PRELIMINARY RESEARCHES ON SOME TECHNICAL-FUNCTIONAL PARAMETERS OF AN EXPERIMENTAL MODEL OF CONVECTIVE DRYER WITH TOTAL ENERGY INDEPENDENCE

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CERCETĂRI PRELIMINARE ASUPRA UNOR PARAMETRI TEHNICO-FUNCȚIONALI AI UNUI MODEL EXPERIMENTAL DE USCĂTOR CONVECTIV CU INDEPENDENȚĂ ENERGETICĂ TOTALĂ

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ABSTRACT

In order to be consumed whole year at a nutritional value close to the freshly picked product, seasonal vegetal products (vegetables, fruits, aromatic and medicinal plants, seeds, berries, mushrooms etc.) are preserved by artificial dehydration. Unlike other preservation methods and techniques, dehydration leads to obtaining products with a weight 8-10 times reduced and a volume 3-4 times smaller, a fact that contributes to the reduction of the spaces required for storage and the substantial reduction of handling and transport costs, compared to those for fresh vegetal products. Taking into account the general context related to global warming, as well as the need to reduce energy consumption from fossil fuels, the paper approaches the preliminary experimental research of a small capacity convective dryer, with total energy independence from the electricity network, intended for small agricultural producers from isolated hill and mountain areas. The technical equipment consists of a thermal generator operating on TLUD principle, which utilizes existing biomass at the local level, a high-efficiency air-air heat exchanger and a drying room with trays. The aim was to determine some important technical-functional parameters in the working process of the equipment, such as: the temperature of the burnt gases, the biomass loading capacity of the gasification reactor, the capacity to regulate the air flow required for the thermo-chemical processes, the temperature at various keypoints inside equipment etc. Following the analysis of the experimental data, there were highlighted quantitative values useful for estimating the inputs required for a normal operation of the equipment.

REZUMAT

Pentru a putea fi consumate tot timpul anului la o valoare nutritivă apropiată de produsul proaspăt cules, produsele vegetale sezoniere (legume, fructe, plante aromatice și medicinale, semințe, fructe de pădure, ciuperci etc.) sunt conservate prin deshidratare artificială. Spre deosebire de alte metode și tehnici de conservare, deshidratarea conduce la obținerea unor produse având o greutate redusă de 8-10 ori și un volumul de 3-4 ori mai mic, fapt care contribuie la reducerea spațiilor necesare pentru depozitare și diminuarea substanțială a costurilor de manipulare și transport, comparativ cu cele pentru produsele vegetale proaspete. Ținând cont de contextul general referitor la încălzirea globală, precum și de necesitatea reducerii consumului de energie provenită din combustibili fosili, lucrarea abordează cercetarea experimentală preliminară a unui uscator convectiv de capacitate mică, cu independență energetică totală față de rețeaua de energie electrică, destinat micilor producători agricoli din zonele izolate de deal și de munte. Echipamentul tehnic are în componență un generator termic cu funcționare pe principiul TLUD, care valorifică biomasa existentă la nivel local, un schimbător de căldură aer-aer cu eficiență ridicată și o incintă de uscare cu tăvițe. S-a urmărit determinarea unor parametri tehnico-funcționali importanți în procesul de lucru al echipamentului, precum: temperatura gazelor arse, capacitatea de încărcare cu biomasă a reactorului de gazeificare, capacitatea de reglare a debitului de aer necesar desfășurării proceselor termo-chimice, temperatura în diverse puncte cheie din interiorul echipamentului etc. În urma analizei datelor experimentale s-au evidențiat valori cantitative utile pentru estimarea input-urilor necesare unei funcționări normale a echipamentului.

INTRODUCTION

Fruits and vegetables have always represented basic elements in human nutrition, due to the intake of proteins, carbohydrates, lipids, as well as vitamins, minerals, fibers, enzymes, volatile aromatic substances etc., their consumption throughout the year being beneficial for health (*Muscalu et al., 2022*). Also, the spontaneous flora offers an extremely rich range of berries, mushrooms, medicinal and aromatic plants, which complete the supply of substances necessary for a rational and balanced human diet.

These products are seasonal, the harvest periods are relatively short, and for most of them the perishability is very high or average, which makes their fresh use possible only after demanding storage, which considerably increases its costs.

The large volume of vegetal products necessary to satisfy consumption needs and their high degree of perishability constitute a problem of great importance in maintaining the quality for food throughout the year.

