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Screw electromechanical hydrolyser for processing poultry by-products

Abstract. The use of keratin-containing products in various industries, including agriculture, cosmetics, and biomedicine requires solving the urgent problem of improving the methods and means of hydrothermal hydrolysis of keratin waste. The purpose of this study is to examine the screw electromechanical hydrolyser to provide modes of efficient conversion of keratin waste into a useful product with added value. The study is based on the basic principles of electrodynamics, heat and mass transfer, mathematical modelling by the finite element method, and experimental verification of the multiphysical parameters of the electromechanical hydrolyser. The experimental model of the electromechanical hydrolyser was used to determine the optimal conditions for hydrothermal hydrolysis of keratin waste in terms of thermal conditions, raw material transportation, pressure, and magnetic field effects. After undergoing the processing, a bulk of brown feather flour was obtained, which had been hydrolysed and possessed a distinct odour. According to the size of the electromagnetic system of the experimental sample, a mathematical model for observing thermal and electromagnetic processes was built. The patterns of magnetic induction distribution were determined for the cross-section, axial distribution on the screw surface, and the upper faces of the screw winding in an electromechanical hydrolyser. Three-dimensional images of the heating of the screw and the screw electromechanical hydrolyser itself were obtained. By comparing the results of mathematical modelling and empirical studies, the adequacy of the mathematical model was confirmed. The findings of the study can be applied in the field of animal husbandry in the production of feed additives of increased digestibility for feeding agricultural animals and poultry

Keywords: keratin material; feather flour; finite element method; Maxwell's equation; energy saving

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INTRODUCTION

The activities of various industries generate billions of tonnes of keratin waste (Bhari *et al.*, 2021). The accumulation or destruction of this waste leads to an aggravation of the environmental problem. Keratin is a structural protein found in hair, feathers, nails, hooves, and wool. This type of material has a high potential for use in the medical, pharmaceutical, cosmetic, and biotechnology industries (Luo *et al.*, 2016; Arshad *et al.*, 2016). The products of these industries are innovative but, currently, feather flour has a narrow range of practical applications (Nurdiawati *et al.*, 2018), which is mainly due to the complexity of feather processing. Chicken feathers consist of 92% keratin, which makes them a valuable source of minerals, amino acids, and peptides (Bhari *et al.*, 2021). B. Wang *et al.* (2016) noted that keratin is remarkable for its ability to withstand a range of physical and chemical stresses. The processing method used greatly impacts the worth of keratin material. The polypeptide chains' amino acid residue count and their arrangement determine the material's chemical and physical characteristics. Intramolecular and intermolecular disulfide bonds, hydrogen bonds, and crystal structure jointly determine the structural stability of the keratin material (Saha *et al.*, 2019). These properties distinguish keratins from other fibrous proteins, such as myofibrillar and collagen proteins (Saha *et al.*, 2019). The disintegration of disulfide covalent bonds and hydrogen bonds within the material's structure is necessary for the successful extraction of keratin. The main methods of extracting keratin from down and feather waste are hydrothermal, acid, alkaline, and enzymatic hydrolysis.

Through deep acid hydrolysis of feather keratin, all molecular bonds are disrupted, and the resulting mixture contains free amino acids. This process is particularly destructive to tryptophan and partially affects serine and threonine. According to Y. Ji *et al.* (2014), asparagine and glutamine are transformed into aspartic and glutamic acid, and free ammonia creates an ammonium salt. The breakdown of methionine into cysteine and cystine occurs during deep alkaline hydrolysis, which also causes partial racemisation of amino acids and the creation of cyclopeptides. Additionally, alkaline hydrolysis produces ammonia and aldehydes that interact with amino groups. Sinkiewicz *et al.* (2017) documented these phenomena. The study by A.K. Nadda & S. Sharma (2019) showed that severe chemical processing conditions result in the depletion of crucial amino acids, racemisation of amino acids within protein hydrolysates, the creation of cyclopeptides, and a decrease in the biological value of the end product. Therefore, discovering sustainable and ecologically sound methods for recycling keratin waste is vital.

