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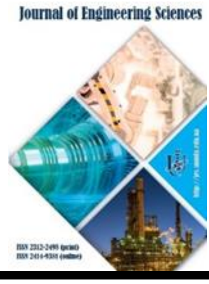

Efficiency Investigation of Coffee Production Waste Drying by Filtration Method

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Abstract. This article presents the results of determining the technologically feasible parameters of filtration drying of coffee production waste based on experimental data on the kinetics of material drying and the hydrodynamics of thermal agent filtration. The lowest total energy costs were observed with the following process parameters: the material layer height of 120 mm, the thermal agent temperature of 90 °C, the velocity through the stationary layer of 1.76 m/s, and the specific energy consumption of 5857 kJ per 1 kg of water. Based on the determined technologically feasible process parameters, an evaluation of the filtration drying method for coffee production waste was performed at an industrial installation. According to the calculation, using the filtration method, 1164 kW h of energy was required to dry about 1000 kg of coffee production waste. A total energy of about 1.65 kW h/kg was required to remove 1 kg of moisture from the material in an industrial filtration drying installation. The results were compared with a drying material with similar initial parameters. It was calculated that to dry 1000 kg of coffee production waste in a rotary dryer, it is necessary to spend about 1625 kW h, and the total energy consumption for removing 1 kg moisture from the studied material is approximately 2.37 kW h/kg. Thus, for a similar output of about 1000 kg/h, filtration drying can reduce energy consumption by about 465 kW·h and reduce the required drying time by more than 20 times. The overall economic effect of using the filtration drying method in industry is expected to be higher, given the significant heat losses to the environment for a rotary dryer due to its large size, long drying time, design features, and the need for energy-intensive auxiliary equipment. After calculating the energy consumption per 1 kg of dry material, it is necessary to spend 12 950 kJ/kg of dry matter, about 41.5 % less than the higher calorific value for experimental samples of briquetted solid fuel made from this material. This result makes it economically feasible to further dry coffee production waste to produce alternative solid fuels.

Keywords: biomass, energy efficiency, technologically feasible parameters, fuel briquettes.

1 Introduction

Recently, the issues of environmental sustainability and the natural resources conservation have become increasingly urgent. The steady population growth, increased consumption, and intensive industrial development significantly increase the waste generated.

Under these conditions, secondary use of raw materials becomes especially important, as it reduces the amount of organic waste of plant origin and uses the planet’s resources more efficiently. In various industries, there is an urgent need to implement environmentally friendly waste disposal and reuse methods. One of the industries where the problem of waste disposal is highly relevant is coffee production [1].

The coffee industry generates vast volumes of plant waste [2], which takes up much space in landfills and harms the environment due to greenhouse gas emissions during decomposition [3, 4].

2 Literature Review

Coffee production waste contains valuable substances that can be used in various industries, such as cosmetics [5, 6], land fertilization [7], biodiesel [8, 9], and bioethanol [10] production, as well as the production of alternative solid fuels [11].

Considering the significant initial moisture content of this secondary food raw material, which is about 65 % wt. [11], it is essential to study methods of drying coffee production waste to increase its shelf life, find technologically feasible process parameters, and determine the efficiency and economic feasibility of the selected drying method.

Rotary dryers are commonly used in industry to dry these materials [12, 13], but they have many disadvantages, which complicate their use and make the drying process energy-intensive. These disadvantages include significant overall dimensions and metal consumption, drying time, and, as a result, high heat losses to the environment. In addition, rotary dryers cannot operate autonomously and require energy-intensive additional equipment, such as powerful motors to rotate the drum and a cyclone to clean the outgoing stream.

Due to this, a highly efficient filtration drying method was used to dry coffee production waste, which has proven to be energy efficient for drying secondary materials of plant origin from the food industry [14]. The principle of the filtration drying method is to supply a thermal agent under the influence of a pressure drop through the porous structure of the gas-permeable material to be dried, respectively. The process of heat and mass transfer occurs on the intra-capillary surface, which exceeds the dimensions of the geometric surface of the material. Mechanical displacement and moisture removal may be present depending on the nature of the moisture connection with the material.

