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MODELING OF THE DEPENDENCE OF CO_2 CONTAINED IN THE EXHAUST GASES ON THE AMOUNT OF HYDROGEN GAS SUPPLIED TO THE ENGINE

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Abstract. The idea of this publication is to show how mathematical modeling presents dependence of CO_2 in the exhaust gases. Using quadratic function obtained results are with good approximation. The future below to hydrogen about marine uses. Mathematical modeling is the best way to show how we can make an experiment with small database and that with mathematical function we receive a full picture of problem that we research with data which can't receive with real experiment.

Keywords: hydrogen; marine engine; modelling dependence of CO_2 in exhaust gases

Introduction

Modern marine engines are designed to improve the overall efficiency of the marine system (Feili et al. 2020). The introduction of new fuels such as hydrogen in maritime transport is considered a challenge due to the harsh environmental conditions in which the motor ship must operate (Jia et al. 2017). Any attempt to introduce a new fuel in the field of maritime transport must be accompanied by sufficient studies and experimental data to provide engineers and ship operators with the sufficient data on the new type of fuel used (Li et al. 2019; Miller et al. 2014; Miao et al. 2021; Sapra et al. 2020)

Objective and research methodologies

The purpose of this publication is to model the dependence of CO_2 contained in the exhaust gases on the amount of hydrogen gas supplied to the engine. The SKL 3NVD24 marine diesel engine was chosen as the object of the study. Place of the conducted experiments – Naval Academy "N. Vaptsarov" – Varna. The hydrogen experiment was performed with a VST 4C gas generator manufactured by Hydrogas.

The engine used is four-stroke, in-line, naturally aspirated. Piston stroke – 240 mm and cylinder diameter – 175 mm. The designation 3NVD24 indicates that the engine is 3-cylinder, N-means that the ratio of the stroke of the piston to the diameter of the cylinder – is less than 1.3. The letter sign V – indicates that the engine is four stroke and D – means that it is a diesel engine. The number after the designation is the stroke of the piston in centimeters. The SKL 3NVD24 engine was manufactured in 1965 at the Karl Libkner plant in Magdeburg in the former DDR. The SKL engine is shown on Figure 1. A hydrogen cell is shown on Figure 2.

Figure 1. Diesel engine SKL3NVD24

Figure 2. Gas generator

The engine's fuel system includes fuel filters, fuel pumps (one for each cylinder) and fuel valves. The engine oil system includes a crankshaft gear oil pump, coarse and fine filters and a double-acting manual piston pump for pre-coupling oil to the main and connection rod bearings.

The cooling system consists of two circuits, an open circuit in which the circulation of seawater is simulated and a closed circuit with fresh water. In case of damage to the cooling circuit with fresh water, the engine can also be cooled with sea water from the open circuit. A piston pump provides the incoming water to the open cooling circuit and a centrifugal pump provides cooling of the cylinder block and the cooling spaces of the cylinder head through water-water cooler. Both pumps are driven by the crankshaft via a gear drive. The engine is started with the help of compressed air at a nominal pressure of 30 bar and a minimum rotation pressure of 12 bar. The nominal speed is 600 min^{-1} and the minimum speed is 300 min^{-1}. The rated power of the engine is 44.1 kW or 60 hp. The working volume of the cylinders is 17.32 dm^3 (5.76 dm^3 for each cylinder). Stand KI2139B-GOSNITI is designed for testing engines with a nominal torque of 25-40 kg/m and a crankshaft speed of 1500-3000 min^{-1}. Since the operating frequency of the engine is 300-600 min^{-1} to increase in conjunction with the electric brake an upshift is required. For this purpose, a multiplier with a gear ratio of 1:5 is installed. The supply voltage of the stand is 380Vq the frequency is 50Hz. Its load capacity is 210kW. The breaking and torque-measuring device is a pendulum-type weighing mechanism.

This machine is an oxyhydrogen gas generator – VST 4C. It produces stoichiometric gas mixture composed of hydrogen and oxygen. The gas mixture is a useful product, which in turn is used to clean internal combustion engines of any types, size, power, fuel and purpose. The VST 4C is automatic and the operator must set the operating mode limits by providing a front-facing display for this purpose performing command and control functions. The gas generator is designed in accordance with the latest technologies and requirements for this type of machine. It is completely reliable and secure in operation (Table 1).

Table 1. Technical characteristics of the gas generator

Model VST 4C	
maximum installed power /KW/	6
maximum gas productivity (litres/hour)	6500
maximum consumption of distilled water (litres/hour)	0,5
weight /kilograms/	150
dimensions /mm/	600/1480/600

The experiment was performed while maintaining the same engine temperature, with a change in the amount of gas supplied (by changing the current of the hydrogen cell) and registration of the components of the exhaust gases. The experiment is performed at rated speed and without load. It is necessary to specify that all tests and the accompanying conclusions refer only to the specific type of hydrogen cell and the respective engine. Their summary on other conditions can only be of a principled nature.

