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Research of Generator Gas Preparation System for Gas Usage as Motor Fuel.

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----------***ABSTRACT***----------
Rapid growth of part of decentralized electricity generation, associated with usage of renewable energy sources for its production, is one of the main areas of modern development of power generating systems. Article deals with the technology of electric energy production with using prepared biomass g gasification. Requirements of manufacturers for quality of gaseous fuels are given in the case of using it as a motor fuel in modern engines. The methods of determining content of polluting components in gas, data on composition of condensate, selected from the generator gas are presented. Gas purification scheme is designed for use of solid residues from gasification process of prepared biofuels. Results of the analysis of sorption properties of coke-ash residue and results of gas purification with its usage as a filter are presented. Results of the complex for production of electric energy by gasification method and its ecological indicators are presented.
Keywords *- electricity, renewable energy sources, biomass, gasification.*

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I. INTRODUCTION

Normative value of technological expenses of electric power for its transmission and supply in electric networks of all classes of voltage in Ukraine is 12.8% [1]. According to the Ministry of Energy and Coal Industry, electricity generation in Ukraine's combined energy system (UES) in 2017 amounts to 155 billion 414.2 million kWh. Thus, 19 billion 893 million kWh were lost during the transportation process. One way to reduce losses is to reduce intermediate chains between power plants and consumers of electricity, which is provided by distributed generation. The Ministry of Energy and Coal Industry of Ukraine considers fact that in developed countries of the world development of distributed generation and renewable sources paid more attention [2].

Since the 1990s, Europe gradually switches from centralized energy supply on fossil fuels and nuclear power plants to a decentralized system based on low power (sometimes periodic), generation and cogeneration from renewable energy sources. This approach provides for more active participation by consumers who themselves become manufacturers, and also contributes to more efficient management and rapid response to changes in their own energy usage. This is a profound change caused by combination of several areas:

- increasing share of renewable energy sources in the energy balance of European countries. Planned increase in the share of renewable energy in energy balance is up to 20% in 2020;
- ensuring more efficient use of energy. Energy losses are planned to decrease by 20% by 2020;
- enhancing the security of Europe's energy supply in order to compensate for the increased share of periodically operating energy sources;
- growth of electricity demand in all European countries, as well as liberalization of energy markets in Europe.

II. GAS GENERATORS FOR ELECTRIC ENERGY PRODUCTION

Evolution of energy supply system will influence the methods of generation control and structure of energy value determination, from production to consumption. One of the promising ways of producing electricity from biofuels is usage of gasification to provide operation of internal combustion engines. This is a well-known technology that has become widespread in years that preceded the Second World War, and some time after it [3]. At the end of the war, more than 500 thousand cars operated on a generator gas from wood were used only in Germany only. Unfortunately, transferring experience of gas preparation, which was distributed in those days, to modern engines is only possible in part. Levels of operating temperatures and compression rates, technological solutions used to create modern engines require higher quality gas preparation than was the case in the past. Requirements for engine reliability have also changed significantly. For comparison, average mileage before

capital repairs of pre-war trucks (GAZ, ZIS) is 60 ... 95 thousand km and the modern cars produced by same enterprises (GAZ, ZIL) - 200 ... 250 thousand km. The motor resource of modern stationary piston machines used as a drive for generators is 50 ... 90 thousand hours. It is clear that fuel quality, with which these engines work, plays a crucial role in ensuring their reliable operation.

Taking into account the necessity of qualitative preparation of gas obtained during gasification process, various systems for purification of such gas have been developed. So in the 1960s the Soviet Union developed a method for generating gas [4], built on scheme "gasification - dust deposition - cooling of gas - centrifugal separation of tar - foam separation-clean-up of gas." But, despite the industrial introduction of this method, it has not received distribution.

In future, purifying system was usually developed separately from gas generators. For example, you can give a way to cool and clean hot gas [5], which includes pre-softening, steam cooled and rinsing with water. To implement this method, an installation comprising a nozzle scrubber and a circular scrubber, an atomization tube, and two separators installed in series with a circular gap clearance scrubber are used. This method is characterized by technological complexity and low quality of cleaning, which limits the possibility of using generator gas as fuel in industrial transport and power generation plants (Table 1).

