Improvement of Gas Generator Technology for Energy Processing of Agricultural Waste

Wacław Romaniuk [1], Piotr A. Savinykh [2], Kinga Borek [1], Yulia A. Plotnikowa [2], Andriej V. Palitsyn [2], Aleksandr N. Korotkov [2], Kamil Roman [3] and Michał Roman [4,*]

[1] Department of Rural Technical Infrastructure Systems, Institute of Technology and Life Sciences—National Research Institute, Warsaw Branch, Falenty, Al. Hrabska 3, 05-090 Raszyn, Poland; w.romaniuk@itp.edu.pl (W.R.); k.borek@itp.edu.pl (K.B.)

[2] FGOU VO Vologodskaya GMCHA im. N.V.Vereszczagina, Vologda-Molochnoye Vologodskaya Oblast', 610007 Kirov, Russia; savinykh@or.ru (P.A.S.); platnikova@oe.ru (Y.A.P.); palitsyn@oe.ru (A.V.P.); korotkov@oe.ru (A.N.K.)

[3] Institute of Wood Sciences and Furniture, Warsaw University of Life Sciences, 166 Nowoursynowska St., 02-787 Warsaw, Poland; kamil_roman@sggw.edu.pl

[4] Institute of Economics and Finance, Warsaw University of Life Sciences, 166 Nowoursynowska St., 02-787 Warsaw, Poland

* Correspondence: michal_roman@sggw.edu.pl

Abstract: The article discusses the issues of increasing the energy efficiency of processing agricultural waste in a gas generator. The main goal of this technological process is the production of gas fuel from agricultural waste. This fuel is generator gas. The energy value or calorific value of the generator gas depends on the elementary composition of the solid fuel being processed (straw, animal droppings, peat, wood, carbon-containing industrial waste, etc.) and also on the conditions under which chemical reactions take place in the gas generator. In order to improve the gas generator technology, some innovative technical solutions have been proposed. The solutions are related to controlling the supply of the oxidizer (atmospheric air) to the reaction zone of the gas generator, to recuperate the thermal energy of the gas generator and the combined combustion engine of the power plant for the needs of the gasification process. The solutions are also related to the use of compensation and accumulation systems for supplying the consumer with generator gas and to the spatial positioning of the gas generator housing. The control mode of the oxidizer supply to the reaction zone of the gas generator was also investigated. The analysis of the experimental material allows us to draw a conclusion about the positive effect of control modes on the energy value of the generator gas at non-nominal consumption of generator gas by the consumer. This is a consequence of the optimization of the flow speed of the oxidant from the blowing nozzles of the gas generator. According to the tests of the chemical composition of generator gas in gas generator, depending on the number of electromagnetic valves operating, the largest CO content (approx. 17%) was with five valves, CO_2 (approx. 5%) with the lower number of valves, and the O_2 was with the highest number of valves. The pressure gauge (discharge in gas generator) was the biggest, according to the lower number of valves. The biggest gas consumption was approx. 6 m^3/h.

Keywords: gas fuel from agricultural waste; generator gas; gas generator technology; internal combustion engine; parametric control

1. Introduction

Agricultural waste processing for energy purposes is an absolute necessity for the contemporary production combined with the agri-processing economy. Applying "green technologies" in process production cycles and a production of waste recycling leads to a decrease in production costs and enhances a general environment-friendliness in the production plant location zone [1–4].

An effective post-production recycling requires considering the agri-processing waste as a homogenous technological process in which all the process stages are interrelated and coordinated, starting from receiving process waste for the final use of materials, products, and resources acquired during the agri-production waste processing [5–9].

An alternative for the traditional natural fertilizer and agricultural waste biogas processing technology can be offered by gas generator technology. Its advantages can include low weight and size characteristics parameters, a high production waste processing speed, and a high adaptability to the input waste material to be processed. There are also disadvantages: a limitation related to moisture and the size of the input material to be processed and a release of thermal energy as a byproduct of technological production process.

With the above in mind, the present research has focused on optimizing the adequately selected gas generator technology elements for agricultural waste post-production processing in gas generators.

Agricultural waste processing uses the devices known as gas generators. Due to the impact of high temperatures at a limited amount of oxidizing agent fed into the reactive zone of gas generators, flammable gas is produced. It is a basic waste processing product. Generator gas can be used as gas fuel for heat generators or as engine fuel for reciprocating internal combustion engines. As a gas generator technology byproduct, some amount of thermal energy is released. As considered by various specialists, the amount of the thermal energy released in the gasification process is from 25–30% of the thermal energy which can be used for immediate burning of the equivalent amount of waste [10].

The experimental prototypes and brought-to-serial-models commercial designs of gas generators for gas production from agricultural waste and carbon-combining biomass, as well as the energy modules for electricity production applying the reciprocating internal combustion engine powered with the gas generator, are proposed for use by some manufacturers [11–15]. A technical and commercial success of a gas generator with energy modules is, to much extent, conditioned by the implementation of a full technological process automation. Loading and feeding solid fuel to the gas generator, ash removal and generator gas purification system control processes, the control of the process, operation parameters, and operation conditions of the reciprocating IC engine energy module have been automated.