Overall, this study aims to investigate the effectiveness of using the filtration method of drying coffee production waste, which is a mixture of coffee, barley, and chicory waste obtained on the production line of JSC "Galca LTD" (Lviv, Ukraine) [11].

For calculating the industrial efficiency of filtration drying of coffee production waste, a filtration drying unit is used (Figure 1). Its operating principle is that the material is dried by moving on a conveyor belt under the influence of a flow of a thermal agent passing through its layer [15].

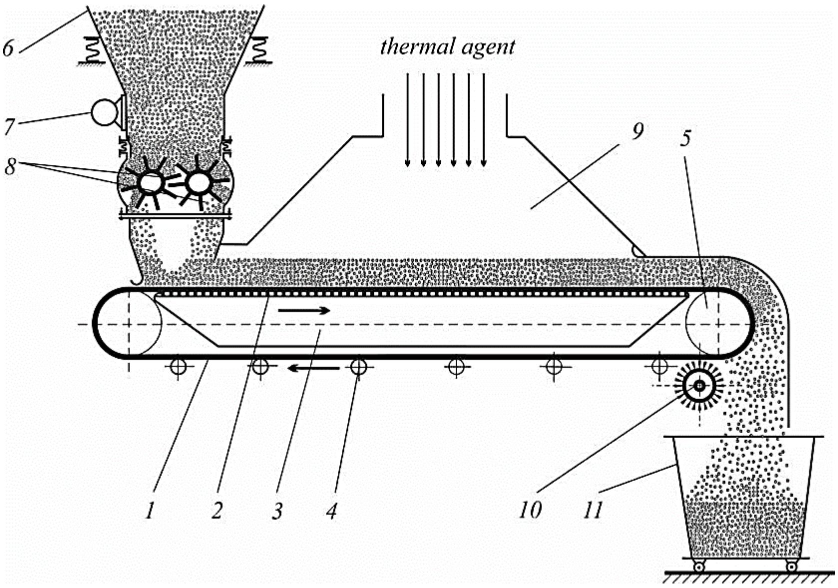

Figure 1 – Filtration drying installation for dispersed materials: 1 – belt conveyor, 2 – the perforated surface of the dilution chamber; 3 – vacuum chamber; 4 – rollers for supporting the belt conveyor; 5 – drive drum; 6 – hopper for wet material; 7 – vibrator; 8 – feeder; 9 – drying chamber; 10 – brush for cleaning the belt conveyor; 11 – hopper for dry material [15]

The unit of filtration drying of dispersed materials consists of a loading hopper 6 with a vibrator 7 and a feeder 8, which is located above the perforated belt conveyor 1 for moving the wet dispersed material to the discharge hopper 11 under the drying chamber 9, where the thermal agent is supplied.

Above the discharge hopper 11 for the dried material, there is a brush for removing the residual dried material 10.

The plant contains vacuum chamber 3 installed under the upper part of the belt conveyor, which is connected to a fan [15].

3 Research Methodology

To determine the effectiveness of using the filtration drying method for drying food waste from industrial coffee production, it was necessary to preliminarily study the kinetic regularities of this process in an experimental installation (Figure 2).

The experimental setup consists of a fan 1 that supplies the thermal agent (air) to an electric heater 2, heated to the desired temperature. After passing through diffuser 3, the air enters container 5 with a layer of the investigated material.

