BIOMASS PYROLYSIS USING A MULTIFUNCTIONAL ELECTROMECHANICAL CONVERTER AND A MAGNETIC FIELD*

M. Zablodskiy[1], A. Zhyltsov[1], V. Nalyvaiko[1], V. Trokhaniak[2], S. Pugalendhi[3], P. Subramanian[3]

[1]National University of Life and Environmental Sciences of Ukraine, Department of Electrical Engineering, Electromechanics and Electrotechnology, Kiev, Ukraine
[2]National University of Life and Environmental Sciences of Ukraine, Department of Heat and Power Engineering, Kiev, Ukraine
[3]Tamil Nadu Agricultural University, Department of Renewable Energy Engineering, Coimbatore, India

The wood waste conversion processes in a dry distillation chamber with an executive body based on a multifunctional electromechanical converter were analysed. It was established that under the influence of a low-frequency magnetic field, the properties of moisture evaporating from biomass change, and the evaporation heat decreases. A method for generating negatively charged molecular complexes in the form of water vapour by heating biomass, exposure to the electric and magnetic field, followed by the injection of negatively charged hydroxide ions of water vapour into a solid carbon product at the final stage of the pyrolysis process is proposed. The possibilities of heat recovery of the screw energy technological complex for preheating biomass in a loading device using the thermal energy of the spent heat carrier, the energy dissipative component of the installation's electromechanical part and the thermal energy utilisation of the produced solid products have been estimated.

exothermic reaction, electromagnetic field, dissipative component of energy, biocarbon, redox potential, heat recovery

sciendo

doi: 10.2478/sab-2020-0009
Received for publication on January 17, 2020
Accepted for publication on May 22, 2020

INTRODUCTION

The use of plant biomass, given its potential as a renewable energy source, is particularly relevant as plant biomass will play a significant role in shaping a country's fuel and energy balance in the future. Today, biomass is the fourth largest energy source in the world covering up to 14% of primary energy consumption. A sustainable development scenario indicates that globally in developing countries the biofuel share can reach 35% of primary energy supply (Gupta, Mondal, 2020). One of the common biomass processing methods is gasification, however the current requirement is to minimise the use of gasification systems and low quality biomass resources (Situmorang et al., 2020). An analysis of thermochemical conversion technologies of low-grade and small-scale resources of plant biomass also indicated that energy technologies are the most promising at present. The energy technology method of plant biomass conversion is a comprehen-

* Supported by the Ministry of Education and Science of Ukraine (Kyiv), Ukrainian-Indian Project No. M/37-2019.

sive method of harnessing its energy potential, since alongside with combustible gas, another valuable product (such as biocarbon) can be produced which is more cost-effective than pressing, gasification or incineration. In addition, the conversion process cannot be carried out effectively based on only one product, i.e. biogas. Therefore, addressing problems related to the development and improvement of technologies and techniques for the conversion of plant biomass aimed at improving its energy efficiency is relevant and requires additional research (Sklyarenko, Bileka, 2016; Fakayode et al., 2020; Iannello et al., 2020). It is to note that such systems can be adapted to a unique control due to the influence of electromagnetic field, and the final bioproducts acquire additional properties. It is experimentally proved that the presence of electromagnetic potentials leads to the effects of increasing the productivity of processes, the ability to control chemical reactions due to the interaction of magnetic field with chemical potential in the systems of charged particles of biomass solutions (Smith, 2004; Falaye et al., 2016; Foong et al., 2020). The present research is aimed at analysing the processes of plant biomass conversion in a dry distillation chamber with an executive device based on a multifunctional electromechanical converter with the influence of an oscillating magnetic field and the possibilities of heat recovery.

MATERIAL AND METHODS

Herein we offer a method and equipment (Fig. 1) for destructive energy processing of plant biomass. Tree trimmings, wood part of urban garbage and waste from wood processing enterprises were used as feedstock. The productivity of the complex is 300 kg h^{-1} in terms of feedstock. As input material, wood chips are used with an initial temperature of 15–20 °C, relative humidity of 30–45%, crushed to a particle size of not more than 10 × 10 × 5 mm. Bulk density of fine-grained chips is 450 kg m^{-3}, volatiles are up to 85%, ash content in dry matter is about 1%, and temperature at the onset of thermal decomposition is 100–250 °C. The gas heat carrier is obtained during the process of mixed conversion of natural gas, when in the products of incomplete combustion of natural gas with excess air $\alpha = 0.7–0.75$, secondary gas was introduced. In the first stage, natural gas is burned in the process firebox with an excess air factor $\alpha = 0.7–0.75$, and in the second stage, a certain amount of natural gas is supplied at the outlet of the combustion chamber so that the temperature of the combustion products is within certain limits. Total excess air was $\alpha_{com} = 0.5$. This conditioned the required coolant temperature of 750–800 °C, physical heat and chemical heat not lower than 3 MJ m^{-3} and 6.5 MJ m^{-3}, respectively. The gas heat carrier is fed for external heating of the dry distillation chamber (1). Crushed fractional biomass is loaded portionwise through the lid with a magnetic gate in the hopper of the loading device (2), where it is pre-dried and heated. Using the feeder (3), the biomass is loaded into an auger watertight of the dry distillation chamber (1), where the biomass layer is heated on one side from the walls of the chamber by the heat carrier, formed by the combustion of fuel in the technological furnace, and on the other side from conductive heat transfer and radiation from the

