ECONOMICS COLLEGE IN STALOWA WOLA

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FEATURES OF THE USE OF SYNTHESIS-GAS IN THE LOW-DISPLACEMENT SHIP POWER PLANTS

Mytrofanov O. S., Proskurin A. Yu.

INTRODUCTION

World experience indicates that shipbuilding is quite a profitable industry and is characterized by high incomes of manufacturers, a large number of jobs created and a powerful influence on the development of the other fields of the economy. Ukraine has favorable climatic conditions, access to the sea and a well-developed network of inland waterways, powerful industrial, scientific and human resources, which causes a very high potential for the development of the industry of low-displacement recreational shipbuilding.

Shipbuilding is a specific industry. Accumulating in its products the achievements of a large number of related industries (metallurgy, engineering, electronics, etc.), shipbuilding simultaneously stimulates the development of these industries and their achievement of a high scientific and technical level. The creation of one workplace in shipbuilding contributes to the appearance of 4-5 jobs in the related industries. It can be said that, on the one hand, shipbuilding is an indicator of the level of the state's economy development, and on the other, it is a stimulating element of the economic development.

The composition of power plants of almost all low-displacement ships include internal combustion engines operating on petroleum-derived fuel. The constant tightening of the requirements for harmful emissions from exhaust gases and the reduction of oil stocks, expected by many experts, requires the introduction and development of energy-saving and environmentally friendly technologies. These circumstances necessitate the development of the use of alternative fuels[1]. In particular, alcohol fuels can be distinguished as the most promising type of fuel for the power plants of low-displacement ships. Along with the advantages (high anti-knock

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[1] Левтеров А.М., Левтерова Л.И., Гладкова Н.Ю. Использование альтернативных топлив в транспортных ДВС. *Автомобильный транспорт*. 2010. № 27. С. 61–64.

resistance, a wide source of raw materials[2], high environmental efficiency[3]) alcohol fuels have several disadvantages (reduced engine and energy system elements life, associated with corrosion, deterioration of lubrication conditions of friction units[4], significant water flooding[5]), which restrain its wide distribution in ship power plants.

One of the promising ways of using alcohol fuels in ship power plants, which can eliminate the main disadvantages, is the use of alcohol fuels in the form of synthesis-gas obtained by the thermochemical utilization of the exhaust gases heat. Mostly synthesis-gas consists of two combustible components – CO and H_2, however, depending on the conditions of production and the raw material, it may also include a number of other components, for example, CH_4, C_2H_4, C_2H_6. In particular, the composition of the synthesis-gas determines the distinct features of the processing and organization of the working cycle of the engine. Therefore, many domestic and foreign researchers pay considerable attention to the field of experimental studies of the effect of synthesis-gas, both in pure form and as additives, on the parameters of the working process of the internal combustion engine.

1. The experimental stand for the study of working processes in power plants of low-displacement ships on the basis of internal combustion engines working on ethanol with the addition of synthesis-gas obtained by the thermochemical utilization of the exhaust gases heat

The actual processes of an internal combustion engine with spark ignition, working on ethanol with the addition of synthesis-gas, and especially the combustion process, depend on many factors of chemical kinetics of fuel burnout, thermodynamics and gas dynamics, heat and mass transfer, and many

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[2] Быкова Е.В., Гемонов А.В., Лебедев А.В. Перспективы применения топливного этилового спирта на транспорте. *Вестник ФГОУ ВПО МГАУ*. 2014. № 3. С. 26–30.

[3] Ethanol as fuel for recreational boats. Url: http://www.dartmouth.edu/~ethanolboat/ethanol_outboard_final_report.pdf

[4] Василевкин Е.В., Егоров В.Н., Руновский К.С. Конструктивные изменения в ДВС, необходимые при переходе на бензоэтанольные топлива. *Известия МГТУ «МАМИ»*. 2013. Т. 1, № 1 (15). С. 10–14.

[5] A study of the effects of running gasoline with 15 % ethanol concentration in current production outboard four-stroke engines and conventional two-stroke outboard marine engines. National renewable energy laboratory. URL: http://www.nrel.gov/docs/fy12osti/52909.pdf/.

others. With the help of mathematical modeling on the basis of classical differential equations and the corresponding initial and boundary conditions, it is not always possible to describe the real processes occurring in the working cylinder, elements of the gas-flow path and the power plant as a whole.

The most difficult is the process of synthesis-gas combustion, which is primarily connected with the presence of many components in the synthesis-gas composition (H_2, CO, CH_4, C_2H_4, C_2H_6), which, in turn, affect the process in different ways. Therefore, the mathematical models require the use of certain assumptions, empirical equations and constants obtained experimentally. The experimental method allows to confirm the accuracy of the accepted assumptions, supplement the mathematical model with the empirical coefficients and dependencies for each individual case, and also to confirm the adequacy of the model as a whole and determine the limits of its use. The purpose of the experimental study is to obtain the reliable data on the synthesis-gas combustion process and determine the influence of the main parameters of the working process on the effective and environmental performance of the engine. The analysis of the results of experimental research allows to determine further ways of improvement of fuel efficiency, power and environmental friendliness of engines.

For the experimental studies of the working cycle of an internal combustion engine with the thermochemical utilization of exhaust gases operating on ethanol with synthesis-gas additives, a stand was developed on the basis of an engine with external mixture formation TE-200 (Fig. 1). The main parameters of the engine are given in Table 1.

Table 1

The main parameters of the TE-200 engine with spark ignition

No.	Parameter	Unit	Value
1	Number of cylinders	pcs.	1
2	Cylinder capacity	cm^3	196
3	Cylinder bore	mm	68
4	Stroke	mm	54
5	Compression ratio	-	8.5
6	Crankshaft speed	rpm	3000
7	Effective power	kW	4.8
8	Specific effective fuel consumption	kg/(kW·h)	0.412

It is a four-stroke gasoline engine that runs on an electric current generator. The engine can operate both on pure ethanol and on a gaseous mixture of ethanol and synthesis-gas obtained as a result of the thermochemical utilization of the exhaust gases heat. Depending on the engine load and the amount of utilized exhaust gases heat, the addition of synthesis-gas to ethanol is diverse.

The TE-200 engine is loaded with the standard alternating current electric generator. The received electrical energy through the load control system *3* goes to the block of heating bundles *4*. The voltage value is determined using a voltmeter. Also, the experimental stand is equipped with the following measuring instruments: tachometer for determining the engine crankshaft speed; instruments for measuring the temperature of exhaust gases in the cylinders. To determine the air flow through the engine, a gas meter RG-40 is installed at the inlet.

From tank *11,* ethanol enters thermochemical reactor of conversion *2*. A chemical reaction occurs in the reactor as a result of which the obtained synthesis-gas enters engine *1*. The heat is taken from the exhaust gases of engine *1* to pass the conversion reaction of ethanol, and the obtained synthesis-gas partially returns the energy of the exhaust gases to the working cycle.

Cooling and condensation of the ethanol unreacted in the synthesis gas occurs in “pipe in pipe” heat exchanger *5*. The condensate residues are collected in retort *15* and hung using scale *16*. The difference between ethanol that got into the reactor and the condensed one allows to obtain the conversion degree. Consumption of synthesis-gas is determined using gas meter *18*.

In order to obtain the reliable indicator diagram, the Kistler 7613C sensor element (Fig. 2) was as close as possible to the combustion chamber. The results of the indicator pressure measurements were transferred to a microprocessor of data processing with galvanic isolation of AI8S-5A type, were processed using the FASTWELL package and were recorded on a PC.