The problems of a variation in the chemical composition and a low calorific value of gas produced in gas generators in various operation conditions were partially alleviated by the designers with the use of a higher number of cylinders in the energy module. For example, in the energy module provided by ENTRADE Energiesysteme AG, a six-cylinder gas module (reciprocating IC engine) with the working capacity of 4.3 L, operating according to the Otto cycle and coupled with the electrical generator with the output power of 25 kW, has been provided [12]. In the energy module by ALL POWER LABS, there has been applied a four-cylinder reciprocating IC engine with the working capacity of 3.0 L, adapted to the operation with gas fuel and coupled with the electric generator with the input power of 15 kW [11]. Similarly, to increase the power and reaction of the reciprocating IC engine throttle with changes in the load of electric generator, a double-engine power-supply system (a diesel cycle) was applied [12].

The byproduct of the gas generator and energy module is a release of thermal energy. To increase the thermal energy conversion efficiency coefficient, some devices are equipped with thermal energy reactors used to heat water and the premises [11–14]. For the process of gasification in the gas generator, no thermal energy collected in the recuperators is used.

Interestingly, all the gas generators are applied to operate with a specific fuel type: fuel briquettes, pellets, etc. The characteristics of those fuels are specific: moisture, ash content, size, volumetric weight, etc. Standardization and unification of solid fuels applied in the gas generator facilitate technological process automation, simplifying the regulation and technical control. With the deviations in fuel characteristics against the optimal parameters assumed for the technological calculations when designing the gas generator,

the performance quality parameters of the gas generator gas characteristics get deteriorated. The calorific value of gas decreases and the tar content increases [5,10,15].

The imperfections of gas generators and energy modules call for researching a dynamic gas generator gasification process control; both in terms of the control of the supply of the oxidizer to the reactive gas generator zone and in terms of the organization of the gasification process and the conditions of generator gas production and consumption by the energy module.

The amount and the conditions of the supply of oxidizer to the reactive gas generator zone affect the qualitative composition of generator gas. The studies of the gas generator design-and-technology parameters optimization facilitated developing the methodology and parameter algorithms for the control of the supply of the oxidizer to the reactive gas generator zone [5]. The technical novelty of the solutions proposed for the planar and volumetric parametric control (static, dynamic, synchronized, dynamic asynchronized) is attested to with invention patents no. 2555486 and no. 257536 RU of the Russian Federation [16,17]. The approval of the control algorithms developed for the cooperation of the reciprocating internal combustion engine and gas generator system confirms a good adaptation of the gas generator for various kinds of agricultural waste [5,18]. The problem of using the byproduct thermal energy from the gasification process in the gas generator is partially solved by applying the thermal energy from the gas generator to heat up the oxidizer [19,20].

The aim of the article is to conduct the practical statistical, dynamic, synchronic, and dynamic asynchronous nozzles blowing nozzle valve control modes. The research is conducted according to changes in the chemical composition of the generator gas produced. The dynamic synchronic gas generator nozzle control mode without compensation devices is also studied as a part of the research. The above study helps to develop the essential advancement in thermal agricultural waste processing technology.

2. Materials and Methods

The study of the cooperation of gas generator and the reciprocating IC engine has shown an inertia of the gas generator during gas production. It has a negative effect on the dynamic characteristics of the reciprocating IC engine electric generator. With the reciprocating IC engine overload due to limiting the gas supply, there is a decrease in the electric generator rotor rotation frequency, which leads to a deterioration of the quality of the electrical energy produced. The electric generator load is probabilistic and so the engine control system and the gas generator eliminate the causes and it cannot react in advance. Partially limiting the gas generation process inertia is possible thanks to the overloading air contour in the gas generator [11]. In the present experiments, its application facilitated shortening the transition time of the engine gas generator with the load from 120 s to 8 s and a maximum decrease in the number of rotations of the electric generator rotor from 2700 min^{-1} to 2310 min^{-1} [13].

Another variant of enhancing the dynamic characteristics can be a reciprocating IC engine supply system with generator [15,21]. Figure 1 shows a system diagram. The device cooperating with the engine includes:

- Gas generator consisting of air collector 1, cylindric gasification chamber 2, charging feeding inlet with a closing mechanism 3, solenoid valve system 4, gas discharge cap 5, air discharge tubes 6, gas container 7, thermal insulation jacket 8, external protective casing 9, set of nozzles 10, ash grate 11, ashpan 12, supports 13, process discharge opening 14.
- Generator gas purification and cooling system which consists of vacuum sensor 15, gas pre-purification filter 16, cooler capacitor 17, thorough gas purification filter 18, vacuum sensor 19.
- Compensation system which consists of rotating compressor 20, electric motor 21, gas flow direction switch 22, gas check valve 23, compressor 24, temporary pressurized generator gas storage container 25.