The main causes for the quality deterioration of these products are represented by mechanical actions (degradation of structure by crushing), aging processes (especially in the case of fruits) and degrading actions of pests (microflora existing on the surface of the products, rodents, birds etc.). The metabolic activity of the microflora is decisively dependent on the available water. A decrease in water activity has important influences on the development of microorganisms (*Murugan and Saji Raveendran, 2021*). In this context, the dehydration of vegetal products is the technological process by which the natural water content is reduced to a level that prevents the activity of microorganisms, without destroying the tissues or depreciating the food value of these products (*Calín-Sánchez et al., 2020; Jambh et al., 2021; Kamiloglu et al., 2016*). Dehydration leads to obtaining products that are 8-10 times lighter in weight and 3-4 times smaller in volume, a fact that contributes to reducing the space required for storage and substantially reducing handling and transport costs, compared to those for fresh vegetal products.

The ensemble of phenomena that occur during dehydration leads to the concentration of valuable principles, to volume reduction of the raw material used and to the increase of the food value and therefore commercial value of the finished product. The raw materials must keep its qualitative characteristics, especially the taste, appearance and nutritional components, and undergo as few changes as possible during dehydration. In general, fresh fruits and vegetables contain approximately 85 – 90 % water, while the maximum moisture content of dehydrated fruits is approx. 20 – 25 %, and of vegetables approx. 5 – 7 %. The excess water that must be removed by dehydration varies depending on the raw material used, as well as depending on the storage time of the finished product.

The removal of excess water through the classical dehydration of vegetal products can be done either with the help of solar heat - natural drying, or with the help of artificially produced heat (combustion gases, hot air, heated surfaces etc.) - artificial drying or dehydration. In recent years, a series of emerging dehydration methods, based on non-thermal processes, have gained increased attention (Heat Pump Drying - *Moses at al., 2014; Rahman, 2020*, Microwave Drying - *Joardder et al., 2013*, Infrared Drying - *Boudhrioua et al., 2009*, Radio Frequency Drying - *Babu et al., 2018; Boudhrioua et al. 2009* etc.) or their combinations with classical processes (Microwave-Assisted Convective Drying - *Kumar and Karim, 2017*, Vacuum-Microwave Drying – *Calín-Sánchez et al., 2012; Figiel, 2009a; Figiel and Michalska-Ciechanowska, 2016; Szychowski et al., 2018; Zielinska and Michalska-Ciechanowska, 2016*, Convective Drying Followed by Vacuum Microwave Drying - *Figiel, 2010b; Kwasnica et al., 2020; Nowicka et al., 2015; Szychowski et al., 2018*, Intermittent Drying of Food Products Assisted by Temperature, Pressure, Humidity, Convection, Radiation, and Microwave – *Kumar et al., 2014; Pham et al. al., 2017a, Pham et al., 2018b*, Ultrasound-Assisted Convective Drying - *Santacatalina et al., 2016; Witrowa-Rajchert et al., 2014*, Pulse electric field-Assisted Convective Drying - *Barbosa de Lima et al., 2015; Wiktor et al., 2015* etc.), which have been reported to enhance the quality attributes of dried products, reduce drying time and energy demand, and increase the overall drying efficiency.

Although these emerging methods have the potential to replace, at an industrial and commercial level, in the future, the classic dehydration methods, however, they are very expensive and some of them have demonstrated results only at the research level.

In the context of the deepening of the energy and food crisis worldwide, the use of clean energy in agricultural production processes, the increase of energy independence in relation to the national energy system and the energy efficiency of processing equipment have become major concerns of the stakeholders in the field.

An important direction addressed in research on the preservation of vegetal products by dehydration refers to the use within this process of solar energy or that obtained from other renewable sources (*Murugan and Saji Raveendran, 2021*).

Taking into account the general context related to global warming, as well as the need to reduce energy consumption from fossil fuels, the paper addresses the preliminary experimental research of a small capacity convective dryer, with total energy independence from the electricity grid, intended for small farmers from hill and mountain isolated areas. The use of improved burn technology, such as the TLUD gasification process, produces thermal energy and biochar which can be used as a basic material for the improvement of degraded soils, and to sequester carbon in the soil over a long period of time, contributing to the reduction of greenhouse gas emissions, to the achievement of an efficient protection of the environment and to the achievement of a sustainable energy development.