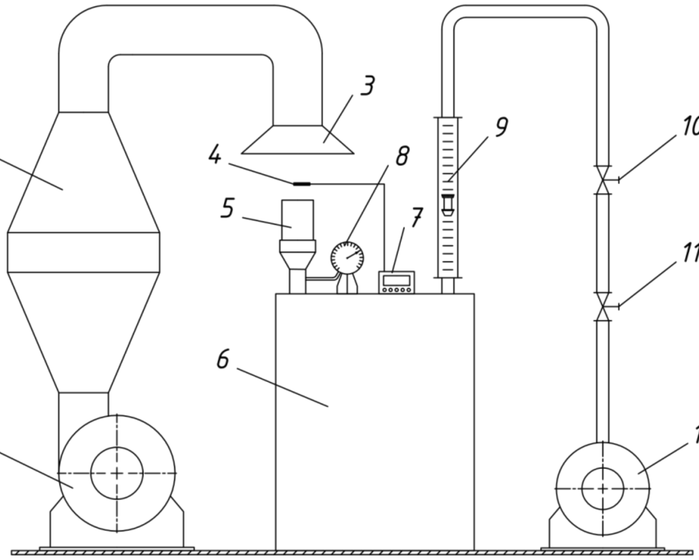

Figure 2 – The experimental installation for the dispersed materials filtration drying: 1 – fan; 2 – electric heater; 3 – diffuser; 4 – thermocouple; 5 – container; 6 – receiver; 7 – control and measuring device SENTOS D1S; 8 – vacuum gauge; 9 – rotameter; 10 – control valve; 11 – shut-off valve; 12 – water-ring vacuum pump

A thermocouple 4 is placed above the container to determine the air temperature at the diffuser outlet. The thermocouple is connected to a "SENTOS D1 S" control and measuring device, which establishes and maintains a constant temperature of the thermal agent.

Vacuum gauge 8 is installed to measure the pressure loss in the material layer. Container 5 is connected to a receiver in which a vacuum is created by a water-ring vacuum pump 12.

A rotameter 9 is located in front of the water-ring vacuum pump to measure the flow rate of the thermal agent. To regulate the flow rate of the thermal agent, a control valve 10 and a shut-off valve 11 are installed.

As a result of the research, it was obtained calculation dependencies can be used to determine the drying rate and its duration in the first period (the period of complete saturation of the thermal agent with moisture) and in the second conditional period (the period of partial saturation of the thermal agent with moisture), respectively [14, 15]:

$$w_I^c = w_0^c(1 - 9.37 \cdot 10^{-6} \cdot \tau T^{1.368} v_0^{0.604} e^{-11.641H}); \quad (1)$$

$$w_{II}^c = (w_{cr}^c - w_e^c) e^{-1.281N(\tau - \tau_{cr})} + w_e^c; \quad (2)$$

$$\tau_I = \frac{1 - \frac{w^c}{w_0^c}}{9.37 \cdot 10^{-6} \cdot T^{1.368} v_0^{0.604} e^{-11.641H}}; \quad (3)$$

$$\tau_{II} = \frac{1.281(w_0^c - w_{cr}^c) - ln\left(\frac{w^c - w_e^c}{w_{cr}^c - w_e^c}\right)}{1.281N}, \quad (4)$$

where w^c, w^c_0, w^c_e, and w^c_{cr} – the running, initial, and equilibrium moisture content of the material, as well as the critical moisture content of the material at the end of the period of complete saturation of the thermal agent with moisture, respectively, kg H_2O/kg dry material; τ – the drying time, s; τ_{cr} – the critical time to reach the moisture content value w_{cr}, s; T – the thermal agent temperature, °C; H – the material layer height, m; N – the drying rate during the period of complete saturation of the thermal agent with moisture, kg H_2O/(kg dry material)/s.

According to previous conclusions and recommendations [15], during the time calculation in the second conditional period of filtration drying, the refinement factors $K\tau_{II}$ = 0.7–0.9 were taken to consider the heat consumption for evaporation of bound moisture and heating of the wet material.

The initial parameters of the studied material were also determined according to the methodology [14], including the initial moisture content of coffee production waste, which was 65.2 % wt., and the bulk density was 380 kg/m^3.

When considering the energy consumption needed to overcome the layer resistance by the thermal agent, the results of hydrodynamic studies were taken into account, which were carried out according to the methodology described in [16]. A dependence was obtained to determine the hydraulic resistance of the stationary layer of coffee production waste depending on its height and the filtration rate of the thermal agent through a stationary layer of wet material:

$$\Delta P = 10^4 \cdot H v_0 (6.397 + 3.181 v_0). \quad (5)$$

The calculation of the technologically feasible parameters of filtration drying based on experimental data and the determination of specific energy consumption for moisture removal was carried out according to the methodology [15].