- Reciprocating IC engine supply system which consists of gas reducer with security and control elements 26, mixer 27, air filter 28.
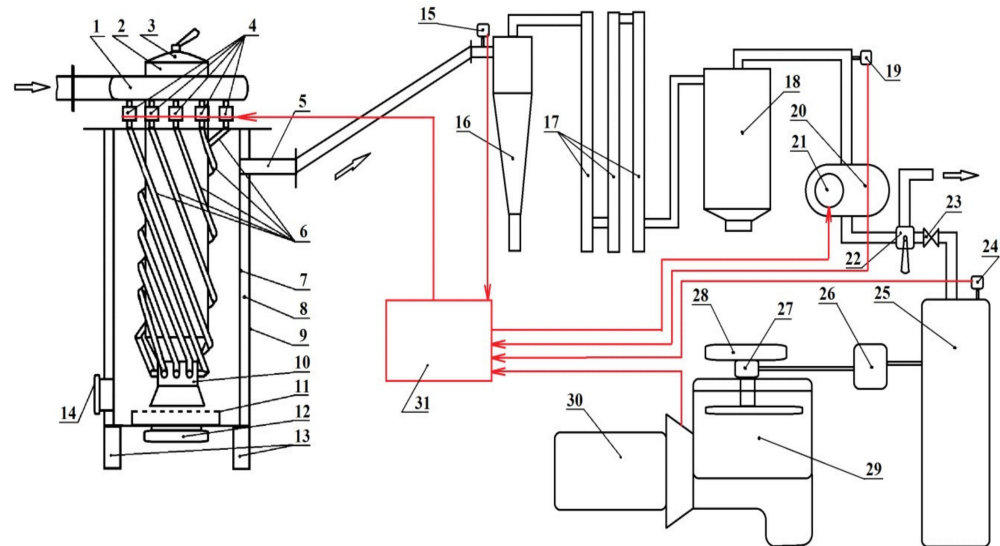- Reciprocating internal combustion engine 29, electric generator 30 and control unit 31.

Figure 1. Diagram of gas generator system cooperating with reciprocating IC engine- own study. 1—air collector, 2—cylindric gasification chamber, 3—discharge opening with a closing mechanism, 4—solenoid valve system, 5—gas discharge cap, 6—air discharge pipes, 7—gas container, 8—thermal insulation case, 9—external protective casing, 10—nozzle set, 11—ash grate, 12—ashpan, 13—supports, 14—process discharge opening, 15—vacuum sensor, 16—gas pre-purification filter, 17—cooler capacitor, 18—thorough gas purification filter, 19—vacuum sensor, 20—centrifugal compressor, 21—electric motor, 22—gas flow direction switch, 23—gas check valve, 24—compressor, 25—overpressure generator gas transition collector, 26—gas reducer with security and control elements, 27—mixer, 28—air filter, 29—reciprocating IC engine, 30—electric generator, 31 control unit.

The gas generator starts its operation from filling in the gasification fuel. Then, the gas generator ignites, and the control block gives a signal to all the solenoid valves to get open and to the electric motor of the rotating compressor to start, to ensure underpressure in the gas generator. The atmospheric air, passing through a joint air collector, solenoid valves, and air-supplying pipes, passes through the nozzles to the gasification chamber into the nozzle tape zone. The reaction zone temperature increases. As soon as the gas generator reaches the working parameters and flammable generator gas flows through the gas discharge valve, the gas stream switches from the gas discharge valve to the transition overpressure generator gas collector. The compressor creates overpressure in the transition gas storage collector controlled with the manometer. Gas flows from the collector to the reciprocating IC engine through the gas reducer with the protection and control elements to the mixer. The reciprocating IC engine cooperating with a given gas generator starts up.

During the operation of the reciprocating IC engine with the gas generator, it is possible to change the operation conditions dependent on the external effects on the system. To lower the dependence of physicochemical generator gas properties on the conditions and the volume of its production, to ensure an accurate and operative regulation of the amount of the gas fed under any reciprocating IC engine operation conditions, and an improvement of its power, economic, and eco indicators under transitional operation conditions and overloads, the control block formulates the algorithms of operation of:

- The gas generator, depending on the gas consumption and the rotation frequency of the reciprocating IC engine crankshaft during the time-controlled range, after a change in pressure in the transitional collector with increased pressure and in the rotation

controller by changing the number and the distribution of gas generator nozzles in gas and the use of their cyclic operation mode.

- The compensation system, depending on the variation in the parameters of input and output vacuum pressure indicators of the generator gas purification and cooling system, an increase in the vacuum pressure variation will point to the pollution of a given system. To compensate an increased system purification and cooling resistance, the control block makes an adequate correction in the rotating compressor operation conditions to increase its efficiency.

The use of the centrifugal compressor in the gas generator to power the reciprocating IC engine with the gas generator with an electric motor and the container for a transient storage of pressurized gas generator facilitates optimizing the gas generator operation. Depending on the reciprocating IC engine operation conditions and load, it improves its operation conditions. In transition conditions, at the expense of the use of generator gas from the container at a change in the generator operation conditions, it enhances the engine cylinder filling with gas by resistance compensation in the gas purification and cooling system, and it increases the efficiency of the rotating compressor as compared with the engine gas demand.

Physical and mechanical structure (density, dimensions, adhesive properties) of agricultural waste varies. For gas generator waste processing to be effective, organizing various gasification process variants is necessary. It is partially possible in gas generators with parametric control [11,12,22]. For the optimal gasification process characteristics, irrespective of the indicators and the type of the input material (agricultural waste), the gasification process must use not only the thermal energy of the gas generator but also the thermal energy of the reciprocating IC engine cooperating with the gas generator. Similarly, to eliminate the effects of bridging, the gas generator must have two degrees of freedom.