Most manufacturers limit maximum content of tar and solid residues in the fuel at 50 mg / m^3, limiting also content of alkali metals (<1 mg / m^3), chlorides (<10 mg / m^3), ammonia (<50 mg / m^3) and compounds containing sulfur (<100 mg / m^3) [6]. At the same time, some manufacturers place more stringent requirements on the content of resins.

Table 1. Technical characteristics of the proposed methods.

Parameter	Patent RU №2091135	Tech. Forest-chem. Productions	Standards for ICEs
Tar in gas, mg/m^3	70	120	50
Dust in gas, mg/m^3	40	90	50
Relative humidity of gas, %	100	100	-
Content, mg/m^3: -chloride -ammonia -sulfur compounds	Depends on fuel	Depends on fuel	 10 50 100

Problems with quality of generator gas preparation, despite the support for development of electricity production from renewable sources, significantly restrict distribution of gas-generating systems, which remain a rarity.

One example of a successful power plant is a 2.3 MW installed system using the GE Jenbacher J620 engines in Gössing, Austria. In order to ensure reliable operation, the content of tar in crude gas at a level of 1500-4500 mg/m^3 due to a complex treatment plant (Fig. 1) was reduced to 10-40 mg/m^3. Technological chain, implemented at the cogeneration complex in Gössing, provides:

- pyrolysis of wet (45 ... 50%) wood chips in a boiling layer using as an intermediate coolant of heated sand containing about 1% Ni;
- cooling of gaseous fuel in a heat exchanger of a superficial type;
- cleaning of gaseous fuel from dust (ash residues and residues of destruction of sand) using a filter;
- flushing of gaseous fuel with diesel fuel, which is made from biological raw materials;
- supply of gaseous fuel to internal combustion engines.

The applied method of purification has proven its efficiency and, despite the high operating costs associated with need to compensate for cost of biodiesel, has become an important link in technology of generator gas preparation. This technology is now widely used in industrial and research facilities, designed for production of electricity through biofuel gasification.

In Ukraine, today there are only a few experimental plants for a gas generator-piston machine for generating electricity. One such plant was created at the Institute of Gas of the National Academy of Sciences of Ukraine on the basis of departments of technologies of alternative fuels and gas technologies. The gasification of the prepared biofuels is provided by a reverse wave gas generator. Usage of this technology can provide the production of a generator gas with tar content close to 100 mg/m^3 [7], which facilitates its further preparation for use as motor fuel. Usage of reverse gasification process makes it possible to simplify its further purification by using nozzle filters for this purpose. The idea of such an approach is based on the properties of coke-ash residue (Table 2) and the assessment of contaminants inclusions ratio in generator gas and volumes of this residue formation.

