q_1 dt, \sqrt{\left( \frac{T}{\int_0^T p_1 dt} \right)^2 + \left( \int_0^T q_1 dt \right)^2} \right) \]

\[ N_2 = f \left( \frac{1}{T} \int_0^T p_2 dt, \int_0^T q_2 dt, \sqrt{\left( \frac{T}{\int_0^T p_2 dt} \right)^2 + \left( \int_0^T q_2 dt \right)^2} \right) \]

\[ N_3 = f \left( \frac{1}{T} \int_0^T p_3 dt, \int_0^T q_3 dt, \sqrt{\left( \frac{T}{\int_0^T p_3 dt} \right)^2 + \left( \int_0^T q_3 dt \right)^2} \right) \]

\[ \ldots \]

\[ N_n = f \left( \frac{1}{T} \int_0^T p_n dt, \int_0^T q_n dt, \sqrt{\left( \frac{T}{\int_0^T p_n dt} \right)^2 + \left( \int_0^T q_n dt \right)^2} \right) \]

(2)

where

- \( p_1, p_2, p_3, p_n \) – instantaneous values of active power, characterizing the conversion, kW;
- \( q_1, q_2, q_3, q_n \) – instantaneous values of reactive power, characterizing the transformation, kvar;
$T$ – period of electric current fluctuations, sec.

Knowing the instantaneous values of the active and reactive components of the power consumption of each category, we determine their amplitude and effective values and then determine the total power and the coefficient of energy efficiency. Apparent power effective values are:

$$
\sum_k S = \sqrt{\sum_k P_k^2 + \sum_k Q_k^2}, \text{[kVA]}
$$

where $P$ – effective value of the active power in the power circuit, kW;
$Q$ – effective value of reactive power in the power circuit, kVAr;
$k$ – number of energy categories of each type.

Let us consider the process of transition to effective values from instantaneous values using the example of active power. Having a certain array of instantaneous values of current $i$ and voltage $u$, we determine the time of their period and amplitude values $I_m, U_m$ and using the relation $X = \frac{U_m}{I_m}$ provide that the signal in the energy circuit is sinusoidal and the industrial cyclic frequency of current oscillations in it is transition to the effective values of the powers.

Knowing the effective values of the active, reactive and total power components, we determine the energy efficiency factor $\cos \varphi$:

$$
\cos \varphi = \frac{\sum_k P_k^2}{\sqrt{\sum_k P_k^2 + \sum_k Q_k^2}}
$$

As shown by the research results [1-4], the most promising methods for separating wax raw materials are sequential grinding with fractional separation of contaminants from the technological material in water during long-term stirring and vibration effects on the contaminated honeycomb placed in water.

The essence of method 1 is the sequential execution of two operational actions: grinding and fractional separation, respectively, the specific energy consumption will consist of two components:

$$
N_{\text{nom1}} = N_{\text{chan}} + N_{\text{sep}}, \text{[kW h]} \text{[volume of products in physical and value terms]}
$$

where $N_{\text{meas}}$ and $N_{\text{sep}} = f (P, Q, S, \varphi, Y)$,
$P$ – effective value of the active power of the operational impact, kW;
$Q$ – effective value of the reactive power of the operational impact, kVAr;
$S$ – effective value of the total power of the operational impact, kVA;
$\varphi$ – phase shift angle between $U$ and $I$, °;
$Y$ – parameter characterizing the influence of design and technological factors on energy characteristics.

The essence of method 2 is the implementation of a vibrational operational impact:

$$
N_{\text{nom2}} = N_{\text{vibr}}, \text{[kW h]} \text{[volume of products in physical and value terms]}
$$

Based on the results [2, 3, 5-7], it was found that the most significant factors capable of influencing the energy efficiency of method 1 are the weight of the sample $m$ and the concentration of waxes $v_c$, in the case of method 2, the amplitude $A$ and the frequency of cyclic oscillations $v$. The parameters describing the energy characteristics were taken as the active and reactive power of the operational actions. Accordingly, to determine the level and nature of the influence of the selected factors on the parameters described in [3, 8-12].

When comparing the energy characteristics, a low-power asynchronous electric motor of the AIR71V4 type, with a rated power $P_{\text{nom}} = 0.75$ kW and a rated rotational frequency of the rotating magnetic flux in the stator without slip $n = 1350$ min$^{-1}$, is used as a drive for both methods.

3. Results and discussion
The results of experimental studies in the form of energy characteristics of the considered methods are presented in tables 1, 2, 3.

**Table 1.** Energy characteristics of the grinding operation of method 1

| No. | Sample weight $m, \text{kg}$ | Active power $P, \text{W} \cdot \text{h/kg}$ | Reactive power $Q, \text{VAr} \cdot \text{h/kg}$ | Capacity $E, \text{kg/h}$ |
|-----|-----------------------------|--------------------------------|---------------------------------|--------------------------|
| 1   | 0.05                        | 70.57                          | 62.24                           | 3.221225                 |
| 2   | 0.1                         | 102.46                         | 90.37                           | 3.7149                   |
| 3   | 0.15                        | 137.49                         | 121.26                          | 4.331025                 |
| 4   | 0.2                         | 175.64                         | 154.91                          | 5.0696                   |
| 5   | 0.25                        | 216.93                         | 191.32                          | 5.930625                 |
| 6   | 0.3                         | 261.35                         | 230.50                          | 6.9141                   |
| 7   | 0.35                        | 308.90                         | 272.43                          | 8.020025                 |
| 8   | 0.4                         | 359.59                         | 317.13                          | 9.2484                   |
| 9   | 0.45                        | 413.40                         | 364.59                          | 10.599225                |
| 10  | 0.5                         | 470.35                         | 414.81                          | 12.0725                  |
| 11  | 0.55                        | 530.42                         | 467.80                          | 13.668225                |