MATERIALS AND METHODS

The experimental research was carried out using an experimental model of a convective dryer with total energy independence, fig. 1 – left side, consisting of a hot air generator operating on the TLUD principle (top-lit updraft gasifier) (1), which utilizes locally existing biomass, a high-efficiency air-to-air heat exchanger (2) and a drying chamber with trays (3). The functional diagram of a TLUD energy module (*Maican et al., 2017*) is presented in fig. 1 – right side. The experimental model was developed within a research project carried out in a partnership formed by an SME and two research institutes.

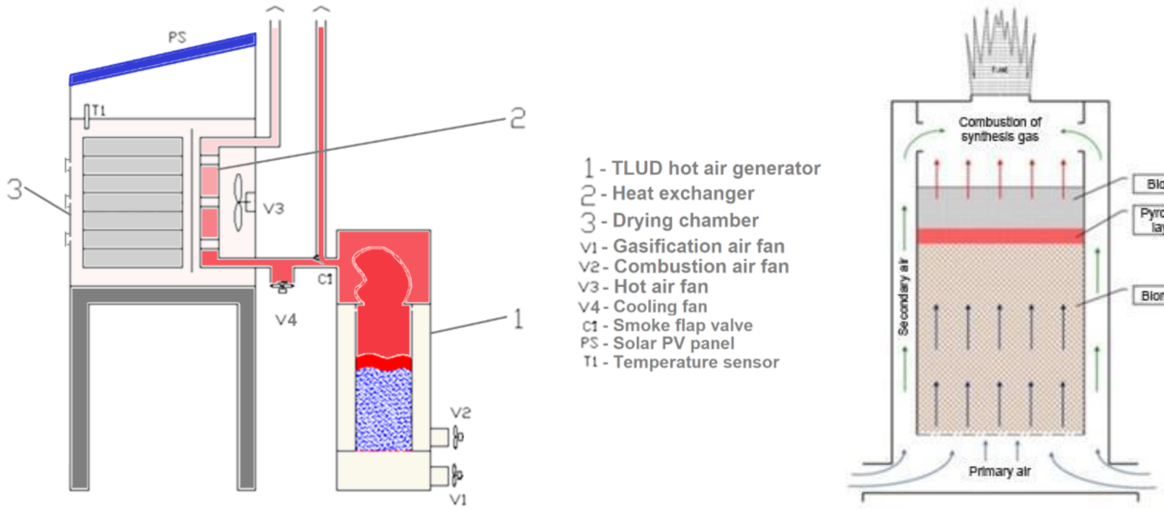


Fig. 1. Experimental model of convective dryer with total energy independence and the TLUD functional diagram

The biomass is introduced into the reactor and rests on a grate through which the primary air for gasification passes, from bottom to top. The process starts with the ignition of the top layer of biomass. Primary air flows upward, through the biomass bed. Partial oxidation of biomass takes place in the presence of oxygen from the primary air. Due to the heat generated by the oxidation process, the biomass in the proximity will decompose through pyrolysis resulting in synthesis gas, tar and coal. The tars pass through the layer of incandescent coal, are cracked and completely reduced due to the heat radiated by the pyrolysis front and the flame in the upper part, the pyrolysis layer progressively moving downward (*Maican et al., 2017*).

Within the experimental model of a convective dryer with total energy independence, the temperature in the drying chamber is monitored by means of a temperature sensor (T1) which influences the manual modification of the smoke flap valve position (C1) and the direction of the flow of hot burnt gases to the heat exchanger (2) from the drying chamber (3) or to the atmosphere through the natural draft tubing, depending on the temperature requirements of the specific drying technology. If the drying temperature is accidentally exceeded or the drying process requires reducing the temperature in the drying chamber, then it is manually operated the smoke flap valve (C1) in order to block the route to the heat exchanger and the cooling fan (V4) will be operated in order to introduce cold atmospheric air into exchanger, cooling it. The electrical energy required for the operation of the equipment is provided by a pack of solar batteries charged from the photovoltaic panel (PS). In the experimental model version of the dryer, the actuation of the execution elements is done manually in order to be able to independently control the operation of each one and observe their influence on the drying process. Also, the heat exchanger was executed in two versions: with location inside the drying chamber and outside it. In order to be able to efficiently monitor the temperature of the thermal agent at the exit from the heat exchanger, the heat exchanger variant located outside the drying chamber was used, and to monitor the temperature variation in the drying chamber, the heat exchanger variant located inside the drying chamber was used.

The preliminary testing of the experimental model of convective dryer with total energy independence was carried out using a data acquisition system equipped with sensors and automatic systems. The diagram of the experimental data acquisition system is presented in figure 2.

