RESEARCH OF OPERATION OF A DIESEL ENGINE WITH SUPPLEMENTARY ETHANOL FEED

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Abstract

Technical characteristics of the engine tested, schematic view of the equipment used in testing ethanol effect on diesel engine, dependence of heat energy consumption on torque of the engine and the amount of ethanol, dependence of heat energy consumption on torque of the engine and the amount of ethanol with n = 1950 r.p.m. and with n = 2200 r.p.m, the dependence of the optimal amount of ethanol on the engine speed n and torque of the engine are presented in the paper.

1. Introduction

The problem of developing the alternative kinds of fuel is urgent all over the world, since the traditional ones can hardly meet the ever – growing demand, as well as causing environment pollution. Most suitable alternative kinds of fuel for diesel engines may be considered vegetable oil or fuel obtained from the animal fat, because their characteristics are similar to those of common diesel oil.

The rape grown in Lithuania could be a perfect source for producing the fuel, however, the introduction of production technology requires large investments, which Lithuania can not afford at the moment. The alternative way could be the use of other biological fuels, such as ethanol [1, 2, 3], which is obtained from agricultural products abundant in Lithuania. Moreover, its production does not require large investments.

The present paper describes tests carried out with diesel engine fed with ethanol (in addition to diesel oil) supplied by various systems. Various ways of supplying ethanol are well – known [4], being widely investigated in 1980 – 1990. In some cases, diesel oil is supplied by a commonly used system, while ethanol is injected into the cylinders by a similar system provided with high-pressure fuel pump and injectors. Another case is when ethanol is fed via carburettor into the air sucked by an engine, while the portion of diesel oil injected by a commonly used system ignites the mixture [5, 6]. Tests were based on two main models. First, the engine was tested in various operation modes, with the invariable amount of ethanol supplied. Second, the engine operation mode was constant, while the amount of the supplied ethanol varied.

Present investigation was based on varying both the mode of engine operation and the amount of ethanol supplied. A major goal was to determine the optimal quantity of bioethanol, ensuring most economic operation of an engine in a particular mode.

2. Investigation methods

Tests were carried on in the laboratory of internal combustion engines by using the turbo diesel engine of the car Audi – 80. Technical characteristics of the engine are given in Table 1.

Table 1.

Technical characteristics of the engine tested

Characteristics	Description
type of engine	1Z
volume V_h, cm^3	1896
compression ratio ε	19.5
power P_e, kW	66 (4000 min^{-1})
torque M_s, Nm	180 (2000…2500 min^{-1})
cylinder diameter D, mm	79.5
piston stroke S, mm	95.5
idle speed, r.p.m.	780…860

In Fig. 1, a diagram of test equipment is presented. The engine is connected to the testing bed of electric motors **12**. In testing, fuel consumption **5,6** was determined by weight approach, while the amount of air consumed 4 was found by variable pressure difference method. Ignition pressure in the engine cylinders was measured by piezoquartz pressure sensor **13**, the temperature of combustibles and the air – by thermocouples **1**, while the determining of smoking was based on photometric absorption principle.