Research method: in the performed research, a significant difference in the data was found, due to the selected factors and to external disturbances (Bakalova et al. 2020). An experimental – statistical method – regression analysis was chosen for processing the experimental material. Excerpts from 9 experiments were used. Obtaining qualitative regression models was achieved after performing the following a two-step procedure: determining the parameters of a pre-selected structure of the model and statistical analysis of the results (Bakalova 2020). The finally selected model can be used to predict the effect of the fuel- hydrogen mixture on the exhaust components. Due to the nature of hydrogen cell operation, a regression dependence of the change in the amount of hydrogen gas on the strength of the electric current was obtained at the beginning of the study. In all subsequent studies, the amount of hydrogen gas was taken as a factor and the content of gases was taken as a starting point. The results of the research are presented in Table 2.

Table 2. Exhaust gas content depending on the amount of hydrogen gas

dimension	I try	II try	III try	IV try	V try	VI try	VII try	VIII try	IX try
amperage (A)	40	50	60	70	80	90	100	110	120
gas	3	3.3	3.2	3.6	4.3	4.3	4.8	5	5.1
diesel	36	38	33	38	39	40	37	38	42
CO	14.45	14.49	16.4	16.5	16.7	16.8	17	17.1	17.2
CO_2	2.4	2.4	2.3	2.4	2.4	2.5	1.7	1.8	1.7
NO	150	152	90	106	111	118	77	77	80
O_2	17.8	17.8	18	17.9	17.8	17.7	18.7	18.6	18.6
NO_x	150	152	90	106	111	118	77	77	80
qA	44.2	46.1	37.3	39.5	41.5	45.7	52.6	58.3	59.1
Eta	55.8	53.9	62.7	60.5	58.5	54.3	47.4	41.7	40.9

Table 3 contains the values of the hydrogen gas in the nine experimental trials.

Table 3. Amount of hydrogen gas depending on the amperage of the cell

x (A)	3	3.3	3.2	3.6	4.3	4.3	4.8	5	5.1
Y-CO_2	2.4	2.4	2.3	2.4	2.4	2.5	1.8	1.7	1.8

The results of the application of the regression analyses are given in Table 4.

Table 4. Results obtained from mathematical modeling

dependence modeling results – amount of CO_2 (y) от H_2(x); y=f(x)						
type of model	coefficient of the model	adequacy of the model	standard error S_y	coefficient of correlation	correlation of the remains	stationarity of the disp.
$y=b_0+b_1x$	$b_0=3.4238$ $b_1=-3.3037$	yes	0.22104	0.76641	-	yes
$y=b_0+b_1x+b_2x^2$	$b_0=-3.0952$ $b_1=3.027$ $b_2=-0.4103$	yes	0.13862	0.92785	no	yes
$y=b_0+b_1\ln x$	$b_0=3.7893$ $b_1=-1.1559$	yes	0.23415	0.73281	-	no
chosen model	$y=-3.0952+3.027x-0.4103x^2$					

The analysis of the data from the table shows that of the three adequate models with minimal standard error is the second model /quadratic function. It is adequate and with a maximum correlation coefficient. This model satisfies the conditions for applying regression analysis: no correlation of the residues, constant value of the variance, normal distribution of the residues e_i and $\sum e_i \equiv 3.004e-012$, value assumed to be zero. It is finally chosen to approximate the data and the dependence: the amount of CO_2 contained in the exhaust gases from the hydrogen gas supplied to the engine. The graph below shows for comparison the real experimental data (*) and those obtained by the model (-), which shows a good approximation.

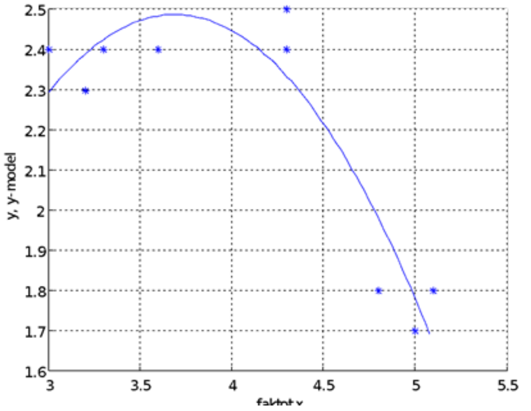

Figure 3. Comparison between experimental data (*) and obtained model (-)

Conclusions

In conclusion, we can summarize that the mathematical modeling shows that a very good approximation is obtained between the data from the real experiment and those obtained during the mathematical processing. The quadric function is adequate with a maximum correlation coefficient.

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