Results Of An Experimental Statistical Study Of The Influence Of Hydrogen On The Co Release And The Fuel Consumption Of A Marine Diesel Engine. Quantitative Analysis

Part II

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Abstract: The application of Regression Analysis and the results of the study and evaluation of the influence of Hydrogen 5.0 F50 P200 on fuel consumption under variable load operation of a marine diesel engine SKL 3NVD24 with two types of fuel are considered. A technology for quantitative analysis is proposed.

Key words: efficiency, marine diesel fuels, mathematical models, hydrogen technology.

1. Introduction

The second part examines the results of mathematical modeling based on data from experiments conducted with a medium-frequency marine diesel engine SKL 3NVD24: four-stroke, 3 cylinders, rated power at 600 (min-1) – 44.1 kW, cylinder volume –5.76 (dm3), with variable load in the range of 0- 18 kg and operation on two types of fuel: diesel and Hydrogen 5.0 F50 P200. The experiments were conducted in the laboratory of the Naval Academy “N.Y. Vaptsarov”, Varna [3,7, 8].

The research technology includes a scientific search for qualitative mathematical models of the relationships load G kg, consumption for both types of fuel. The processing of experimental data is by the method of Regression Analysis (RA): determination of the coefficients of a model with a pre-selected structure and statistical analysis of its quality. Based on the mathematical models and their solutions, the degree of consumption of the respective fuel is determined. The relative error is determined, which is compared with the error from the experiments, after which a justified decision is made about the degree of influence of the fuel Hydrogen 5.0 F50 P200, compared to diesel fuel alone. The strategy of scientific research is: starting with the simplest structure of the model and complicating it, after checking its qualities, in order to reach a model with high quality [1, 4].

1. Mathematical model of the load-diesel fuel consumption relationship of a marine diesel engine

10 sets of data were processed using data from the registration of the engine load G (kg) and the fuel consumption Con(g/h). The load was considered as a factor and is denoted by x, and the objective functions by y. The experimental data used, recorded as a row vector are: G=[0 2.3 4.1 6.2 8.0 10.4 12.5 14.2 16.6 18.9]; Con=[3183.2 3475.9 4259.2 4447.1 5125.4 5498.2 6300.0 7200.0 8400.0 9163.6];

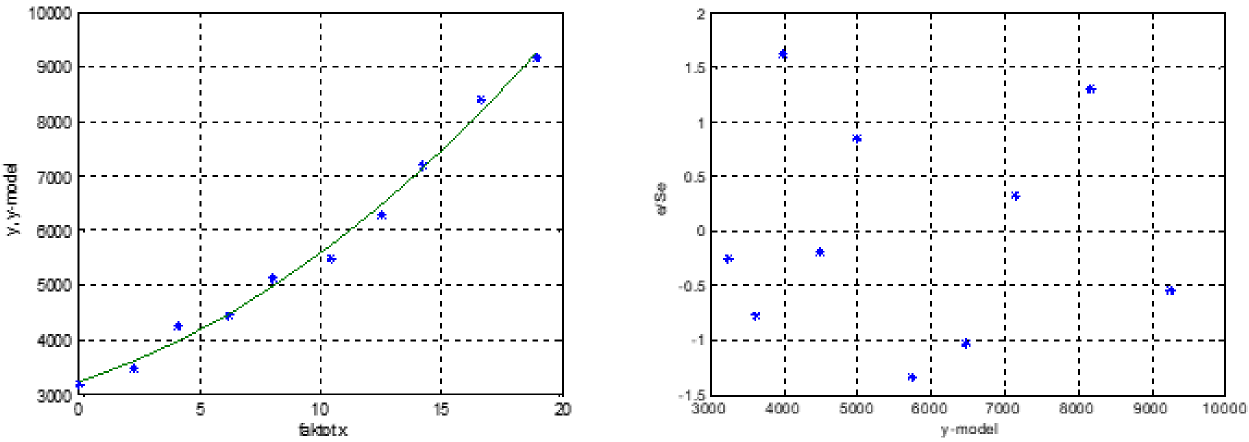
Results of studying the influence of the load G on fuel consumption (g/h) of a marine diesel engine SKL 3NVD24, when using diesel fuel