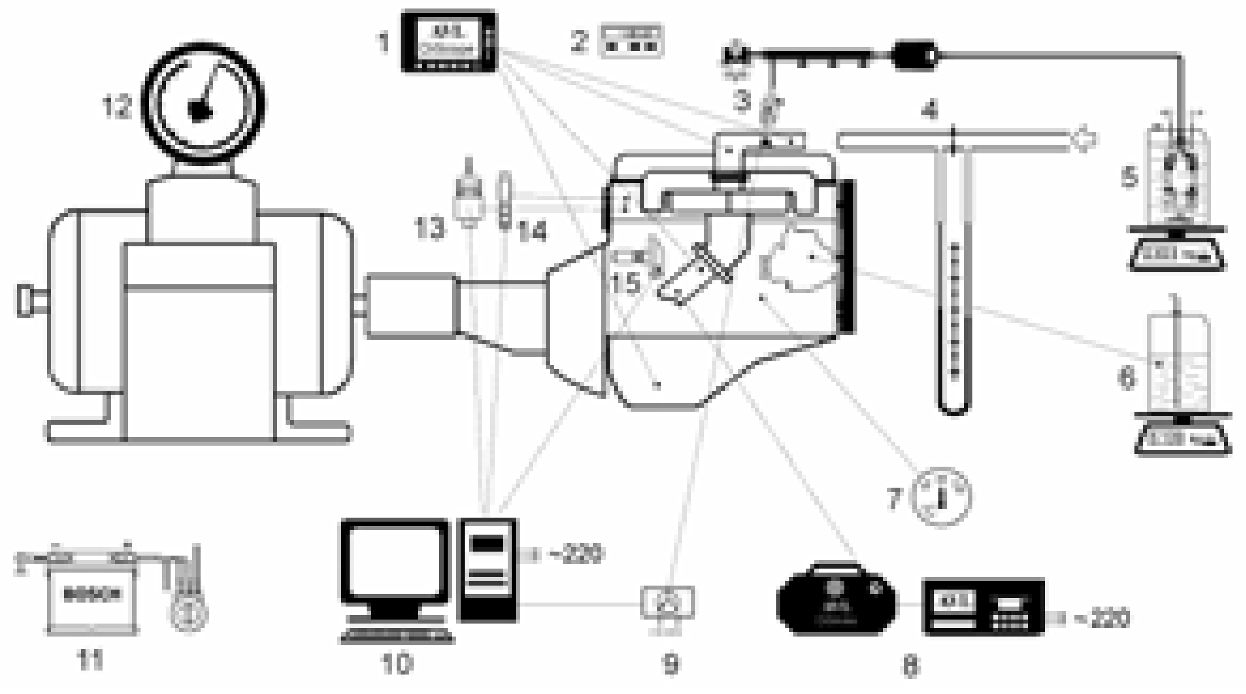

Fig. 1. *Schematic view of the equipment used in testing ethanol effect on diesel engine: 1 – diagnostic facility AVL DiScope 865 for measuring thermocouple voltage; 2 – electronic chronometer; 3 – equipment for supplying ethanol; 4 – equipment for measuring air consumption; 5 – scales for measuring alcohol consumption; 6 – scales for measuring diesel oil consumption; 7 – cooling liquid thermometer; 8 – fuel analyser AVL DiSmoke; 9 – pulse generator; 10 – personal computer; 11 – 12 V storage battery; 12 – engine testing bed КИ – 5543; 13 – piezokwartz pressure sensor; 14 – diesel oil injection timer; 15- engine speed/position sensor*

Ethanol was injected into the air sucked by the engine with the help of electromagnetic injector 3, controlled by pulse generator 9, while frequency was controlled by personal computer 10. The composition of ethanol is given in Table 2.

Table 2.

Compression of denaturated ethyl alcohol

Components	Quantity by volume, %
absolute alcohol	92.1
water	2.6
aldehyde, methyl and other admixtures	0.3
A 95 – grade petrol	5.0

A special testing plan has been made to reduce the number and duration of tests, as well as efforts and tools used. A complete three – level factorial plan 3^k has been selected, because it allows the modelling of curved surfaces of the echo function, as well as facilitating the investigation of square relationship between the surface and each of the factors (at the 3 – d level). However, the above plan requires to make more tests. The levels of factors and variation intervals are given in Table 3.

Table 3.

Levels of factors and variation intervals

Factors	Levels			Variation intervals
	-1	0	+1	
engine speed *n*, r.p.m.	1700	1950	2200	250
torque M_s, Nm	34,49	69,18	103,87	34,69
amount of ethanol B_s, kg/h	0	0,75	1,5	0,75

Note: the operation mode of an engine, most typical of city traffic, has been chosen

The optimal amount of ethanol needed for an engine operating in various modes was determined by stating the dependences of heat energy consumption and their optimization.

Relative heat consumption by the engine q_e (MJ/(kW·h)) was calculated according to the formula:

$$q_e = \frac{H_d \cdot B_d + H_s \cdot B_s}{P_e} \tag{1}$$

where H_d, H_s – lower heat generation level of diesel oil and ethanol, MJ/kg;
B_d, B_s – expenditures of diesel oil and ethanol, kg/h;
P_e – engine power, kW.

3. Discussion of results

Graphical representation of the heat energy consumption by the engine operating in all the modes investigated was provided on the basis of statistical processing of data obtained in the tests performed (see Fig. 2, 3 and 4).