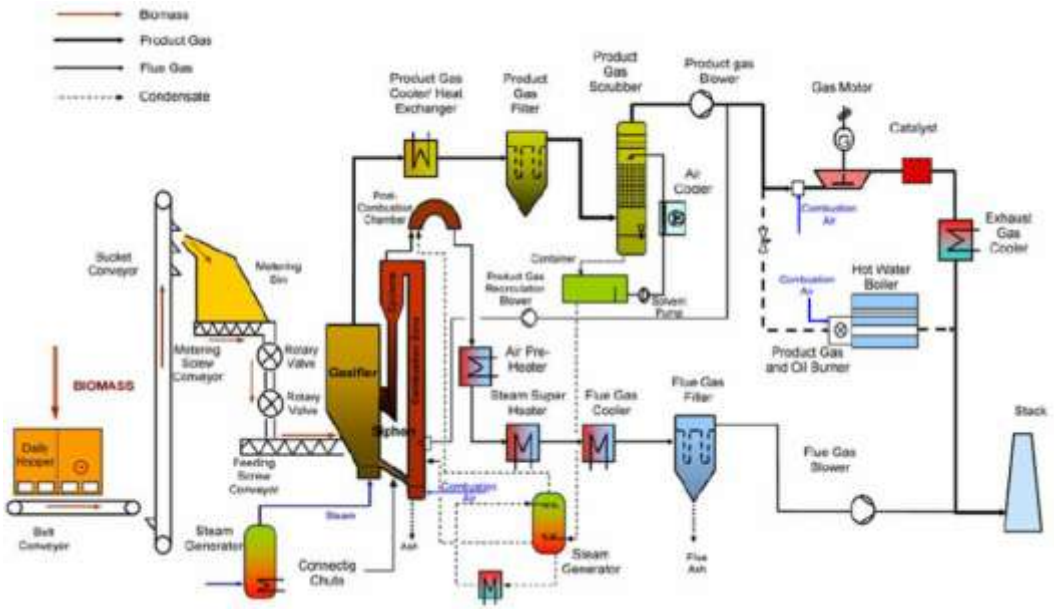

Fig.1 Technological scheme electricity generation of from biomass by its gasification in Gösing, Austria During operation of reverse wave process gas generator, developed in Institute of Gas, on prepared wood produces a coke-ash residue, which amounts to about 10% of weight of input material. Thus, from about 1 ton of biofuel, about 100 kg of coke-ash residue is formed.

Table 2. Results of analysis of coke-ash residue sorption properties after wood gasification

№	Parameter	Value
1	Humidity %	0,92
2	pH 1%	7,6
3	Bulk density, g /cm^3	0.12
4	Specific volume of pore over benzol, cm^3/g	2,712
5	Specific volume of pore over water, cm^3/g	0.21
6	Lighting capacity for methylene blue,%	55
7	**Specific adsorption on oil, g/g**	**10,2**
8	**Engine oil capacity g/g**	**9,75**
9	**Capacity for diesel fuel g / g**	**11,34**
10	The residue on the sieve is 0.063 mm,%	99.1
11	The residue on the sieve is 0.18 mm%	2,78
12	Ash, %	0,45
	The main components of the ash residue	
1	Content Si%*	3,7
2	Content Ca %*	22,9
3	Content Zn %*	0,18
4	Content Fe %*	0,98
5	Content P %*	0,07

At the same time, amount of condensate formed during the gasification of biofuels corresponds to the moisture content of source fuel. That is, in a gas made from one ton of wood with a moisture content of 10 ... 12%, condensates about 100 kg of moisture. Selection and study of substances composition contained in the generator gas was carried out according to the methodology developed by scientists of the Kingdom of the Netherlands [8] using the installation, the principal scheme of which is shown in Fig. 2

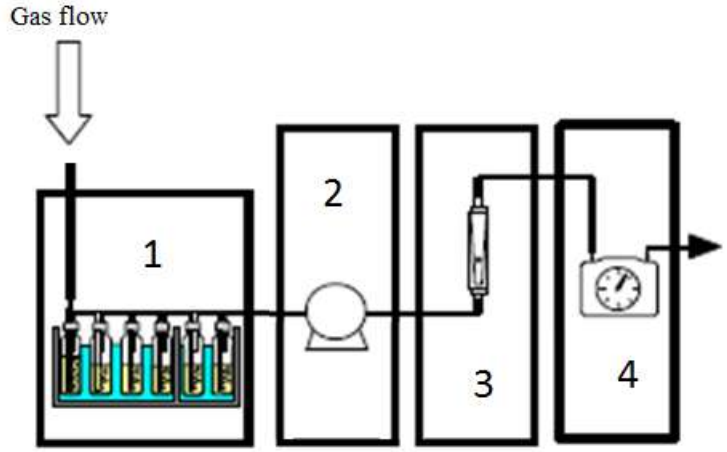

Fig.2 Principle diagram of setting measurement of condensate content in gaseous fuels. Designation: 1 - condensate deposition module, 2 - vacuum pump, 3 - rotameter; 4 – volume flowmeter.

The results of the analysis of condensate carried out on the Shimadzu-2010QP chromatomass spectrophotometer showed condensation contamination with acids, phenols, aromatic and boundary hydrocarbons (Table 3). To use this gas as a motor fuel, it is necessary to remove the inclusions included in composition of condensate, followed by its disposal. Best method for such recycling is thermal destruction - burning.

III. GAS INSTITUTE GAS GENERATOR GAS PURIFYING SYSTEM

Generator gas, which is formed in the reverse gasification process, has a high temperature. The lowering of the temperature of gas necessary for its further use as motor fuel is complicated by the fact that generator gas is a dusty stream containing water and a gaseous tar. As a result, during the cooling process, water and tar condense, eliminating heat-exchange equipment. In the technology of gas preparation proposed by Institute of Gas [9], the problem of removing dust, resins and moisture from the gas is carried out by a complex of equipment, scheme of which is presented in the scheme (Fig. 3).

