Alternative power resources in the motor vehicles supply

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Abstract. The rapid development of engineering, technology and mass motorization during the transition to the fourth industrial revolution is accompanied by negative processes in ecosystems and leads to a change in the economic paradigm - to the circular economy. Reducing resource consumption while decreasing the growth of waste production and consumption will reduce the negative load on the environment. The search for global solutions to ensure comfortable living conditions on the planet is determined by minimizing the adverse environmental impact of solid industrial and household waste (MSW). The article presents a new technology of energy- and resource saving in automobile transport using MSW as an alternative fuel and exhaust gas cleaning filters for internal combustion engines, that will allow to reduce pollution by the slowly decomposing polyethylene of the world ocean, which is now becoming a global scale catastrophe.

1. Introduction

Industry 4.0 assumes the rational use of natural and technical resources. Energy from waste in the programs Industry 4.0 is an important factor in improving the ecological purity of the environment and the quality of life of the population of cities [1-4].

The fourth industrial revolution in Europe is taking place under conditions of accelerated growth in the vehicles fleet with internal combustion engines, especially diesel ones, which causes a significant deterioration in air quality in urban agglomerations. The most negative impact on the state of the air environment have emissions of nitrogen mono- and dioxide in the exhaust gases of internal combustion engines, including those using natural gas as a fuel. Nitrogen oxides, possessing high toxicity, are able to form even more toxic complexes and play a significant role in the formation of photochemical red fogs (smog), which is observed in many cities with developed industry (especially in summer with low airflow through streets and avenues) [5-10]. Hazardous chemicals and other pollutants (for example, plastic waste) are still produced in large volumes. They are universally present in the human body and the environment and accumulate in stocks of raw materials and products. According to the World Health
Organization, in 2016, the burden of disease due to exposure to individual chemicals was estimated at 1.6 million lives (this estimate is likely to be underestimated).

Research of United Nations Environment Assembly and partner’s estimations showed that in 2014 about 280 million tons of plastic (polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC)) were produced, and only a small percentage of its waste reused. Instead, plastic, which has lost its consumer properties, found its last refuge in the world ocean, thus causing damage to marine ecosystems, equal to several billion dollars annually, since they are not biodegradable in the marine environment. It was found that under marine conditions, fragmentation occurs rather slowly and can take up to 5 years, during which the ocean continues to be fouled with plastic garbage (Figure 1). In recent years, plastic micro-particles (0.1–5 mm in diameter) are becoming more and more disturbing, since they often become food for marine organisms, including birds, fish, mussels, worms, and zooplankton [11-12].

The fourth session (Nairobi, 11–15 March 2019) of the United Nations Environment Assembly made disappointing key findings on the Global Chemicals Outlook II. The global goal to minimize the adverse effects of chemicals and waste will not be achieved by 2020. This task can be accomplished, but this requires urgent and more ambitious actions by all interested parties around the world. Thus, the creation of industries for the processing of solid industrial waste, for example, polyethylene, with the production of additional marketable products in the form of power generator gas is relevant task.

Figure 1. Clogging the ocean with plastic garbage.

2. The purpose of the work
Reducing the temperature of the mixture in the combustion zone. It is the most important measure for the disposal of industrial waste, aimed at reducing the concentration of harmful substances in any equipment for burning solid, liquid and gaseous fuels and in internal combustion engines.

3. Methods of achieving the goal
The use of synthetic combustible gas on the basis of generator gas, obtained from solid industrial and household wood waste, including with the addition of polyethylene waste, both in mobile and stationary gas-generating installations, can be taken as a promising direction.

The use of alternative sources of motor fuel has its own history. Thus, the Second World War, the “war of motors,” as it was later called, required a tremendous strain on all sectors of the national economy, including oil-producing ones. At the same time, the lion's share of liquid fuel (in all the belligerent countries, and not only in the USSR) was directed to the needs of the front, to provide armoured formations, aircraft, and the navy. But at the same time, economical gas-generating trucks, tractors, and truck tractors [13–14] were perfectly suited for the needs of the rear. Currently, the use of gas generators in the CIS countries is often presented as evidence of "poverty" and industrial "backwardness". Meanwhile, such power plants were used much more in Europe in general, and in Germany in particular, especially after the start of the Second World War [15].

In 1936 in Western Europe there were about 10 thousand gas-generating motor vehicles. With the outbreak of hostilities, their number increased by more than 50 times. Only in Germany there were almost 300 thousand of such trucks, and they were used in the Wehrmacht as logistic support vehicles.
and in military transport connections. Figure 2 presents the Volkswagen Type 82 car with a box engine and a gas generator operating on wood (1944) [16].