R. Bhari *et al.* (2021) found out that conventional methods of feather hydrolysis require high energy consumption and reduce the amino acid content and amount of pure protein. One of the most effective methods of processing down and feather waste on an industrial scale is the hydrothermal hydrolysis method. Hydrothermal hydrolysis is a method of processing keratin waste that involves the use of water under high pressure and at high temperatures to destroy the protein structure. As a result of this process, hydrolysates are formed – mixtures of amino acids, peptides, and other organic compounds. Increasingly, the hydrothermal hydrolysis of poultry by-products is performed in screw conversion devices. In the studies (Singha & Muthukumarappan, 2016; Mazlan *et al.*, 2019; Feng, 2019), the use of a screw converter is prefered because of its versatility in processing various kinds of materials, regardless of the pace of the technological process.

The purpose of this study was to examine a screw electromechanical hydrolyser for the efficient conversion of keratin waste into a useful product – protein flour using the hydrothermal hydrolysis method. To achieve this purpose, the following objectives were set: to investigate the optimal conditions for the hydrothermal hydrolysis of keratinous waste – chicken feathers, namely, the multiphysical parameters of the reaction; to analyse the properties of the resulting hydrolysate.

LITERATURE REVIEW

Numerous publications exist that focus on electromechanical converters utilising screwing mechanisms. Studies conducted by P. Singha & K. Muthukumarappan (2016), F. Campuzano *et al.* (2019), and P. Brassard *et al.* (2017) examined the torque of screw-based electromechanical converters. The studies mentioned highlighting the crucial role of torque in determining operating expenses. Therefore, optimizing time-varying hydrolysis procedures, such as screw speed and processing medium temperature, is vital for efficient industrial processing and controlled energy consumption. The impact of hydrolysis parameters on mixing torque was examined using single- and twin-screw electromechanical converters in the works of M. Mazlan *et al.* (2019), P. Singha & K. Muthukumarappan (2016), and C. Feng *et al.* (2019). The parameters studied include the temperature of the processing medium, screw rotation speed, and moisture content of the raw material. Surface response regression models were developed in this study to establish a correlation between system parameters and time-varying parameters. The results indicated that an increase in the processing temperature beyond the recommended levels resulted in a reduction in the viscosity of the raw material, pressure within the processing medium, and specific mechanical energy. Furthermore, M. Mushtruk *et al.* (2020) investigated the issue of high energy costs associated with processing in an electromechanical screw converter. In this study, mathematical modelling was performed and the power and energy parameters of the technical system were determined. X. Shi *et al.* (2019), S. Jalalifar *et al.* (2020), G. Fülöp *et al.* (2021) described vibrations occurring in screw electromechanical converters. These publications analysed the oscillation process of an electromechanical screw transducer with the materials placed within it, constructed an equivalent device circuit, determined the differential equations of system oscillation, and obtained their analytical solution using numerical methods.

Among the existing publications, there are many papers devoted to thermal processes occurring in screw converter devices. F. Campuzano *et al.* (2019) investigated the effects of heat transfer on the processing material. It was established that the heat transfer effect in a twin-screw converter is better than in a single-screw converter. Insufficient attention has been paid to the influence of the screw blade geometry on the output and quality of raw material processing. F. Qi & M.M. Wright (2020) performed mathematical modelling of the processes of hydrodynamics, heat transfer, and chemical reactions of particles in a twin-screw converter. The publication used the method of discrete elements to build a mathematical model. It was found that biomass processing in a twin-screw mechanism is considerably affected by the heat of the reaction parameters in the kinetic model. The disadvantages of the proposed model include the complexity of its use, which is associated with the need for careful calibration of the heat of reaction parameters to improve the kinetic model. A. Funke *et al.* (2018) observed the inefficiency of the screw converter in the initial mixing area, which leads to uneven heat transfer under suboptimal conditions. A mathematical model was constructed to eliminate these inefficiencies and, accordingly, increase the initial average heat transfer coefficient compared to the original design of the screw converter. E. Aliiev *et al.* (2022) explored the influence of design and technological parameters of the equipment on the productivity and technical and economic efficiency of the feed preparation line. The publication presented analytical calculation methods that accounted for the geometry of the ripper auger, incorporated mechanisms of solid movement and destruction, utilised the discrete element method to describe the solid component movement, improved the physical and mathematical understanding of solid component movement in the screw channel, and developed a numerical modelling approach.