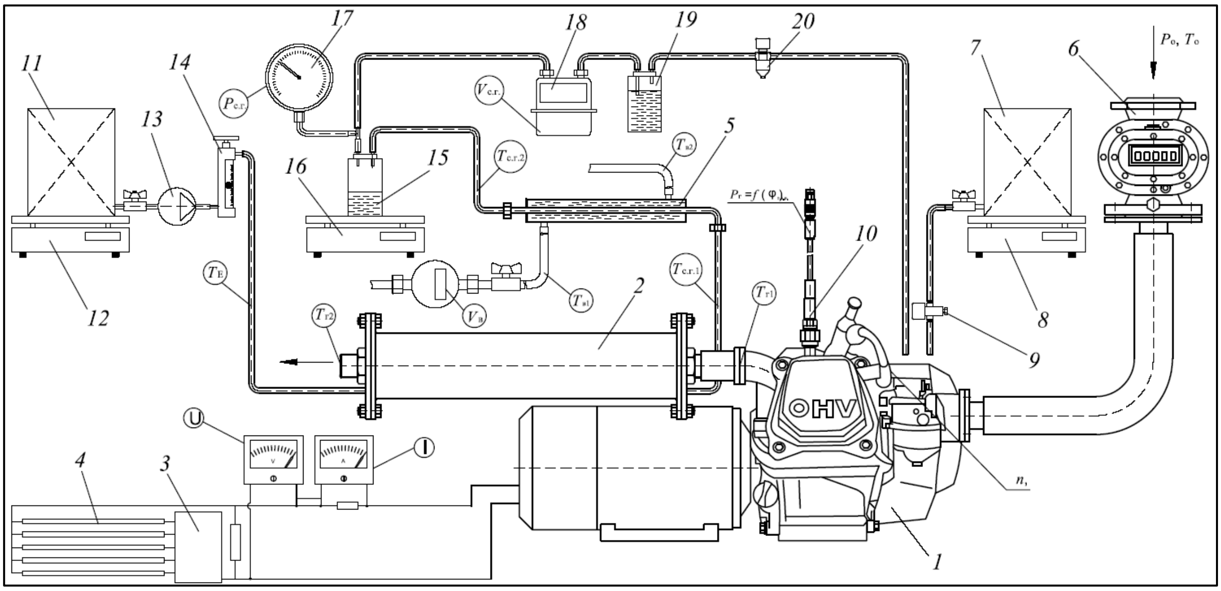


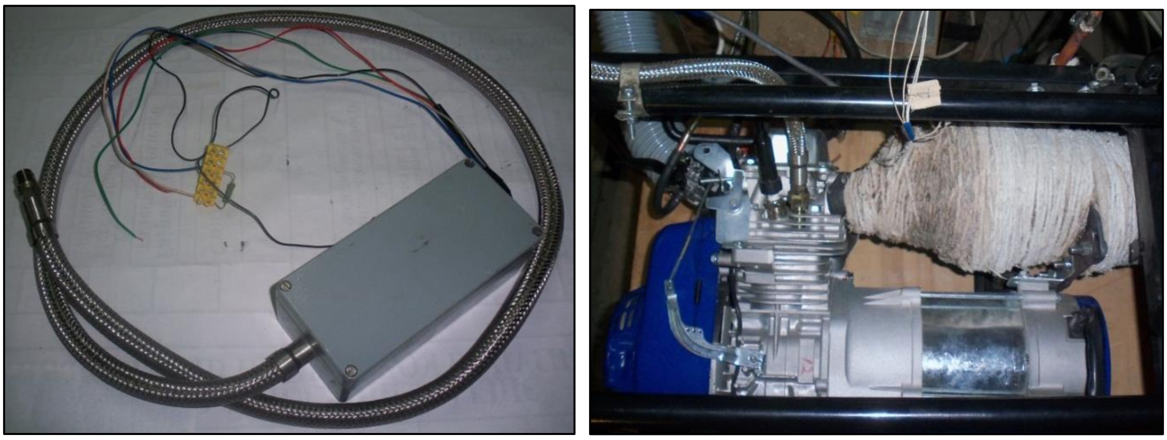
Fig. 1. Experimental stand on the basis of the TE-200 engine:

1 – TE-200 spark ignition engine; 2 – thermochemical reactor; 3 – load management system; 4 –block of heating bundles; 5 – heat exchanger of the “pipe in pipe” type;

6 – RG-40 gas meter; 7, 11 – tank with ethanol; 8, 12, 16 – scales; 9 – solenoid valve; 10 – pressure sensor; 13 – ethanol feed pump to the reactor; 14 – rotameter;

15 – condensate collection retort; 17 –manometer; 18 – gas meter; 19 – water seal;

20 – solenoid gas valve with filter.



a *b*

Fig. 2. 7613C Kistler pressure sensor:

a – general view of the pressure sensor; b – pressure sensor assembled with engine.

To carry out experimental studies of the processes occurring in the thermochemical utilization of exhaust gases system, and also to obtain synthesis-gas, a conversion reactor was developed. The reactor was installed in place of the engine muffler. In this case, the reactor began to perform the functions of a heat utilizer and an air silencer.

The composition of the synthesis-gas was determined by the chemical analysis in the Environmental Laboratory of the Admiral Makarov National University of Shipbuilding using a NeoCHROM Class B chromatograph, which was pre-calibrated using sample mixtures according to TS-6-16-2956-87. According to the chromatographic analysis, the composition of the synthesis-gas obtained by the complete conversion of ethanol contains 3 main components (vol): Hydrogen H_2 (43%), carbon monoxide CO (34%) and methane CH_4 (23%) (Fig. 3).

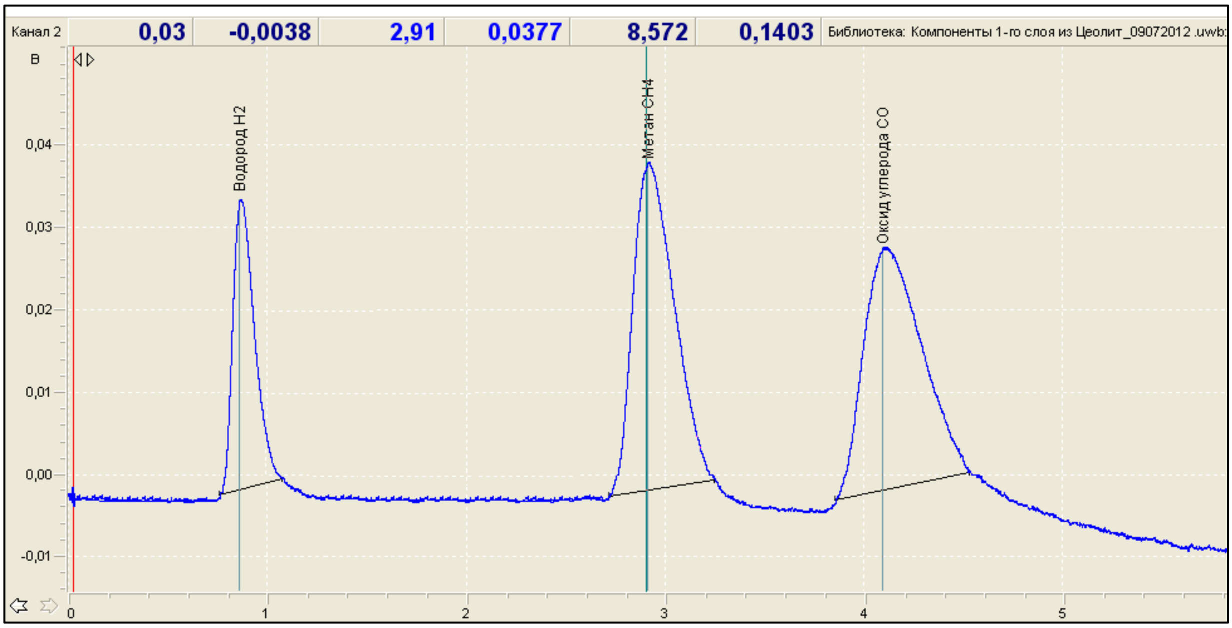


Fig. 3. Chromatogram of the synthesis-gas.