4 Results

The obtained experimental data on the filtration drying kinetics [14] were used to determine the required energy consumption for heating the thermal agent to remove 1 kg of moisture $Q^{lab}_{t.a}$. Simultaneously, based on the obtained hydrodynamic data, the energy consumption to overcome the hydraulic resistance of the stationary layer when removing 1 kg of moisture $Q^{lab}_{\Delta P}$ of coffee production waste was calculated. The total energy consumption Q^{lab} was defined as the sum of $Q^{lab}_{t.a.}$ and $Q^{lab}_{\Delta P}$.

The results of the calculations to determine the technologically feasible parameters of filtration drying of coffee production waste at the experimental installation are given in Tables 1, 2. The numbers of the experiments in Table 1 correspond to those in Table 2.

After analyzing the calculations presented in Tables 1, 2, it was observed that the lowest total energy costs were observed for experiment no. 7 with the following parameters of the filtration drying process of coffee production waste: the height of the studied material layer H = 120 mm, the thermal agent temperature T = 90 °C, and its filtration velocity through the stationary material layer v_0 = 1.76 m/s.

Thus, these parameters were chosen as the most rational, and the energy consumption was 5856 kJ/kg H_2O or 1.63 kW h/kg H_2O (Table 2).

Table 1 – Initial values for calculating the energy consumption of the filtration drying process of coffee production waste at the experimental installation

<table>
<tr><th>Exp. no.</th><th>H, m</th><th>T_1, °C</th><th>v_0, m/s</th><th>$\rho_{t.a.}$, kg/m^3</th><th>G_1, kg</th><th>W, kg</th><th>$G_{t.a.}$, kg/s</th><th>$V_{t.a.}$, m^3/s</th><th>ΔP, Pa</th><th>τ, s</th></tr>
<tr><td>1</td><td>0.04</td><td rowspan="4">70</td><td rowspan="7">1.76</td><td>1.03</td><td>0.11</td><td>0.08</td><td>0.01</td><td>0.01</td><td>8445</td><td>384</td></tr>
<tr><td>2</td><td>0.08</td><td>1.03</td><td>0.23</td><td>0.16</td><td>0.01</td><td>0.01</td><td>16890</td><td>678</td></tr>
<tr><td>3</td><td>0.12</td><td>1.03</td><td>0.34</td><td>0.23</td><td>0.01</td><td>0.01</td><td>25335</td><td>1039</td></tr>
<tr><td>4</td><td>0.16</td><td>1.03</td><td>0.46</td><td>0.31</td><td>0.01</td><td>0.01</td><td>33780</td><td>1581</td></tr>
<tr><td>5</td><td rowspan="6">0.12</td><td>60</td><td>1.06</td><td>0.34</td><td>0.23</td><td>0.01</td><td>0.01</td><td>25335</td><td>1419</td></tr>
<tr><td>6</td><td>80</td><td>1.00</td><td>0.34</td><td>0.23</td><td>0.01</td><td>0.01</td><td>25335</td><td>848</td></tr>
<tr><td>7</td><td>90</td><td>0.97</td><td>0.34</td><td>0.23</td><td>0.01</td><td>0.01</td><td>25335</td><td>627</td></tr>
<tr><td>8</td><td rowspan="3">70</td><td>1.24</td><td>1.03</td><td>0.34</td><td>0.23</td><td>0.01</td><td>0.01</td><td>15388</td><td>1365</td></tr>
<tr><td>9</td><td>2.29</td><td>1.03</td><td>0.34</td><td>0.23</td><td>0.02</td><td>0.02</td><td>37597</td><td>853</td></tr>
<tr><td>10</td><td>2.82</td><td>1.03</td><td>0.34</td><td>0.23</td><td>0.02</td><td>0.02</td><td>52004</td><td>790</td></tr>
</table>