MATERIALS AND METHODS

The screw electromechanical hydrolyser is a simplified implementation of the twin-screw electromechanical hydrolyser presented by (Zablodskiy *et al.*, 2021a; Zablodsky *et al.*, 2021b). The screw electromechanical hydrolyser consists of a feedstock loading unit, a screw, a deaerator for air removal, an outer shell of the working medium, a heating and magnetic field effect unit, a feedstock unloading unit, a metal profile structure, an electric drive, and a vacuum pump. The outer shell of the working chamber is made of aluminum pipe.

In this hydrolyser, the loaded feather raw material passes through two impact zones. In the first working area of the screw, the feathers are preheated to 60°C and exposed to a magnetic field with a frequency of 1-50 Hz and an induction of 0.025 T. The raw material in the first working zone is compacted to form a raw material seal (plug) by reducing the auger cross-section shown in Figure 1. At a compaction pressure of 1-20 MPa, the raw material is fed into the second working zone, where it is loosened by a reduced diameter part of the screw turns, moved at a temperature of 180-260°C, exposed to a magnetic field with a frequency of 1-50 Hz with an induction of 0.065 T for 110 s, and vacuum is applied at the outlet of the second working zone every 10-60 s. For the installation of the vacuum pump, the HS-115 R-134 HongSen charging hose, HS-466NAH valve manifold, the universal hose for charging freon, and the Universal crane were used.

Figure 1. The screw of an electromechanical hydrolyser
Source: developed by the authors

The following measuring devices were used during the empirical studies: Analog spring universal dynamometer NK-300, designed to measure screw forces and torque, accuracy class 0.5%; Tenmars TM-191 Magnetic Field Meter, designed to measure ultra-low frequency electromagnetic fields from 30 Hz to 300 Hz; Tenmars TM-190 Multi Field EMF Meter, a compact device for measuring high-frequency electromagnetic fields in the frequency range from 50 MHz to 3.5 GHz and low-frequency electric and magnetic fields in the frequency range of 50-60 Hz; infrared, optical pyrometer BENETECH GM533A, measuring range – 50-530°C, visibility index 12:1, thermal radiation coefficient 0.1-1, spectrum 5-14 microns. The magnetic field is applied using two single-phase stators with starting capacitors of 720 W each – HCSE 0.5-40U (Fig. 2).

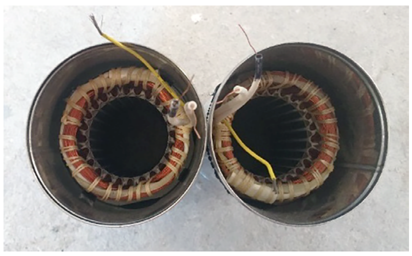

Figure 2. HCSE 0,5-40U, 720 W single-phase stators
Source: developed by the authors

The raw material is preheated to 60°C in the first working area using a self-regulating heating cable SRF 30-2CR with a power of 30 W/m and a length of 1 m. The main heating of the raw material to a temperature of 180-260°C is achieved using a heating device EHKм 52×200, 1.2 kW, 230 V – a micanite ring with a heating temperature of up to 350°C. The temperature control and regulation in the raw material compaction zones, ranging from 180 to 260°C, are accomplished using a TENSE DT-36E digital thermostat equipped with a J-type thermocouple.

The experimental sample of the screw electromechanical hydrolyser is shown in Figure 3. The examination of thermal properties was conducted indoors with an ambient temperature of 24°C. The temperature was measured with an infrared, optical pyrometer BENETECH GM533A at a distance of 0.5 m from the object of study. The heat sources were connected to the network in turn, and before the next measurement, a time delay was performed to cool the object of study to ambient temperature.