The suitability of fuel for an internal combustion engine is determined by its motor properties, such as, for example, energy, temperature and ignition limits, flame propagation speed, lower heat value, and others. The use of synthesis-gas as a fuel for internal combustion engines allows to change the approaches to the organization of the working cycle, thereby significantly improve fuel efficiency and reduce the amount of harmful emissions of exhaust gases. Therefore, when conducting experimental studies should take into account these properties of synthesis-gas. Due to the low stoichiometric ratio of synthesis-gas to air and rather low density (0.63 kg/m^3) of synthesis gas, the heat value of the fuel mixture of stoichiometric composition will be lower than the air-fuel mixture of traditional fuel. This in turn will lead to decrease in engine power. It is possible to conduct a comparative assessment of the specific power of an engine operating on synthesis-gas and a conventional one due to the energy intensity of the charge. Table 2 shows the comparison of some of the motor properties of motor fuels, synthesis-gas and its components. According to the above data, it is possible to increase the energy intensity of the charge of the cylinder by forcing synthesis-gas into the cylinder when the valves are closed, thereby solving the problem of reducing engine power.

Table 2

Motor properties of gasoline[6] and synthesis-gas[7].

No.	Property	Gasoline		Hydrogen		Carbon monoxide		Synthesis-gas (67% H_2, 33% CO)		Synthesis-gas (43% H_2, 34% CO, 23% CH_4)	
1	Combustion value, kJ/kg	43961		120000		10096		24083		28790	
2	Air amount, kg/kg	14.95		34.2		2.46		6.52		8.27	
3	Air amount, m^3/m^3	50.06		2.38		2.38		2.38		4.02	
4	Density, kg/m^3	750		0.089		1.25		0.472		0.629	
5	Mixture formation	external	internal	external	internal	external	internal	external	internal	external	internal
	Energy intensity of the charge, kJ/m^3	3553	3624	3190	4530	3733	5302	3368	4784	3425	4617

[6] Хачиян А.С. Использование водорода в качестве моторного топлива для автомобильных двигателей внутреннего сгорания / А.С. Хачиян, В.Ф. Водейко. *Транспорт на альтернативном топливе.* 2008. № 8 (3). С. 57–61.

[7] Иссерлин А.С. Основы сжигания газового топлива: справочное пособие / А. С. Иссерлин. Л.: Недра, 1980. 271 с.

Synthesis-gas can also be used as a fuel for diesel engines. In this case, the feed of synthesis-gas can be carried out on the compression line and be inflamed by feeding an inflammatory dose of liquid fuel, or supplied at the end of the compression stroke along with the inflammatory dose of fuel. With external or internal mixture formation, the degree of homogenization of the mixture is determined by such properties as boiling point and diffuse property. Hydrogen, which is in the composition of synthesis-gas, has quite good indicators of these parameters, in particular, the boiling point is 253° C (this ensures the absence of the liquid phase of synthesis-gas in the mixture) and the diffusion coefficient of 0.63 cm^2/s. In case of internal mixture formation, the time that is allotted for the formation of a mixture is quite small. These parameters are able to provide high rates of homogenization of the air-fuel mixture better than any carbohydrate fuel.

The ignition limits of the air-fuel mixture for synthesis-gas due to the significant hydrogen content lie in rather wide limits (α = 0.2...3.5). The most important value is the lower ignition limit of the air-fuel mixture, since it allows to evaluate the degree of effective depletion of the air-fuel mixture and determines the method of engine regulation. Even at low temperatures, it is possible to qualitatively regulate the power of the engine, which in turn makes it possible to obtain high fuel efficiency.

When conducting experimental studies on the use of synthesis-gas as a fuel for internal combustion engines, it is necessary to take into account the energy of ignition of the fuel-air mixture. The value of the ignition energy depends on the composition of the air-fuel mixture. The maximum value of energy corresponds to the limits of ignition, and the minimum value – to the stoichiometric composition. The energy required for ignition of synthesis-gas is several times lower than that required for ignition of hydrocarbon fuels and, depending on the composition of the synthesis-gas, is 0.06...0.1 MJ. However, the low value of the ignition energy is also a disadvantage, since it is one of the causes of the autoignition of the fuel-air mixture in the internal combustion engine from, for example, the residual gases, the spark plug electrode, the discharge valve, etc.

The combustion rate of the air-fuel mixture largely depends on the physicochemical properties of the fuel, as well as the conditions of combustion. For engines with forced ignition, the combustion rate is directly related to the speed of propagation of the flame front from the point of ignition. For engines operating on synthesis-gas, the speed of propagation of the flame front is affected by the composition of the synthesis-gas, particularly the hydrogen content and the coefficient of excess air. Fig. 4 shows the change in the flame front speed from the hydrogen content under the normal conditions. With the stoichiometric composition, the speed of propagation of the flame front for synthesis-gas is 2...3 times greater than for gasoline.

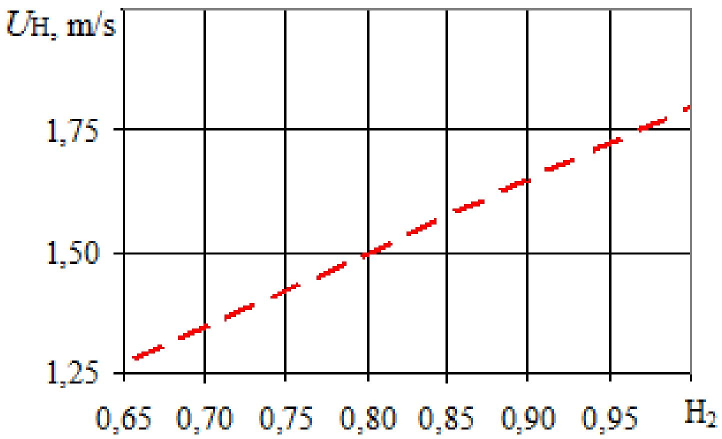


Fig. 4. Dependence of the normal combustion rate from the hydrogen content in the composition of the synthesis-gas

The thickness of the air-fuel mixture layer, in which the oxidation reaction chain is broken due to deactivation of active centers on the surface of the combustion chamber, is called the flame extinction distance. This indicator allows to estimate the volume of the zone of incomplete combustion in the wall layer. The emission of hydrocarbons with exhaust gases largely depends on the flame extinction distance. The flame extinction distance for synthesis-gas is several times less than for gasoline, which significantly reduces the zone of incomplete combustion. Moreover, when using synthesis-gas, the combustion occurs in the gap between the cylinder and the piston above the first piston ring, which significantly increases the efficiency of the combustion process.