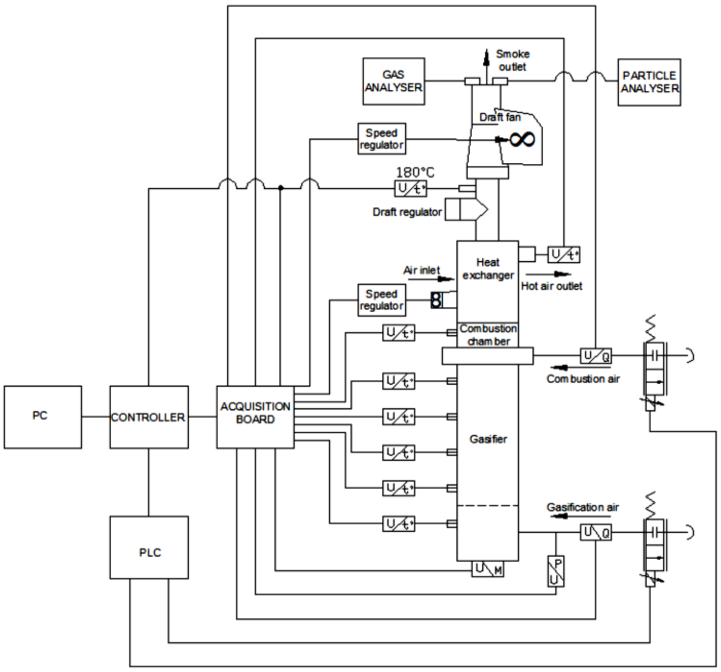


Fig. 2. Data acquisition system equipped with sensors and automatic systems

In order to test the experimental model of the convective dryer, a virtual instrument type application was created in the LabView environment and also the temperature regulator developed as an IoT device, using the REST architecture to transmit data via the Internet to other terminals.

For the experimental data collection there are used 8 temperature transducers, 2 air flow transducers, a weighing dose (load cell), a pressure transducer and gas and particle analyzers. The application panel, fig. 3, contains the sketch of the TLUD hot air generator with numerical indicators for viewing the parameters during operation. On the panel there are also thermometer-type indicators, graphical display blocks of parameter variation and a cursor-type button for adjusting the air flow with the help of a proportional valve.

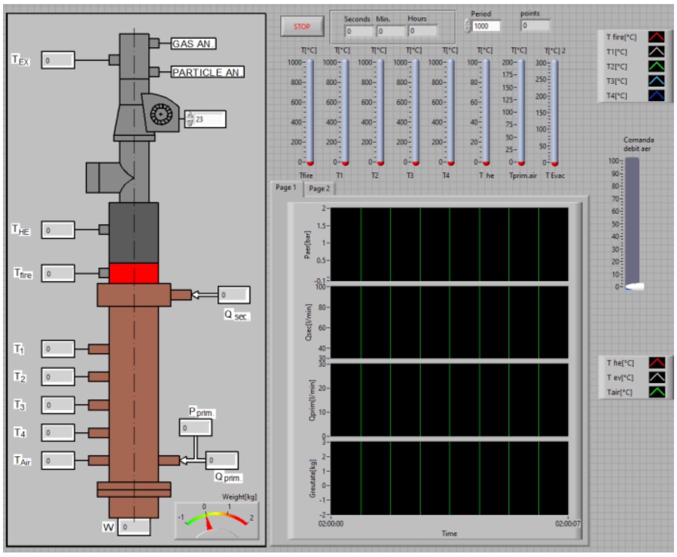


Fig. 3. The panel of the virtual instrument type application made within the LabView environment for the preliminary testing of the experimental model of the convective dryer

The meaning of the numerical indicators on the TLUD installation diagram is as follows:

-T_1, T_2, T_3, T_4 - the temperature values indicated by the temperature sensors of the installation, positioned equidistantly on the height of the gasification reactor, between the primary and secondary air intake points, °C;

- T_{air} - primary air temperature (gasification), [°C];
- p_{prim} - primary air pressure, [bar];
- Q_{prim} - primary air flow, [l/min];
- Q_{sec} - secondary air flow rate (combustion of syngas), [l/min];
- T_{fire} - flame temperature, at the level of the combustion chamber, [°C];
- T_{HE}- temperature at the exit from the air-air heat exchanger, [°C];
- T_{EX} - the temperature of the flue gas-smoke mixture on the chimney, [°C];
- PARTICLE AN - plug for the particle analyzer;
- GAS AN - plug for the gas analyzer;
- W - the load cell, which indicates the loss of mass through the gasification process over time, during the operating cycle (compared to time T_0 - start of the gasification process).