Table 1

Fuel consumption (g/h)						
Model	Adequacy	Standard error SY	Normality check on Jacques-Bera curve	Homoskedasticity according to Glaser's criterion	Pearson's Ryx	DERBIN-WATSON correlation check
y = 2733.6 + 318.8.x	Fem= 255.1755 F(0.05;1;8)=5.32 **Conclusion**: **yes**	375.9343	JBem = 0.7215 JBт(0.05;2) = 5.99 **Conclusion**: Normal distribution	FFem =0.4801 Ft(0.05;1;8)= 5.32 **Conclusion**: **yes**	0.98468	d = 0.8584 1alfa=5%; dL= 0.879 dU= 1.32 0<d<dL **Conclusion**: positive autocorrelation
y = 3227.2+145.0.x + 9.2. x^2	Fem= 472.9905 F(0.05;2;7)=4.74 **Conclusion**: **yes**	197.5571	JBem= 0.7462 JBт(0.05;2) = 5.99 **Conclusion**: Normal distribution	FFem= 0.0952 Ft(0.05;1;8)= 5.32 **Conclusion**: **yes**	0.99632	d =2.3836 alfa=5%; dU= 1.32 dU<d<4-dU=2.68 **Conclusion**: No autocorrelation available

The results of the research and the subsequent conclusions are given in tabular form, including: type of model; results of checking the quality of the model through adequacy, standard error SY, value of the Pearson correlation coefficient Ryx, as well as checking the conditions for applying the Regression analysis: normality, absence of correlation, stationarity and ∑ei=0 of the residuals, after processing the data with the Least Squares method (LSM). For universality in the entries in all tables following the presentation, x denotes the values of the load factor G, and yd denotes the objective functions. Table (1) presents results of processing experimental data obtained when working with diesel fuel.

The first row of Table 1 gives the results of determining the parameters of a linear model. It is adequate, satisfies the requirements for applying the Regression analysis (RA), with the exception of the Durbin-Watson check. In Table 1, the second row gives a nonlinear quadratic model with its characteristics: It is adequate, with the standard error SY= 197.5571 and the Pearson correlation coefficient Ryx=0.99632. This model satisfies the conditions for applying Regression Analysis: normal distribution of the error, stationarity of the error, the sum of the error values here is ∑ei=-2.683e-011, taken as zero. Fig. 1 shows the real data (*) and according to the model (-), and the second figure shows the normalized error. Here, the dependence of the normalized error e/Se has a random nature and does not indicate a change in the nature of the selected mathematical model.



Figures 1. Results of the nonlinear model

The comparative analysis of the two models shows that both are adequate and satisfy the assumptions for the application of Regression Analysis, except for the Durbin-Watson check, from the linear model. The parabolic model satisfies all the criteria, it is more accurate, with a smaller standard error SY= 197.5571 and a large Pearson correlation coefficient Ryx=0.99632, which is the reason for it to be chosen as the Regression model of the relationship between the engine load G (kg), and fuel consumption (g/h). The model in real variables has the form (1)

con = 3227.2+145.0.G + 9.2. G2 (1)

Conclusion: For a mathematical description of the relationship between the engine crankshaft load G (kg) and fuel consumption (g/h), a parabolic mathematical model is adopted. It is adequate and of good quality.

2. Mathematical model of the load-fuel consumption relationship when using Hydrogen 5.0 F50 P200 of a marine diesel engine

10 sets of data from the registration of the engine load G (kg) and the fuel consumption

using Hydrogen 5.0 F50 P200 (g/h) were processed, given below.

G= [0 2.3 4.1 6.2 8.0 10.4 12.5 14.2 16.6 18.9];

Con= [3183.2 3475.9 4259.2 4447.1 5125.4 5498.2 6300.0 7200.0 8400.0 9163.6];