With the above in mind, a gas generator design has been developed [16]. Figure 2 presents a device diagram.
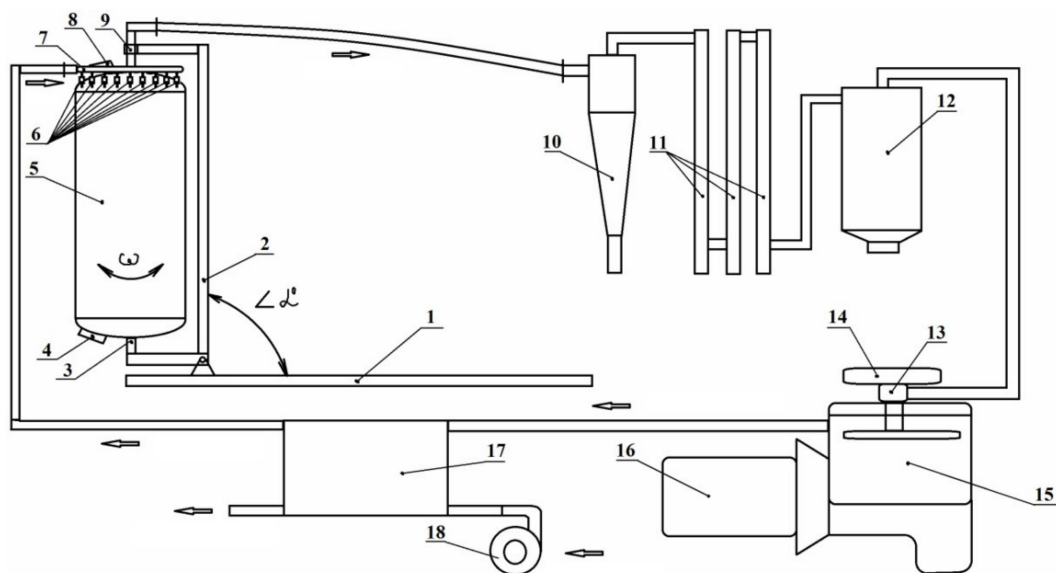

Figure 2. Design of the gas generator system, cooperating with the reciprocating IC engine—own study. 1—foundation, 2—mobile frame, 3—support, 4—ashpan, 5—gas generator core, 6—solenoid valve system, 7—air collector, 8—loading chute, 9—support, 10—gas pre-purification filter, 11—capacitor, 12—gas purification filter, 13—mixer, 14—air filter, 15—reciprocating IC engine, 16—electric generator, 17—recuperator, 18—gas generator.

The device cooperating with the reciprocating IC engine consists of base 1, mobile frame 2, which, thanks to the inclination angle change mechanism, facilitates a change in the gas generator core position 5 in the space by angle α in the 0–90° range, supports 3 and

9, facilitating the gas generation position change in space at the angular velocity from tens to thousands of rotations per hour with a rotary mechanism, ashpan 4 and loading chute 8, and solenoid valve system 6, combined with the general air collector 7. Each solenoid valve is connected to the air supply pipe with the blowing nozzle at the end. Generator gas from the gas generator is supplied to the gas pre-purification filter 10, then it moves into the gas cooling capacitor 11, and then to the thorough gas purification filter 12. The reciprocating IC engine 15 receives the generator gas with the mixer 13 and the air through the air filter 14. The characteristics of the reciprocating IC engine load are cohesive with the electric generator 16. The exhaust gases of the engine are directed to the recuperator 17, where the atmospheric air is heated up and directed to the gas generator. There is also a ventilator where the initial gas ignites 18.

In the gas generator cooperating with the reciprocating IC engine, there is a two-stage system of heating up the atmospheric air directed to the gas generator:

- The first stage; heating up the recuperator air with reciprocating IC engine flue gas.
- The second stage; heating up the heated air with physical heat of the generator gas during its flow through the air discharge pipes in the gas generator core.

Depending on the physicochemical properties of solid fuel for gasification (dimensions, density, adhesive properties), it would be possible to change the gas generator position by angle α, which allows for the gas generator gasification chamber to apply various gasification methods (superficial, layer, in the pseudo-fluidal bed, etc.) thanks to the control of the amount and position in the gas generator blowing into the nozzle planes.

Together with the change in angle α, to prevent the effects of the formation of vaults and uneven supply of solid fuel to the reactive zone of gas generator when suspended or in a rapid fall, it would be possible to change the gas generator position in space at angular velocity ω.

The gas generator operates as follows: it is filled in with fuel. Then, the gas generator ignites, all the solenoid valves open, and the electric motor of the ignition fan is started. The atmospheric air goes through the recuperator and it is directed through the common air collector, solenoid valves, and air pipes, then it goes through the blowing nozzles to the gasification chamber in the nozzle tape region, where it starts interacting with charcoal.