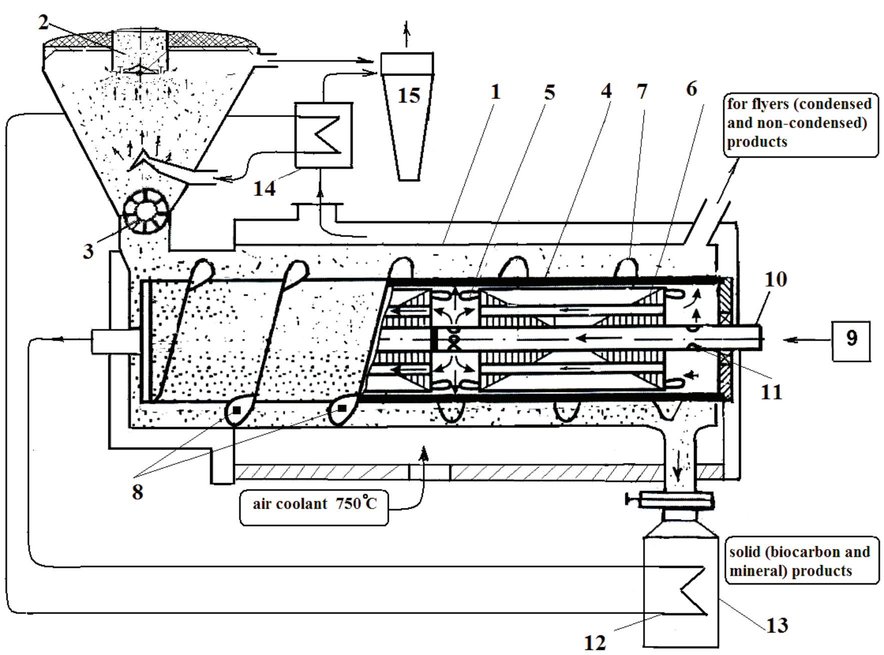

Fig. 1. Scheme of a system for plant biomass destructive energy processing
1 = dry distillation chamber,
2 = loading device,
3 = feeder,
4 = solid rotor,
5 = polyfunctional electromechanical converter,
6 = inductors,
7 = screw blades,
8 = contactless temperature sensors,
9 = air supply system,
10 = fixed hollow shaft,
11 = its through holes,
12 = heat exchanger,
13 = chamber of unloading of solid products,
14 = heat exchanger of waste heat-transfer fluid,
15 = cyclone,
16 = technological ball

outer surface of a solid rotor (4), forming a part of a polyfunctional electromechanical converter (5) connected to a three-phase power supply. The inductors (6) of the electromechanical converter, operating in a counter-current mode, create rotating magnetic fields exciting eddy currents in the external solid rotor (4), due to which the latter one is heated to a temperature of 300–350 °C. Biomass is heated to 350–500 °C, a temperature of its thermal decomposition into volatile (condensed and non-condensed) and solid (biocarbon and mineral) products. Biomass is loaded to the pyrolysis chamber from the moment of reaching the initial pyrolysis temperature (about 200 °C). When the rotating magnetic fields and eddy currents interact, the resultant electromagnetic torque is created, which rotates the outer solid rotor (4) that in turn pushes the biomass by screw blades (7) along with the dry distillation chamber (1). Mobility of the layer and the two-way heat input allow to intensify the heat and mass transfer processes and to obtain biocarbon of uniform quality without burning and sintering; moreover, to prevent the biomass from heating up and wall layers from scorch during exothermic reactions. Separate reaction zones have been created in accordance with the number of auger turns. In the first zones from the feeder, the transitional phase of drying to humidity 20–23% and the phase of internal diffusion, i.e. removal of bound moisture, are completed.

With each subsequent reaction zone, the feedstock is heated to a higher temperature than in the previous reaction zone. This allows us to control the onset of exothermic reactions in the feedstock by means of contactless temperature sensors (8), which are located in the array of screw blades (7) of the solid rotor (4). When the temperature reaches 450–500 °C, the exit of volatiles is practically finished, since their maximum release is observed at 300–350 °C temperatures that trigger intense exothermic reactions. Since on the surface of the solid rotor (4) there is an electric potentials difference of the eddy currents circuits, the electrolysis of aqueous solutions takes place under a partial evolution of hydrogen.