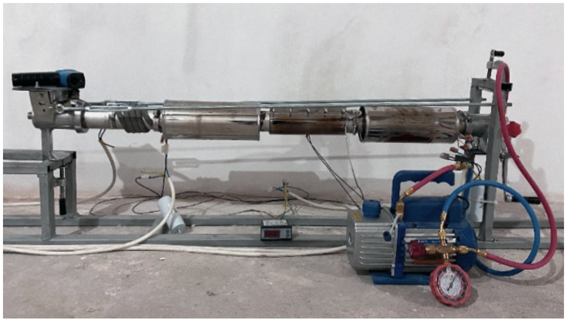

Figure 3. Screw electromechanical hydrolyser
Source: developed by the authors

To understand in detail the full picture of the temperature and magnetic fields in the screw electromechanical hydrolyser, a finite element simulation was performed in the Comsol Multiphysics software environment. The electromagnetic field is analysed based on Maxwell's system of equations. The vector potential was formulated according to the following equations (1)-(4) (Zablodsky *et al.*, 2021b):

$$\nabla \times H = J, \tag{1}$$

where H – is the magnetic field strength vector, A/m; J – is the current density vector, A/m^2.

$$B = \nabla \times A, \tag{2}$$

where B – is the magnetic field density vector, T; A – is the vector magnetic potential, Wb/m.

$$E = -\frac{\partial A}{\partial t}, \tag{3}$$

where E – is the electric field intensity vector, V/m.

$$J = \sigma E, \tag{4}$$

where σ – is the electrical conductivity, S/m.

The equation of the scalar potential is (Zablodsky *et al.*, 2021b):

$$\nabla \cdot B = 0. \tag{5}$$

Magnetic isolation as a separate type of magnetic potential boundary condition equates the tangential component of the magnetic potential to zero (Zablodsky *et al.*, 2021b):

$$n \cdot B = 0. \tag{6}$$

The B-H curve describes the magnetisation of the rotor and is determined from the equation (Zablodsky *et al.*, 2021b):

$$B = f(|H|)\frac{H}{|H|}. \tag{7}$$

Homogenised multi-turn coils are used as a boundary condition, a current source simulating a bundle of wires wound together and separated by insulation (Zablodsky *et al.*, 2021b):

$$J_e = \frac{NI_{coil}}{A} e_{coil}, \tag{8}$$

where N – is the number of turns in the winding; A – is the total cross-section, the area of the winding domain, m^2; I_{coil} – is the current, A; e_{coil} – is a vector variable for visualising the direction of turns in the winding.

The heating model of the screw electromechanical hydrolyser is developed by combining principles from magnetic field physics, solid heat transfer, and electromagnetic heating. The model is solved within the frequency-transition domain of the study. The heat transfer equation is formulated based on Fourier's law in differential form and incorporates an additional term for the heat source (Zablodskiy *et al.*, 2021a):

$$d_z \rho C_p \frac{\partial T}{\partial t} + d_z \rho C_p u \cdot \nabla T + \nabla \cdot q = d_z Q + q_0 + d_z Q_{ted}, \tag{9}$$

where d_z – is the thickness of the domain in the nonplanar direction, m; ρ – is the density, kg/m^3; C_p – is the specific heat capacity at constant pressure, J/(kg·K); T – is the temperature, K; t – is the time, s; u – is the velocity vector, m/s; q – is the heat flux, W/m^2; Q – is the heat source, W/m^3; q_0 – is the internal heat flux, W/m^2; Q_{ted} – is the thermoelastic damping, W/m^3.

$$q = -d_z k \nabla T, \tag{10}$$

where k – is the thermal conductivity, W/(m·K).

Thermal insulation is applied to the outer borders of the model (Zablodskiy *et al.*, 2021a):

$$-n \cdot q = 0, \tag{11}$$

where n – is the refractive index.

The heat flux from the surfaces is determined from the equation (Zablodskiy *et al.*, 2021a):

$$-n \cdot q = d_z q_0, \quad (12)$$

$$q_0 = h(T_{ext} - T), \quad (13)$$

where h – is the heat transfer coefficient, W/(m^2·K); T_{ext} – is the outdoor temperature, K.

