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# THE ANALYSIS OF THE ENERGY BALANCE OF THE ENGINE POWERED BY DIESEL OIL MIXTURE WITH BUTANOL

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***Abstract***

*The development of motorisation involves using bigger amounts of fuels. These fuels are, until now, mainly petroleum. However, the fuels of bio origin must be used as well. It follows from the necessity of ensuring $CO_2$ balance and from the fact that oil sources sooner or later will become exploited. Not less important is the fact that, principally, it is difficult to change the proportions of petrol and diesel oil extracted from crude oil, and the use of diesel oil increases proportionally faster than petrol. Therefore, it is necessary to use bio additives in diesel oil. One of such additives is dense alcohols. The aim of the present work is to determine the energy balance of diesel engine powered by diesel oil and butanol mixture. The work field includes making of energy balance of the engine in its characteristic points responsive 13 phase ESC test as well as determining on this basis the consolidated values concerning the differences in the engine energy balance. It has been proved, that powering the engine by mineral diesel oil with doped butanol (20% v/v) does not lead to essential differences in the energy balance of the engine-which does not mean, that the essential differences are absent in the particular characteristic points of the engine. It requires more detailed explanation (in the further research works) because losses in the combustion process do not show differences, but in the other balance components the differences are shown.*

***Keywords:*** *diesel engine, fuels, dense alcohols, energy balance*

## 1. Engine energy balance

The analysis of the engine energy balance concerns the balance between the energy, which is provided to the engine $Q_o$, and the energy changed into effective work $N_e$ and carried out in the form of heat $Q_s$. The energy carried out in the form of heat is treated as losses, which might be used for effective work (so work which enables making of the determined task). The losses of energy in the form of heat were grouped in several kinds [4].

The energy balance is made in the condition of set engine work. The fundamental dependence describing the energy balance results from the law of conservation of energy and it is presented as follows:

$$Q_o = N_e + Q_{ch} + Q_w + Q_{ns} + Q_{dys} + Q_r \,, \qquad (1)$$

where:

$Q_o$ – total amount of heat provided to the engine,
$N_e$ – heat changed into effective work,
$Q_{ch}$ – heat carried out to cooling factor,
$Q_w$ – losses heat of fumes exhaust,
$Q_{ns}$ – lost heat by incomplete combustion of fuel,
$Q_{dys}$ – dissociation loses heat,
$Q_r$ – reminder of heat losses, there belongs e.g. radiation heat, heat carried out outside.

Total heat provided to engine is determined from the dependence (2) as a product of fuel value of fuel, which powers the engine, and mass of fuel provided in the determined unit of time. For diesel oil fuel value $W$ amounts to 42700 kJ/kg, on the other hand, for the tested mixture that value amounts to 41464 kJ/kg.

$$Q = G_e \cdot W \, , \tag{2}$$

where:
$G_e$ – the amount of fuel provided in a time unit,
$W$ – fuel value of fuel.

Value of the energy changed into effective work is determined intermediately through making measurement of torque and rotating speed. It is the most frequently applied method, characterized by large accuracy and simplicity of measurement, which is used for diesel engines researches [4].

$$N_e = \frac{M_o \cdot n}{9543.4} \, , \tag{3}$$

where:
$M_o$ – torque,
$n$ – rotation speed.

Another factor engaged in energy balance is the cooling heat losses. It is the amount of heat carried out of the engine, systems and its constituents. The amount of carried out heat is dependent on the kind of applied cooling system, and its measurement might be more or less complicated. The easiest way of assigning it, is for the engines cooled by fluid, in which there have been applied so-called intermediate cooling systems. The heat jet may be assigned from the following dependence:

$$Q_{ch} = Q_{ch1} + Q_{ch2} + Q_p \, , \tag{4}$$

where:
$Q_{ch}$ – heat jet of cooling losses,
$Q_{ch1}$ – heat jet of cooling losses of engine block,
$Q_{ch2}$ – heat jet of cooling losses of oil pan,
$Q_p$ – heat jet of block radiation losses.

The heat jet of block radiation losses, because of the difficulties it makes through assigning, is often skipped and its value is converted to value of the reminder of heat losses, whereas the other components are assigned as following:

$$Q_{ch1} = M_{1cw1} \, \Delta T_1 \, , \tag{5}$$

$$Q_{ch2} = M_{2cw2} \, \Delta T_2 \, , \tag{6}$$

where:
$m_1$, $m_2$ – jets of cooling factor,
$c_{w1}$, $c_{w2}$ – specific heat of cooling fluid,
$\Delta T_1$, $\Delta T_2$ – temperature difference between system inflow and outflow.

The measurement of amounts necessary for assigning heat of cooling losses is made by the use of temperature sensors and flowmeters inbuilt in a cooling system.