The condensed part of biomass pyrolysis products is a complex mixture of pyrogenetic moisture, acids, methanol, compounds of different classes (aldehydes, ketones, esters). The main requirement for a high biocarbon yield, with good physico-chemical characteristics, is the absence of free oxygen in the pyrolysis chambers. However, it is impossible to get a fully oxygen-free regime under these conditions. And most of the oxygen will interact with carbon, reducing the carbon production and degrading its adsorption properties while burning its surface.

A method for generating negatively charged molecular complexes in the form of water vapour by biomass heating, electric and magnetic field action, and with followed-up injection of negatively charged hydroxide ions of water vapour into a solid carbon product at the final stage of the pyrolysis process is proposed. Negatively electrostatically enhanced types of water, that can affect the processing of solid carbon materials in the gasifier system, can be selected to achieve the desired result, e.g. to increase the purity of gas of the selected product, to increase its calorific value. Moreover, the use of these negatively electrostatically enhanced water types can be considered as an example of a dynamic adjustment of the process parameter.

The theoretical background of the magnetic field influence on the physico-chemical reactions of biomass water solutions is additionally confirmed by the experiment results. Under the influence of magnetic field, the degree of electrolytic dissociation and the rate of chemical reactions increase:

$$\omega_m = \omega \exp \mu (K^2 B^2 + 2KBv_n) N_a / 2RT, \tag{1}$$

$$\alpha_m = \alpha \exp\left(\frac{\mu(K_i^2 B^2 + 2K_i Bv)}{2RT}\right), \tag{2}$$

where:
ω_m = rate of chemical reaction under the influence of magnetic field (mol l^{-1}s^{-1})
ω = rate of chemical reaction without the influence of magnetic field (mol l^{-1}s^{-1})
μ = reduced mass of ions (kg)
B = magnetic induction (T)
v = velocity of ions (m s^{-1})
K = coefficient depending on ions concentration and type, and on the re-magnetisations number (m s^{-1}·T)
N_a = Avogadro number (molecules per mol)
R = universal gas constant (J mol^{-1} K)
T = temperature (K)
α_m, α = degree of electrolytic dissociation after and before processing in a magnetic field.

The degree of ions readiness to accept electrons reflects the redox potential (RP). The change in the RP of a solution is determined by the Nernst equation (Pokorny et al., 2005):

$$\Delta RP = 2.3\frac{RT}{zF}\left(\lg fC_2 - \lg fC_1\right) = 2.3\frac{RT}{zF}\left(\lg C_2 - \lg C_1\right) \tag{3}$$

where:
z = ion valence
F = Faraday number (C mol^{-1})
f = activity factor
C_1 = ions concentration before magnetic processing (mol l^{-1})
C_2 = ions concentration after magnetic processing (mol l^{-1})

Accordingly,

$$\Delta RP = \frac{2.3^2 \mu N_a K}{zF}\left(\frac{KB^2}{2} + vB\right) \tag{4}$$

Magnetic treatment effects were investigated using an I-160M ionomer (LLC "Measuring equipment", Russian Federation, https://www.izmteh.ru) using an experimental design method and using an orthogonal centrally composite plan. For magnetic induction the values of the upper, lower and main levels were 0, 0.065 and 0.13 T, respectively; the solution movement speed was 0.4, 0.6 and 0.8 m s^{-1}, respectively. The regression equations for the RP of solutions were as follows:

corn, initial RP + 505 mV,

$\Delta RP = -0.972 - 1163B + 1.25v + 211.538Bv + 6075B^2$

buckwheat, initial RP + 365 mV,

$\Delta RP = -3.287 - 836.325B + 5.417v + 134.615Bv + 4392B^2$

soybeans, initial RP + 540 mV,

$\Delta RP = -1.25 - 602.137B + 2.639v + 108.974Bv + 3314B^2$

sunflower, initial RP + 370 mV,

$\Delta RP = -4.213 - 1230B + 7.083v + 185.897Bv + 6141B^2$

poplar white, initial RP +160 mV,

$\Delta RP = -5.65 - 751 + 6.093v + 152.412Bv + 5423B^2$

As the magnetic induction increases from 0 to 0.065 T, the RP of solutions of all cultures decreases, and with its further increase the RP increases. However, a stronger change in the RP occurred at lower speeds of the solution, although overall the speed of the solution is less effective than the magnetic induction.