The radiation from the model surface to the environment is determined from the equation (Zablodskiy *et al.*, 2021a):

$$--n \cdot q = d_z \varepsilon\sigma(T^4_{amb} - T^4), \quad (14)$$

where ε – is the surface emissivity; σ – is the Stefan-Boltzmann constant, W/(m^2·K^4); T_{amb} – is the ambient temperature, K.

Electromagnetic heating is determined from equations (Zablodskiy *et al.*, 2021a):

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u \cdot \nabla T = \nabla \cdot (k\nabla T) + Q_e, \quad (15)$$

where Q_e – is the electromagnetic heat source, W/m^3.

$$Q_e = Q_{rh} + Q_{ml}, \quad (16)$$

where Q_{rh} – is the resistive loss, W/m^2; Q_{ml} – is the magnetic loss, W/m^2.

$$Q_{rh} = \frac{1}{2} Re(J \cdot E^*), \quad (17)$$

$$Q_{ml} = \frac{1}{2} Re(i\omega B \cdot H^*), \quad (8)$$

where R_e – is the Reynolds number; E^* – is the vector of electric field intensity at a given frequency and time, V/m; H^* – is the vector of magnetic field intensity at a given frequency and time, A/m.

RESULTS AND DISCUSSION

The results of the study show that the temperature increase is linear. An electric micanite ring heater EHKм 52×200, 1.2 kW, 230 V, reached the process temperature in 2 minutes, after which the temperature was maintained at the set upper limit of 250°C using a TENSE DT-36E digital thermostat. The SRF 30-2CR heating cable reached a temperature of 85°C in 15 minutes. The HCSE 0,5-40U, 720 W stators reached a temperature of 90°C in 15 minutes.

Mathematical modelling of the processes within the screw electromechanical hydrolyser was conducted to facilitate comparisons with the results obtained from experimental studies. The finite element mesh was created as a physics-controlled mesh. The grid parameters are shown in Table 1. The modelling was performed under the assumption that the main components of the screw electrical hydrolyser, namely, the SRF 30-2CR heating cable, the EHKм 52×200 micanite ring, and the HCSE 0.5-40u single-phase stators, operate at the rated load without additional adjustment. The modeling results are presented in Figures 4-8.

Table 1. Finite element mesh parameters

Grid parameters	Value
Mesh vertices	523509
Tetrahedra	3007747
Prisms	36784
Hexahedra	3072
Triangles	453692
Quads	4288
Edge elements	47708
Vertex elements	1622
Number of elements	3047603
Minimum element quality	0.07147
Average element quality	0.6584
Element volume ratio	1.464E-6
Mesh volume	4.986E7 mm^3

Source: developed by the authors

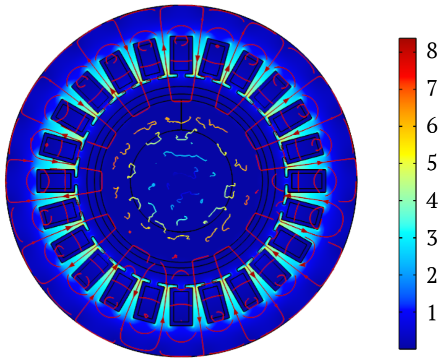

Figure 4. Spatial representation of the magnetic induction distribution for the cross-section of the screw electromagnetic hydrolyser geometry, t

Source: developed by the authors

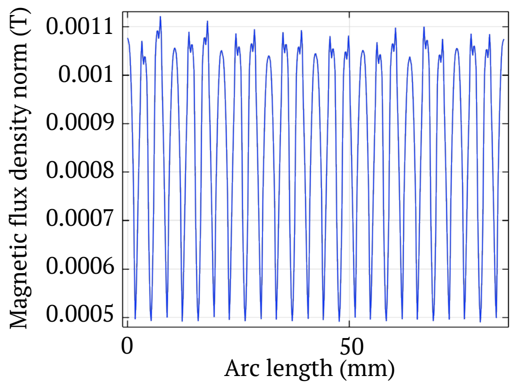

Figure 5. Graph of the distribution of magnetic induction on the surface of the screw of an electrochemical hydrolyser, t