The heat losses of the fumes exhaust are the consequence of getting rid of flue gasses from the engine, which have higher pressure than the surrounding. The assigning of heat losses of the fumes exhaust is made through the measurement of gasses jet and their temperature in the outlet system, as well as the assigning of their specific heat.

$$Q'_w = n'_s (Mc_p)_s T_s - n'_p (Mc_p)_s T_p \, , \tag{7}$$

where:
$n$ – amount of kilomols of gas in time unit,
$Mc_p$ – average specific heat for constant pressure,
$T$ – temperature.

The measurement of kilomols amount in the time unit is the activity which makes many difficulties, thus to its measurement the intermediate method is applied which makes use of the amount of sucked air kilomols and considers the appropriate quotient of mole conversion. The heat losses caused by the incomplete combustion of fuel and dissociation losses should be treated inclusively. They are defined as the combustion losses and are dependent of heat release quotient ($\xi$). It is the measure of combustion chamber heat load. For engines working in rated working conditions, the values of this quotient are included in determined limits dependent on the type of engine. For diesel engines, it is included in the limits of 0.70-0.90.

$$Q_{ns} + Q_{dys} = (1-\xi)\, G_e\, W \,, \tag{8}$$

where:

$G_e$ – mass of fuel provided in time unit,
$W$ – fuel value of fuel,
$\xi$ – heat release quotient.

$Q_r$ which is the reminder of heat losses it the energy in the form of heat transmitted into surrounding. For these losses, there should be counted radiation heat – resulting from raised temperature of engine elements (through input of cooling fluid or fumes) heat carried out outside – resulting from friction of elements and heat equivalent combustion kinetic energy [4].

For graphic representation of heat, balance there is used the Sankley diagram. The example figure is presented in Fig. 1. The heat balance may also be presented in variable working conditions e.g. in engine rotation speed function.

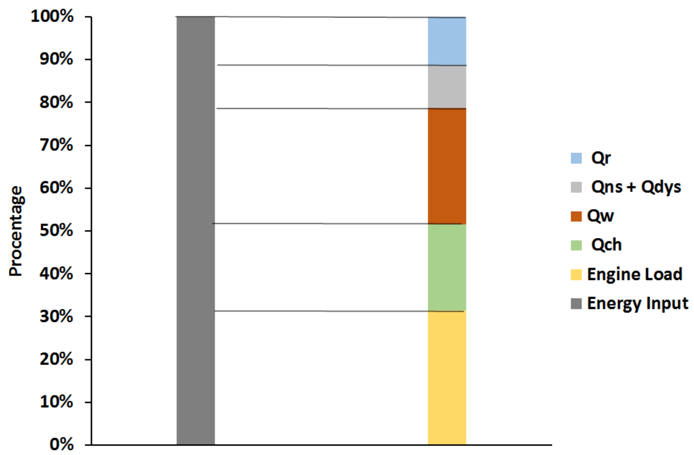


*Fig. 1. Example of engine energy balance*

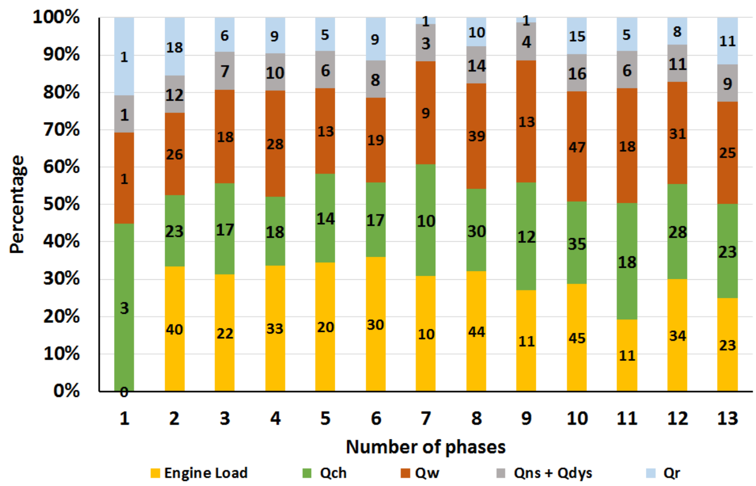


*Fig. 2. Constituents of energy balance in particular ESC test phases, in powering diesel engine by diesel fuel (ON)*

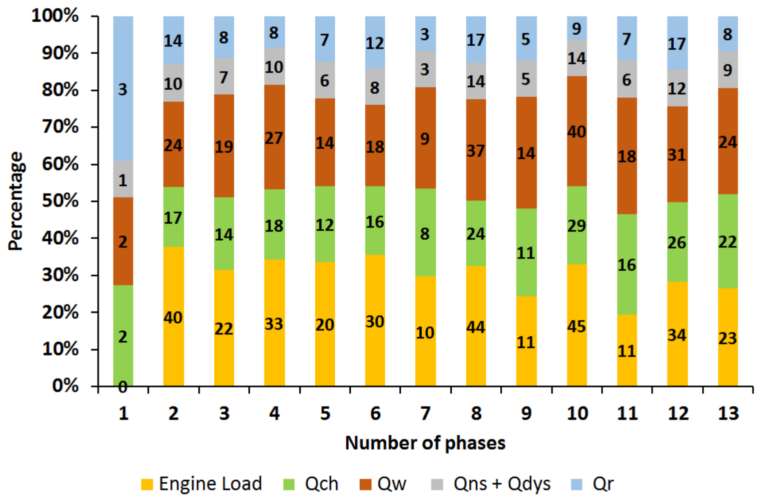


*Fig. 3. Constituents of energy balance in particular ESC test phases, in powering diesel engine by diesel fuel plus butanol (ON+BUT)*

