INVESTIGATIONAL STUDY OF ENVIRONMENTAL PERFORMANCE OF POWER GENERATOR OPERATING ON GENERATOR GAS

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Abstract. The analysis of scientific investigations makes it possible to make a conclusion about the usefulness of the generator gas as a fuel for internal combustion engines of mobile power generators. Under the conditions of agricultural production and in rural areas, the generator gas can be generated from biomass (wood, straw, corn stalks and other plant refuse). The paper recommends to use a gasifier of the reverse process for gas generation. The side of the recovery zone of the gasifier is 200 mm long, and the recovery zone is – 70 mm high. The number of tuyere holes is 20, the diameter of the tuyere holes is 10 mm. The research was conducted in order to determine the effects of the produced generating capacity on generator gas and air consumption, as well as on emissions of greenhouse gases (C_xH_y and CO). The paper shows the nature of the effects of the produced generating capacity on generator gas and air consumption by the engine of a mobile power generator. As follows from the investigation, under the generating capacity, which corresponds to nominal electric generator charge, under the use of generator gas generated from wood CO emission is up to 25 times less, and C_xH_y emission is up to 9 times less as compared to gasoline fuel. While using the generator gas generated from straw, CO emission is up to 25 times less, and C_xH_y emission is up to 4 times less as compared to gasoline fuel. The paper also shows the results of the investigation as to the impact of the engine exhaust supply of a power generator engine into the combustion area of a gas generator on the power generator schedule, as well as on the dynamic pattern of the generated effective power.

Keywords: straw, wood, emission, toxic gases, gasifier.

Introduction

The analysis of scientific investigations makes it possible to make a conclusion about the usefulness of the generator gas as a fuel for internal combustion engines of mobile power generators [1-3]. Under the conditions of agricultural production and in rural areas, the generator gas can be generated from biomass (wood, straw, corn stalks and other plant refuse) [4-5].

Particularly, the researchers checked the operation of a mobile generator, which operated on the generator gas received from biomass. The research data were directed toward the estimation of the performance parameters of a gasifier of the reverse process, particularly, the equivalence ratio effects on the generated gas quality was estimated. Gas consumption by the power generator engine and its ecological performance (toxic gases emissions, in particular) were not estimated.

Technical and economic analysis of the system (a gasifier – a mobile power ganerator), which was made in the research [7-8], makes it possible to show the economic effectiveness of using these systems as compared to using gasoline fuel. But as follows from the research [7], the environmental performance of the power generator was not controlled either. The power generator environmental performance was controlled in the research [8] but only for wood, as that gasifier construction was not suitable for generating gas from straw.

In the research [9] it has been shown that straw can be an available fuel for generator gas production in the EU countries. The energetic independence of agricultural production can be achieved by using straw pellets for generator gas production [10].

Though there are some difficulties when using straw (in particular, solid agglomerates formation) [10-12], there are some constructions, which are able to generate gas from straw [13].

The effects of a gasifier capacity on the generated gas quality were studied in the research [13]. But comparative research with the use of straw and, for example, wood and gasoline fuel, was not conducted. The air consumption depending on the type of fuel and on the received electric capacity was not estimated in the analysed research.

In our opinion, in order to use straw fuel efficiently, it is necessary to determine the effects of the generated capacity on the generator gas and air consumption, as well as on toxic greenhouse gasses emissions (C_XH_y and CO). The researchers [14] consider carbon dioxide (CO) and hydrocarbons (C_XH_y) to be the main pollutants of exhaust gas emissions from gasoline engines.

The research on the effects of exhaust gasses supply from the power generator into the combustion area of a gasifier on the power generator operational state, as well on the changes in the received generating capacity, is interesting with due regards to exhaust gasses utilization.

Materials and methods

An experimental unit (Fig. 1) was used for analysing the performance of a power generator working on gasoline and generator gas.