Table 3. Composition of condensate formed during wood gasification

№	Components	Units of measurement	Value
1	Water	% (mass)	97,5
2	Acids		
	- ant's	% (mass)	0,1
	- acetic	% (mass)	0,05
	- fumarov	% (mass)	0,05
3	Phenols		
	- Phenol	% (mass)	0,4
	- cresol	% (mass)	0,2
	- hydroxybenzoic acid	% (mass)	0,1
4	Heterocycles		
	- furfural	% (mass)	0,05
	- methylfurfural	% (mass)	0,05
	- оксиметилфурфурол	% (mass)	0,05
5	Aromatic hydrocarbons		
	- azulen	% (mass)	0,05
	- naphthalene	% (mass)	0,05
	- benzene	% (mass)	0,01
6	Boundary hydrocarbons (C17-C28)	% (mass)	1,34

Seeing the problems of gas cleaning, general principle scheme of complex purification system, shown in Fig. 4, was developed.

The developed system of purifying generator gas works as follows: after working in the gas generator of the reverse action portion of fuel from the prepared biomass, such as wood pellets, pellets from sunflower husk, and others, they obtain a coke-ash residue having filtering characteristics close to those in activated carbon . This residue falls in the coal filter B.

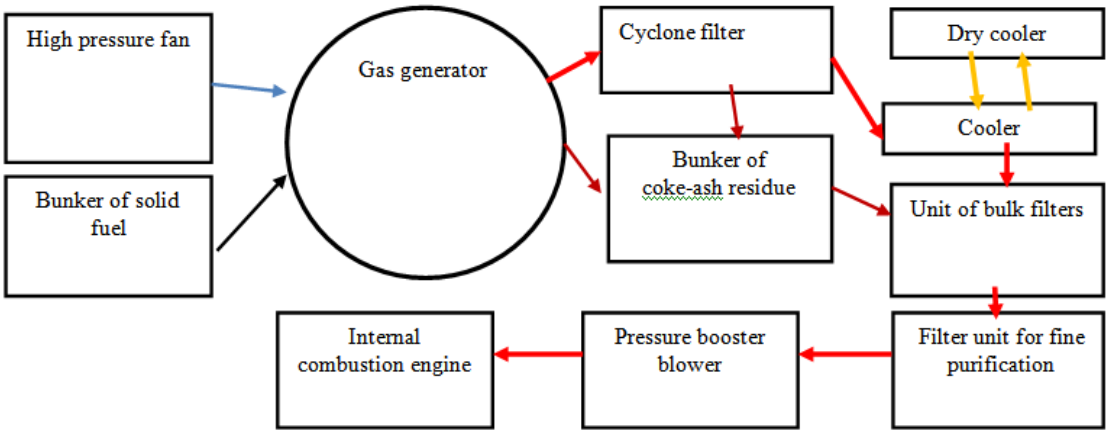

Fig. 3 Principal scheme of production, preparation and usage of generator gas.

During the operation, hot gas from the outlet of gas generator is fed to a coolant-condenser A, which cooled it to 140-200 ° C. In this case, the cooled moisture from gas and part of tar are condensed and through nozzle are drained from the system, heat energy received in heat exchanger is discharged into heat supply system or for technical needs in form of hot water. Cooled gas is fed from condenser cooler to the carbon filter B. When passing through layer of coke-ash residue, gas is further cooled to 100-120 °C and purified from tar to passport standards of gas corresponding to the operation of internal combustion engines. Further, gas is fed to fabric fine filter C. while passing through it, gas detain residual micro dust from the carbon filter. At exit of the block of filters, cooled and purified generator gas is supplied to internal combustion engine or to combustion in units that require pure gas. After completion of work, coke-ash residue, with tar and high caloric content, is fed from filter for combustion into a solid fuel boiler, and filter is filled with a coke-ash residue from next cycle of gas generator operation.