Table 2 – Specific energy consumption of the filtration drying process of coffee production waste at the experimental installation

Exp. no.	$Q^{lab}_{t.a.}$, kJ/kg H_2O	$N^{lab}_{t.a}$, kW h/kg H_2O	$Q^{lab}_{\Delta P}$, kJ/kg H_2O	$N^{lab}_{\Delta P}$, kW h/kg H_2O	Q^{lab}, kJ/kg H_2O	N^{lab}, kW h/kg H_2O
1	5642.5	1.57	1100.4	0.31	6742.9	1.87
2	4980.1	1.38	1942.4	0.54	6922.5	1.92
3	5082.1	1.41	2973.3	0.83	8055.3	2.24
4	5803.8	1.61	4527.4	1.26	10331.2	2.87
5	5724.1	1.59	4063.7	1.13	9787.8	2.72
6	4836.5	1.34	2426.4	0.67	7262.9	2.02
7	4060.3	1.13	1796.3	0.50	5856.6	1.63
8	4704.9	1.31	1671.9	0.46	6376.7	1.77
9	5433.6	1.51	4717.5	1.31	10151.1	2.82
10	6193.3	1.72	7437.5	2.07	13630.8	3.79

The industrial installation (Figure 2) for filtration drying of dispersed secondary plant material of organic origin proposed in [15] was calculated based on the selected optimal technologically feasible process parameters. Thus, to calculate the efficiency of using filtration drying of coffee production waste on an industrial scale, the initial parameters presented in Table 3 were used. The parameters of the thermal agent in the process under consideration were determined using the I-D diagram of the state of humid air [17].

The calculation of the filtration drying efficiency at an industrial plant was conducted according to the proposed methodology in [15]. The obtained calculated values are presented in Table 4.

After analyzing Table 4, there is a slight discrepancy between the values of the calculated mass flow rate of the thermal agent $G_{t.a.}$ according to the experimental data and theoretical calculations based on the data of the material $G^{/}_{t.a.}$ and the heat balance $G^{//}_{t.a}$.

Table 3 – Input parameters for the filtration drying efficiency

Indicator	Value
Productivity by source material G_1, kg h	1000
The initial moisture content of the material ω_1, %	73
The final moisture content of the material ω_2, %.	14
Bulk density of the material ρ_b, kg/m^3	380
Ambient temperature T_0, °C	20
The initial humidity of the thermal agent ϕ_0, %.	60
The inlet temperature of the thermal agent T_1, °C	90
The outlet temperature of the thermal agent T_2, °C	35
Inlet material temperature t_1, °C	20
Outlet material temperature t_2, °C	33
Velocity of the thermal agent v_0, m/s	1.76
Height of the material layer H, m	0.12

Table 4 – Calculation results of the filtration drying process

Indicator	Value
Productivity by source material G_1, kg h	1000
The initial moisture content of the material $w^c{}_0$, kg H_2O/kg dry material	2.7
The final moisture content of the material w^c, kg H_2O/kg dry material	0.16
Total drying time τ, s	0.18
Belt conveyor width B, m	0.5
Belt conveyor length L, m	8
Material volume on the conveyor V_{mat}, m^3	0.48
Material weight on the conveyor G_{mat}, kg	182.4
Conveyor speed v_{conv}, m/s	0.0125
Revised capacity for source material $G^{/}{}_1$, kg h	1030.6
Volumetric flow rate of the thermal agent $Q_{t.a.}$, m^3/s	25 344
The mass flow rate of the thermal agent $G_{t.a.}$, kg h	24 659.7
Weight of dry material G_d, kg h	278.3
Outlet material weight G_2, kg h	323.6
Moisture amount W, kg h	707.0
Inlet moisture content of the thermal agent d_1, kg H_2O/kg dry air	0.0087
Outlet moisture content of the thermal agent d_2, kg H_2O/kg dry air	0.03
The mass flow rate of the thermal agent $G^{/}{}_{t.a.}$, kg h	33 193.8
Heat for moisture evaporation from the material Q_{ev}, kJ h	$1.626 \cdot 10^6$
Heat for vaporization Q_v, kJ h	2658.4
Heat for heating moisture in material Q_{water}, kJ h	38 511.9
Heat for heating wet material Q_{mat}, kJ h	6977.9
Amount of heat for heating residual moisture in the material Q_{res}, kJ h	2467.4
Total heat consumption Q, kJ h	$1.844 \cdot 10^6$
The mass flow rate of the heat transfer agent $G^{//}{}_{t.a.}$, kg h	33203.6
Energy to heat the required amount of thermal agent $N_{t.a.}$, kW h	807.15
Energy costs for the removal of 1 kg of moisture in terms of the required amount of thermal agent $l_{t.a.}$, kW h/kg H_2O	1.41
Required fan power N_{fan}, kW h	356.7
Total amount of energy required for the filtration drying process N, kW h	1163.9
Total energy consumption for removing 1 kg of moisture for the filtration drying process l, kW h/kg H_2O	1.65