2. Results of the experimental studies of the working cycle of the TE-200 engine with spark ignition working on ethanol with the addition of synthesis-gas obtained by the thermochemical utilization of the exhaust gases heat

The study of the working process of ICE is associated with great difficulties due to the complexity and transience of the individual stages of this process. The study can be carried out in different ways, but the most common and accurate is the indication, that is, the removal of the indicator diagram of the engine operation[8].

Engine performance indicators are divided into indicator (internal) and efficient (external) ones. Indicator values characterize the perfection of the working cycle and take into consideration only the thermal losses in the cylinder. Efficient indicators, in addition to thermal losses, account for the mechanical losses that are formed when the energy of gases expansion is transferred through the piston and crank mechanism to the engine crankshaft. Processing of the indicator diagrams makes it possible to acquire data on the progress of ICE working process and its main indicators. The accuracy of the results obtained when processing the indicator diagrams first of all depends on their reliability. Therefore, the importance is given to the selection of the necessary equipment, the adjustment of indicator diagrams for taking into account the cyclic instability of the working process and the correction of mistakes that were made during the removal and processing of the diagrams. The dispersion of single work cycles is subject to the normal distribution law and, accordingly, an averaged indicator diagram must be obtained. As a result of processing of indicator diagrams it is possible to get the following engine parameters:

– to determine the total indicators of the working process (indicator work L_i, average indicator pressure p_i, indicator efficiency coefficient η_i);

– study of dependences for the heat release during combustion;

– determination of parameters characterizing individual stages of the working process (admission coefficient η_v and residual gases γ_r, intermediate pressure at pumping strokes p_{nh}, polytropic coefficient of compression n_1 and expansion n_2, etc.).

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[8] Двигатели внутреннего сгорания: Теория поршневых и комбинированных двигателей: учеб. для втузов по специальности «Двигатели внутреннего сгорания» / Д.Н. Вырубов, Н.А. Иващенко, В.И. Ивин [и др.]; под ред. А.С. Орлина, М.Г. Круглова. [4-е изд., перераб. и доп.]. М.: Машиностроение, 1983. 372 с.

One of the most important indicators of engine operation, except for the effective ones, is ecological. Therefore, when testing the engine, the analysis of the combustion products is carried out. Exhaust gases (EG) analysis allows to obtain a number of important data in the work process, namely:

– to establish the final results of the combustion process and determine the volumes of chemical and physical incompleteness of combustion, EG heat losses;

– to study the dependences of the processes of mixture formation, gas exchange and purging;

– to determine the influence of various factors on the process of fuel combustion in order to effectively manage the individual parts of this process.

The experiments were carried out at the ambient temperature of 298 K, atmospheric pressure of 101 kPa, using the AI-95 petrol according to the State Standard (SS) (GOST) 4840-2007 (complies with the European standard EN 228-2004), using ethanol according to the SS 4221-2003, and the synthesis-gas. The estimated specific lower heat value of synthesis-gas combustion is 28.79 MJ/kg. The values for parameters of the environment and the synthesis-gas composition were constant during the study.

The results of the experimental study of the TE-200 engine operating on ethanol are shown in Fig. 5 in the form of a fragment of the consecutively measured indicator diagrams. These diagrams quite clearly demonstrate the stability of the engine operation under mode and their quality.

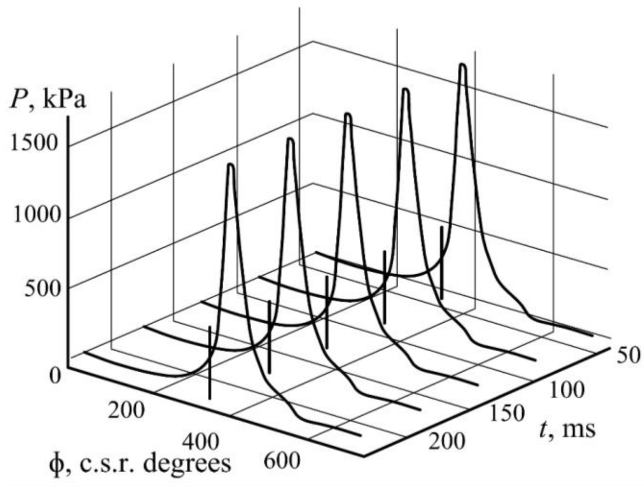


Fig. 5. Fragment of the series of consecutive indicator diagrams when operating on ethanol.

The processed (expanded and collapsed) indicator diagrams for different modes of engine operation are presented in Fig. 6. In this case, the ignition advance angle is $\Theta = 20^{\circ}$ c.s.r., excess air coefficient is $\alpha = 0.98...1.04$, and the engine crankshaft speed is n = 3000 rpm. Depending on the load of the TE-200 engine and the amount of waste heat of exhaust gases by the thermochemical utilization, the synthesis-gas additive to ethanol is different. Results of experimental study of the TE-200 engine operation on ethanol with additives of the synthesis-gas in the amount of 2.1…6.5 % by weight are shown in Fig. 7 in the form of a fragment of the consecutively measured indicator diagrams.

The processed (expanded and collapsed) indicator diagrams for various operation modes of the engine are presented in Fig. 8. In this case, the ignition advance angle is $\Theta = 20^{\circ}$ c.s.r., excess air coefficient is $\alpha = 1.05...1.18$, the engine crankshaft speed is n = 3000 rpm.

As a result of the cycle, the thermal energy released during the combustion of the synthesis-gas and ethanol mixture is converted into useful work, which develops in gases in the engine cylinder. At the same time, the value of the useful work of the cycle increases with an increase in the additive of synthesis-gas, which is quite clearly seen from the indicator diagrams. The analysis of indicator diagrams (Fig. 8) revealed that the presence of the synthesis-gas in the fuel and air mixture leads to the increase in the maximum combustion pressure to 200 kPa and shifts it toward the upper dead point (UDP) to 7° c.s.r. The shift of the maximum of combustion towards UDP and the increase in the maximum pressure of combustion does not lead to more rigid engine operation, since they do not exceed the dynamic loads on the parts of the crank mechanism.