Source: developed by the authors

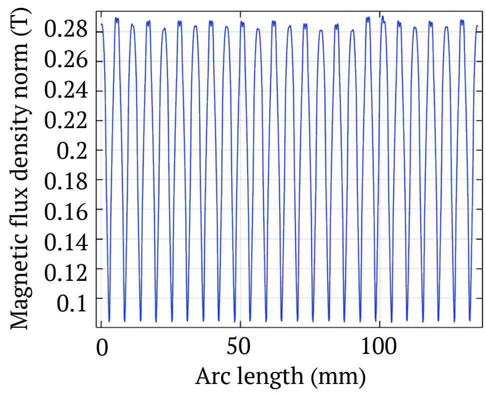

Figure 6. Graph of the distribution of magnetic induction along the upper face of the screw blades of the screw mechanical hydrolyser, t

Source: developed by the authors

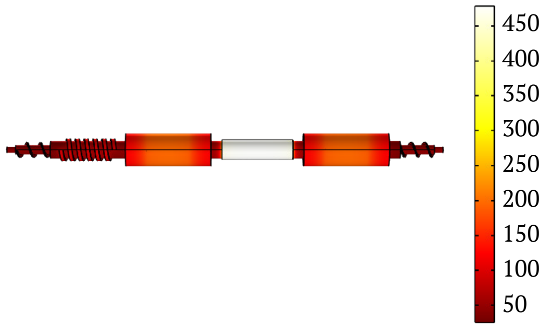

Figure 7. Three-dimensional image of heating of the screw electromechanical hydrolyser, side view, °C

Source: developed by the authors

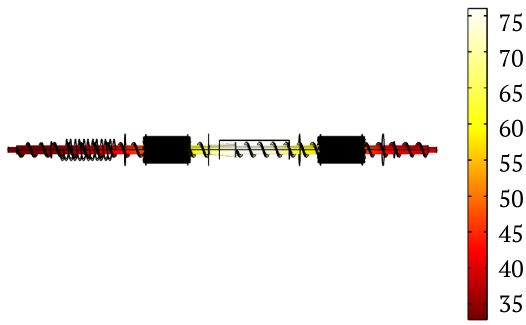

Figure 8. Three-dimensional image of the heating of the screw of an electromechanical hydrolyser, °C

Source: developed by the authors

Based on empirical studies and the results of mathematical modelling of the screw electromechanical hydrolyser, the processing of chicken feathers according to the method of hydrothermal hydrolysis was analysed. The working areas of the screw electromechanical hydrolyser were preheated for 20 minutes. For this purpose, the self-regulating heating cable SRF 30-2CR was connected directly to the 220 V network, and the single-phase stators of the HCSE 0,5-40U were connected to the 220 V network using CBB60-G 25 μF capacitors. The electric micanite ring heater EHKм 52×200 was connected to a 220 V network using a TENSE DT-36E digital thermostat. The maximum temperature value was set at 220°C, the temperature was controlled by a J-type thermocouple. Upon completion of the preheating of the working chambers, the shredded chicken feathers were fed in small, loosened portions, 163400 mm^3

(6.25 g), to the raw material loading unit until the first working area was filled. By investigating the movement of chicken feathers in the working area of a mock-up sample of an electromechanical screw hydrolyser using a borosilicate glass pipe as the outer shell of the working area, it was found that the feathers travel from the raw material loading unit to the sealing cylinder in 300 revolutions. The volume of the first working area was 158300 mm^3. The initial working zone is filled with feather raw materials through the compaction caused by the mechanical motion of the screw and the weight of the material, involving the loading of 12 small portions of fluffed feathers, totalling 75 g. The compacted feather raw material is transferred to the second working zone under a pressure of 1-20 MPa, where it is exposed to a magnetic field with a frequency of 1-50 Hz and an induction of 0.065 T for 110 seconds at a temperature of 180-260°C. Figure 8 shows the effect of induction heating on the auger of the prototype of the screw electromechanical hydrolyser, which, when acting simultaneously with other heating equipment, creates conditions for comprehensive heating of the processing raw material – chicken feathers in the processing environment.