**Table 2.** Energy characteristics of the separation operation of method 1

| No. | Wax raw material concentration $v_c, \text{gr/l}$ | Percentage of dirt removed from the wax, % | Active power $P, \text{W} \cdot \text{h/kg}$ | Reactive power $Q, \text{VAr} \cdot \text{h/kg}$ |
|-----|--------------------------------------------------|-------------------------------------------|--------------------------------|---------------------------------|
| 1   | 50                                               | 25.7175                                   | 16.3945                          | 14.46                           |
| 2   | 75                                               | 25.989375                                 | 16.647375                        | 14.68                           |
| 3   | 100                                              | 25.59                                     | 17.004                           | 15.00                           |
| 4   | 125                                              | 24.519375                                 | 17.464375                        | 15.40                           |
| 5   | 150                                              | 22.7775                                   | 18.0285                          | 15.90                           |
| 6   | 175                                              | 20.364375                                 | 18.696375                        | 16.49                           |
| 7   | 200                                              | 17.28                                     | 19.468                           | 17.17                           |
| 8   | 225                                              | 13.524375                                 | 20.343375                        | 17.94                           |
| 9   | 250                                              | 9.0975                                    | 21.3225                          | 18.80                           |
| 10  | 275                                              | 3.999375                                  | 22.405375                        | 19.76                           |
| 11  | 290                                              | 0.6183                                    | 23.1049                          | 20.38                           |

**Table 3.** Energy characteristics of method 2

| No. | Amplitude of vibrations $A, \text{mm}$ | Vibration frequency $v, \text{Hz}$ | Active power $P, \text{W} \cdot \text{h/kg}$ | Reactive power $Q, \text{VAr} \cdot \text{h/kg}$ |
|-----|----------------------------------------|----------------------------------|--------------------------------|---------------------------------|
| 1   | 1                                      | 45                               | 6.46                           | 5.70                            |
| 2   | 1.2                                    | 46                               | 6.408                          | 5.65                            |
| 3   | 1.4                                    | 47                               | 6.636                          | 5.85                            |
| 4   | 1.6                                    | 48                               | 7.144                          | 6.30                            |
| 5   | 1.8                                    | 49                               | 7.932                          | 7.00                            |
| 6   | 2                                      | 50                               | 9                              | 7.94                            |
| 7   | 2.1                                    | 51                               | 10.084                         | 8.89                            |
| 8   | 2.2                                    | 52                               | 11.388                         | 10.04                           |
| 9   | 2.3                                    | 53                               | 12.912                         | 11.39                           |
| 10  | 2.4                                    | 54                               | 14.656                         | 12.93                           |
| 11  | 2.5                                    | 55                               | 16.62                          | 14.66                           |
Below in Figures 1 ... 4, we present graphical dependences of the influence of the calculated and experimental values of the reactive power of grinding, separation and vibration effects on the weight of the sample, the concentration of raw materials, amplitude and frequency of oscillations.

**Figure 1.** Dependence of the calculated and experimental values of the reactive power of grinding on the mass of the sample

**Figure 2.** Dependence of the calculated and experimental values of the separation reactive power on the weight of the sample

**Figure 3.** Dependence of the calculated and experimental values of reactive power of vibration effects on the amplitude of oscillations
After processing the results of experimental studies, mathematical models were obtained in the form of quadratic polynomials, describing the influence of design and technological parameters on the reactive power of operational influences and the energy efficiency of the methods in general.

The influence of the sample mass on the experimental values of the reactive grinding power can be described by a quadratic polynomial with the coefficients of determination $r^2 = 0.994$:

$$Q_u = 410.66 \cdot m^2 + 593.14 \cdot m + 39.97.$$  \hfill (7)

The influence of the concentration of raw materials on the experimental values of the reactive power of separation can be described by a quadratic polynomial with the coefficients of determination $r^2 = 0.986$:

$$Q_c = 0.00007 \cdot v_c^2 - 0.00023 \cdot v_c + 14.28706.$$  \hfill (8)

The influence of the vibration amplitude of the vibrator on the experimental values of the reactive power of the vibration action can be described by a quadratic polynomial with the coefficients of determination $r^2 = 0.989$:

$$Q_a = 6.358 \cdot A^2 - 16.816 \cdot A + 16.544.$$  \hfill (9)

The influence of the vibration frequency of the vibrator on the experimental values of the reactive power of the vibration effect can be described by a quadratic polynomial with the coefficients of determination $r^2 = 0.995$:

$$Q_v = 0.095 \cdot v^2 - 8.6531 \cdot v + 204.13.$$  \hfill (10)

As the analysis of the results of experimental studies and mathematical models (7-10) has shown, there is a discrepancy between the experimental and calculated values of reactive power, which can be explained by the influence of the technological properties of the processed material on the optimality of the selected parameters and modes of working bodies. Accordingly, it can be concluded that the optimality of the selected operating modes of devices and the technological properties of materials largely determine the energy efficiency of operating actions and methods in general.

4. Conclusion
On the basis of the conducted experimental study, it was found that the most complete assessment of the energy efficiency of separating methods for wax raw materials can be done using a set of parameters in the form of active and reactive components of power.

Mathematical models were obtained in the form of quadratic polynomials (7-10) characterizing the influence of design parameters on energy characteristics.
The influence of the design parameters of the device and the technological properties of the exposed materials, in the form of wax raw materials, on the values of active and reactive power has been proved.

It has been established that the most rational measure for increasing the energy characteristics of devices for separating wax raw materials is to optimize their design and technological parameters.

The direction of further research is to determine the influence of other design and technological factors of devices for separating wax raw materials on their energy characteristics.

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