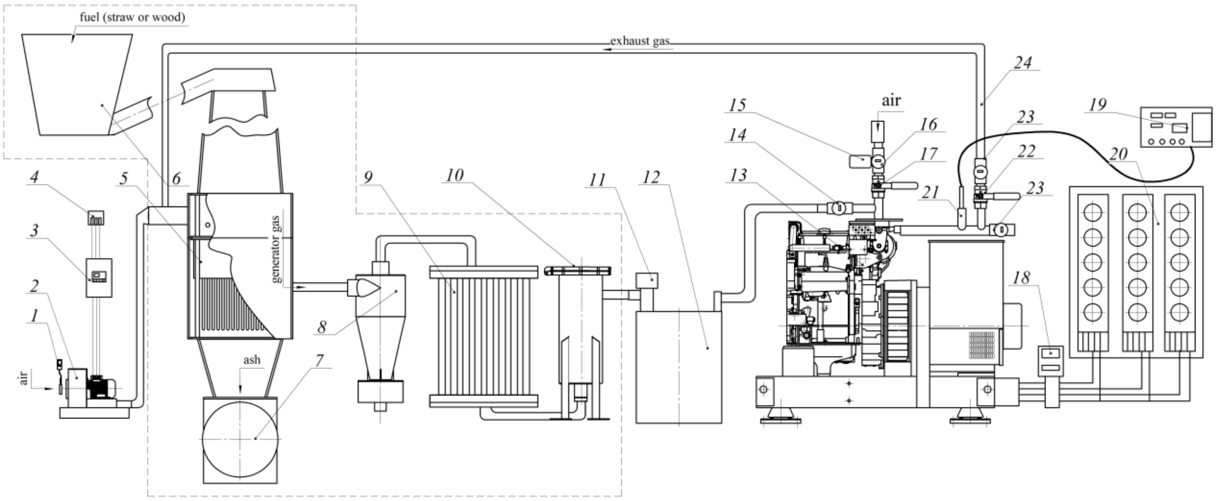

Fig. 1. **Plant appearance and diagram for study of the working process of the generator gas power plant:** 1 – anemometer; 2 – fan for supplying air to the gasifier; 3 – frequency converter; 4 – source of electrical energy 0.4kV; 5 – gasifier; 6 – bunker with a screw for fuel; 7 – ash discharger; 8 – prime filter; 9 – cooler; 10 – fine filter; 11 – valve; 12 – receiver; 13 – power plant; 14 – gas meter; 15 – blower; 16 – air counter; 17 – air supply regulator; 18 – device for measuring current consumption parameters; 19 – exhaust gas analyser; 20 – electric load; 21 – selection of exhaust gas for analysis; 22 – exhaust gas supply regulator; 23 – exhaust gas counter; 24 – exhaust gas pipeline

The experimental unit contained a gasifier of the reverse process. The gasifier has a square workspace in section. Lack of horizontal fire-grate is its characteristic property. Circular air motion in the zone of fuel combustion (described in paper [13]) was formed in the work zone of the gasifier.

The renewal zone of the gasifier was 70 mm high and 200 mm wide and long, respectively. The number of tuyere holes was 20, the diameter of the tuyere holes was 10 mm. A fixed amount of air was supplied into the gasifier (by pumping in) by means of a fan Goorui GHBH-0D5-34-1R2.), 12 liters per second. Under such parameters the received gas had the highest fuel efficiency.

The gasifier was equipped with gas purification filters and a gas cooler. The received gas passed into the internal combustion engine through the receiver and through a special mixer, which can regulate air supply into the engine. The amount of fuel and air consumption by the engine was registered by means of gas meters G-6-RL.