Further, the keratin raw material is loosened and continues to move to the raw material unloading unit and is exposed to vacuum pulses every 60 seconds using a Leeto XZ-1A vacuum pump. Using a prototype of an electromechanical screw hydrolyser with the dimensions and characteristics described in this paper, 1.17 kWh of electrical energy was consumed to produce 8500 mm^3 (642 g) of hydrolysed feather meal. The results of empirical studies and mathematical modelling of the electromagnetic system of a screw electromechanical hydrolyser are close to those obtained during the study of the electromagnetic system of a twin-screw electromechanical hydrolyser (Zablodskiy *et al.*, 2021a; Zablodsky *et al.*, 2021b). As a result of processing, a brownish, loose, hydrolysed feather meal with a specific odour was obtained. Figure 9 shows a sample of hydrolysed feather meal.

Figure 9. Hydrolysed feather meal
Source: developed by the authors

The use of the influence of an electromagnetic field is one of the trends in the search for ways to increase the efficiency of processing keratin-containing raw materials and breaking disulfide bonds. Y.S. Lee *et al.* (2016) proposed a complex hydrothermal and microwave treatment using sodium hydroxide, which substantially reduces feather hydrolysis. Yet the applicability of this method is limited by high cost and significant energy consumption. Microwave alkaline treatment at a frequency of 2450 MHz and power level of 800 W consumes more than 66.5 kWh per kg of raw material, which is considerably higher than the consumption (1.3 kWh/kg) recorded for the experimental sample of the screw electromechanical hydrolyser. When comparing the energy costs with the findings of the study conducted by Vavrova *et al.* (2022), it is important to highlight that modifications to the method of hydrothermal hydrolysis of bird feathers using electricity were analysed. The energy consumption for electric heating of the reactor during hydrolysis using malic acid amounted to 1.6 kWh/kg.

Currently, the experimental sample of the screw electromechanical hydrolyser is not yet completely developed in terms of thermal insulation. The addition of a protective housing with the necessary thermal insulation layer should substantially reduce heat radiation to the environment. This can increase the efficiency of the device by up to 95%. In this regard, the ratio of energy consumption to the weight of processed chicken feathers can be reduced for an industrial model of an electromechanical screw hydrolyser.

It is worth noting an important aspect of the proposed method and means, namely the strategy of successive changes in the physical properties of keratin-containing raw materials before hydrothermal hydrolysis. The proposed design has unique properties in terms of the effect on keratin-containing raw materials. In the sealing cavity of the working part of the screw unit, the down and feather raw material is compacted 8-10 times, heated at a pressure of 0.5-5.0 MPa to a temperature of 60°C, and exposed to a gradient magnetic field with a frequency of 1-50 Hz and an induction of up to 0.025 T to inhibit the process of moisture evaporation. Moreover, the down and feather raw materials are deaerated in the sealing cavity using a deaeration chamber, where high magnetic intensity is created to suck in paramagnetic oxygen, thus, in the sealing cavity of the working area of the screw unit, voids are removed from the down and feather mixture as much as possible, in which water can be converted into steam and further, due to the removal of oxygen, the quality of the resulting product is impacted due to oxidation. The sequential hydrolysis strategy was also incorporated by N.D.A. Pedrosa *et al.* (2022) using three reactors. The disadvantage of this technology is the use of alkaline dissolution, a long process duration (more than 10.5 hours), and significant energy consumption of 4.0 kWh/kg.