The temperature in the reaction zone increases. Once the gas generator achieves the operation conditions, from the discharging cap, combustible generator gas flows and a gas stream switches from the gas discharge cap to the reciprocating IC engine, and the ignition fan stops. Then, the reciprocating IC engine cooperating with a given gas generator is started.

3. Results and Discussion

The dependence between the consumption and the chemical composition of the generator gas acquired from the gas generator was studied [5]. A change in the uptake of the gas generator gas by the customer, with a lack of the parametric gasification process control, leads to a change in the rate of the air outflow from the blowing nozzle, a decrease in its impact, and it finally limits the "far-reaching property" and interferes with the homogeneity of the temperature field in the generator gasification chamber of the nozzle zone plane. The chemical composition of the generator gas (CO, CO_2, and O_2 components) and underpressure in the gas generator, depending on the gas uptake by the user, is presented in Table 1.

For the experiments, birch charcoal was used at a fixed number of solenoid valves (k = 6).

Table 1. Change in the chemical composition of generator gas depending on its uptake.

Effect (System Reaction)				Cause
CO, %	CO_2, %	O_2, %	Vacuum Gauge (Discharge in Gas Generator), kPa	Consumer Gas Consumption, m^3/h
16.2	3.04	0.9	−8.33	V_1 = 5.7
15.9	4.1	1.1	−6.37	V_2 = 4.6
15.6	4.3	1.35	−4.21	V_3 = 3.2

The approval of the static control mode shows that the change in the number of working solenoid valves leads to a change in the characteristics of the operation of the gas generator system, a gas appliance. At a constant speed of the rotations of centrifugal compressor (for the ranges of a single experiment), the production of generator gas decreases due to an increase in resistance in the gas generator. There is also a change in the chemical composition of gas in terms of CO, CO_2, and O_2 carriers. The results of the experiments of the control of solenoid valve with the air blown in a static mode are presented in Table 2.

Table 2. Change in the chemical composition of generator gas in the gas generator depending on the number of electromagnetic valves operating.

Cause	Effect (System Reaction)				
Number of Valves, pcs	CO, %	CO_2, %	O_2, %	Pressure Gauge (Discharge in Gas Generator), kPa	Gas Consumption, m^3/h
6	16.2 [a,b]	3.04 [a,b]	0.9 [a,b]	−8.33 [a]	5.7 [a]
5	16.1 [a]	3.56 [a]	0.9 [a]	−8.92 [a]	5.1[a]
4	15.8 [a,b]	4.08 [a,b]	0.9 [a,b]	−9.8 [a]	4.6 [a,b]
3	15.6 [b]	4.24 [b,c]	1.18 [b]	−11.76 [a]	3.3 [a,b]
2	15.1 [c]	5.3 [c]	1.48 [c]	−12.74 [a]	2.5 [b]
6	15.9 [a,b]	4.1 [a,b]	0.7 [a,b]	−6.37 [a]	4.6 [a]
5	16.2 [a]	3.62 [a]	0.8 [a]	−6.86 [a]	4.2 [a]
4	15.9 [a,b]	4.42 [a,b]	0.9 [a,b]	−7.84 [a]	3.8 [a,b]
3	15.8 [b]	4.18 [b,c]	1.18 [b]	−8.82 [a]	3 [a,b]
2	15.1 [c]	5.04 [c]	1.6 [c]	−9.31 [a]	2.2 [b]
6	15.6 [a,b]	4.3 [a,b]	1.35 [a,b]	−4.21 [a]	3.2 [a,b]
5	16.6 [a]	2.74 [a]	0.68 [a]	−4.9 [a]	2.9 [a,b]
4	16.1 [a,b]	3.5 [a,b]	0.85 [a,b]	−5.09 [a]	2.6 [a,b]
3	15.2 [b]	5.06 [b,c]	1.1 [b]	−5.78 [a]	2.4 [a,b]
2	14.8 [c]	5.76 [c]	1.4 [c]	−6.17 [a]	2 [b]

[a,b,c]—homogeneus group.

Table 2 show the mean values for the evaluation of the process parameters of the changes in the chemical composition of generator gas in the gas generator, depending on the number of electromagnetic valves operating. As part of the analysis of the obtained results, the parameters of the fermentation mixture process were analyzed. During the parameter evaluation, the ANOVA method with Duncan's post-hoc test was used. This method allowed the determination of the influence of the analyzed parameters among themselves. In statistical analysis, the STATISTICA computer program was used. The expected marginal means that characterized the influence of fermented material on the amount of obtained biogas were determined. Statistical analysis confirmed a relationship between the analyzed factors. In a specific case, the ANOVA analysis allowed the influence of individual factors on the initial parameter to be determined by classifying homogeneous groups and mutual relationships of the analyzed parameters. In all cases, the critical level of significance determining the assignment to a particular homogeneous group was below 0.05 (5%). The significance level p showed a lower value than the established level ($p < 0.05$)

for the empirical value of the statistics F (9, 20) = 119.56. All of the results of the ash statistical analysis are presented in Table 2.