The absolute deviation is 25.7 % and 25.7 %, respectively. This difference can be explained by the intensive removal of moisture from the test material during filtration drying, which leads to an increase in the saturation of the thermal agent with moisture at the outlet of the stationary layer and, consequently, a decrease in its final temperature.

According to the calculation, using the filtration method, 1164 kW h of energy is required to dry about 1000 kg of coffee waste. Simultaneously, most of the required energy consumption, 807.2 kW h, is spent on heating the thermal agent to the required initial temperature. In addition, 356.7 kW h is required to overcome the hydraulic resistance of the stationary layer of coffee production waste with the drying agent. Thus, the total energy consumption required to remove 1 kg of moisture from the material in an industrial filtration drying installation is about 1.65 kW h/kg H_2O.

To evaluate the efficiency of industrial filtration drying of coffee production waste, a rotary dryer [18, 19] was additionally calculated for similar initial parameters of the studied material presented in Table 5. Considering the peculiarity of the plant material under study, the efficiency of the rotary dryer was calculated at a thermal agent temperature of t_1 = 140 °C [20].

Table 5 – Output parameters of the drying process of coffee production waste in a rotary dryer

Indicator	Value
Productivity by source material G_1, kg h	1000
The initial moisture content of the material ω_1, %	73
The final moisture content of the material ω_2, %.	14
Bulk density of the material ρ_b, kg/m^3	380
Ambient temperature T_0, °C	20
The initial humidity of the thermal agent ϕ_0, %.	60
The inlet temperature of the thermal agent T_1, °C	140
The outlet temperature of the thermal agent T_2, °C	75
Inlet material temperature t_1, °C	20
Outlet material temperature t_2, °C	73
Velocity of the thermal agent v_0, m/s	3
Coefficient of filling the drum with wet material β	0.2
Saturation of the working volume of the drum with moisture A_V, kg/m^3·h	15

The calculation of the rotary dryer was carried out according to the methodology [15]. The fan's power was additionally considered to ensure the thermal agent's movement. The hydraulic resistance of this dryer was taken according to the recommendations [12], considering a small margin to consider possible changes in the pressure drop that may occur depending on the nozzle type.

Table 6 shows the efficiency of the rotary dryer. The error between the values of the mass flow rate of the thermal agent calculated based on experimental data and the verification calculation is 0.18 %, which confirms its correctness.

Thus, to dry 1000 kg of coffee production waste in a rotary dryer, consuming approximately 1629 kW h is necessary. Simultaneously, the primary energy consumption, 1615 kW h, is used to heat the heat transfer agent to an initial temperature of t_1 = 140 °C. The total energy consumption for removing 1 kg of moisture from the test material approximately equals to 2.37 kW h/kg H_2O.