N. Zablodskiy *et al.* (2021a), N. Zablodsky *et al.* (2021b) investigated a twin-screw electromechanical hydrolyser for processing poultry by-products. Such a hydrolyser is based on the principles of using the dissipative energy component and integrating the functional features of the technological process in one device. N. Zablodskiy *et al.* (2021a), N. Zablodsky *et al.* (2021b) conducted several studies on electromagnetic, electromechanical, thermal, vibration, and some other processes that occur in this kind of device. The screw electromechanical hydrolyser presented in this paper is characterised by a simple design compared to the twin-screw hydrolyser: it is easy and quick to disassemble, which substantially speeds up the maintenance process. Despite the simplicity of the design, the screw electromechanical hydrolyser can provide identical hydrothermal hydrolysis parameters as the twin-screw hydrolyser but is inferior in energy efficiency and the ability to narrowly control the hydrolysis parameters.

CONCLUSIONS

According to the results of the examination of thermal characteristics, the screw electromechanical hydrolyser is capable of providing the necessary thermal conditions for the hydrothermal hydrolysis of poultry by-products. The level of the oscillating electromagnetic field is sufficient to exert a magnetic field effect on the raw material for processing – chicken feathers. The results of the mathematical modelling of the thermal characteristics correspond to the data obtained during empirical studies of a prototype of a screw electromechanical hydrolyser, so this mathematical model can be considered adequate.

The use of a magnetic field source and induction heating in conjunction with other heating equipment creates conditions for a comprehensive impact on the raw material and expands the ability to control the hydrolysis process to apply the optimal mode depending on the properties of the feedstock and the quality requirements of the final product. The proposed method and means of processing keratin-containing raw materials are focused on the use of environmentally friendly energy for conversion into value-added products. The ratio of energy consumption to the weight of processed chicken feathers at the level of 1.3 kWh/kg makes this method attractive for investment.

The scientific and technical originality of this study lies in the application of an electromagnetic field source to induce a magnetic field effect on keratin-based raw materials, the utilisation of the dissipative energy component, and the implementation of induction heating in the screw of the electromechanical hydrolyser. Simultaneous operation with other heating devices enables comprehensive heating of the processed raw materials.

The results obtained can be used in further studies on the development of structures and control systems for industrial models of an electromechanical screw hydrolyser. In addition, the findings present promising opportunities for future investigations into the physicochemical analysis of the final product, feather meal, to determine in detail the impact of the magnetic field on the raw material.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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None.

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Шнековий електромеханічний гідролізер для переробки побічних продуктів птахівництва

Анотація. Використання продуктів переробки кератин-вмісних речовин в різних галузях, включаючи, зокрема, сільське господарство, косметику та біомедицину, потребує вирішення актуальної задачі удосконалення способів і засобів гідротермічного гідролізу кератинових відходів. Метою даної роботи було дослідження шнекового електромеханічного гідролізера для забезпечення режимів ефективного перетворення кератинових відходів у корисний продукт з доданою вартістю. Дослідження ґрунтуються на основних положеннях електродинаміки, тепломасообміну, математичного моделювання методом скінченних елементів і експериментальній перевірці мультифізичних параметрів електромеханічного гідролізера. На експериментальному зразку електромеханічного гідролізера здійснено визначення оптимальних умов гідротермічного гідролізу кератинових відходів щодо забезпечення теплового режиму, транспортування сировини, тиску та впливу магнітного поля. Як результат переробки було отримано сипуче, гідролізоване пір’яне борошно коричневого кольору, що володіє специфічним запахом. Згідно розмірів електромагнітної системи експериментального зразка побудована математична модель для досліджень теплових і електромагнітних процесів. Визначено закономірності просторового розподілу магнітної індукції для поперечного перерізу, осьового розподілу на поверхні шнеку та верхніх гранях шнекової навивки електромеханічного гідролізера. Отримані тривимірні зображення нагріву шнеку та безпосередньо самого шнекового електромеханічного гідролізера. Порівнянням результатів математичного моделювання та емпіричних досліджень підтверджена адекватність математичної моделі. Результати дослідження можуть знайти застосування в галузі тваринництва при виготовленні кормових добавок підвищеної засвоюваності на потреби годівлі сільськогосподарських тварин та птиці

Ключові слова: кератинова сировина; пір’яне борошно; кінцево-елементний метод; рівняння Максвелла; енергозбереження