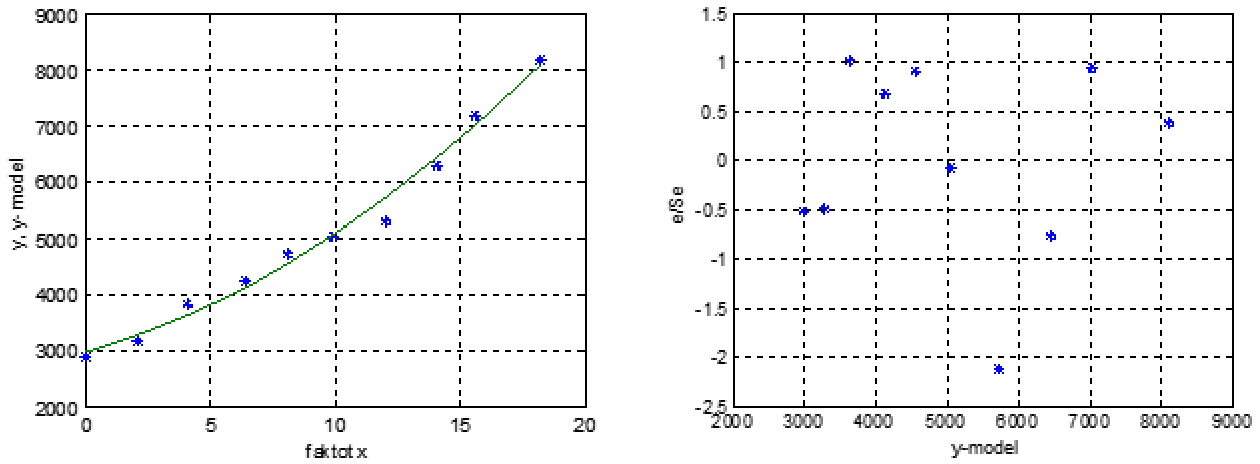
Table 2 presents the results and analysis of the modeling.

Results of the study of the influence of the load G on the fuel consumption (g/h) of a marine diesel engine SKL 3NVD24, when using hydrogen fuel 5.0 F50 P200

Table 2

Fuel consumption (g/h)						
Model	Adequacy	Standard error SY	Normality check on Jacques-Bera curve	Homoskedasticity according to Glaser's criterion	Pearson's Ryx	DERBIN-WATSON correlation check
y = 2555.1+ 280.0.x	Fem= 206.545 F(0.05;1;8)=5.32 **Conclusion**: **yes**	350.8298	JBem = 0.1887 JBт(0.05;2) = 5.99 **Conclusion**: Normal distribution	FFem = 3.2526 Ft(0.05;1;8)= 5.32 **Conclusion**: **yes**	0.98118	d = 0.7406 1alfa=5%; dL= 0.879 dU= 1.32 0<d<dL **Conclusion**: positive autocorrelation
y = 2979.0+124.0.x + 8.6.x^2	Fem= 276.2349 F(0.05;2;7)=4.74 **Conclusion**: **yes**	217.2538	JBem= 1.1782 JBт(0.05;2) = 5.99 **Conclusion**: Normal distribution	FFem= 0.2477 Ft(0.05;1;8)= 5.32 **Conclusion**: **yes**	0.99372	d =1.4135 alfa=5%; dU= 1.32 dU<d<4-dU=2.68 Conclusion : No correlation

The first row of Table 2 gives the results of determining the parameters of a linear model. It is adequate, satisfies the requirements for applying the Regression Analysis, with the exception of the Durbin-Watson check. In Table 2, the second row gives a nonlinear quadratic model with its characteristics: the model is adequate, with the standard error SY= 217.2538 and the Pearson correlation coefficient Ryx=0.99372. This model satisfies the conditions for applying Regression Analysis: normal distribution of the error, stationarity of the error, the sum of the error values here is ∑ei)=-2.0145e-010, taken as zero. All the quality criteria for the coefficients when applying the Least Squares method (LSM) are also satisfied. Fig. 2 shows the real data (*) and the model curve (-), and the second figure shows the normalized error e/Se . The dependence on y_model is random and does not indicate a change in the nature of the selected mathematical model [2,5,6].



Figures 2. Results of the nonlinear model

The comparative analysis of the two models shows that both are adequate and satisfy the assumptions for the application of the Regression analysis, except for the Durbin-Watson check, from the linear model. The parabolic model satisfies all the criteria, it is more accurate, with a smaller standard error SY= 217.2538 and a large Pearson correlation coefficient Ryx=0.99632, which is the reason for choosing it as the Regression model of the relationship between the engine load G (kg), and fuel consumption (g/h). The model in real variables has the form (2),

$$con = 2979.0+124.0.G + 8.6.\ G^2 \qquad (2)$$

Conclusion: For a mathematical description of the relationship between the engine crankshaft load G (kg) and fuel consumption using Hydrogen 5.0 F50 P200 (g/h), a mathematical model of a parabolic type is adopted. It is adequate and of good quality.