Figure 2. Volkswagen Type 82 (Kübelwagen).

According to the technical data, Volkswagen KdF-11 ("Volkswagen Käfer"), produced since 1933, had a four-cylinder four-stroke air-cooled engine with an opposite arrangement of cylinders in the rear part (engine capacity is 1131 cm$^3$, power - 25 hp, shaft speed - 3300 rev / min, maximum torque - 53 NM. The consumption of gasoline with an octane number of 74 with a compression ratio of 5.8: 1 was 7.5 litres per 100 km of run, and the content of carbon monoxide CO in the exhaust gases during track control was 3.0%. It should be noted that the efficiency was estimated by the ratio of the maximum torque to the working volume in litres and was 4.7 NM / L.

The authors carried out the research and development work to improve the environmental level and fuel efficiency of the Ukrainian people's car ZAZ 968M-005 with a V-shaped four-stroke four-cylinder air-cooled engine located at the rear of the body and having a working volume of 887 cm$^3$. The results of the experimental trips (with a mileage of 20 thousand km) showed that the MeMZ-966G engine had power28 hp and it is achieved at a shaft rotational speed of 4300 rpm, and a maximum torque of 53 NM at a shaft rotational speed of 2700 rpm. With a compression ratio of 6.5: 1, operation on gasoline with an octane number of 72 is differed by an average consumption of 9.2 litres per 100 km of run. The content of carbon monoxide CO in the exhaust gases during track control at traffic police stations was recorded at 3.0%. The serviceability of the conventional MeMZ-966G engine, determined by the ratio of the maximum torque to the working volume of the engine, was 61 NM / L [17].

After upgrading the MeMZ-966G engine in 1997, using its own know-how technology, the authors managed to increase the maximum torque to 83 NM at the same working volume and compression ratio. With a frequency rotation of 2900 rpm, serviceability increased 1.77 times (94 Nm / l) and approached the level of the 1997 PORSHIE 911 with a six-cylinder boxer engine at the rear section. As the long-term operation has shown, due to the engine forcing, the average fuel consumption decreased to 6.5 litres per 100 km, and the carbon monoxide CO content in the exhaust gases during track control decreased to 0.3-1.5% under other equal conditions. Maximum power 39.5 hp was achieved at a shaft rotational speed of 4300 rpm, i.e. increased 1.41 times [18]. Thus, while reducing the fuel consumption, and hence thermal pollution of the environment by 1.5 times, the level of CO emissions also decreased by 2-10 times with different operating modes of the MeMZ-966G engine.

At the same time the conducted pilot experiments on the recirculation of energy supply showed the prospects of using both liquid and gaseous motor fuels at the automobile transport unit. It will ensure a reduction in consumption of liquid motor fuels by 3-4 times while reducing emissions of toxic substances with exhaust gases. A significant disadvantage of using conventional technology for converting automobiles with gasoline engines to generator gas derived from wood waste is the inevitable drop in torque on the output shaft and power by 50% or more, under all other equal conditions. It leads to a loss of speed and actual load capacity transportation of goods and passengers.

The later calculations for similarly designed engine structures ZMZ-53, MeMZ-966G, Volkswagen Type 82, D240 showed the possibility of increasing the torques after the transition to the low calorific value generating gas produced on the modernized gas generator [19].
Figure 3. Traction characteristics of the GAZ-53 car when working on gasoline and generator gas:

ordinary gasoline, ordinary gas-generating gas, the proposed gas-generating gas.

Figure 3 shows the actual traction characteristic (the dependence of the thrust force \( P_k \) on the speed \( V \)) of a GAZ-53 car with a ZMZ-53 engine running on gasoline.

For comparison, the calculated traction characteristics are presented for the same vehicle with the ZMZ-53 engine converted to a conventional gas generator on wood and after upgrading using know-how technology and operating on a gas generator on a mixture of solid wood and polyethylene waste.

The analysis showed that when the GAZ-53 car is converted to a conventional generating gas, its dynamics fall by 33%, while after the proposed modernization of the engine and gas generator it can grow by 17%, all other equal conditions.

4. The research results and discussion

The following outlines the basics of a simplified justification of ways to improve gas-generating processes with using different types of solid fuels based on the principles of heat engineering [20].