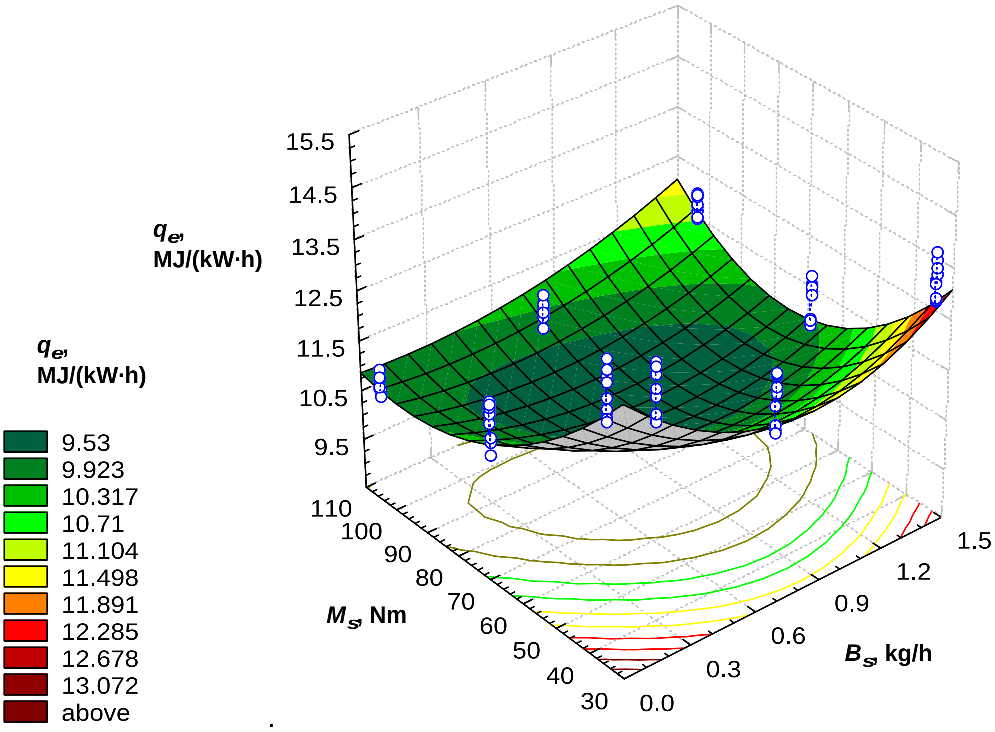

Fig. 2. *Dependence of heat energy consumption q_e on torque of the engine M_s and the amount of ethanol B_s, with n = 1700 r.p.m.*

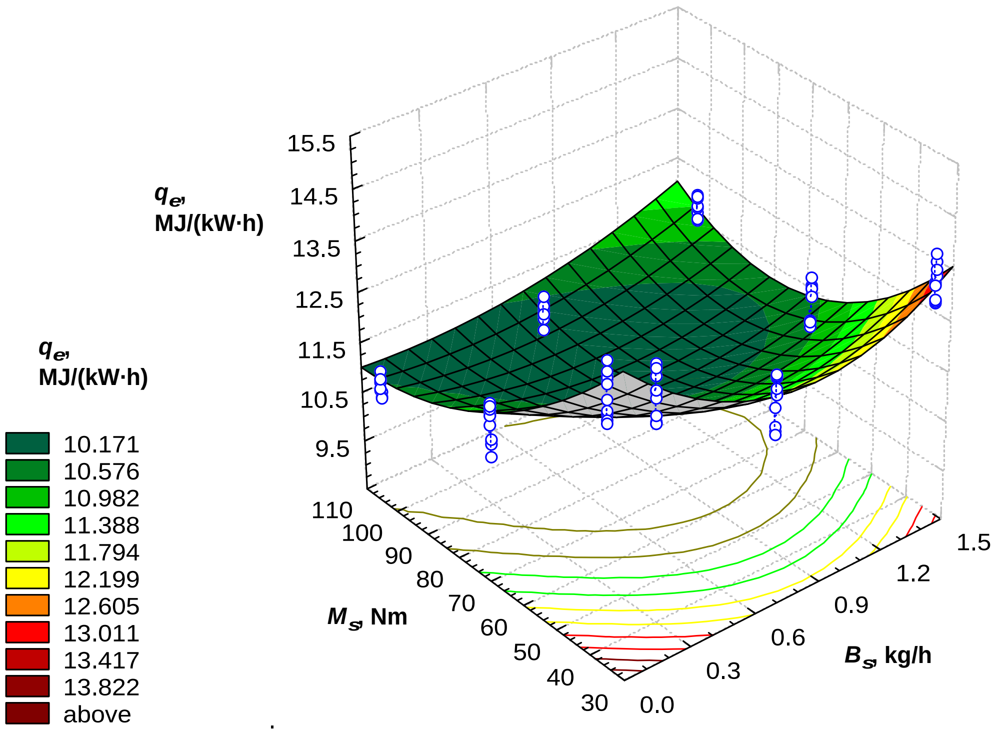

Fig. 3. *Dependence of heat energy consumption q_e on torque of the engine M_s and the amount of ethanol B_s, with n = 1950 r.p.m.*