Let us evaluate the possibilities of heat recovery on the example of a screw energy technology complex for energy processing of wood waste that does not provide heat recovery in the loading hopper (Z a b l o d s k y i et al., 2017). The complex is built on the basis of a multifunctional electromechanical converter (MFEC) using the principle of integration of properties and structures of devices such as the heater, electric drive and actuator. Thus all kinds of dissipative energy are used in the technological process of dispersed substances processing. The material flows of the heat exchanger system of the unit can be divided into two groups: the first group, including the flows that need to be heated (cold streams), and the second group, including the flows that require cooling before they are further processed (hot streams). Changes in the heat content of these flows are analysed on the temperature-enthalpy base. The relationship between the change in the flow temperature and the decrease (increase) of its heat content – enthalpy – is reflected by a nonlinear function (Z a b l o d s k y i et al., 2017):

$$\Delta H_T = C_p \times M \times \Delta T \quad (5)$$

where:

H_T = heat content of the stream

C_p = specific heat capacity of the substance in the process stream at constant pressure

M = mass flow of the stream substance

T = temperature

The hot stream consists of three main components: the air thermal agent with initial temperature of 1000 °C at an air flow rate of 300 m^3 h^{-1} obtained during combustion of the fuel; the heat flow of convective-conductive heat transfer to biomass from a 65 kW MFEC rotor; the heat flux generated in biomass during exothermic reactions starting at 270 °C. The heat flux of convectively-conductive MFEC transmission is in turn determined from a preliminary calculation of twelve components related to its equivalent thermal circuit. The cold flow of the heat exchange system consists of two main components: (1) the inlet flow of cooling air, which receives heat energy on the path of convectively-conductive heat transfer during cooling of a MFEC stator; (2) the wet biomass stream with initial temperature of 20 °C and productivity of 300 kg h^{-1}. The heat exchange of the cold and hot streams occurs through the internal and external heat exchanging surfaces of the active parts and structural elements of the complex for energy technological processing of wood waste. The values of streams along the enthalpy axis are deposited separately for each cold or hot stream, and then, with the preservation of the total enthalpy, the components of the cold and hot streams curves are plotted (Fig. 2).

A significant hot flow energy ($Q_{c\ min}$ = 84 kW) is either emitted into the atmosphere or some additional costs to cool the hot flow down to 40 °C are needed. The heat exchange system provides heat recovery only at the level of overlap of the cold and hot streams curves (Q_{REC} = 20 kW).

The minimum distance between the component curves along the temperature axis (pinch) determines the minimum temperature convergence of flows ΔT_{min} in the heat exchange network. Based on the recommended value ΔT_{min} = 20 °C for known heat exchanger designs, the problem of increasing the efficiency of the unit can be resolved using the residual energy of the hot streams sequentially in the heat exchange system of the hopper. The heat exchange system of the hopper should provide the following functions: heating of the feedstock in order to reduce additional hot utilities (fuel consumption) when heating the air heat transfer agent to achieve the initial temperatures

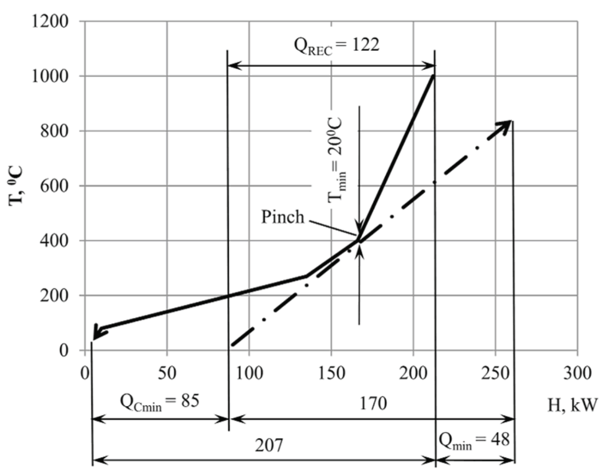

Fig. 2. Heat exchange of cold and hot streams, internal and external heat exchanging surfaces of active parts

of exothermic reactions in the dry pyrolysis chamber; evaporation of excess moisture of the feedstock.

The air coming from the air supply system (9) inside the fixed hollow shaft (10) and through a part of its through holes (11) enters the internal cavity of the massive rotor (4), it cools the active parts of the inductors of the rotating magnetic field (6) and through the second part of the through holes (11) it again flows to the second separate cavity of the immovable hollow shaft (10) and beyond, through the heat exchanger (12) of the chamber of unloading of solid products (13), the heat exchanger (14) of the waste heat-transfer fluid, it enters the middle of the loading device (2) and then it is released to the atmosphere through a cyclone (15). The calculated airspeed should be sufficient to create a 'boiling' layer of loaded biomass. The thermal energy of the waste heat-transfer fluid, the dissipative component of the electromechanical part of the installation and the utilisation of thermal energy of the produced solid products in the heat exchanger are used for preliminary drying during the period of removing free moisture to achieve the air-dry state (30–35%) and partially during the transitional period of drying (20–25%), as well as for biomass heating in the boot device (2). This provides a stable mode of heating the biomass along the length of the pyrolysis chamber and reaching the initial temperature of exothermic reactions regardless of its initial humidity without requiring additional heat from the combustion of fuel in the furnace.