A synchronous generator was used to transform the mechanical energy of the engine into electrical one. An alternative current aggregate AB-4-T/400-M1 was used as an engine and as an electric generator. The given aggregate was supplied with a double cylindrical gasoline engine UDA-25-4, which develops a nominal power 5.9 kW under 3000 rotations per hour of the crankshaft. The power generator had nominal power 4 kW and generated a three-phase current of 220 V. A testing unit for charging the electric generator was made. The testing unit consisted of three variable power blocks (each 1400 kW maximally). The blocks were phase-connected to the generator, the parameters of each phase were controlled by a digital panel meter Socomec Diris A20.

Pieces of wood (10…40 mm long) and straw pellets were used as a raw material for gas generating. Gasoline A92 was used as well (Table 1).

Gasoline consumption was controlled by a weigher, gas consumption – by a gas meter. Gas-analyzer Infrakar-M2T was used to determine CO and C_xH_y concentrations in the exhaust gases of the power generator engine.

Table 1

Characteristics of raw materials and fuel [15]

Raw materials and fuel	Content, %						Lower heating value, $J \cdot kg^{-1}$
	Moisture	C	S	O	N	H	
Gasoline	-	85	-	-	0	15	43960
Wood	8…10	48…50	0…0,05	38…42	1…2	6…6,5	16100…16800
Straw pellets	8…10	43…45	0,1…0,2	41…45	0,5…1,5	4…6	14040…16300

The experiment planning stage included the following steps: factor encoding, scheduling, randomization tests, implementation plan of the experiment, testing the reproducibility of the experiments, calculation of regression coefficients, assessment of regression coefficient significance and test model adequacy. The experiment consisted of 9...13 tests at threefold repetition.

Results and discussion

As follows from the results of the research, the maximal power generator capacity, when using gasoline, equaled – 4 kW (that corresponds to nominal power capacity); when using gas generated from straw, the maximal power generator capacity equalled 3.2 kW (80% of a nominal power capacity) that corresponds with the studies conducted in the research [14], and when using wood, the maximal power generator capacity equalled 2.7 kW (67.5% of the nominal power capacity). Lower power capacity can be explained by a lower heat value of fuel. Using gas generated from straw makes it possible to achieve by 18.5% higher power capacity than when using gas generated from wood (Fig. 2).

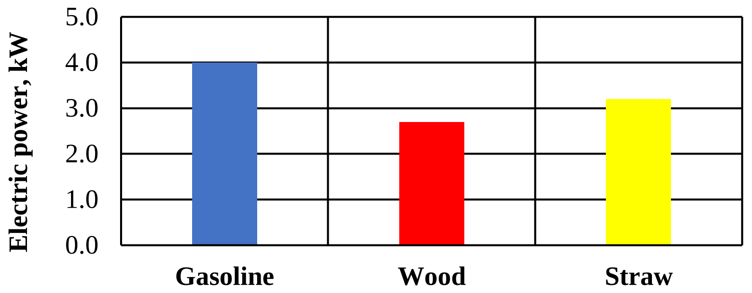

Fig. 2. **Maximal power generator capacity**

Air consumption by the engine of the power generator increases as the electric power capacity increases. When achieving maximal power capacity, the air consumption, when using gasoline, equals 0.44 $m^3 \cdot min^{-1}$, when using gas generated from straw, it equals 0.30 $m^3 \cdot min^{-1}$ and when using gas received from wood, it equals 0.37 $m^3 \cdot min^{-1}$. (Fig. 3, Table 2).

