Method for forecasting engine indicators for its work on different fuels

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***Abstract**: Analysis of physicochemical and operational performance of petroleum and alternative motor fuels showed that their lower heat of combustion can differ significantly. However, the heat of combustion of fuel-air mixtures of these fuels differs slightly. Therefore, the assessment of energy and fuel-economic performance of the engine during its operation on different fuels is proposed to do the calculation method for the consumption and heat of combustion of fuel-air mixtures. According to the developed method, engine power and fuel consumption during engine operation on biodiesel, biomethane and petroleum diesel fuel were determined. To determine the heat of combustion of fuel-air mixtures, the lower heat of combustion of fuels was used. Fuel-air consumption was determined by engine displacement and crankshaft speed. The tests show that the highest power and lowest fuel consumption of the engine running on petroleum diesel fuel and slightly worse values of the engine running on biodiesel. The gas engine with spark ignition converted from diesel running on biomethane shows the lowest indicators.*

***Keywords:** PETROLEUM DIESEL FUEL, BIOFUEL, HEAT OF COMBUSTION, FUEL-AIR MIXTURE*

INTRODUCTION

Nowadays, each country has a large mobile fleet of agricultural machinery with diesels which operate on diesel fuel from oil. But the price of diesel fuel increases all the time. The environmental situation is deteriorating. One of the main ways out of this situation is adapting of diesel engines to work on alternative fuels [1-3], which include biofuels: bioethanol, biodiesel, biogas, which belong to renewable energy sources and is a product of agriculture. But the implications of alternative motor fuels are ambiguous. This is due to differences in the physico-chemical properties of these fuels.

Energy indicators represent a significant interest in the use of biofuels. Energy efficiency, operation stability of an engine was determined by bench tests of the engine. This process requires of expensive equipment. The aim of the study is to evaluate energy and fuel-economic indicators of the engine working on the biofuels and petroleum diesel oil.

PRERQUISITES AND MEANS FOR SOLVING THE PROBLEM

To find out, biofuels (bioethanol, biodiesel, biogas) will solve this problem, we evaluate the physical-chemical and operational characteristics in comparison with conventional fuels (tabl.1) [4-6].

Table 1. *Physico-chemical and performance characteristics of traditional and alternative fuels*

Index	Diesel fuel (summer)	Compressed natural gas	Bioethanol	Biodiesel fuel	Biogas
Viscosity at 20°C, mm^2/s	3,5–6,0	–	1,76	3,5–8,0	–
Octane number		100–110	106	20–25	115 –
Cetane number	40–45	–	8	50–55	–
Ratio C/H	6,5	3	4	6,5	–
Lower heat combustion MJ/kg (MJ/m^3)	42–43	49–50	25	37–38	17–23
The heat of combustion of the fuel-air stoichiometric mixture MJ/m^3	3,4	3,2	3,6	>3,4	≤3,0
The amount of air needed for complete combustion of 1 kg of fuel, kg	14,0–14,5	17,0–17,5	8,5	13,5–14,5	3,5–10,2

Lower combustion temperature of fuels differs greatly. The heat of combustion of fuel-air mixtures for various liquid fuels is little different and is not proportional to the heat of combustion of appropriate fuels. This can be explained as follows. The amount of air required for complete combustion of 1kg of fuel depends on the same variables and lower heat of combustion. The more oxygen is consumed for combustion of the fuel, the more heat is allocated. The heat of combustion of the fuel-air mixture depends on the elementary composition of the fuel and the amount of air in the fuel-air mixture.

Natural gas and alcohol fuels, the esters do not contain sulfur, olefin and aromatic hydrocarbons. Environmental problem of protection from sulfur-containing compounds, polycyclic aromatic carbohydrates and other harmful substances practically disappears when used. Note that the introduction of gasoline alcohols and their derivatives increases the octane number of gasoline. It takes the edge off of the need out of leaded gasoline, but also reduces the content of aromatic hydrocarbons. More complex is the question of the relationship of the parameters of the engine's power and toxicity of combustion products.

Emissions of hydrocarbons, carbon monoxide and nitrogen oxides are reduced when using the alcohols and gaseous fuels. Fuel consumption increases by about half when using alcohols and and increases slightly when using biodiesel fuel. Power parameters of the engine, on the contrary, in the case of the alcohols slightly rising and and reduced when operating on gaseous fuel. Since the use of bioethanol in diesel engines is problematic, we will consider biodiesel and biogas in the future. The use of biogas in diesel engines is possible in two directions his conversion: in diesel engine and gas engine with spark ignition [6]. Most commonly used esters of rapeseed oil as biodiesel fuels: methyl and ethyl.

SOLUTION OF THE EXAMINED PROBLEM

The authors use the link between useful work (effective power N_e, which is obtained at the output of the engine) and the amount of heat Q_e expended to obtain it to calculate engine power [7]:

$$Q_e = N_e = H_{sm} \cdot \frac{B_m}{3,6 \cdot 10^3} \cdot \eta_e \text{, mWh,} \qquad (1)$$

where Hs_m – heat of combustion of the fuel-air mixture, MJ/m^3;

B_m – hour consumption of the fuel-air mixture, m^3/h;

η_e – effective efficiency of the engine.