The numerical simulation of hydrodynamic processes in the boot device was carried out using the software package ANSYS Fluent (Version 18.0, 2017). The mathematical model is based on the Navier-Stokes equation (Gorobets et al., 2018; Khmelnik, 2018; Trokhaniak, Klendii, 2018) and the energy transfer equation for convective flows. In the calculations we used the standard k-ε turbulence model (Bardina et al., 1997) and the Dense Discrete Phase Model (DDPM) (ANSYS, 2017).

RESULTS

Fig. 3 shows the air velocity distribution in the boot device containing waste heat-transfer fluid, dissipative energy component of the electromechanical part of the installation, the thermal energy wastage recovery of produced solid products in heat exchangers. Biomass with air enters the loader at speeds ranging from 6 to 8 m s^{-1}. The average transport velocity of biomass is 3.7 m s^{-1} and that of the waste heat-transfer fluid is 2.4 m s^{-1}. Fig. 4 presents streamline of the air and biomass in the boot device. The air, the velocity of which at the inlet is 6 m s^{-1}, rises with the biomass for a short distance due to periodic biomass fill. For more efficient biomass mixing the inlet air velocity must be increased to 9–10 m s^{-1}.

Our simulation results on the fluid dynamics of a fluidised bed were extensively compared with those reported by various authors (Kulkarni, Joshi, 2005; Koralkar et al., 2015), who used various stability criteria for a fluidised bed. To check the convergence of the simulation results, an analytical

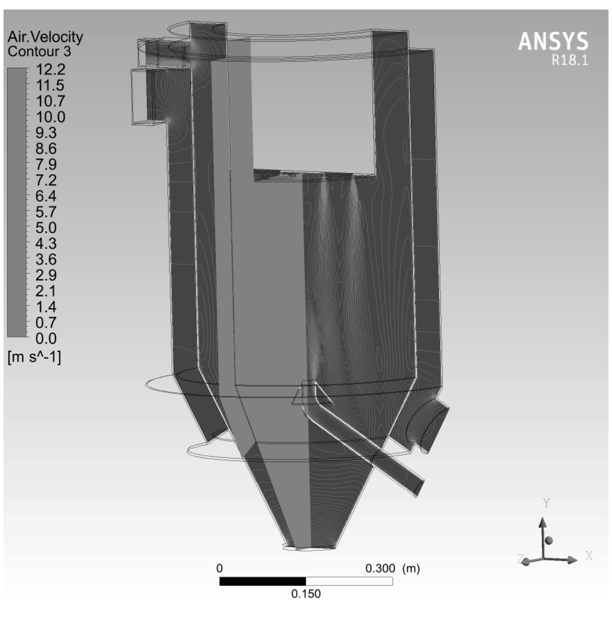

Fig. 3. Air velocity distribution in boot device

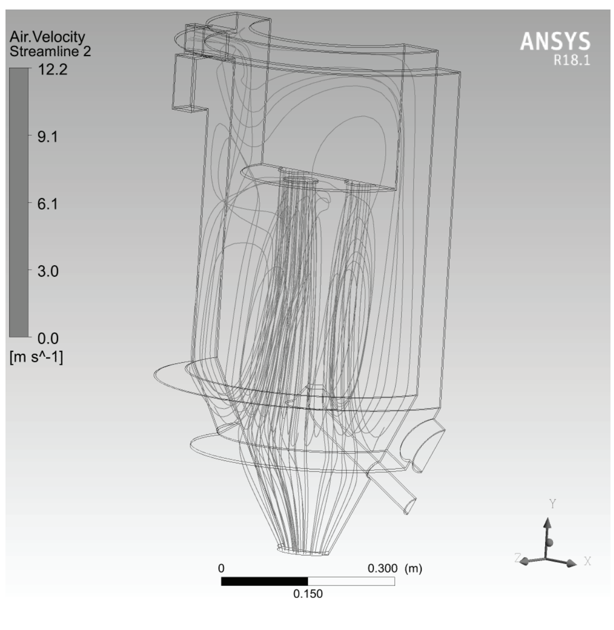

Fig. 4. Streamline of air and biomass in boot device

calculation of the biomass fluidised bed in the loading hopper was carried out. The calculation had been done for the beginning stage of the immobile layer of solid particles transition into a suspension state when using the air flow from the electromechanical part of the dry distillation chamber with the similarity criteria of Archimedes Ar, Lyaschenko Ly and Reynolds Re. The Lyaschenko Ly criterion describes the ratio of inertia, weight and lift:

$$Ly = \frac{Re^3}{Ar} = \frac{w_f^3 \cdot \rho_b^2}{\mu_a\left(\rho_b - \rho_a\right)g} = \frac{2.39^3 \cdot 0.835^2}{0.024 \cdot \left(1060 - 0.835\right) \cdot 9.81^{-3}} = 38.2$$

where:

μ_a = dynamic viscosity ratio of the liquid agent (Pa·s)
ρ_b = density of biomass particulate matter (kg m^{-3})
ρ_a = density of the liquid agent (kg m^{-3})
w_f = fictitious speed of the liquid agent (m s^{-1})
g = acceleration of gravity (m s^{-2})

The fictitious speed of the liquid agent is determined taking into account the real volume flow rate of the liquid agent V_a provided by the high-pressure fan, and the cross-section area of the biomass layer F_l

$$w_f = \frac{V_a}{F_l} = \frac{0.37}{0.163} = 2.39$$

Based on the correlation of the similarity criteria of Archimedes Ar, Lyaschenko Ly, and Reynolds Re, we find the criterion Archimedes Ar = 210^6 for a given porosity of the weighted layer ε = 0.5 and Ly = 38.2, and, accordingly, we find the required diameter of spherical particles of the same diameter, which will start to move into a weighted state:

$$d = \sqrt[3]{\frac{Ar \cdot \mu_a^2}{\rho_a \cdot \rho_b \cdot g}} = \sqrt[3]{\frac{2 \cdot 10^6 \cdot 0.024^2 \cdot 10^{-6}}{1060 \cdot 0.835 \cdot 9.81}} = 5.1 \cdot 10^{-3} \text{ m}$$

A stable weighted state of the biomass will be ensured at the speeds of the liquid agent greater than 5 m s^{-1}, which coincides with the simulation results (Figs. 3, 4). For irregularly shaped particles, the critical flow rate can be determined by taking into account the shape factor:

$$\Phi = 0.207 \cdot \frac{S}{V^{2/3}}$$

where:

Φ = the shape factor
V = volume of a particle (m^3)
S = surface of a particle (m^2)

It is assumed that the equivalent diameter is d^e = Φ·d^b where d^b is the diameter of the ball (in m), the volume of which is equal to the volume of the particle. But it should be borne in mind that the density of the liquid agent will change as it moves up within the biomass layer in the loading device due to its saturation with evaporated moisture. Since the viscosity of the agent determines the degree of its mobility, the outlet pressure and the speed of the agent must be increased. To ensure a weighted condition of the chips, they must be ground to a size of 7 × 10 × 5 mm, and the inlet velocity of the liquid agent should be increased to 9.5 m s^{-1}. These recommendations are consistent with the requirements that were set in the simulation.

Fig. 5. Experimental installation with an automated control system for plant biomass destructive energy processing

Fig. 5 presents an experimental installation sample with an automated control system for the destructive energy processing of plant biomass, on which researches of the recovery processes of the waste heat-transfer fluid in the loading hopper were carried out. Crushed wood chips with particle sizes of no more than 7 × 10 × 5 mm were used for the research. The following parameters were changed in the experiments: heat-transfer fluid temperature, temperature of the pyrolysis process, biomass consumption, and relative humidity of raw materials. We recorded the speed and temperature of the air flow in the nozzles of the loading hopper, heated by the dissipative energy component of the electromechanical part of the installation, by the part of the waste heat-transfer fluid heat, and by the thermal energy utilisation of the produced solid products in the heat exchangers. In the stable operation mode of the plant with a biomass consumption of 55 kg h^{-1}, pyrolysis temperature of 425 °C and feedstock relative humidity of 45%, when the biomass was unloaded from the hopper in a screw tight chamber of dry distillation, it had an average humidity of 29% and temperature exceeding 9 °C compared with the initial temperature (Fig. 5).

The sample will be used for a future in-depth study of the magnetic field influence on the final products of biomass thermochemical conversion in a two-way system in pyrolysis chambers of dry distillation and calcination.