3. Study of the influence of fuel Hydrogen 5.0 F50 P200 on fuel consumption (g/h). Efficiency assessment

The mathematical models created by the Regression Analysis method when registering 10 sets of experimental data and using diesel fuel alone (1) and Hydrogen 5.0 F50 P200 (2) are given below. They reflect the statistical relationship of the influence of the engine load G (kg) when using both types

$$Con1 = 3227.2+145.0.G + 9.2.\ G^2 \qquad (1)$$

$$Con2 = 2979.0+124.0.G + 8.6.\ G^2 \qquad (2)$$

The designations Con1 and Con2 are used because a comparison of the processes in pairs is made when operating on diesel fuel and hydrogen.

According to the equations, when the load changes in the load range G= [0 2 4 6 8 10 12

14 16 18], which is of research interest, the values for Con1 and Con2 were obtained, given as a vector of rows:

Con1 = [3227.2 3554.0 3954.4 4428.4 4976.0 5597.2 6292.0 7060.4 7902.4 8818.0];

Con2 = [2979.0 3261.4 3612.6 4032.6 4521.4 5079.0 5705.4 6400.6 7164.6 7997.4];

The difference between the values predicted by the two models Con _e = Con1 – Con2 is

Con_e =[248.2 292.6 341.8 395.8 454.6 518.2 586.6 659.8 737.8 820.6];

The relative error between the two processes in percent is

Con_e% =(Con_e./Con1)*100

Con_e% =[7.6909 8.2330 8.6435 8.9378 9.1359 9.2582 9.3229 9.3451 9.3364 9.3060]

The relative error Con_e% exceeds the experimental error of 5% in the entire load range of the diesel engine, which indicates that the reduction in fuel consumption during operation is significant and ranges from 7.6909%, at idle speed, to over 9.3%, when using Hydrogen 5.0 F50 P200. .

The difference in Fuel Consumption (g/h) for Hydrogen 5.0 F50 P200 is minimal at idle and increases with increasing engine load. At average and maximum load, the percentage reduction in consumption remains almost constant, 9.1-9.3%.

Conclusion: The influence of the fuel type Hydrogen 5.0 F50 P200 on the consumption (g/h) when operating the diesel engine, compared to using diesel fuel alone, is significantly above the experimental error and should be considered significant in the entire load range.

The economic benefit of reducing Fuel Consumption (g/h)using Hydrogen 5.0 F50 P200, when operating the diesel engine, compared to when using diesel fuel alone can be determined using the following approach. It is assumed that due to disturbing factors, the engine load varies in the interval G1 – G2, valid for the entire load range. The average value of consumption concp, in this interval, is determined. After taking into account equations (1) and (2) the average consumption value will be

$$con_{cp} = \frac{1}{G2 - G1}\int_{G1}^{G2}(Con1(G) - Con2(G)).dG = \frac{1}{G2 - G1}[248.2.(G_2-G_1) + 10.5.(G_2^2-G_1^2)+0.2.(G_2^3-G_1^3)].$$

Based on it and the operating time in this interval Δt, the economic benefit of reducing consumption of using Hydrogen 5.0 F50 P200 compared to diesel alone is determined, i.e. $consumption_{benefit}$ = concp * Δt. In terms of price, the economic efficiency of using hydrogen fuel should also take into account the prices of both types of fuel: diesel and Hydrogen 5.0 F50 P200.

2. Conclusion

The proposed research technology allows us to state with high confidence that the use of

Hydrogen 5.0 F50 P200 fuel in a marine diesel engine leads to an 8-9% reduction in fuel consumption in the load range. The research and results refer to a specific type of marine engine. Experimental statistical study on the influence of hydrogen addition on CO emissions and fuel consumption in a marine diesel engine depends entirely on the results of the statistical analysis. Regardless of the specific results, we must always Include Acknowledge any limitations, such as the specific engine type, limited range of operating conditions, potential measurement errors, or small sample size. These limitations should be discussed in the context of the conclusions drawn.

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