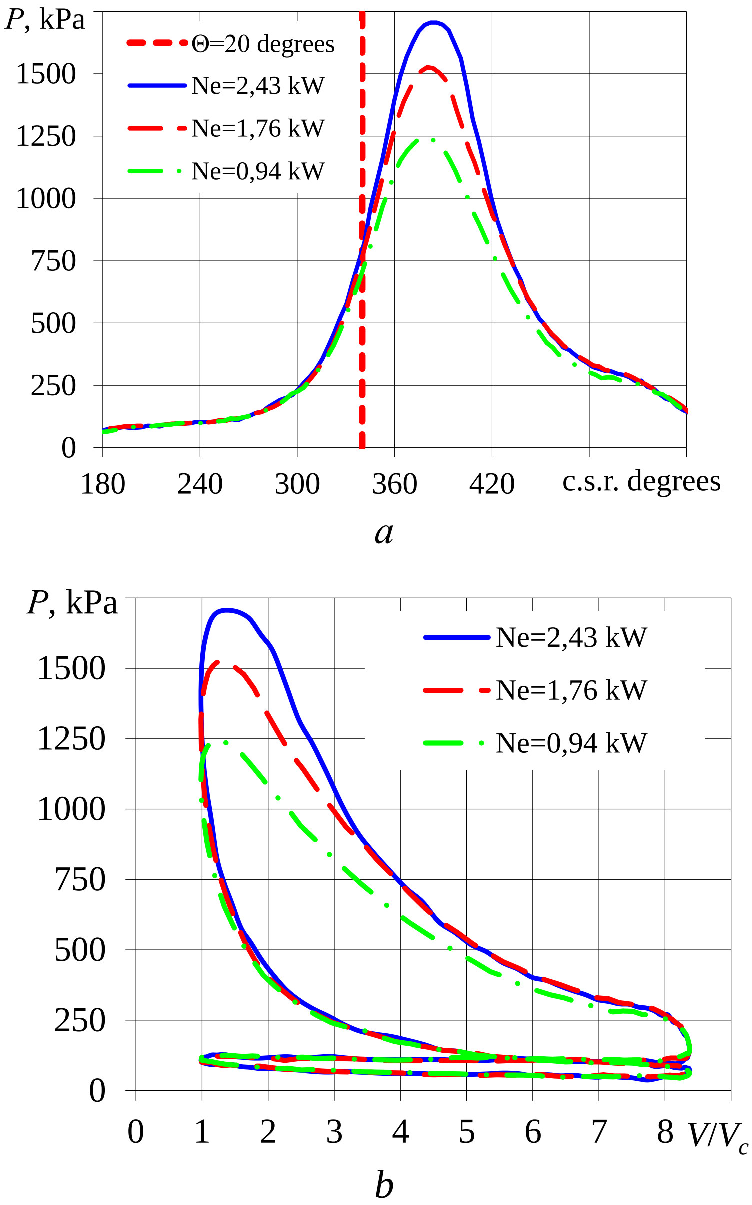


Fig. 6. Experimental indicator diagrams of the TE-200 engine when operating on ethanol:

a – expanded; b – collapsed.

These diagrams quite clearly demonstrate the stability of the TE-200 engine operation under mode.

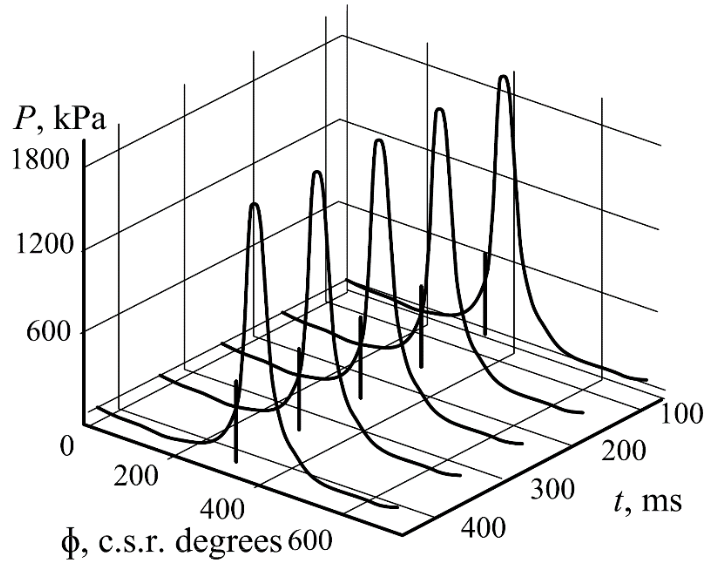
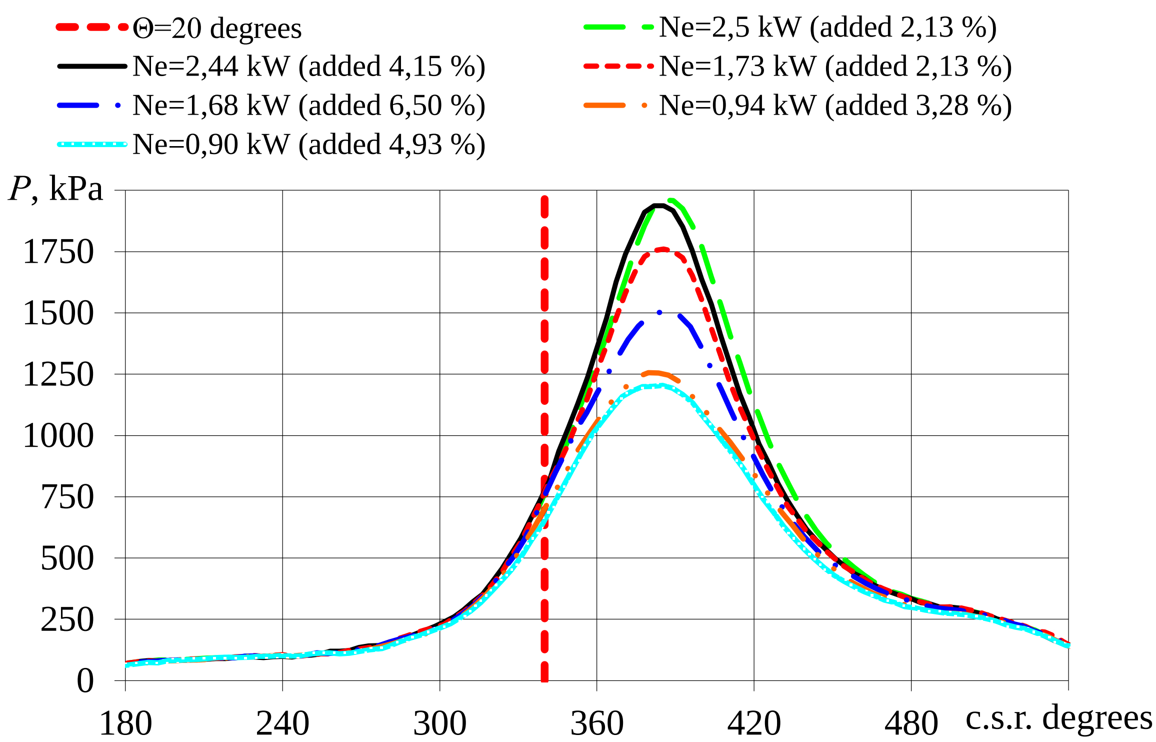
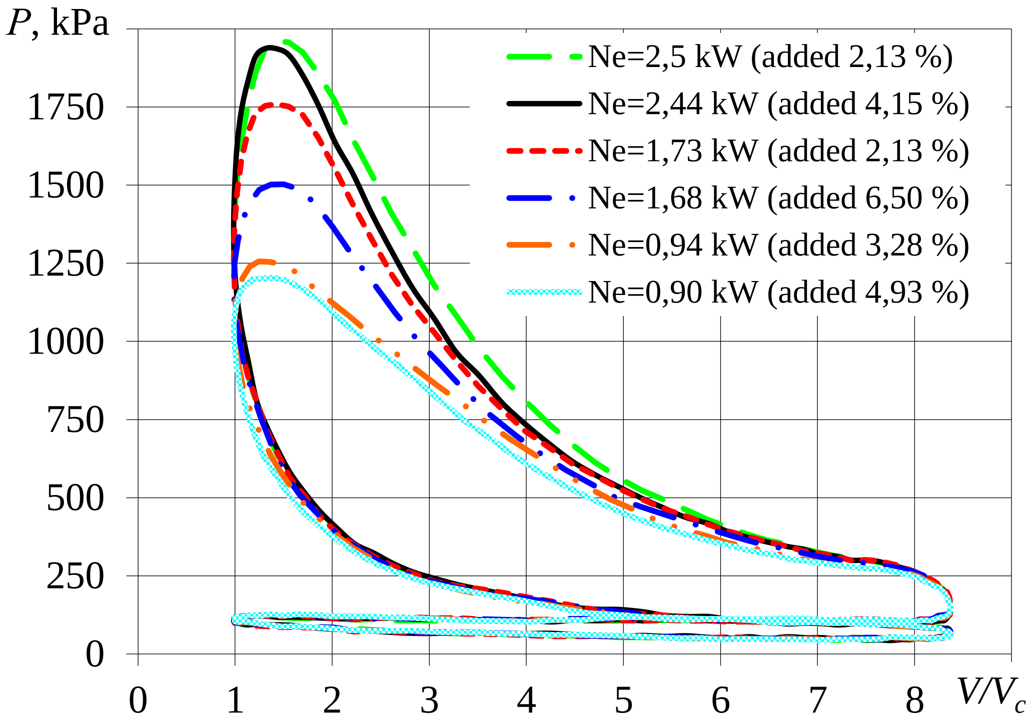