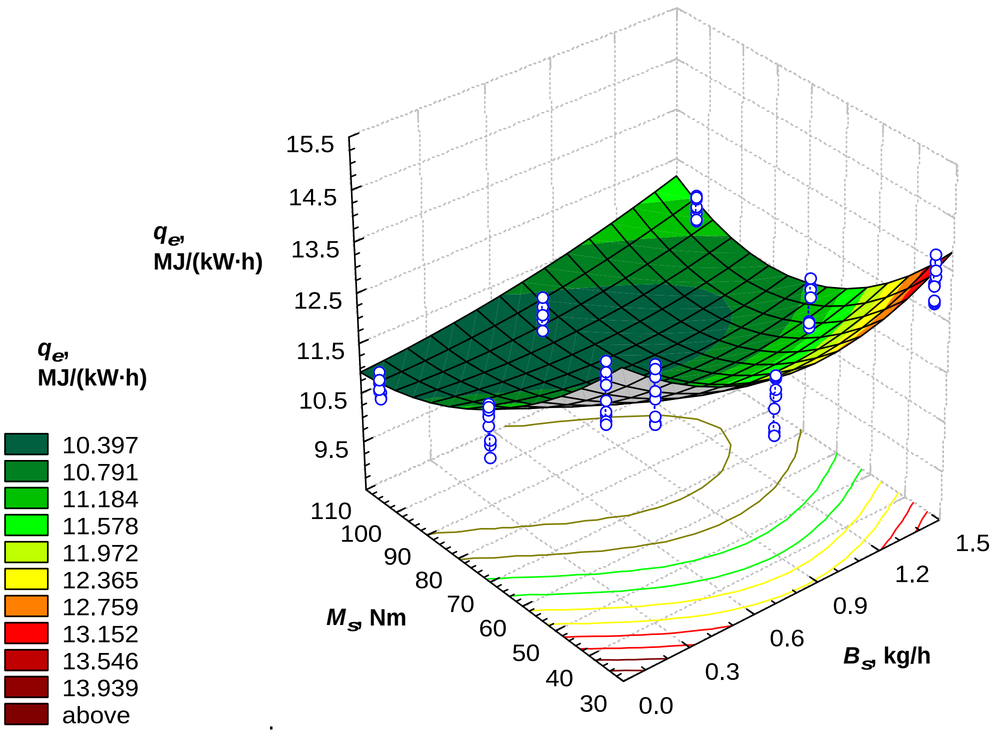

Fig. 4. *Dependence of heat energy consumption q_e on torque of the engine M_s and the amount of ethanol B_s, with $n = 2200$ r.p.m.*

Thus, the dependence of the consumption q_e on the torque M_s and engine speed n of the engine was expressed mathematically as follows:

$$\begin{aligned} q_e = {} & -3{,}4467 - 106{,}8579 \cdot 10^{-3} \cdot M_s + 1{,}6667 \cdot 10^{-3} \cdot M_s^2 - 8{,}3106 \cdot B_s + 6{,}3256 \cdot B_s^2 - \\ & 91{,}6199 \cdot 10^{-6} \cdot n \cdot M_s - 507{,}1813 \cdot 10^{-9} \cdot n \cdot M_s^2 + 36{,}5981 \cdot 10^{-9} \cdot n^2 \cdot M_s - \\ & 967{,}6084 \cdot 10^{-6} \cdot n \cdot B_s^2 + 397{,}9746 \cdot 10^{-9} \cdot n^2 \cdot B_s + 60{,}116 \cdot 10^{-3} \cdot M_s \cdot B_s - \\ & 57{,}3388 \cdot 10^{-3} \cdot M_s \cdot B_s^2 - 918{,}5742 \cdot 10^{-9} \cdot M_s^2 \cdot B_s + 214{,}3919 \cdot 10^{-6} \cdot M_s^2 \cdot B_s^2 - \\ & 5{,}3052 \cdot n^2 + 21{,}3255 \cdot 10^{-3} \cdot n - 3{,}06 \cdot 10^{-6}. \end{aligned} \tag{2}$$

Then, the above dependence was optimized for various modes of engine operation by minimizing the function values. In this way, it was found that the optimal amount of ethanol fed as additional fuel be written as follows:

$$\begin{aligned} B_{s\,opt} = {} & -6{,}8053 + 8{,}1376 \cdot 10^{-3} \cdot n - 2{,}2869 \cdot 10^{-6} \cdot n^2 + 0{,}2917 \cdot M_s - 3{,}0962 \cdot 10^{-3} \cdot M_s^2 - \\ & 0{,}3097 \cdot 10^{-3} \cdot n \cdot M_s + 3{,}2871 \cdot 10^{-6} \cdot n \cdot M_s^2 + 87{,}9469 \cdot 10^{-9} \cdot n^2 \cdot M_s - 0{,}9261 \cdot 10^{-9} \cdot n^2 \cdot M_s^2. \end{aligned} \tag{3}$$

In Fig. 5, this function is graphically represented.