As a part of statistical analysis, especially, the post-hoc test helps to divide factors into homogeneous groups, which were also missing in the article. A very interesting observation concerning gas consumption, m^3/h, is presented above. The test divided data into two groups and statistically proved that a number of valves were involved in the gas consumption. The empirical value of the statistics F (4, 10) = 3.0421, for the significance level p, was 0.06994, showing statistically significant differences in the impact of number of valves on the gas consumption. The number of valves has no statistical effect on the pressure gauge (discharge in gas generator) during gas production.

The application of a dynamic synchronic blowing nozzles control mode results in pressure fluctuations in the gas system, caused by fluctuations in the flow rate of the oxidizer supplied to the gas generator. It leads to a development of the oscillation processes at the generator gas receiver, e.g., an oscillation of the rotational speed of the reciprocating IC engine crankshaft. Limiting the effect of the oscillation processes conditioned by the application of dynamic synchronic conditions of generator blowing nozzles control on the generator gas receiver is possible with the intermediate receiver for generator gas collection [14]. In addition, it is possible, to some extent, to increase the pulse frequency controlling the solenoid valves, namely, increasing the frequency of the operation of solenoid valves. It is, however, limited by the design speed of the solenoid valve.

As for the practical application, a dynamic asynchronous blower control mode is most interesting. The control system is a symbiosis of a static and dynamic control system. It allows for eliminating a static control mode—a heterogeneity of the temperature field in the gasification chamber nozzle tape plane as well as a defect of a dynamic synchronic regulation mode, a pressure pulsation in the generator, and the generator gas flow pulsation. It is possible thanks to a reasonable selection of the valve operation and the time of shifting the operation of a single valve against the other one [5].

Further studies on agricultural waste gasification technology advancement are performed using the experimental gas generator [16,17]. Figure 3 presents a impact of number of valves on the gas consumption. Figure 4 presents a general outline of the gas generator, as well as production waste which can be used as material for gas generator gas production. The gas generator is equipped with a system of parametric control of oxidizer supply to the reaction zone in the gas generator and two degrees of freedom of the gas generator mobility in space. Figure 5 presents a change in the position of the gas generator core in space by angle α.
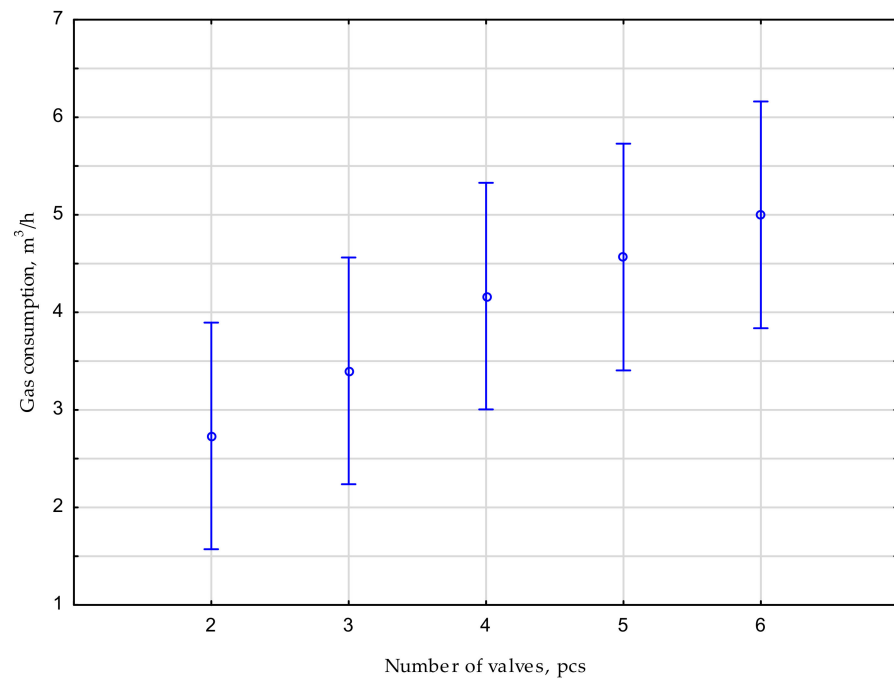
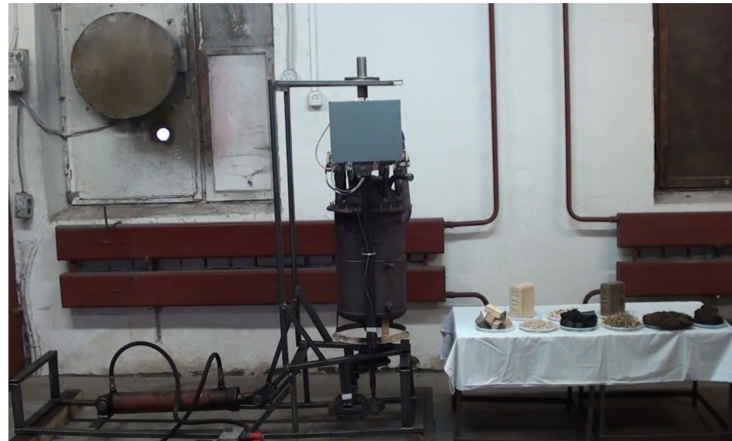**Figure 3.** Impact of number of valves on the gas consumption.