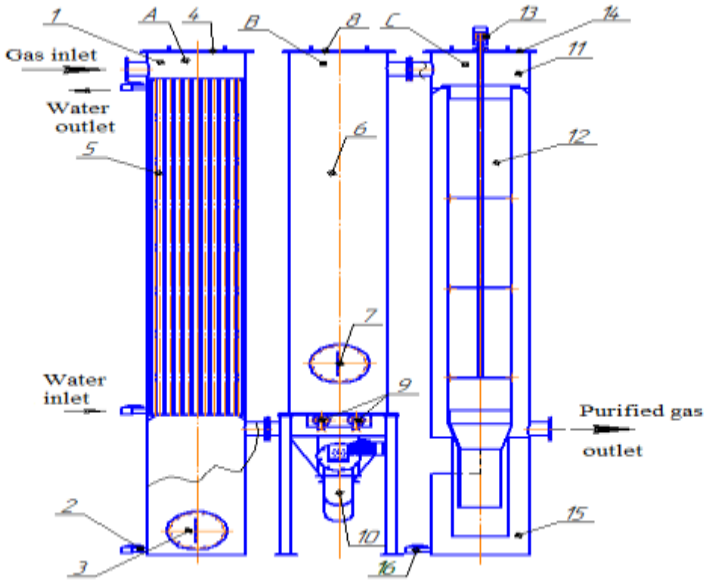

Fig. 4 Gas generator cleaning system.

A - cooler-condenser; B - coal filter; C - fabric filter of fine purification.

Amount of coke-ash residue and condensate produced is equivalent to about 1 kg of condensate per kilogram of solid residue, the total amount of pollutants in which does not exceed 25 g. After using coke-ash residue for gas purification, wetted product is to be burned, or from adding binders to briquet and use as solid fuel, which, after removing excess moisture, exceeds briquettes from fossil fuels - brown coal, peat - according to its energy parameters.

Developed system of filters, after preliminary tests at Institute of Gas of the National Academy of Sciences of Ukraine, was installed on a gas generator in the city of Yelena (Republic of Bulgaria, Bolshaya Tyrnovo), which provides production of up to 210 m^3/h of generator gas from wood. At the beginning of studies,

test of content of tar during the operation of the reverse type gasifier during the work on prepared (humidity 10-12%) crack of softwood species showed a significant dependence of tar content in the gas from the load (Table 4).

Table 4. Characteristics of generator gas from softwood and technical characteristics of reverse gas generator in the city of Yelena.

№	Parameter	Air flow rates, m^3/h		
		90	120	150
1	Heat of combustion, MJ/m^3 - Higher - Lower	 5,45 5,12	 4,97 4,63	 4,30 4,10
2	Generator gas flow rate, m^3/h	142,7	174,2	206,8
3	Capacity of the gas generator, kW	203,0	224,1	235,3
4	Tar content, mg/m^3	10560	4240	980
5	Solid fuel consumption, kg/h	64,0	68,0	71,0
6	Efficiency of the gas generator,%	71,5	74,5	75,0

Operation of the gas generator in all tested modes does not provide necessary maintenance of the engine to reduce the content of resins. Work on such gas without preliminary preparation (Fig. 4) in the long-term mode is not possible.

Fig.4 Condition of fabric filter placed in gas line after 20 minutes of operation of gas generator without a cleaning system

Installing developed cleaning system allowed to receive gas, the quality of which meets requirements of engine manufacturers (Table 5). An important indicator of installation operation is the maintenance of the nozzle filter on one charge for a time interval not less than the time of formation of the amount of coke-ash residue necessary to change the nozzle.

Nozzle filter having a filling height of 3.0 m and a 0.6 meter cross section requires about 100 kg of coke-ash residue. When working on a nominal mode, a gas generator generates 7 ... 8 kg of coke-ash residue. Thus, the amount of coke-ash residue necessary for work maintenance is formed no more than in 15 times of complex's operation. Tests conducted within 20 hours showed that weight of the nozzle from ash residue increased by 30.6 kg. The nozzle filter provides two movements of generator gas. Gas is fed to the top of the filter and, moving down, is cleared of tar and moisture. The bottom part provides a turn and gas flow up the other filter channel. Appearance of moisture in bottom of the filter is a prerequisite for refilling the nozzle. The velocity of gas in the filter is 0.4 m/s, which causes a relatively long period of generator gas processing (more than 10 seconds) and a weak removal of carbon particles.