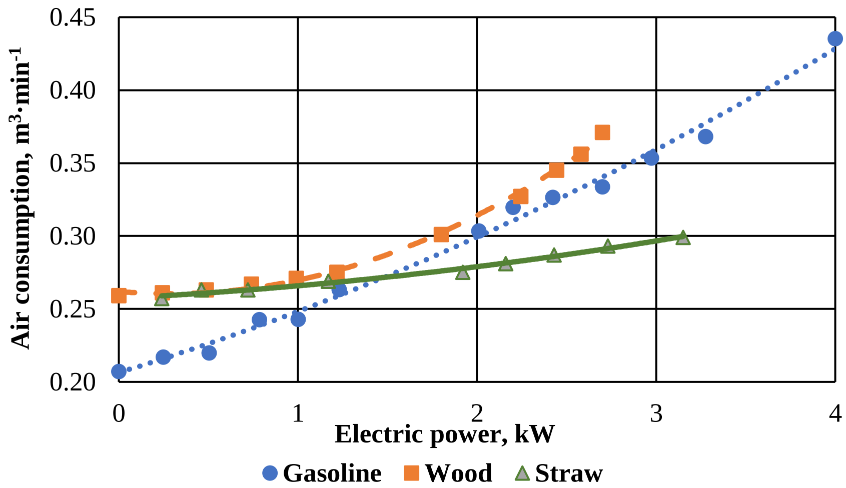

Fig. 3. **Air consumption**

For comparison, under the power capacity of 2.5 kW, the air consumption, when using gasoline, equals 0.33 $m^3 \cdot min^{-1}$, when using gas generated from straw, it equals 0.29 $m^3 \cdot min^{-1}$ and when using gas received from wood, it equals 0.35 $m^3 \cdot min^{-1}$.

Air consumption for gasoline and gas generated from wood is nearly the same, and it is a bit lower for gas generated from straw. It is necessary to admit that air consumption for gases consists of air consumption by the power generator engine as well as by the gasifier.

Table 2

Air consumption

Raw materials and fuel	Empirical equation	Confidence level
Gasoline	$A = 0.0045P^2 + 0.0373P + 0.2064^*$	0.98
Wood	$A = 0.0183P^2 - 0.0106P + 0.262^*$	0.98
Straw pellets	$A = 0.0023P^2 + 0.0062P + 0.2574^*$	0.97
where A – air consumption, $m^3 \cdot min^{-1}$; P – electric power, kW; *The equations are adequate in the range of power values from 0 to 4 kW		

Fuel consumption for gasoline increases when the capacity increases and it equals 43 $g \cdot min^{-1}$ under maximal capacity. Gases consumption increases in a parabola. For a maximal capacity the consumption for gas generated from straw equals 0.36 $m^3 \cdot min^{-1}$, for gas generated from wood the consumption equals 0.35 $m^3 \cdot min^{-1}$ (Fig.4, Table 3). The increase in fuel consumption can be explained by the adjustment of the fuel supply system of the power generator engine to using gasoline.

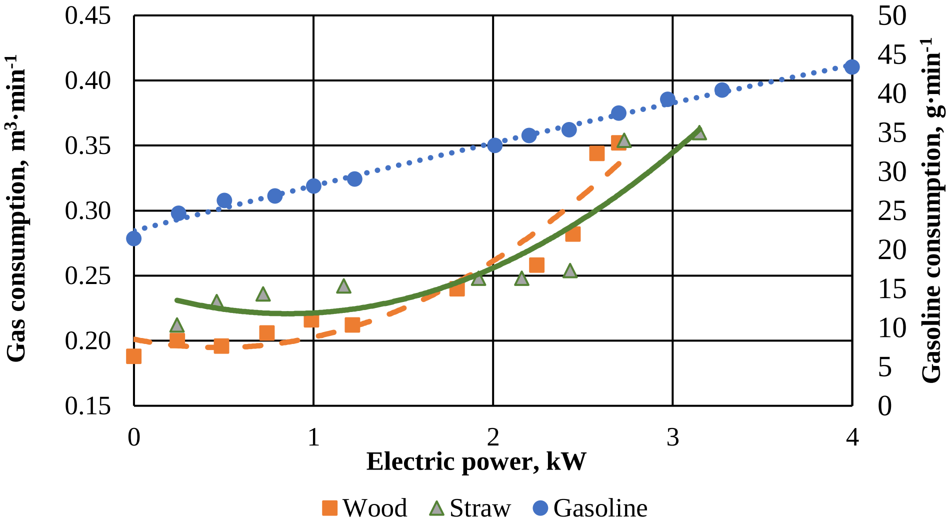

Fig. 4. **Fuel consumption**

The content of CO in exhaust gases of the power generator engine when using gases is significantly lower than when using gasoline. Under maximal capacity, CO content for gasoline equals 8.1% (Fig. 5), for gas generated from straw it equals 0.24% (by 34 times less), for gas generated from wood it equals 0.14% (by 58 times less).