Table 6 – Results of efficiency calculation of rotary dryer for coffee production waste drying

Indicator	Value
Productivity by source material G_1, kg h	1000
The initial moisture content of the material $w^c{}_0$, kg H_2O/kg dry material	2.7
The final moisture content of the material w^c, kg H_2O/kg dry material	0.16
Total drying time τ, s	4.24
Weight of dry material G_d, kg h	270
Outlet material weight G_2, kg h	313.95
Moisture amount W, kg h	686.05
Rotary drum volume $V^{r.d.}$, m^3	45.74
Rotary drum length $L^{r.d.}$, m	14
Rotary drum diameter $D^{r.d.}$, m	2.2
Real volume of drying space $V_2{}^{r.d.}$, m^3	53.2
Material weight in the dryer $G^{r.d.}$, kg	4043.1
Inlet moisture content of the thermal agent d_1, kg H_2O/kg dry air	0.0087
Outlet moisture content of the thermal agent d_2, kg H_2O/kg dry air	0.0325
The mass flow rate of the heat transfer agent $G^{r.d.}{}_{t.a.}$, kg h	28 825.5
Amount of heat for moisture evaporation from the material Q_{ev}, kJ h	$1.578 \cdot 10^6$
Amount of heat for vaporization Q_v, kJ h	45 862.2
Amount of heat for heating moisture in material Q_{water}, kJ h	57 490.7
Amount of heat for heating wet material Q_{mat}, kJ h	27 604.0
Amount of heat for heating residual moisture in the material Q_{res}, kJ h	8394.3
Total heat consumption Q, kJ h	$1.889 \cdot 10^6$
The mass flow rate of the heat transfer agent $G^{/}{}_{t.a.}{}^{r.d.}$, kg h	28 773.6
Hydraulic resistance of the drum ΔP, Pa	1000
Energy to heat the required amount of thermal agent $N_{t.a.}$, kW h	1614.5
Energy costs for the removal of 1 kg of moisture in terms of the required amount of thermal agent $l_{t.a.}$, kW h/kg H_2O	2.35
Required fan power N_{fan}, kW h	14.74
The total amount of energy required for the drying process N, kW h	1629.3
Total energy consumption for removing 1 kg of moisture for the drying process l, kW h/kg H_2O	2.37

Therefore, the evaluation of the use of filtration drying of coffee production waste in an industrial installation showed its prospects for over-drying in a rotary dryer (Table 7).

It is worth noting that the above calculation of the coffee production waste drying process is an estimate and does not include calculations of the energy consumption of auxiliary equipment.

However, according to the results obtained, for a similar productivity of about 1000 kg/h of initial material, filtration drying can reduce energy consumption by about 465 kW h and reduce the required drying time by more than 20 times.

Table 7 – Comparison of the main results of the industrial process calculation of drying coffee production waste by the filtration method and in a rotary dryer for the productivity of about 1000 kg of initial material

Indicator	Filtration drying	Rotary dryer
Productivity by source material G_1, kg h	1031	1000
The total drying time τ, s	0.18	4.24
The total amount of energy required for the drying process N, kW h	1163.9	1629.3
Total energy consumption for removing 1 kg of moisture for the drying process l, kW h/kg H_2O	1.65	2.37

5 Discussion

It is also worth noting that the overall economic effect will be higher due to significant heat losses to the environment for a rotary dryer due to its large size, long drying time, and the need for energy-intensive auxiliary equipment to separate the waste thermal agent from the fine fraction.

The filtration drying method also allows secondary heat in enterprises, while the rotary dryer requires heating the thermal agent by burning gaseous or solid fuels. The use of secondary heat as a thermal agent contributes to the rational use of resources and significantly reduces operating costs, which provides a significant economic effect.

Thus, spending 1164 kW h of energy (Table 7) while drying about 1000 kg of the initial material, it is possible to obtain 323.6 kg (Table 4) of dried coffee production waste. Regarding 1 kg of dry material, spending 12 950 kJ per 1 kg of dry material is necessary (Figure 3).

It is known that the higher calorific value of experimental samples of briquetted solid fuel made from this material is approximately 22 147 kJ/kg [11], which exceeds the required energy for drying an equivalent amount of material by about 41.5 %.

Simultaneously, to obtain 1 kg of dried material using a rotary dryer, it is necessary to consume approximately 18 682 kJ/kg of dry matter, which is about 84.4 % of the calorific value of the obtained experimental briquette samples.