The calorific value of the fuel-air mixture of stoichiometric composition (when the excess air ratio equal to one) are shown in table 1 and other sources. However, diesels in all modes work on poor mixtures.

The heat of combustion of the fuel-air mixtures of different fuels:

$$H_{sm} = \frac{H_u - \Delta H_u}{\alpha \cdot L_0} \cdot \eta_e \quad (2)$$

where H_u – lower heat of fuel combustion, MJ/kg (MJ/m^3 for gas fuels);

ΔH_u – chemical incompleteness of fuel combustion, MJ/kg (MJ/m^3);

α– coefficient of excess air, which characterizes the composition of the fuel-air mixture (poor or rich);

L_0– amount of air required for complete combustion of 1kg of fuel theoretically.

At the previous stage of the nature of the change η_e is accepted the same as for the basic engines, although mechanical losses of the engines on alternative motor fuel (AMF), in particular on gas fuel are considered lower by improving lubrication conditions.

The expense of the fuel-air mixture for a particular engine design is determined by the formula:

$$B_m = \left(\frac{V_h \cdot i}{1000} \cdot \frac{60 \cdot n}{\tau}\right) \cdot \frac{T_0 \cdot P_a}{T_a \cdot P_0} \cdot \eta_v \cdot \gamma, \text{ m}^3\text{/h} \quad (3)$$

where V_h, i – volume and number of cylinders;

τ – cycle of engine;

n – rotation frequency, min^{-1};

η_V– coefficient of admission;

T_0, T_a, p_0, p_a – accordingly, the temperature and pressure of the environment and and the working fluid at the end of the intake;

γ = 1,11 ... 1,14 – coefficient of completeness of charge taking into account the delay closing the intake valve.

The consumption of liquid and gas fuels are given to a common unit: by effective specific fuel consumption g_e is determined by the specific consumption of heat introduced into the engine with fuel:

$$q_e = g_e \cdot H_u, \text{ Mj/kWh·h} \quad (4)$$

where g_e – effective specific fuel consumption in kg / kWh*h (m^3 / kWh*h).

RESULTS AND DISCUSSION

Need to know the lower calorific value of the fuels to determine engine power. But this value is usually unknown for new fuels. This situation was with new biodiesel – isopropyl ester of rapeseed oil (IERO).

The elementary composition (carbon C, hydrogen H and oxygen O) isopropyl ester of rapeseed oil (IERO) according to the acid content in rapeseed oil was determined [8]: ester of erucic acid – 50,0 %, oleic – 29,0 %, linoleic – 15 %, other esters of other acids (table. 2).

The lower calorific value, IERO was determined by the elementary composition of the fuels and known formula of D. Mendeleev. The indicators of diesel fuel (DF), methyl ester of rapeseed oil (MERO) and ethyl ester of rapeseed oil (EERO) are provided for comparison in table 2. A smaller portion of the carbon in the molecules of biodiesel fuels leads to reduction their lower heat of combustion. The increased oxygen content leads to intensification of the combustion process. The result is the reduction of soot in the exhaust gases.

Table 2. *Chemical and energy characteristics of petroleum diesel and biodiesel fuels*

Indicator of fuel	DF	MERO	EERO	IERO
Fuel composition, %				
carbon C	87,0	77,5	77,54	76,28
hydrogen H	12,6	12,0	12,04	13,16
oxygen O	0,4	10,5	10,42	10,05
Theoretically required amount of air for combustion of 1 kg of fuel, kg	14,45	12,70	12,73	12,98
The lower heat of combustion, MJ/kg	42,44	37,50	37,56	38,33

In order to perform calculations adopted dependence of the heat of combustion of the fuel-air mixtures Hs_m various fuels for different values of the coefficient of excess air (fig. 1). According to thermal calculations of an engine for different rotation frequencies installed the changes of coefficient of admission for the engine during its operation on various fuels.

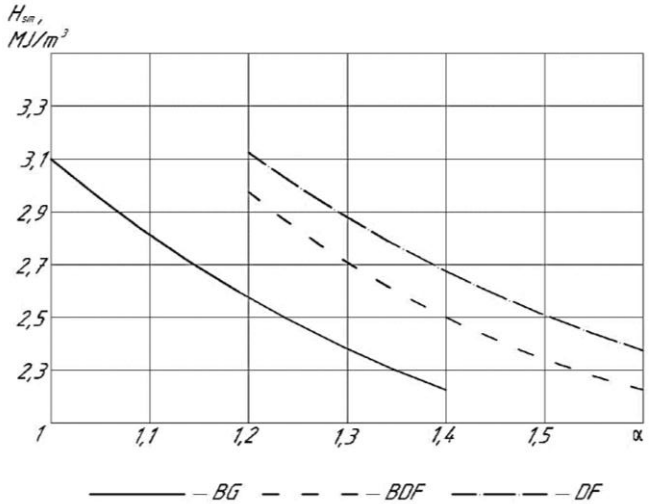

Fig. 1. *The dependence of the heat of combustion of fuel-air mixtures of different fuels from the composition of the mixture (BG – biogas; BDF – biodiesel fuel (in this case, IERO); DF – diesel fuel)*

Low methane content (60 %) and a significant number of ballast are problematic enough to power mobile energy resources due to use of biogas. Carbon dioxide causes a decrease in power. The hydrogen sulfide contained in biogas causes corrosion of engine parts.