Within the experimentation, the temperature control on the chimney was achieved through the loop created with the temperature regulator developed as an IoT device, using the REST architecture for transmitting data via the Internet to other terminals. Fig. 4 shows the block diagram of the regulator. The value of the temperature of the chimney exhaust gases is measured using a thermoresistance type temperature transducer with a current output signal of 4...20 mA, two-wire connection and the measuring range 0...200 °C. The temperature of the combustion gases is controlled by the flow of air introduced into the combustion chamber, flow varied by means of a proportional valve having the role of an air intake valve. The gasification air flow, which also controls the temperature on the chimney, is proportional to the control signal of the air inlet valve, unified current signal 4...20 mA. The temperature regulator function is provided by the temperature controller that uses a proportional-integral-derivative regulation law (PID controller). The temperature controller integrates an RS485 serial data communication line, which allows the monitoring and control of process variables, namely the desired temperature, the flue gas temperature and the control of the air inlet valve. The communication protocol implemented on the serial line is MODBUS-RTU.

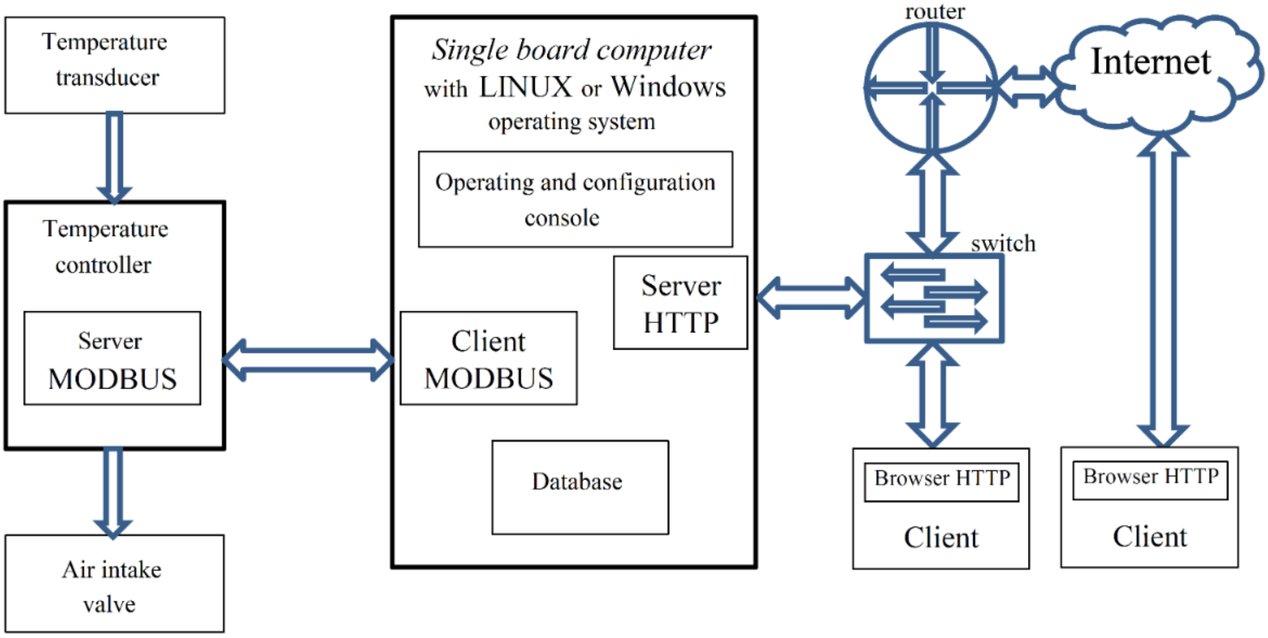


Fig. 4. Block diagram of the temperature controller developed as an IoT device, using the REST architecture

The preliminary experimentation of the equipment aimed to determine some technical-functional parameters important within the working process, such as:

- biomass loading capacity of the gasification reactor;
- the ability to regulate the flow of air necessary for the development of thermo-chemical processes;
- the temperature of the burnt gases as well as the temperature in various key points inside the equipment.

RESULTS

Following the processing and interpretation of the experimental results, a series of useful information was obtained for the estimation of the inputs necessary for a normal operation of the equipment.