DISCUSSION

This study brings about a significant improvement in the energy technology method of plant biomass conversion (Sklyarenko, Bileka, 2016). Due to the electromechanical converter (5) the adjustment of the heating rate is flexible, which is an effective means for the process intensity control, influencing the qualitative composition of the pyrolysis products and shifting the course of the process in the direction of the predominant formation of liquid, gaseous or solid products. In the calculations, the heat of exothermic reactions is taken at the level of 5.6% of the biomass combustion heat. At temperatures above 270 °C, part of the required heat is covered by the heat of exothermic reactions, and the rest is compensated by the additional heat supplied from the walls of the dry distillation chamber (3) and the surface of the external solid rotor (4) of the electromechanical transducer (5). Under the action of low-frequency (8–55 Hz) magnetic field, the amplitude of which on the surface of the external solid rotor (4) reaches 0.3 T, the properties of moisture evaporating from biomass is changed, namely the grid structure of hydrogen bonds, thermal conductivity, and surface tension. In addition, the heat of magnetised water evaporation decreases. Water molecules, their associates, hydrated ions make thermal oscillations, thus arises resonance occurring with a particular group of molecules, which is accompanied by bond deformation. It is known that clusters containing 3–18 water molecules have a significant dipole moment, creating an electric field around them, and in the magnetic field under the action of Lorentz forces create domains of oriented water molecules, which are stabilised by ions, and unstable compounds are decomposed into single molecules. This contributes to the intensification of the biomass thermal decomposition process. The external solid rotor (4) is a source of infrared radiation, especially in the end zones of inductors. All gas components, consisting of at least two different atoms, actively absorb the energy of infrared radiation, which is transferred into the thermal motion of molecules, i.e. increases the temperature and pressure, which leads to a more intense movement of the pyrolysis gas products to the calcination chamber and the intensification of the recovery reactions. The magnetic field aftereffect is also observed in water vapour. The greatest effect of water activation by the magnetic field is reached when water contains mainly paramagnetic ions (Franczak et al., 2016). Water itself is a diamagnet and it is characterised by small values of magnetic permeability. Since oxygen is a paramagnetic substance, its presence in the quantity of 10^{-3} mg dm^{-3} is sufficient to consider water as a system with di- and paramagnetic properties. It has been determined that, if the field density is 0.2 T, magnetic conductivity of water rises four times at the increase in the concentration of oxygen dissolved in it (up to 30 mg dm^{-3}). The oxidation of water with oxygen, like the oxidation of any other fuel, is a process in which electrons (hydrogen atoms) are transferred from an oxidizing substance, in this case water, to an oxidizer – the oxygen, which is then restored to water molecules:

$$2H_2O + O_2 \rightarrow \left(ROS{:}O_2^-, H_2O_2 etc\right)$$

In the course of oxidation, electrons form daily low-stable, short-lived compounds with a high chemical activity (Voeikov, 2009). These products are free radicals, peroxides, singlet molecular oxygen (O_2^-), and are collectively referred to as reactive oxygen species (ROS).

In a study by Koralkar et al. (2015), two analytically derived criteria for the transition to boiling bed stability are proposed, in which a minimal set of three dimensionless independent parameters is used: the density coefficient, $De = \rho_p/\rho_f$, where ρ_p and ρ_f are the density of liquid (gas) and the density of particles, respectively, and superficial gas velocity U^* of particles with reduced diameter d^*_p. The dimensionless view now allows us to compare the results of an extensive database of fluidised bed transition studies and simulations in CFD-DEM (Computational Fluid Dynamics – Discrete Element Method, ANSYS). For the systems gas agent–wood waste in the form of sawdust (fraction up to 3 mm), the predictions for both criteria of the fluidised bed in the feed hopper are consistent with the simulation results (Koralkar et al., 2015). However, in the case of larger fractions of wood particles with a high (up to 60%) relative humidity, i.e. fluidisation of gas–liquid–solid systems, the forecasts are unstable. The results of modelling and testing on an experimental setup, when evaluating the process according to the criteria of Archimedes Ar, Lyaschenko Ly, and Reynolds Re number (Kulkarni, Joshi, 2005), show a higher rate of convergence.

On the example of a screw energy technology complex for energy processing of wood waste, which does not provide heat recovery, Zablodskyi et al. (2017) showed the implementation of the principles of energy efficiency through the design, modelling and experimental verification of heat recovery from the use of double-hopper.

CONCLUSION

We analysed the processes of plant biomass conversion in a dry distillation chamber with an executive device based on a polyfunctional electromechanical converter with the following outcomes:

(1) Mobility of the layer and the two-way supply of heat allow to intensify the heat and mass transfer processes and to obtain biocarbon of uniform quality without burning and sintering; to avoid the biomass heating up and burning of wall layers during exothermic reactions.

(2) Under the action of a low-frequency (8–55 Hz) magnetic field with the amplitude reaching 0.3 T on the surface of the external solid rotor (4), the properties of moisture evaporating from biomass change, namely the hydrogen bonds grid structure, and thermal conductivity and surface tension. In addition, the heat of magnetised water evaporation decreases.

(3) According to the proposed method we implemented the step of generating negatively charged, electrostatically reinforced water objects by using magnetic field, the step of preheating water objects to obtain aqueous solutions in the form of vapour having a pure negative charge, injection of negatively charged and electrostatically reinforced water objects in the aforementioned solid carbon materials in the pyrolysis chamber, the release of the synthesis gas produced from solid carbon materials.

(4) Under the influence of oscillating magnetic field, the degree of electrolytic dissociation and the rate of chemical reactions increase.

(5) The assessment of heat recovery possibilities in the loading hopper on the example of the screw energy technology complex for wood waste showed that the thermal energy of the spent coolant, the dissipative component energy of the electromechanical part of the installation and the utilisation of thermal energy produced by solid products in heat transfer to air-dry condition (30–35%) and partially during the transitional period of drying to humidity (20–23%), as well as heating the biomass in the loading device. This provides a stable mode of biomass heating along the length of the pyrolysis chamber achieving the initial temperature of exothermic reactions, regardless of its initial humidity and not requiring additional heat from fuel combustion in the furnace.