Fig. 7. Fragment of the series of consecutive indicator diagrams of the TE-200 engine when operating on ethanol with additives of the synthesis-gas



a



b

Fig. 8. Experimental indicator diagrams when the TE-200 engine is operating on ethanol with the synthesis-gas additives in the amount of 2.1…6.5 % by weight:

a – expanded; b – collapsed.

A further increase in the amount of additive of the synthesis-gas to ethanol (more than 10%) without the adjustment of excess air coefficient upwards and the ignition advance angle downwards might adversely affect engine operation. The increase of $dp/d\varphi$ (Fig. 9) adversely affects the engine operation.

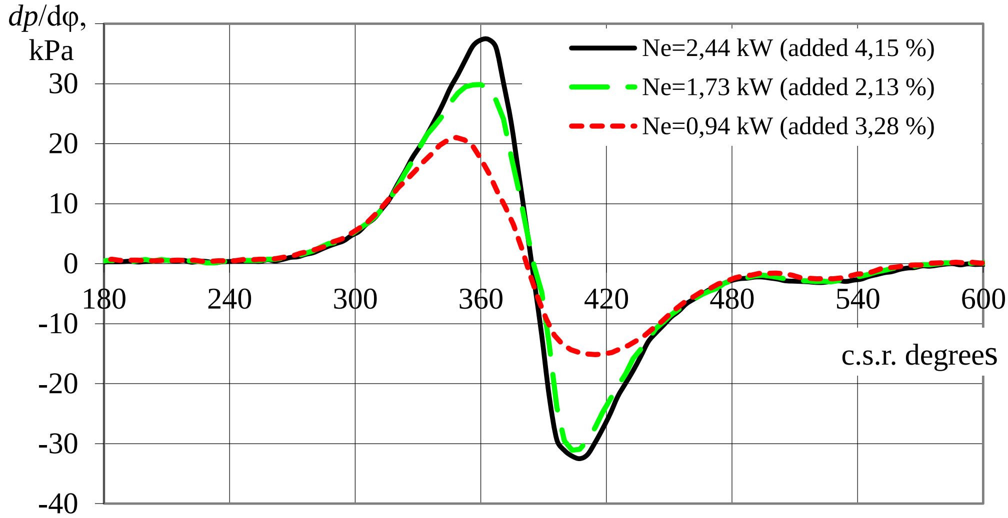


Fig. 9. Change of the pressure increase speed depending on the additives of the synthesis-gas.

Thus, a number of researchers in their works directly point to an experimental confirmation of the direct connection between the rigidity of the engine working cycle with reliability and the noise of its work.

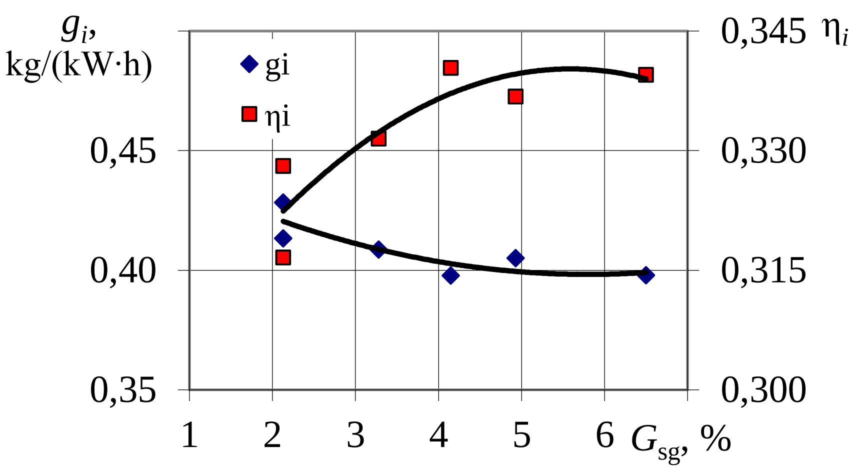
The rigid operation of the engine accompanied by high values of maximum combustion pressure, is not allowed in the operation of ICE, as it leads to the increase in the dynamic load on the parts of the crank mechanism, as well as the destruction of the bearings. Furthermore, with the additives of synthesis-gas, a positive influence on the working cycle is provided by taking into account the degree of compression, admission coefficient in a cylinder, valve timing, and method of mixture formation.

As a result of the processing of the indicator diagrams, the obtained total indicators of the working process are obtained. The changes of engine indicators depending on the synthesis-gas additive are presented in Fig. 10.

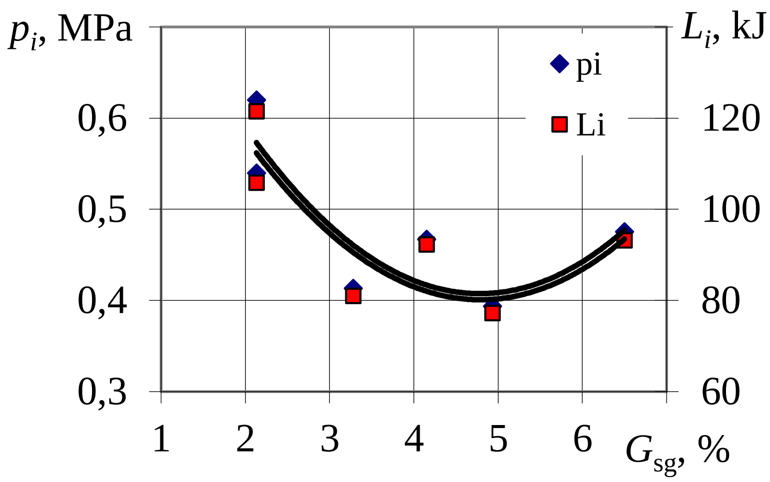
During the analysis of experimental data in the process of combustion of a mixture of ethanol vapor with synthesis-gas, according to the generally accepted separation[9], three phases of combustion have been identified.

[9] Петриченко Р.М. Физические основы внутрицилиндровых процессов в двигателях внутреннего сгорания: учеб. пособие / Р.М. Петриченко. Л.: Изд-во Ленингр. ун-та, 1983. 244 с.