The duration of operation is measured from the initiation of the combustion process until the completion of the combustion. The entire period includes an initiation phase (10-15 min), a phase of operation in stabilized gasification mode (60-90 min, depending on the size of the gasifier and the amount of biomass introduced) and a phase of total combustion of the biochar (10-25 min). In the end, a small amount of ash will be obtained. It is obvious that the combustion process continues even after the completion of the gasification, by burning the biochar, but it must be monitorized very carefully so that the process is not accompanied by emissions of smoke or unburned gases. When the pyrolytic front has moved to the base of the reactor, and the thickness of the biochar layer has decreased under the conditions of maintaining the gasification air flow, the combustion process accelerates and the time is shortened. Even after reducing the combustion process, the generator will provide warm air, due to thermal inertia. Completion of the biomass gasification process and the beginning of biochar combustion (gasification) is also determined by the change in the color of the flame, which becomes bluish when the biochar burns. The further burning of biochar is a purely economic choice of the user. The amount of biochar is, under normal conditions, between 15 and 25 percent of the biomass used, depending on the type of biomass. Experiments have shown that by stopping the gasification process when the biochar starts burning, the amount left on the sieve is approx. 2 kg, representing a percentage of 18% of the mass of the pellets introduced into the solid fuel basket of the reactor.

The operating period in stabilized mode of the reactor, when using spruce pellets as solid fuel, until the completion of the biomass gasification process and the start of combustion (gasification) of the biochar was 96 min and the operating period in stabilized mode of the reactor until the complete combustion of the biochar was 108 min.

Regarding the ***verification of the biomass loading capacity***, it was determined theoretically, by calculation, depending on the useful geometric volume of the reactor and the density of the biomass. Taking into account the geometric characteristics of the fuel basket, respectively the position of the sieve and the holes for burning the syngas, the volume of biomass loaded into the gasification reactor, determined by calculation, was 16.73 dm^3, the equivalent of 11.04 kg pellets, respectively 7.20 kg biomass chopped wood (the specific weight of pellets is 0.66 kg/dm^3, and of chopped biomass with dimensions 30...50 mm and 18 % humidity is 0.43 kg/dm^3).

To ensure the good functioning of the generator, it is necessary for the equipment to enter a stabilized gasification regime as quickly as possible. This period lasts from the ignition of the flame at the level of the oxidizing material in the reactor to its passage to the burner, where the combustion of the syngas takes place through the turbulent mixing with the secondary air flow that brings in oxygen for complete combustion. The period until entering the stabilized regime is also influenced by the type and amount of fuel used for ignition. The period between the ignition of the biomass and the entry of the reactor into the stabilized gasification regime was approximately 10...15 min.

For the efficient management of the gasification process, the ***air flows necessary for the proper development of the thermo-chemical processes*** must be ensured. In a TLUD type gasifier, part of the air is used in the biomass gasification process and part in the combustion process of the synthesis gas obtained. In both situations, the amount of air has an essential role because the combustion of the resulting gas can only be achieved in the presence of combustion air. It is very important that the gasification air is well separated (isolated) from the combustion air.

The volume of oxygen required for complete combustion of one fuel unit (minimum oxygen required for combustion) is O_{min}:

$$O_{min} = 22.414 \cdot \left(\frac{c}{12} + \frac{h}{4} + \frac{s}{32} - \frac{o}{32}\right), \left[\frac{m_N^3\, O_2}{kg_{fuel}}\right] \tag{1}$$

where ”c”, ”h”, ”s” and ”o” are the mass shares of the main combustible chemical elements specific to the type of biomass used, [kg component / kg fuel].

For spruce, the percentage content of chemical components is as follows: C=49.9%, H=8.2%, S=0.03% si O=38.1%, and their mass participation for 1 kg of solid fuel is: c=0.499 kg C, h=0.082 kg H, s=0.0003 kg S si o=0.381 kg O. Substituting in relation (1), the following is obtained:

$$O_{min} = 22.414 \cdot \left(\frac{0.499}{12} + \frac{0.082}{4} + \frac{0.0003}{32} - \frac{0.381}{32}\right) = 1.1207, \left[\frac{m_N^3\, O_2}{kg_{fuel}}\right] \tag{2}$$

Considering that the minimum oxygen required for combustion is procured from the air that is wet, containing an amount of moisture x [kg water vapor / kg air] and as the volume participation of oxygen within the air is 21 %, it can be calculated the minimum volume of air required for combustion. It was considered that the air has a temperature of 25 °C and a relative humidity of 45 % and the moisture content is 0.009 kg water vapor / kg air. In this situation, the minimum volume of air required for burning 1 kg of fuel is L_{min}:

$$L_{min} = \frac{O_{min}}{0.21} \cdot (1 + 1.61 \cdot x) = \frac{1.1207}{0.21} \cdot (1 + 1.61 \cdot 0.009) = 5.41, \left[\frac{m_N^3\ air}{kg_{fuel}}\right] \tag{3}$$

where:

L_{min} is the minimum volume of air required for burning 1 kg of fuel, $\left[\frac{m_N^3\ air}{kg_{fuel}}\right]$;

O_{min} – the minimum volume of oxygen required for combustion, $\left[\frac{m_N^3\ O_2}{kg_{fuel}}\right]$;

x - the amount of moisture contained within the air, [kg water vapor / kg air].