REFERENCES

ANSYS (2017): ANSYS Fluent theory guide. Release 18.0. ANSYS Inc., Canonsburg.

Bardina JE, Huang PG, Coakley TJ (1997): Turbulence modeling validation. Testing and Development. AIAA Meeting Paper, 28th Fluid Dynamics Conference, Snowmass Village, USA. doi: 10.2514/6.1997-2121.

Fakayode OA, Aboagarib EA, Zhou C, Ma H (2020): Co-pyrolysis of lignocellulosic and macroalgae biomasses for the production of biochar – a review. Bioresource Technology, 297, Article 122408. doi: 10.1016/j.biortech.2019.122408.

Falaye BJ, Sun GH, Silva-Ortigoza R, Dong SH (2016): Hydrogen atom in a quantum plasma environment under the influence of Aharonov-Bohm flux and electric and magnetic fields. Physical Review E, 93, Article 053201. doi: 10.1103/PhysRevE.93.053201.

Foong SY, Liew RK, Yang Y, Cheng YW, Yek PNY, Mahari WAW, Lee XY, Han CS, Vo DWN, Le QV, Aghbashlo M, Tabatabaei M, Sonne C, Peng W, Lam SS (2020): Valorization of biomass waste to engineered activated biochar by microwave pyrolysis: Progress, challenges, and future directions. Chemical Engineering Journal, 389, Article 124401.

Franczak A, Binnemans K, Fransaer J (2016): Magnetomigration of rare-earth ions in inhomogeneous magnetic fields. Physical Chemistry Chemical Physics, 18, 27342–27350. doi: 10.1039/C6CP02575G.

Gorobets VG, Trokhaniak VI, Antypov IO, Bohdan YO (2018): The numerical simulation of heat and mass transfer processes in tunneling air ventilation system in poultry houses. INMATEH: Agricultural Engineering, 55, 87–96.

Gupta GK, Mondal MK (2020): Bioenergy generation from agricultural wastes and enrichment of end products. In: Kumar RP, Gnansounou E, Raman JK, Baskar G (eds): Refining biomass residues for sustainable energy and bioproducts. Academic Press, 337–356.

Iannello S, Morrin S, Materazzi M (2020): Fluidised bed reactors for the thermochemical conversion of biomass and waste. KONA Powder and Particle Journal, 37, 114–131. doi: 10.14356/kona.2020016.

Khmelnik SI (2018): Navier-Stokes equations. On the existence and the search method for global solutions. “MiC” – Mathematics in Computer Corp., Bene-Ayish.

Koralkar N, Kottakota G, Bose M (2015): Transition criteria for fluidized beds revisited. Particulate Science and Technology, 33, 393–405. doi: 10.1080/02726351.2014.981903.

Kulkarni AA, Joshi JB (2005): Bubble formation and bubble rise velocity in gas−liquid systems: A review. Industrial and Engineering Chemistry Research, 44, 5873–5931. doi: 10.1021/ie049131p.

Pokorny J, Hasek J, Jelinek F (2005): Electromagnetic field on microtubules: Effects on transfer of mass particles and electrons. Journal of Biological Physics, 31, 501–514. doi: 10.1007/s10867-005-1286-1.

Situmorang YA, Zhao Z, Yoshida A, Abudula A, Guan G (2020): Small-scale biomass gasification systems for power generation (< 200 kW class): A review. Renewable and Sustainable Energy Reviews, 117, Article 109486. doi: 10.1016/j.rser.2019.109486.

Sklyarenko EV, Bileka BD (2016): Experimental study of thermochemical conversion process for plant biomass into combustible gas and biocarbon on installation of screw type. Energy Technologies and Resource Saving, 2, 43–49.

Smith CW (2004): Quanta and coherence effects in water and living systems. Journal of Alternative and Complementary Medicine, 10, 69–78. doi: 10.1089/107555304322848977.

Trokhaniak V, Klendii O (2018): Numerical simulation of hydrodynamic and heat-mass exchange processes of a microclimate control system in an industrial greenhouse. Bulletin of the Transilvania University of Brasov, Series II: Forestry, Wood Industry, Agricultural Food Engineering, 11, 171–184.

Voeikov VL (2009): The key role of a stable nonequilibrium state of water systems in bioenergy. Russian Journal of General Chemistry, 53, 41–49.

Zablodskyi MM, Pliuhin VY, Hrytsiuk VY (2017): Electric multifunctional units in processing switches of dispersed materials. CP 'Komprint', Kiev. (in Ukrainian)

Corresponding Author:

Viktor T r o k h a n i a k , Ph.D. Eng., National University of Life and Environmental Sciences of Ukraine, Department of Heat and Power Engineering, Heroyiv Oborony st. 15, Kyiv, Ukraine, phone: +38 067 351 3082, e-mail:trohaniak.v@gmail.com