The diagrams seem to be similar. It follows from the fact that powering the engine by the mixture with butanol does not contribute essential differences (which would be desired). However, to confirm that, there has been made the analysis of average differences in which the t-Student test has been used.

$$T = \frac{X_1 - X_2}{S_{x1-x2}},$$
$$S_{x1-x2} = \sqrt{\frac{(n_1-1)\cdot s_1^2 + (n_2-1)\cdot s_2^2}{n_1+n_2-2}\cdot\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}, \tag{9}$$

where:
$T$ – t-Studet test,
$X_1$ – avareage for first group,
$X_2$ – average for second group.

## 2. Chosen results of roller dynamometer researches

From the received data there follows that e.g. the average value of heat losses jet ($Q_{ns} + Q_{dys}$) in the case of powering engine by diesel fuel amounts to 15.62 kW, and when the engine is powered by diesel fuel plus butanol, it amounts to 15.20 kW. After verification of static difference of both averages there has occurred that the value of variable t of test amounts $t = 1.793$ while $t_{kr} = 14.089$ (Fig. 4). That accuracy is present in relation to each ESC test phase. It does not mean, however, that it is accurate in realtion to every kind of losses. If analise e.g. cooling losses $Q_{ch}$, it occures that in some engine characteristic points (phases) the differences of averages values are essential (Fig. 5.)

## 3. Ending and conclusions

The aim of the work was to assign the energy balance of diesel engine powered by the mixture of diesel oil with butanol. The field of the present work includes making of engine energy balance in its characteristic points related to 13-phase ESC test and assigning on that basis the collective values concerning differences in engine energy balance. It has been shown that:

1. Powering the engine by mineral oil with doped butanol (20% v/v) does not lead to essential differences in the energy balance of the engine.

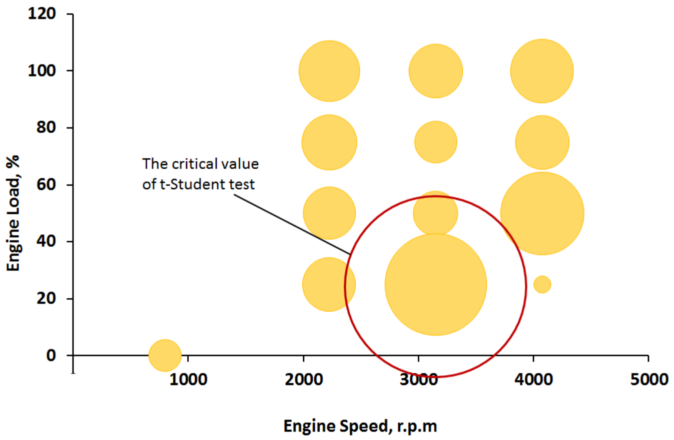


*Fig. 4. The value of t test in comparison to critical value $t_{kr}$ of combustion losses ($Q_{ns}$ + $Q_{dys}$) in particular ESC test phases*

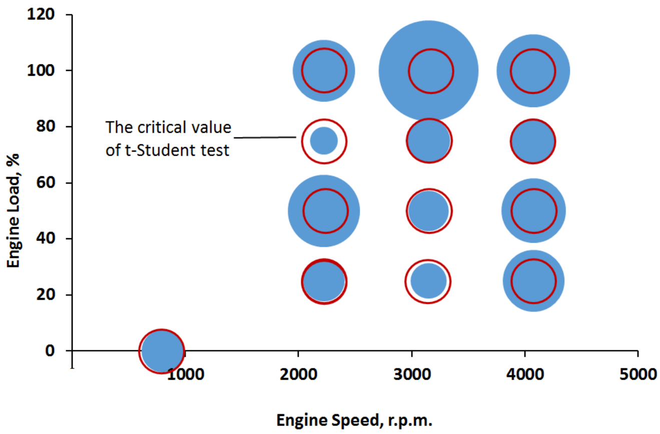


*Fig. 5. The value of t test in comparison to critical value $t_{kr}$ of combustion losses ($Q_{ch}$) in particular ESC test phases*

2. Differences (statistically reasoned) occur in relation to particular constituents of balance and engine working points.
3. It has been affirmed that e.g. combustion process losses does not indicate differences, and in the remaining balance components the differences are present- which has been also proved after making appropriate statistic analyses.

The observed differences require more detailed explanation which is planned in the further researches.

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