The total volume of air for the complete gasification of a load of pellets (11.04 kg, which is the capacity of the fuel basket) is 59.73 m_N^3. Taking into account the time recorded for the gasification of the load (108 min), it results by calculation an air flow rate of 553.06 l/min (138.27 l/min for gasification, respectively 414.79 l/min for syngas combustion).

If it is desired to obtain biochar (18 % of the mass of the load), the volume of air for the gasification of 9.05 kg of biomass is 48.96 m_N^3. The process lasted 96 min, the required air flow being 510 l/min (127.50 l/min for gasification, respectively 382.50 l/min for syngas combustion).

Experimental research in the field of TLUD biomass gasification reactors led to the conclusion that the optimal ratio between primary air (gasification) and secondary air (combustion) is 1:3. Depending on the construction of the gasification reactor and the type of biomass, this ratio can be different and can only be established experimentally, aiming to reach the predetermined power with a clean combustion.

The monitoring of temperatures in various key points, during the preliminary experiments, highlights the thermal inertia of the equipment and provides useful information for choosing the proportionality constants involved in the automatic management of the drying process for the prototype phase of the equipment. The test conditions were the following:

- The solid fuel used into the gasification reactor: spruce pellets with a specific weight of 0.66 kg/dm^3 and humidity 15 %;
- Ambient air temperature: 4...30 °C;
- The initial temperature of the air in the drying chamber: 8.6 °C;
- Pre-set temperature in the drying chamber: 80 °C.

The temperature values obtained at various key points during the experimentation are presented within table 1:

Table 1

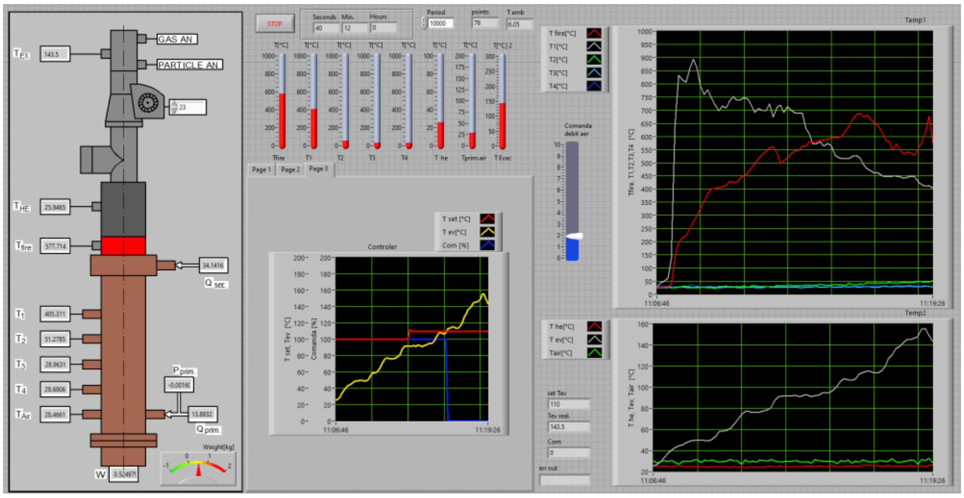
Temperatures recorded at various key points of the equipment

No.	Characteristic	UM	Value
1	Flame temperature in the combustion chamber	°C	450-600
2	The maximum temperature in the combustion chamber when establishing a ratio of 1:3 between gasification air and syngas combustion air		576.9
3	The temperature of the burnt gases at the chimney output		80-180
4	Hot air temperature at the exit from the heat exchanger		40-90
5	The temperature in the drying chamber after the total closure of the exchanger flue gas intake circuit		85

Aspects during temperature monitoring in various key points, in the version with a heat exchanger located outside the drying chamber, are presented in figure 5:

Fig. 5. Images during testing in the version with a heat exchanger located outside the drying chamber, using sensors and automatic systems

Figure 6 shows the graphic interface of the virtual instrument type application made in LabView:



T_{EX} 143.5
T_{HE} 25.9465
T_{fire} 577.714
$Q_{sec.}$ 34.1416
T_1 405.311
T_2 51.2785
T_3 28.9631
T_4 28.6806
T_{Air} 28.4661
$P_{prim.}$ -0.0016(
$Q_{prim.}$ 13.8832
W 0.52497
Seconds 40
Min. 12
Hours 0
Period 10000
points 76
Tamb 6.05
set Tev 110
Tev real. 143.5
Com 0

Fig. 6. The panel of the virtual instrument type application made within the LabView environment - during equipment testing

When actuating the valve regulating the flow of thermal agent (burnt gases) through the air-air heat exchanger, the system reacts with a certain delay due to thermal inertia. The periods that have passed since the command was sent and until the target values for the temperature in the drying room are reached, are presented in table 2:

Table 2

The periods of time until reaching some target values for the temperature in the drying chamber

No.	Characteristic	UM	Value
1	The period of time until the temperature in the drying chamber increases within the interval ΔT=80-8.6=71.4 °C	min	15
2	The period of time until the temperature in the drying chamber increases within the interval ΔT=85-80=5 °C		5
3	The period of time until the temperature in the drying chamber returns from the maximum value (85 °C) to the preset value (80 °C)		6

Aspects during the monitoring of the temperature variation in the drying room, in the version with a heat exchanger located inside the room, are presented in figure 7:

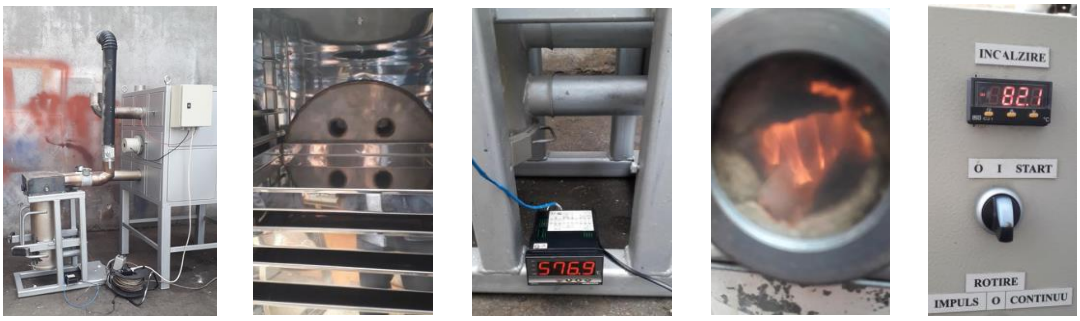


Fig. 7. Images from testing in the version with a heat exchanger located inside the drying chamber

CONCLUSIONS

In order to be consumed whole year at a nutritional value close to the freshly picked product, seasonal vegetal products (vegetables, fruits, aromatic and medicinal plants, seeds, berries, mushrooms etc.) are preserved by artificial dehydration.

Unlike other preservation methods and techniques, dehydration leads to obtaining products with a weight 8-10 times reduced and a volume 3-4 times smaller, a fact that contributes to the reduction of the spaces required for storage and the substantial reduction of handling and transport costs, compared to those for fresh vegetal products.

The removal of excess water through the classical dehydration of vegetal products can be done either with the help of solar heat - natural drying, or with the help of artificially produced heat (combustion gases, hot air, heated surfaces etc.) - artificial drying or dehydration.

In recent years, a series of emerging dehydration methods based on non-thermal processes or their combinations with classical processes have gained increased attention, reporting that they enhance the quality attributes of dried products, reduce drying time and energy demand, and increase the overall drying efficiency.

Although these emerging methods have the potential to replace, at an industrial and commercial level, in the future, the classic dehydration methods, however, they are very expensive and some of them have demonstrated results only at the research level.

Taking into account the general context related to global warming, as well as the need to reduce energy consumption from fossil fuels, the paper addresses the preliminary experimental research of a small capacity convective dryer, with total energy independence from the electricity grid, intended for small farmers from hill and mountain isolated areas.

The preliminary tests carried out on the experimental model of the convective dryer demonstrated the functionality of the product, the possibility of adjusting within wide limits the main process parameters, in accordance with the dehydration technologies of different plant species, as well as the possibility of automatic management of the working process for the prototype phase of equipment. Also, the thermal power of the gasification reactor can be adjusted around the optimal operating point which stabilizes when the ratio between primary air (gasification) and secondary air (combustion) is 1:3.

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