For gasoline and for gas generated from wood CO content does not depend on the capacity, generated by the power generator. For gas generated from straw, when the capacity increases, CO content in exhaust gases decreases. It happens as a result of improving the gas quality when a gasifier works under optimum operation, that corresponds with the research [14]. It is necessary to mention that CO content in emissions from modern gasoline engines can reach 5% [16].

The content of CxHy in exhaust gases of the power generator engine for gases is also significantly lower than that for gasoline. Under maximal capacity, the content of CxHy for gasoline equals – 310 mln-1 (Fig. 6), for gas generated from straw – 62 mln-1 (by 5 times less), for gas generated from wood

– 24 mln-1 (by 13 times less). It is necessary to mention that CxHy content in emissions from modern gasoline engines can reach 250 mln-1 [17].

Table 3

Fuel consumption

Raw materials and fuel	**Empirical equation**	**Confidence level**
Gasoline	$G = 5.348P + 22.721$	0.99
Wood	$Z = 0.0285P^2 - 0.0269P + 0.2011$	0.92
Straw pellets	$Z = 0.027P^2 - 0.0463P + 0.2407$	0.83

where G – gasoline consumption, $g \cdot min^{-1}$;
Z – gas consumption, $m^3 \cdot min^{-1}$;
P – electric power, kW
*The equations are adequate in the range of power values from 0 to 4 kW