Thus, the drying of coffee production waste for further production of alternative solid fuels is economically feasible.

In addition, it is worth noting that the economic effect of such use should be clarified by additional calculations, considering the cost of raw materials, energy costs for solid fuel formation, and logistics costs.

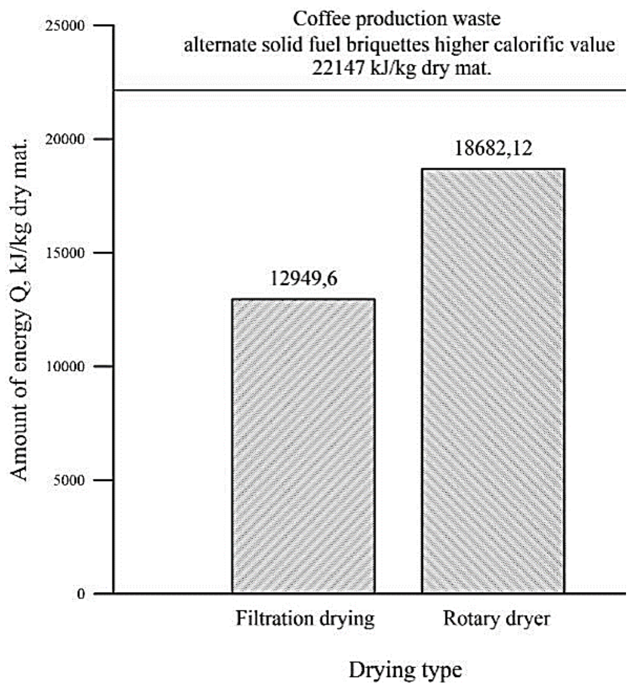

Figure 3 – Comparison of the required amount of energy per 1 kg of dried coffee production waste for different drying methods and the higher calorific value of the briquetted solid fuel samples

6 Conclusions

In this paper, the technologically feasible parameters of drying the coffee production waste were determined based on the experimental data of kinetics regularities of material drying and the data on the dependence of the layer's hydraulic resistance on the thermal agent's filtration rate.

The lowest total energy consumption is observed for experiment no. 7 with the following parameters of the filtration drying process of coffee production waste: the material layer height of 120 mm, the thermal agent temperature of 90 °C, and its velocity of 1.76 m/s.

Thus, these parameters were chosen as the most rational, and the energy consumption is 5856.6 kJ/kg H_2O or 1.63 kW h/kg H_2O.

Based on the determined technologically feasible process parameters, an estimate of using the filtration drying method for coffee production waste at an industrial installation was made. According to the calculation, 1163.9 kW h of energy is required to dry about 1000 kg of coffee production waste using the filtration method, and the total energy required to remove 1 kg of moisture from the material at an industrial filtration drying installation is approximately 1.65 kW h/kg H_2O.

Additionally, the obtained results were compared with the results of drying the material with similar initial parameters in a rotary dryer widely used for drying dispersed materials. Thus, to dry 1000 kg of coffee production waste in a rotary drum dryer, it is necessary to spend approximately 1629.3 kW h, and the total energy costs for removing 1 kg of moisture from the studied material are approximately 2.37 kW h/kg H_2O.

Thus, for a similar productivity of approximately 1000 kg/h of initial material, filtration drying can reduce energy consumption by about 465 kW h and the required drying time by more than 20 times.

Regarding 1 kg of dry material, 12 949.6 kJ/kg of dry material should be consumed. It is known that the higher calorific value of experimental samples of briquetted solid fuel made from this material is approximately 22 147 kJ/kg, which exceeds the required energy for drying an equivalent amount of material by 41.53%. Therefore, drying coffee production waste for further production of alternative solid fuels is economically feasible.

The overall economic effect of using the filtration drying method in the industry will be even higher due to the significant heat losses to the environment for a drum dryer due to its large size, long drying time, and the need for energy-intensive auxiliary equipment.

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