The heat of combustion of a wide range of organic substances depends on the elemental composition in% and is well determined by the D.I. Mendeleev formula:

\[
Q_i = 0.34 C + 1.03 H - 0.11(O - S) - 0.025 W, \text{MJ/kg}.
\]  

An approximate stoichiometric equation for the combustion of methane in a mixture with air in an engine with an excess coefficient \( \alpha = 1.0 \) is:

\[
CH_4 + 2 \cdot (O_2 + 4N_2) = CO_2 + 2H_2O + 8N_2 + Q_1, \tag{2}
\]

It is known from heat engineering that when “burning” 1 m3 of air and burning organic fuel, 3.8 MJ of heat is released, and when methane is burned, according to the formula presented, heat will be released in a volume of 860 MJ, which is equivalent to the heating value of natural gas at 38 MJ / m3.

For comparative calculations of the change in the process of converting an automobile engine to mixed types of fuel, an approximate formula of gasoline of \( C_8H_{18} \) on isooctane type with a specific density of 692 kg / m3 and calorific value of 44 MJ / kg was taken.

The approximate stoichiometric equation for the combustion of \( C_8H_{18} \) gasoline mixed with air in an engine with an excess coefficient \( \alpha = 1.0 \) is:

\[
C_8H_{18} + 12.5(O_2 + 4N_2) = 8 CO_2 + 9 H_2O + 50 N_2 + Q_2, \tag{3}
\]

where the calculated value of the released heat will be \( Q_2 = 5310 \) MJ per 114 kg of gasoline when heating the total mass of 1914 kg of burned gases at about 2770°C with an average heat capacity of the process of 1 MJ / kg deg. According to the theory of internal combustion engines, about half of the released heat is consumed on the engine shaft and the temperature of the gases in the cylinders before opening the exhaust valves drops to 1385°C and less, taking into account the heat losses in the walls of the cooled cylinders, piston and combustion chamber. After the exhaust process ending, the exhaust gas temperature drops to 700-900°C when gas enters the silencer system. This was observed in actual
operating conditions of the MeMZ-966G forced engine. Thus, non-production losses of the fuel power carrier exceed 50% or more with a very large level of emission of toxic and greenhouse gases and substances, and thermal pollution of the surrounding air environment due to harmful afterburning of excess hydrocarbons.

An exemplary process for producing generator gas from wood waste with a moisture content of 10% consists in feeding an ordinary gas generator to the reaction zone. This can be represented by a formula adapted to the partial component volume parts of the incoming gases:

\[ 0.054(\text{C}_6\text{H}_{10}\text{O}_5 + \text{H}_2\text{O}) + 0.097(\text{O}_2 + 4 \text{N}_2) = 0.161 \text{H}_2 + 0.209 \text{CO} + 0.092\text{CO}_2 + 0.023\text{CH}_4 + 0.388\text{N}_2 + 0.009 \text{O}_2 + 0.117\text{H}_2\text{O} + Q_3. \]  

(4)

An approximate stoichiometric equation for combustion of a generator gas mixed with air in an engine with an excess coefficient \( \alpha = 1.0 \) is:

\[ 0.161 \text{H}_2 + 0.209 \text{CO} + 0.092\text{CO}_2 + 0.023\text{CH}_4 + 0.388\text{N}_2 + 0.009 \text{O}_2 + 0.117\text{H}_2\text{O} + 0.222 (\text{O}_2 + 4 \text{N}_2) = 0.324 (\text{H}_2\text{O} + \text{CO}_2) + 1.276 \text{N}_2 + Q_4, \]

where the calculated value of the released heat is \( Q_4 = 95 \text{ MJ per 9.7 kg of wood waste under the total mass of the burnt gases is 55.7 kg heated to approximately 1590^\circ \text{C} with an average heat capacity of the process of 1 MJ / kg deg.} \]

According to the theory of internal combustion engines, about half of the released heat is consumed on the realization of the useful torque on the engine shaft, and the temperature of the gases in the cylinders before opening the exhaust valves drops to 795^\circ \text{C} and lower taking into account the heat losses in the walls of the cooled cylinders, piston and combustion chamber. After the exhaust process ending, the temperature of the exhaust gases drops to 350-450^\circ \text{C} when gas enters the silencer and neutralizer system. The estimated calorific value of wood waste in the processing into generator gas in a conventional gas generator will be: \( Q_{\text{ggn}} = 9.85 \text{ MJ / kg.} \)

An exemplary process for producing generator gas from a mixture of 90% solid household wood waste with a moisture content of 10% and 10% polyethylene waste consists in feeding an air to the reaction zone of a conventional gas generator and can be represented by a formula that is adapted to the partial component volume parts of the incoming gases and ethylene:

\[ 0.054(\text{C}_6\text{H}_{10}\text{O}_5 + \text{H}_2\text{O}) + 0.097(\text{O}_2 + 4 \text{N}_2) + 0.076(\text{CH}_2) = 0.161 \text{H}_2 + 0.209 \text{CO} + 0.092\text{CO}_2 + 0.023\text{CH}_4 + 0.388\text{N}_2 + 0.009 \text{O}_2 + 0.117\text{H}_2\text{O} + 0.038 \text{C}_2\text{H}_4 + Q_5. \]