Figure 4. General gas generator image picture.
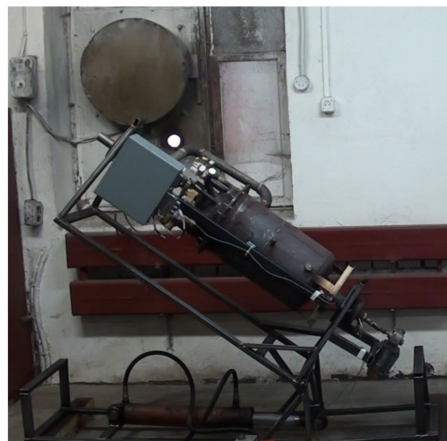

Figure 5. Change in the inclination of gas generator by angle α.

4. Conclusions

With the results of research performed to cover practical statistical, dynamic and synchronic, and dynamic asynchronous nozzles blowing nozzle valves control modes, the following conclusions can be formulated:

(1.)　The most obvious change in the chemical composition of the generator gas produced, with a lack of parametric gasification process control, is found in inconsiderable costs. The analysis of Table 1 facilitates drawing a conclusion that with 1.73-fold limitation of the generator gas consumption by the receiver, there is recorded a 1.038-fold decrease in CO, with a 1.41-fold increase in the content of CO_2, and the amount of oxygen consumption 1.5-fold increased. It means that the energy value of a generator gas volumetric unit decreases due to an increase in the content of incombustible components.

(2.)　The mode which is easiest to use is the static control mode. Limiting the number of the solenoid valves started increases the hydraulic resistance of the gas generator, which results in a decrease in the amount of the gas produced. For example, limiting the number of working solenoid valves from six to two increases the underpressure in gas generator 1.52-fold, with a 2.12-fold decrease in the volume of the generator produced for consumption conditions V_1 (Table 1). In generator gas consumption conditions V_2 (Table 1), the underpressure in gas generator increases 2-fold, and in conditions V_3—1.46-fold, while limiting the volume of the gas produced by 1.58-fold.

(3.)　The dynamic synchronic gas generator nozzle control mode without compensation devices for the accumulation of generator gas is not useful for a practical application, as it results in pressure fluctuations in the gas generator and the gas supply to the customer. The optimal gas generator control process organization variants are dynamic asynchronous blowing nozzle system control conditions, specific for static and dynamic synchronic conditions.

(4.)　An essential advancement in thermal agricultural waste-processing technology can be accomplished with a comprehensive use of the control systems of parametric oxidizer supply to the reactive gas generator zone, a spatial gas generator core positioning, and a recuperation of thermal energy of the gas generator and the reciprocating IC engine cooperating with it, as well as the use of compensation and accumulation systems of gas supply to the customer.

Author Contributions: Conceptualization, W.R., P.A.S., K.B., Y.A.P., A.V.P., A.N.K., K.R. and M.R.; methodology, W.R., P.A.S., K.B., Y.A.P., A.V.P., A.N.K., K.R. and M.R.; software, W.R., P.A.S., K.B., Y.A.P., A.V.P., A.N.K., K.R. and M.R.; validation, W.R., P.A.S., K.B., Y.A.P., A.V.P., A.N.K., K.R. and M.R.; formal analysis, W.R., P.A.S., K.B., Y.A.P., A.V.P., A.N.K., K.R. and M.R.; investigation, W.R., P.A.S., K.B., Y.A.P., A.V.P., A.N.K., K.R. and M.R.; resources, W.R., P.A.S., K.B., Y.A.P., A.V.P., A.N.K., K.R. and M.R.; data curation, W.R., P.A.S., K.B., Y.A.P., A.V.P., A.N.K., K.R. and M.R.; writing—original draft preparation, W.R., P.A.S., K.B., Y.A.P., A.V.P., A.N.K., K.R. and M.R.; writing—review and editing, W.R., P.A.S., K.B., Y.A.P., A.V.P., A.N.K., K.R. and M.R.; visualization, W.R., P.A.S., K.B., Y.A.P., A.V.P., A.N.K., K.R. and M.R.; supervision, W.R., P.A.S., K.B., Y.A.P., A.V.P., A.N.K., K.R. and M.R.; project administration, W.R., P.A.S., K.B., Y.A.P., A.V.P., A.N.K., K.R. and M.R.; funding acquisition, W.R. and M.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects.

Data Availability Statement: Not applicable.