The first phase of combustion is the formation of the initial flame from the electric spark and the development of a turbulent flame front, that is the moment from the formation of a spark to the start of a pressure jump in the cylinder when working with additives of synthesis-gas. It is approximately 12° c.s.r. that is 6° c.s.r. less than ethanol.



a



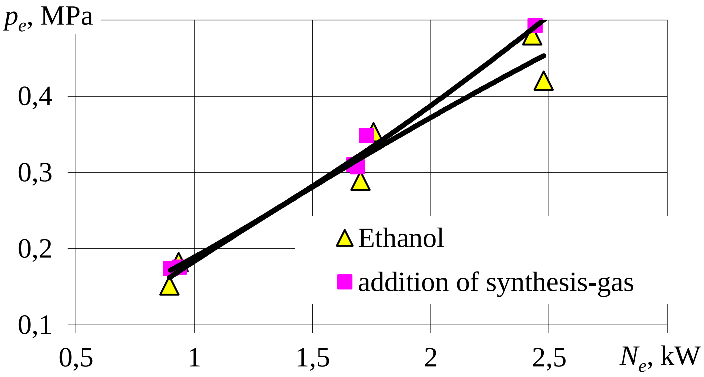
b

Fig. 10. Indicator values of the TE-200 engine:

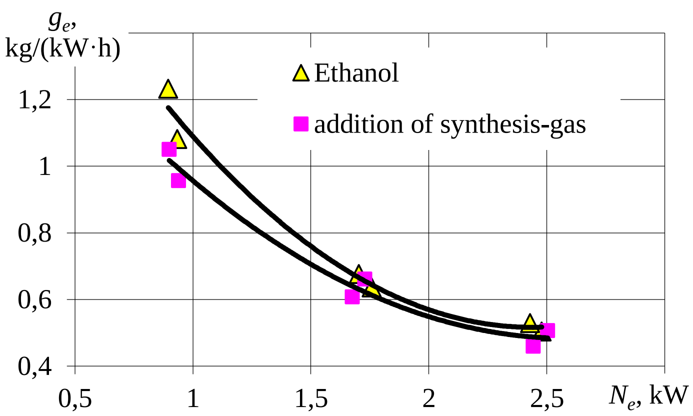
a – indicator fuel consumption and indicator efficiency coefficient; b – average indicator pressure and indicator cycle work.

The second phase of combustion is the phase of rapid combustion, in which the flame front spreads in most of the space of the combustion chamber, reaches the walls of the cylinder and ends when the maximum combustion pressure. It is approximately 28° c.s.r.

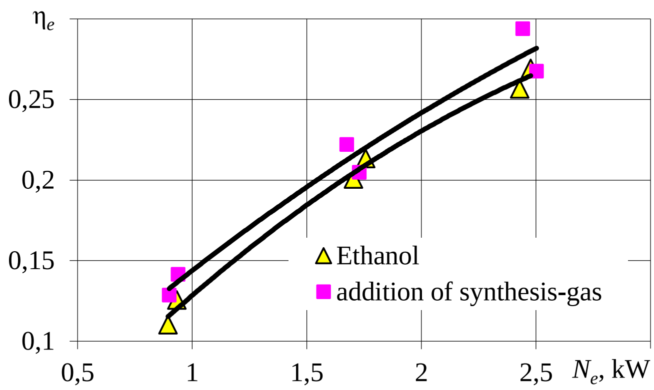
The third phase, afterflaming is about 8° c.s.r. In the third phase, there is the afterflaming of products of incomplete oxidation of the fuel behind the flame front and in the near-wall layer, in the gaps between the piston and the cylinder head, as well as the recombination of molecules. One of the features of the end of fuel combustion is the equality of the speed of heat release to heat transfer speed to the walls (the quasi-adiabatic point of the process). The results of experimental studies on the change in average efficient pressure, efficient fuel consumption (ethanol and ethanol mixture with synthesis-gas) and efficiency coefficient from engine power are given in Fig. 11.



a



b



c

Fig. 11. Change of the effecient indicators of the engine from the effecient power:

a – the average effecient pressure p_e; b – effecient fuel consumption g_e;
c – effective efficiency coefficient of the engine η_e.

The excess air coefficient when working on ethanol was α = 0.98...1.04, and when working with the additives of synthesis-gas – α = 1.05...1.18. Due to the significant content of hydrogen in the composition of the synthesis-gas, the combustion process is significantly improved, it is quite clearly reflected in the improvement of the effective efficiency coefficient of the engine, and in the reducing of the efficient fuel consumption. Depending on the amount of synthesis-gas additive, the reduction in the specific efficient fuel consumption is 2.5...12.4%.

The increasing efficiency coefficient of the engine causes also the expansion in the limits of ignition of the fuel-air mixture. An increase in the cycle efficiency coefficient with the increase of α is associated primarily with the reduction of heat capacity and heat content of combustion products, which in turn reduces the proportion of thermodynamic losses.

The dependences of change in the specific efficient fuel consumption at different operating modes depending on the additive of the synthesis-gas are shown in Fig. 12. These diagrams quite clearly demonstrate the reduction of specific fuel consumption in all modes of operation.

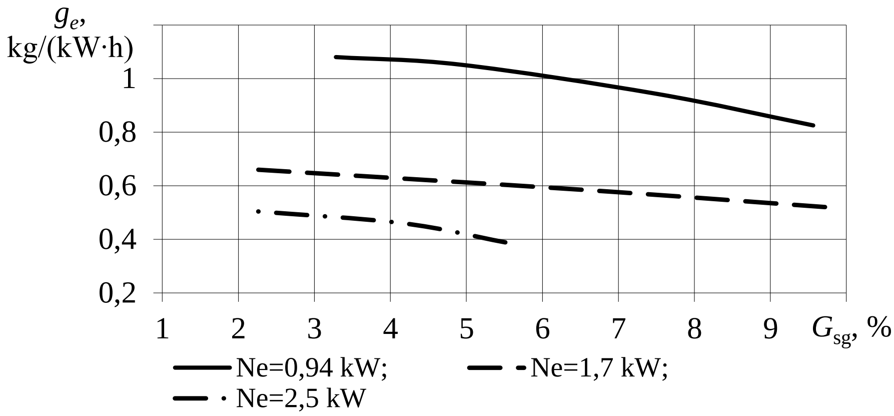


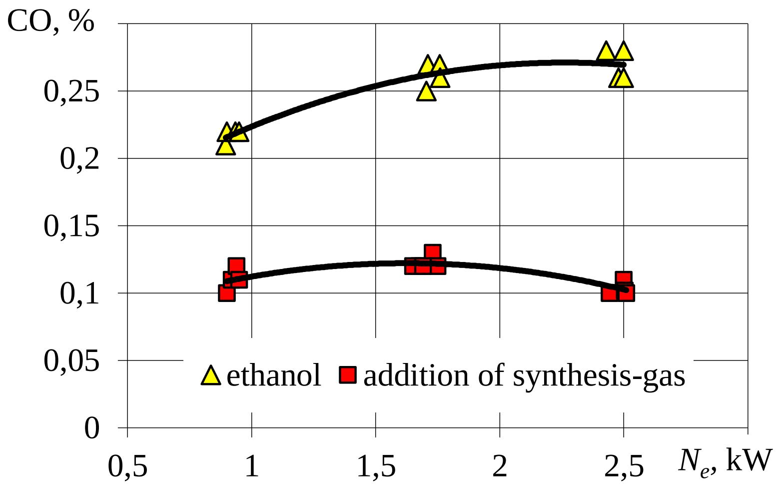
Fig. 12. Change of specific efficient fuel consumption at different modes of operation of the TE-200 ICE depending on the additive of the synthesis-gas.