(6)

An approximate stoichiometric equation for combustion of a new generating gas mixed with air in an engine with an excess coefficient \( \alpha = 1.0 \) is:

\[ 0.161 \text{H}_2 + 0.209 \text{CO} + 0.092\text{CO}_2 + 0.023\text{CH}_4 + 0.388\text{N}_2 + 0.009 \text{O}_2 + 0.038 \text{C}_2\text{H}_4 + 0.117\text{H}_2\text{O} + Q_6. \]

(7)

where the calculated value of the released heat is \( Q_6 = 160 \text{ MJ per 10.77 kg of a mixture of 90% wood waste and 10% polyethylene waste under heating a total mass of 85 kg of burnt gases at about 1880^\circ \text{C with an average heat capacity of the process of 1 MJ / kg deg.} \]

According to the theory of internal combustion engines, about half of the released heat is consumed on the engine shaft and the temperature of the gases in the cylinders before opening the exhaust valves drops to 940^\circ \text{C} and lower, taking into account the heat losses in the walls of the cooled cylinders, piston and combustion chamber. After the exhaust process ending, the exhaust gas temperature drops to 380-490^\circ \text{C} when gas enters the silencer and neutralizer system. The calculated calorific value of a mixture consisting of 90% wood waste and 10% polyethylene waste during processing into generator gas in a conventional gas generator will be: \( Q_{\text{ggn}} = 14.7 \text{ MJ / kg. (M. tak: To mixture having 90% wood waste and 10% polyethylene waste during processing into generator gas in a conventional gas generator calculated calorific will be)} \)

The special interest is the changes assessment in the technical and economic indicators of the vehicles conversion from liquid motor fuel to the mixed power consumption of liquid fuel and generator gas. As a baseline, we can take the option of using 114 kg of gasoline for the vehicles operation, in which 5310 MJ is generated.
For the first option (a vehicle with a mixed fuel consumption - 28.3 kg of gasoline and generator gas produced from wood waste), the required mass of wood waste can be determined from the condition for obtaining heat in a volume equal to the difference between the total heat and the heat generated by the gasoline part: \(5310-1335 = 4005\) MJ. Then the estimated required mass of wood waste will be: \(M_w = \frac{Q_w}{Q_{g-g}} = \frac{4005}{9.85} = 420\) kg.

For the second option (using generating gas from a mixture of 90% wood waste and 10% polyethylene waste) the total mass of waste is required: \(M_w = \frac{4005}{14.7} = 278\) kg, of which 251 kg are wood and 27 kg are polyethylene waste.

If for the base case with the fuel price of 1 litre 50 roubles, the fuel cost will be 8250 roubles, then for the first option of mixed consumption of 28.3 kg of gasoline worth 2062 roubles and wood waste worth 1260 roubles. (at a price of 3 roubles / kg), total expenses will amount to 3322 roubles, i.e., 2.48 times less.

And for the second option, it will take 890 roubles on a mixture of wood and polyethylene waste. This in total amounts to 2952 roubles, i.e., 2.78 times less than gasoline.

5. Conclusion

1. The use of gas generators consuming solid waste of wood- and polyethylene-containing origin, as a regenerative source of power carrier when recirculation of exhaust gases, will reduce the temperature of combustion of the fuel-air mixture in the cylinders of the internal combustion engine and reduce emissions of nitrogen oxide and carbon in the exhaust gases.

2. The use of technology forcing engines such as ZMZ-53, MeMZ-966G, Volkswagen Type82, D240, when using the equipment of gas generators, operating on solid waste will allow to compensate the loss of their dynamical properties and preserve the characteristics of motor vehicles and tractors.

3. Modernized transport units with gas generators expand the scope of application and technical and economic indicators of autonomous energy systems operating in remote areas and consuming local types of fuel and solid waste of local production and livelihoods.

4. Modernization of engines can be performed in the sites of operation of transport and technological machines in the conditions of workshops and service stations.

5. The use of gas generator equipment will reduce the consumption of liquid motor fuels by 3–4 times due to the use of local solid fuels and solid waste.

6. The fuel cost for vehicles in the presence of gas generating equipment of recirculation type can be reduced by 2-3 times.

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