Acknowledgments: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Fedorenko, V.F. Innowacyjne. In *Innowacyjne Technologie Produkcji Biopaliwa Drugiej Generacji*; FGNU Rosinformagrotech: Moscow, Russia, 2009; p. 68.
2. Federal Classification Catalog of Waste (FKKO) with Amendments and Additions with 24 07 2017. Available online: https://docs.cntd.ru/document/542600531 (accessed on 30 April 2021).
3. Nungniezera, V.V. *Inżynieria-Mechanika Produkcji Rolniczej*; FGNU Rosinformagrotech: Moscow, Russia, 2011; p. 492.
4. Czekała, W.; Gawrych, K.; Smurzyńska, A.; Mazurkiewicz, J.; Pawlisiak, A.; Chełkowski, D.; Brzoski, M. The possibility of functioning micro-scale biogas plant in selected farm. *J. Water Land Dev.* **2017**, *35*, 19–25. [CrossRef]
5. Korotkov, A.N. *Optymalizacja Konstrukcyjno-Technologicznych Parametrów Urządzenia Gazogeneratorowego dla Zwiększenia Efektywności Wykorzystania Odpadów Produkcji Rolnej*; State Eductional Institution of Higher Education: Cheboksary, Russia, 2020; p. 169.
6. Wałowski, G. Multi-phase flow assessment for the fermentation process in mono-substrate reactor with skeleton bed. *J. Water Land Dev.* **2019**, *42*, 150–156. [CrossRef]
7. Domański, M.; Paszkowski, J.; Otroshko, S.; Zarajczyk, J.; Siluch, D. Analysis of energy properties of granulated plastic fuels and selected biofuels. *Agric. Eng.* **2020**, *24*, 1–9. [CrossRef]
8. Jansa, J.; Hradilek, Z.; Modrik, P. Energy rating of biogas station. *Prz. Elektrotech.* **2014**, *90*, 120–123. [CrossRef]
9. Wałowski, G. Development of biogas and biorafinery systems in Polish rural communities. *J. Water Land Dev.* **2021**, *49*, 156–168. [CrossRef]
10. Aleshina, A.S. *Gazyfikacja Biomasy Roślinnej w Gazogeneratorach Gazu ze Złożem Fluidalnym*; State Eductional Institution of Higher Education: Sankt Petersburg, Russia, 2013; p. 165.
11. All Power Labs. Carbon Negative Power & Products. Carbon-Negative ENERGY. From Biomass-Powered Gensets. Available online: http://www.allpowerlabs.com/wp-content/uploads/2016/09/APL_2016catalog_9_5_16Small.pdf (accessed on 30 April 2021).
12. Pieriedieriy, S. Ponowne Przesyłanie Generatorów Pelletu w Zdecentralizowanej Energii. № 2 (116). 2016. Available online: https://lesprominform.ru/media/_protected/journals_pdf/1414/lesprominform_116.pdf (accessed on 10 April 2021).
13. Pieriedieriy, S. Zdecentralizowana Energia Oparta na Biomasie Drzewnej. № 3 (117). 2016. Available online: https://lesprominform.ru/media/_protected/journals_pdf/1415/lesprominform_117.pdf (accessed on 8 April 2021).
14. Boyarov, O.D. Przemysłowy Generator Gazu Mini-CHP na Biomasę (Odpady Drzewne): Technologia, Sprzęt, Doświadczenie w Użyciu na Przykładzie Indii i Perspektywy Zastosowania w Rosji. Available online: http://www.combienergy.ru/stat/1045-Promyshlennye-gazogeneratornye-mini-TEC-na-biomasse (accessed on 17 April 2021).
15. De, S.; Kumar Agarwal, A.; Moholkar, V.S.; Thallada, B. Coal and Biomass Gasification. In *Recent Advances and Future Challenges*; Springer Nature Singapore Pte Ltd.: Singapore, 2018; p. 521. ISBN1 978-981-10-7334-2. ISBN2 978-981-10-7335-9. [CrossRef]
16. Ostretsov, V.N.; Zubakin, A.S.; Palichyn, A.V.; Korotkov, A.N. Gazogenerator. Russian Federation Patent. No. 2555486, 11 July 2013.
17. Ostretsov, V.N.; Zubakin, A.S.; Palichyn, A.V.; Korotkov, A.N.; Kipriyanov, F.A.; Rassvetalov, A.S. C10J3/20 (2006.01). Gazogenerator. Russian Federation Patent. No. 2575536, 20 February 2016.
18. Savinyh, S.; Palichyn, A.V.; Ivanovs, S.; Korotkov, A. *Investigation of Possibility to Utilise Agricultural Waste in Gas Generator with Parametric Process Control*; Engineering for Rural Development: Jelgava, Latvia, 2020; pp. 1349–1354. [CrossRef]
19. Korotkov, A.N.; Palichyn, A.V.; Savinyh, S. *Problems of Intensification of Animal Production Including Environment Protection and Alternative Energy Production as well as Biogas*; Monograph under the scientific editorship of prof; Wacław Romaniuk: Warsaw, Poland, 2019; pp. 82–87.
20. Plotnikov, S.A.; Ostretsov, V.N.; Kipriyanov, F.A.; Palichyn, A.V.; Zubakin, A.S.; Korotkov, A.N. Układ Zasilania Gazem Generatora Dla Silnika Spalinowego. Russian Federation Patent. No. 2605870, 6 December 2016.
21. Plotnikov, S.A.; Zubakin, A.S.; Ostretsov, V.N.; Plotnikova, Y.A.; Palichyn, A.V.; Korotkov, A.N. Urządzenie Gazogeneratorowe. Russian Federation Patent. No. 2696463, 1 August 2019.
22. Savinykh, P.A.; Kipriyanov, F.A.; Palitsyn, A.V.; Zubakin, A.S.; Korotkov, A.N. A New Device for Energy Recovery from Carbon-Containing Waste and Plant Biomass. *Pet. Coal* **2020**, *62*, 516–524.