Table 5. Indicators of the work of the power generating complex

№	Parameter	Time from the beginning of the test, h				
		1	5	10	15	20
1	Air flow rates, m^3/h	180	200	188	202	190
2	Fuel consumption, kg/h	70	72	70	74	68
3	Electric power of the complex, kVA	54	56	55	57	53

4	Gas temperature at the entrance to the engine, ^{o}C	32,3	32,6	33,5	34,8	35,3
5	Concentration of tar residues in gaseous fuels, mg/m^3	46	44	48	47	50
6	Changing the weight of the carbon nozzle, kg					30,6

Worked out residue from nozzle, relative humidity of which is 30%, is mixed with condensate from the bottom of the cooling heat exchanger. For 20 hours of testing 175.1 kg of condensate was formed. Absorption of such a quantity of contaminated water by a carbon nozzle results in an increase in its relative humidity to 67.3%, which, even at high energy indices of the coke-ash residue, makes it a very low-value and problematic fuel. Improvement of formed residue quality is possible in case of its granulation and drying using the excess heat energy generated during operation of the internal combustion engine. Components of the heat flow - heat from cooling shirt, utilization of exhaust gases heat and oil cooling in engine lubrication system. Drying of cake-ash residue briquette not only increases its energy performance, but also improves its organoleptic characteristics.

Additional cooling of the generator gas to 40 °C was made possible by use of a surface heat exchanger and a water circuit, which was used to reduce temperature through additional heat exchanger (Fig. 4) using water of mountain river with a temperature of 6 ... 8 ° C. Providing such a cooling level when working from a dry cooler requires a significant increase in heat transfer area, taking into account surface contamination during operation of the equipment.

Fig. 4. Water-water heat exchanger for discharging excess heat from the cooling circuit of the generator gas.

Main indicators of the power generating system are its power and efficiency. In course of adjustment works, power of 57 kVA was reached, which is about 75% of the rated payload. Unfortunately, it was not possible to achieve the nominal performance of installation because of limitations of the gas generator power. Complex showed reliable work and, thanks to usage of a modern engine, high efficiency. Comparison of results obtained on the test bench of Institute of gas equipped with engine and the FF10 / 8.8, refined to work on gaseous fuels, and installations in the city of Yelena, equipped with the GE08TI GEN-PACK engine showed a higher efficiency of this installation (Fig. 5) At a load of 75% of nominal, efficiency of the plant in relation to energy potential of incoming fuel (wood with a moisture content of 10%) is about 24%. Such an indicator for capacities of less than 1 MW is unattainable for any other technology designed to be used as a solid biofuel energy source.

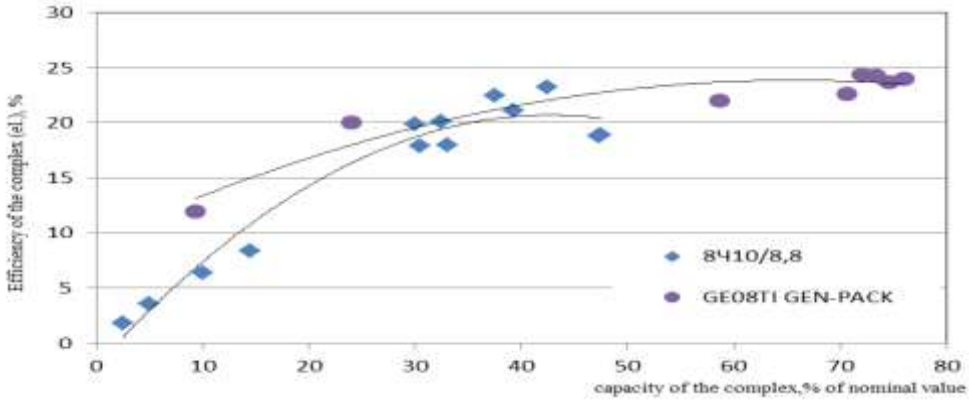

Fig. 5. Dependence of efficiency of the complex "gas generator-internal combustion engine-electric generator" on the power.

IV. ENVIRONMENTAL ASPECT

In addition to reliability and efficiency, one of the important indicators of gas-piston plant operation quality is formation of pollutants during its operation. Main problem of such equipment operation is the formation of combustion gases with nitrogen oxides. Transition to usage of gaseous fuels with low thermal power - generator gas, significantly reduces emission of nitrogen oxides. At the same time, increase in excess air, both in this study and in the results of work [10] leads to a decrease in the concentration of NOx in exhaust gases (Fig. 6).