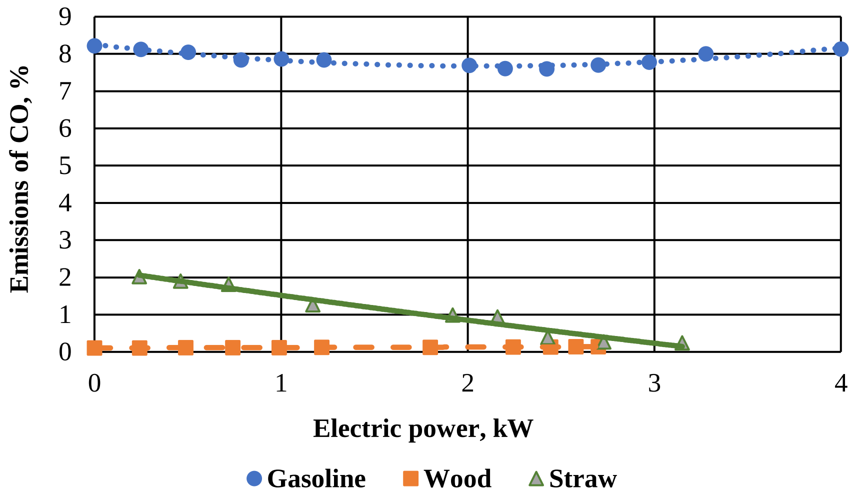

Fig. 5. **Emissions of CO**

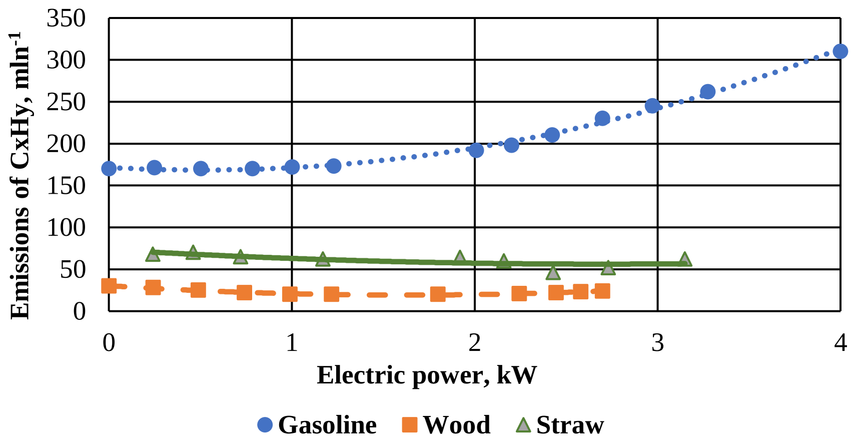

Fig. 6. **Emissions of C_xH_y**

The research in the effects of exhaust gas supply of the power generator engine into the combustion area of the gasifier on the generated electric capacity was conducted (Fig. 7).

The research showed that when supplying exhaust gases into the combustion area of the gasifier, the power output of the generating station decreases even under insufficient concentrations of exhaust gases at the inlet into the gasifier.

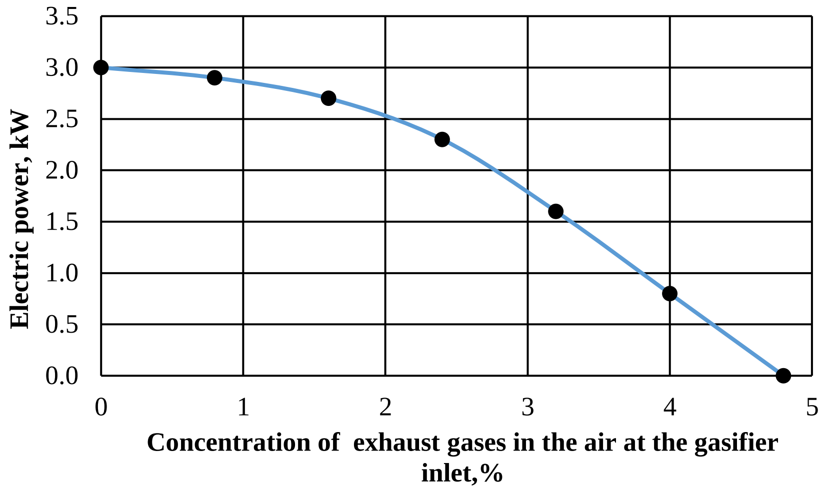

Fig. 7. **Effects of exhaust gas concentration in the air at the gasifier inlet on the operational state of the generating station**

Conclusions

1. Maximal power generator capacity, when using gasoline, equals – 4 kW (100% of nominal power capacity); when using gas generated from straw, maximal power generator capacity equals 3.2 kW (80% of nominal power capacity), and when using wood, maximal power generator capacity equalled 2.7 kW (67.5% of nominal power capacity).
2. Fuel consumption for gasoline increases, it equals 43 $g \cdot min^{-1}$ under maximal capacity. For maximal capacity the consumption of gas generated from straw equals 0.36 $m^3 \cdot min^{-1}$, for gas generated from wood the consumption equals 0.35 $m^3 \cdot min^{-1}$. Air consumption for gasoline equals 0.44 $m^3 \cdot min^{-1}$, for gas generated from straw it equals 0.30 $m^3 \cdot min^{-1}$ and for gas received from wood it equals 0.37 $m^3 \cdot min^{-1}$.
3. The content of CO in exhaust gases of the power generator engine for gases is significantly lower than that for gasoline. Under maximal capacity, CO content for gasoline equals 8.1%, for gas generated from straw it equals 0.24% (by 34 times less), for gas generated from wood it equals 0.14% (by 58 times less).
4. The content of C_xH_y in exhaust gases of the power generator engine for gases is also significantly lower than that for gasoline. Under maximal capacity, the content of C_xH_y for gasoline equals – 310 mln^{-1}, for gas generated from straw – 62 mln^{-1} (by 5 times less), for gas generated from wood – 24 mln^{-1}(by 13 times less).

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