Fig. 5 allows us to realize major principles of ethanol (B_s) feeding. It is clear that the higher the engine load M_s, the smaller the amount of ethanol supplied. This is accounted for the fact that under low loads the excess – air/fuel ratio α of the engine cylinders is rather high. The effect of engine rotations n on $B_{s\ opt}$ is insignificant, slightly increasing in the modes of maximum engine loading M_s.

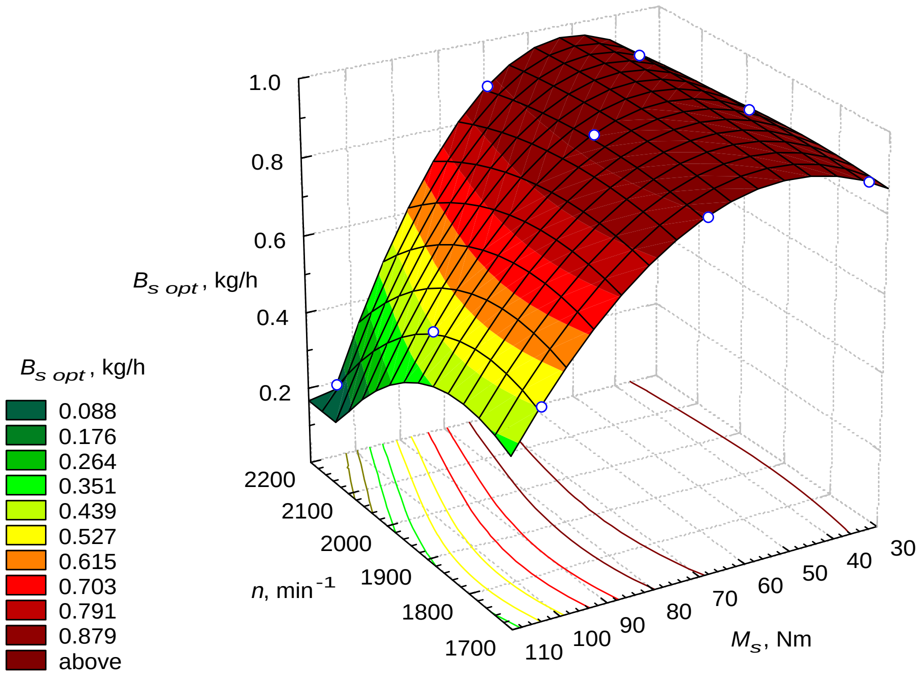

Fig. 5 *The dependence of the optimal amount of ethanol $B_{s\ opt}$ on the engine speed n and torque M_s of the engine*

4. Conclusions

1. The engine consumes the smallest amount of heat energy q_e = 9.13 MJ/(kW·h) when making 1700 r.p.m. engine speed, its torque being 69.18 Nm, and the amount of ethanol fed reaching 26% of the total amount of fuel used. This relationship is expressed by the equation (2).
2. The tests have shown that the highest amount of ethanol (0.90 – 0.95 kg/h) can be supplied when the torque of the engine reaches 50 – 60 Nm (not taking into account the number of engine speeds). This makes 42 – 47% of the total amount of fuel used.

References

1. P. Whalen, K. Kelly, R. Motta, J. Broderick. Alternative fuel Light-Duty Vehicles / Summary of Results from the National Renewable Energy Laboratory's Vehicle Evaluation Data Collction Efforts. Department of Energy, 1996. 27 p.
2. M. Abu-Qudais, O. Haddad, M. Qudaisat. The effect of alcohol fumigation on diesel engine performance and emissions // Energy Conversion and Management. ISSN: 0196-8904. 2000, Vol 41 (4), p. 389-399.
3. C. E. Goering, R. T. Parcell, C. P. Ritter. Hydrated Ethanol as a Fuel for a DI, CI Engine // Transactions of the ASAE, 1998, Vol. 41(5), p. 1255–1260.
4. А. С. Хачиян. Применение спиртов в дизелях // Двигателестроение, 1984. № 8, 30–34 с.
5. A. K. Singh, B. P. Pundir, A. Singh. A Fuel System for Dual – Fuel Operation of an Automotive Diesel. – Paper B-42, p. 507-511.
6. S. Pukalskas. Alternatyvinių degalų įtaka dyzelinio variklio ekonomiškumo ir toksiškumo rodikliams: magistro tezės. /Vadovas prof. habil. dr. A. Butkus/. Vilnius: VGTU, 1997. 39 p.