One of the main directions of improving ICE at the present stage of development is the reduction of toxicity of EG and increase of fuel efficiency. The experience of previous researches and work of foreign scientists show that all the traditional methods of reducing toxicity, as a rule, reduce the economic performance indicators of the engine. Toxicity of EG and fuel efficiency of spark-ignition engines are determined primarily by the composition of the fuel-air mixture, that is, the excess air coefficient α, which, when using conventional fuels, such as gasoline, is within α = 0.8...1.2. Also, the toxicity of the exhaust gases is strongly influenced by the chemical composition of the fuel. For example, the use of alcohol with the addition of synthesis-gas instead of conventional gasoline as a motor fuel improves the combustion process of the fuel due to the formation of radicals that activate chain reactions of oxidation.

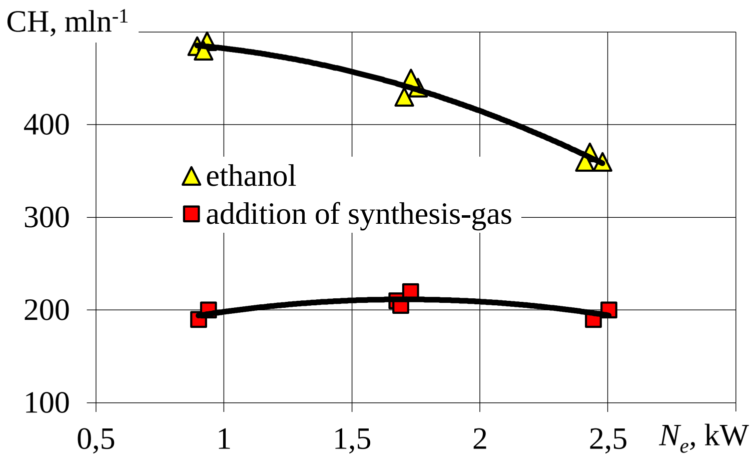
The characteristic of the change in the concentration of the main toxic components is determined by the reaction-kinetic dependences. In areas of rich mixtures, a significant increase of CO and CH concentrations is observed due to the lack of oxygen for the complete oxidation of the fuel, and at the same time this fact contributes to the reduction of emissions of nitrogen oxides NO_x. In contrast, in the areas of poor mixtures the fate of CO and CH is insignificant, and the concentration of NO_x increases. Using conventional fuel with a further increase in the excess air coefficient $\alpha > 1,1$, the concentration of CH in the EG increases as a result of slow and incomplete combustion of highly depleted mixtures. However, reducing the temperature of the cycle with the depleted mixture helps to reduce the concentration of nitrogen oxides. Consequently, neither the enrichment nor the depletion of the mixture when using conventional fuel does not allow to achieve the reduction of all harmful components simultaneously. The implementation of the region changes of the excess air coefficient, beneficial from the point of view of reducing the concentration for toxic components and ensuring the fuel efficiency of the engine, possibly in the case of using fuels with wide concentration limits of ignition and high combustion rates with significantly depleted mixtures. Such fuel can be pure hydrogen or synthesis-gas. Moreover, as a fuel, these gases can be used as an independent fuel or as additives for improving the environmental performance indicators and combustion of standard motor fuel (gasoline, diesel, ethyl or methyl alcohol, etc.).

Using the additives of synthesis-gas in the composition of the main fuel, there is an opportunity to increase the value of the excess air coefficient more than 1.1. However, due to the significant content of hydrogen in the composition of the synthesis-gas, the rate of combustion does not reduce, which in turn does not lead to an increase in the concentration of CH in the exhaust gases.

The dependences in the concentration of harmful emissions in the exhaust gases depending on the engine load are presented in Fig. 13. Depending on the additive of synthesis-gas in all modes of operation, there is a twice indicator decrease of harmful emissions from exhaust gases.



a



b

Fig. 13. Comparison of the change in the concentration of harmful components in EG of the TE-200 engine depending on the load when working on ethanol and with the addition of synthesis-gas:
a – concentration of CO in EG; b – concentration of CH in EG.

CONCLUSIONS

1. The given experimental data allow to conclude that the developed stand and the measurement system can be applied to research work processes in power plants based on the piston ICE with forced ignition, working on ethanol with the use of thermochemical utilization of the exhaust gases heat, and the obtained data can be considered reliable. The experimental stand based on the TE-200 engine allows to determine the changes of the main

parameters of the engine when working on ethanol with the synthesis-gas additives by the load characteristics.

2. The experimental studies have confirmed the feasibility and efficiency of thermochemical utilization of the exhaust gases heat, as well as with sufficient accuracy allowed to obtain the characteristics of changes in the main parameters of the conversion process of ethanol into synthesis-gas. It was experimentally established that when the full conversion by the decomposition is achieved, all liquid ethanol entering the thermochemical reactor is completely converted to a combustible synthesis-gas, the main components of which are hydrogen H_2 (43%), carbon monoxide CO (34%), and methane CH_4 (23%). And, the estimated specific lower heat value of synthesis-gas is 28.79 MJ/kg. In this case, for obtaining of 1 kg of synthesis gas, 4.0 MJ of thermal energy is consumed.

3. Due to the presence of a significant amount of H_2 in the synthesis-gas, the ignition limits of the combustible mixture were expanded, which ensured engine operation at all load modes with synthesis-gas additives in a wider range of change in excess air coefficient from 1.05 to 1.18. In this case, the speed of combustion does not decrease, which, in turn, does not lead to an increase in the concentration of CH in the exhaust gases. Depending on the synthesis-gas additive in all modes of operation, there is a decrease in the content of harmful emissions from EG, namely CO by 53.5%, CH by 55.1%.

4. With the use of synthesis-gas additives obtained by thermochemical utilization of the exhaust gases heat, the specific efficient consumption of ethanol decreased by 20…130 g/(kW·h) (2.5…12.4%).

SUMMARY

The actual processes of an internal combustion engine with spark ignition, working on ethanol with the addition of synthesis-gas, and especially the combustion process, depend on many factors of chemical kinetics of fuel burnout, thermodynamics and gas dynamics, heat and mass transfer, and many others. With the help of mathematical modeling it is not possible to describe the real processes occurring in the working cylinder, elements of the gas-flow path and the power plant as a whole. The analysis of the results of experimental research allows to determine further ways of improvement of fuel efficiency, power and environmental friendliness of engines.

The experimental stand for the study of working processes in power plants of low-displacement ships on the basis of internal combustion engines working on ethanol with the addition of synthesis-gas obtained by the thermochemical utilization of the exhaust gases heat was created. Experimental studies of the processes that occur during the thermochemical utilization of the exhaust gases heat were carried out, as well as the experimental studies of the processes that occur when the ICE operates on ethanol with synthesis-gas additives were carried out. It was revealed that due to the presence of a significant amount of H_2 in the synthesis-gas, the ignition limits of the combustible mixture were expanded, which ensured engine operation at all load modes with synthesis-gas additives in a wider range of change in excess air coefficient from 1.05 to 1.18. Depending on the synthesis-gas additive in all modes of operation, there is a decrease in the content of harmful emissions from EG, namely CO by 53.5%, CH by 55.1%. With the use of synthesis-gas additives obtained by thermochemical utilization of the exhaust gases heat, the specific efficient consumption of ethanol decreased by 20…130 g/(kW·h) (2,5…12.4%).

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