Purification indicators of biogas from carbon dioxide and other impurities can be adapted to indicators of natural gas and improve energy and economic indicators of the engine operating on biogas significantly. With the increase of methane content in the biogas (using different purification methods), the indicators of lower heat of fuel combustion, the effective capacity are increasing. However, the effective specific consumption of gas decreases. The methane content in the biogas is 90 %.

The high octane number of biogas (115–130) gives the possibility for a significant increasing the compression ratio of the engine (up to 13 units) and increasing the efficiency of the engine.
Effective power N_e belongs to the energy indicators of the engine. Fuel efficiency of the engine when operating on liquid and gaseous fuels is evaluated by specific consumption of heat per unit effective power (table. 3).

Table 3. *Energy and fuel-economic indicators of engine D-243 when operating on different fuels*

Fuel	Effective engine power N_e, кWh	Effective specific heat rate g_e, MJ/ кWh*h
DF	56,0	8,0
Biodiesel	54,0	9,0
Biogas (methane content 90 %)	53,5	10,2

Table 3 shows that the engine power and its fuel efficiency increases with increasing of heat of combustion of the fuel-air mixtures (tab.1). However, the energy indicators of the engine would be easier to compare by one indicator. Such an indicator may be a mechanical equivalent of one MJ of fuel.

Road fuel consumption and road emissions of the harmful substances of the technological vehicle during the work on different fuels were determined by mathematical modeling. Comparison of fuel and economic and ecological indicators of engines during the work on different fuels was carried out according to experimental load and speed characteristics, described by polynomial models (fig. 2).

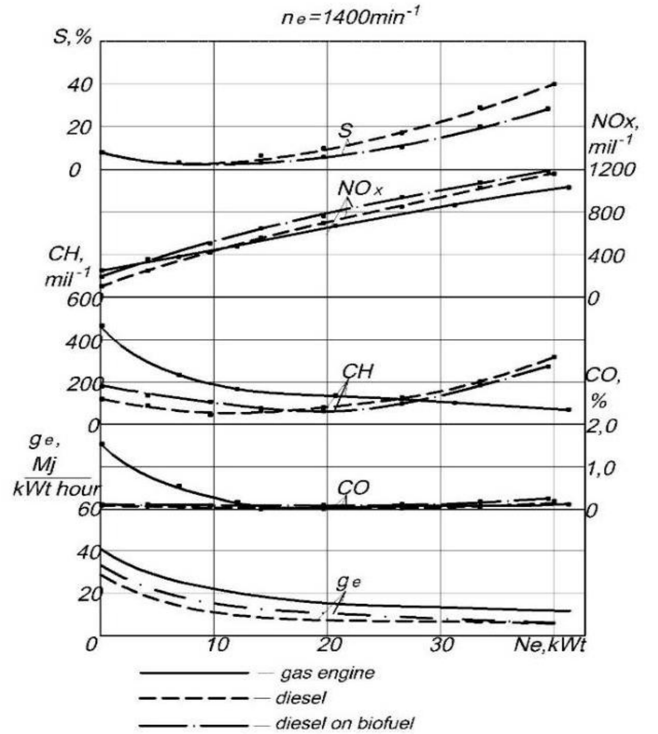

Fig. 2. *Load characteristics with measurement of toxicity of exhaust gases of the engine D-243 when working on different fuels at the frequency of rotation of the crankshaft 1400 min^{-1}*

Note: N_e = effective engine power; g_e = specific effective fuel consumption in Mega Joule of energy at kWt hour

A track fuel consumption and travel emissions of a tractor, being operated on different fuels, are defined by mathematical modeling. The calculations showed that the tractor with a diesel engine, being driven on the adopted driving cycle, consumes (accordingly, on average) 22 % less fuel, and its CO emissions are 47 % less and CH emissions are 90 % less than of the tractor with a gas engine.

This is due to the fact that the gas engine in all modes runs on richer fuel-air mixtures. A tractor with the diesel engine emits nitrogen oxides NO_x 4 % more. It also emits soot unlike the tractor with the gas engine. Comparing the total specific emissions of harmful substances (HS), converted to carbon monoxide ΣCO, taking the relative aggressiveness, it is clear that the tractor with a diesel engine is (36 %) more toxic. The total toxicity of a tractor engine running on biodiesel fuel is also lower than of an engine on oil fuel. But the number of emissions of harmful substances in the exhaust gases does not allow to analyze the environmental safety of the tractor.

CONCLUSIONS

The power of the diesel engine while operating on biofuels is less in comparison with operation on oil fuel. Fuel consumption is more due to the lower heat of combustion of these fuels. The energy indicators of fuels are more appropriate to evaluate for the heat of combustion of fuel-air mixtures. With increasing of the heat of combustion of fuel-air mixtures increases engine power and reduces fuel consumption.

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