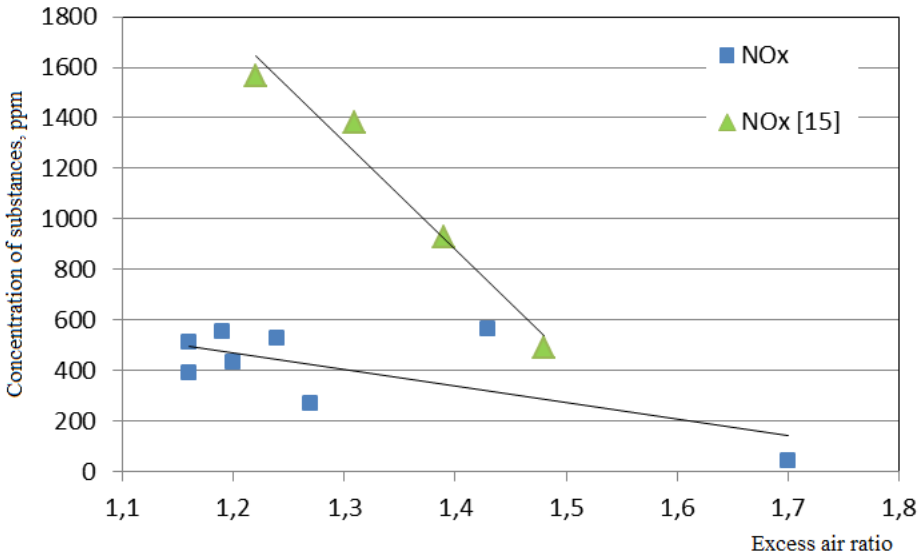

Fig.6. Dependence of nitrogen oxides concentration in the exhaust gases on the excess air in the fuel-air mixture.

Thus, during the operation of the complex, it is possible to select modes that are optimal in terms of efficiency ratio and achievement of satisfactory environmental indicators. Usage of the developed gas purification technology ensures complete utilization of liquid and solid gasification residues. Work in the optimum, relatively excess air, mode, makes it possible to minimize emissions to the atmosphere, ensuring compliance with the norms of Euro-5 (norm: CO - 4,0 g/kWh, NOx - 2,0 g/kWh) as relative formation of CO and NOx for gasoline engines (Table 6). This result is explained by the fact that:

- presence of hydrogen provides a quick ignition of fuel mixture, which is mainly composed of simple molecules, which provides a high degree of burning of fuel components. This ensures low (for internal combustion engines) CO content in the exhaust gases;

- relatively low NOx concentrations are due to the low theoretical combustion temperature of generator gas, which greatly complicates formation of nitrogen oxides.

Achieved results partly correspond to even Euro-6 requirements for stationary spark ignition engines. Euro-6 requirements for CO - 4.0 g/kWh, relative to NOx - 0.4 g/kWh [11]. Thus, results of debugging work on created technological complex confirmed its high environmental performance.

Table 6. Dependence of formation of pollutants in products of combustion of generator gas from power

№	Capacity of the complex,% of nominal value	Emissions, ppm		Emissions, g/kWh	
		CO	NO_x	CO	NO_x
1	2,5	2822	618	2,95	1,06
2	10,0	2952	589	3,08	1,01
3	32,5	2015	575	2,10	0,98
4	37,5	2458	490	2,57	0,84
5	42,5	2472	445	2,58	0,76
6	58,7	2270	336	2,37	0,57
7	76,0	2140	269	2,23	0,50

V. CONCLUSION

Transition to decentralized energy and widespread use of renewable energy sources is one of today's challenges. Developed technology of generator gas preparation has shown its efficiency and provided work of electrogenerating system in the composition of reverse action gas generator - internal combustion engine. A power plant was built in the village of Yelena, Velyka Tyrnovo (Republic of Bulgaria), and electric power of the unit at 57 kVA was achieved. High energy and ecological indicators of the complex are confirmed. Efficiency of the complex in relation to production of electric energy is 24%. Environmental indicators for atmospheric emissions of CO and NOx meet Euro-5 requirements. Method of treatment of waste formed during the operation of the complex is worked out. Method involves absorption of condensate removed from generator gas during its preparation for use, the coke-ash residue of biofuel gasification, followed by use of this product as solid fuel.

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