TEKA. COMMISSION OF MOTORIZATION AND ENERGETICS IN AGRICULTURE – 2012, Vol. 12, No. 1, 149–154

Equivalent fuel consumption of engines from swedish automotive companies

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Summary. The paper presents problems of specific fuel consumption as a parameter used to assess the use of the field of supply of the engine torque used to drive a truck with a high load capacity. A new rate of this assessment has been proposed in the form of equivalent fuel consumption and tests have been carried out with its use in the engines of the Scania and Volvo trucks.

Key words: engine, specific fuel consumption, load capacity.

INTRODUCTION

In accordance with the assumptions of the paper, one of the basic operating parameters of modern diesel engines and with direct injection i.e. the specific fuel consumption has been subject to the research. These engines are used to drive high load capacity trucks, and more and more often also to drive cars. The problem of reducing the fuel consumption by these engines is quite widely described in the literature [2,3,4,5,8,9,10,12,13,14,15,16,18,19], but there is a lack of publications referring to the tests of specific engines. After analysing the available data, the author has decided to address this issue. Performance tests on engine test bed and simulation tests have been carried out for a wider approach to the subject.

SPECIFIC FUEL CONSUMPTION

Operational fuel consumption is calculated on the basis of road test, which is carried out under certain traffic conditions, at constant or variable speed of the vehicle. This value is dependent on the vehicle and engine parameters as well as many operational factors, such as:

- technical condition of the engine and the vehicle components and
- mechanisms,
- weight and distribution of passengers, baggage and cargo,
- properties of the road, its shape and the type, quality and condition
- of the pavement,
- traffic conditions,
- atmospheric factors.

Knowledge of the minimum value of the fuel consumed by the engine allows for its conversion into the hourly rate, and then for planning the purchase of fuel for vehicles used in transport companies. The manner of driving process as an operational factor can be also taken into account, to a great extent conditioned by the subjective actions of the driver, depending on his / her mental and physical condition. The costs related to the purchase of fuel are among the highest expenses in the vehicle use [3, 9, 10, 12, 14, 16] Figure 1

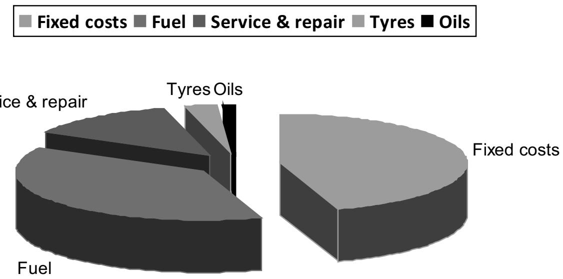

Fig. 1. Structure of the maintenance costs of vehicles [15]

In the theoretical analysis of the fuel consumption, it is possible to include the impact of only certain operational factors such as velocity profile, longitudinal profile of the road and the type and condition of the roadway affecting the value of the coefficient of rolling resistance.

Also, the road tests are carried out under strict conditions, which include: proper technical condition of the vehicle and the engine, specified loading of the vehicle with the weight of properly placed people and cargo, no wind and precipitation, road with a good surface ensuring good traction for the wheels. The data informing about the parameters and performance of vehicles the most often includes the nominal fuel consumption, which is a function of many variables. Consider the fact that the smaller the fuel consumption of the engine, the less the global quantity of toxic compounds emitted by the engine into the atmosphere. In this way, the key problem allowing for compliance with the demands of friendly operation is to reduce the fuel consumption by the engine that - next to the toxicity of exhaust gases and dynamic properties - are the measures of performance characteristics of the vehicle.

The most general rate of the economic efficiency of the engine operation (economy of a vehicle) is the fuel consumption measured in dm^3/100 km. However, this is an indicative and inaccurate rate, not taking into account such operating conditions as speed, its duration, load, road condition and service life. On the other hand, it is the most commonly used rate, given in the technical descriptions of vehicles. Sometimes, in relation to trucks, a monitoring fuel consumption at a certain speed of driving is given (e.g., V = 60 km/h) [16, 17, 19], whereas in relation to cars the average value of fuel consumption in urban and extra-urban driving is given.

Consider the fact that the smaller the fuel consumption of the engine, the less the global quantity of toxic compounds emitted by the engine into the atmosphere. In this way, the key problem allowing for compliance with the demands of friendly operation is to reduce the fuel consumption by the engine that - next to the toxicity of exhaust gases and dynamic properties - are the measures of performance characteristics of the vehicle. However, these are the results of simulation tests, carried out during a certain agreed operational cycle, not the road test results. With regards to the engines there is a more accurate rate - the specific fuel consumption, which is sometimes also given in technical descriptions, especially of trucks of high load capacity.

The specific fuel consumption expressed in g/kWh (g/ HPh) indicates what weight of fuel (and the chemical energy contained in it) is to be converted into mechanical work in order to produce one kilowatt-hour by the engine. It is a very positive rate that does not depend on the engine volume capacity (its size) and the type of fuel used and therefore one can compare different types of engines, designed for different purposes, powered by both petrol and diesel fuels or fuels derived from plants.

The manufacturers, due to the advertising reasons, the most often give the value of the minimum specific fuel consumption or, less often, its value at the engine speed corresponding to the rated power. Both the first and the second values - to a limited extent - characterise the engine in terms of economy, however this is much more useful information for practical purposes than the previous one.

Unfortunately, with regards to the fuel, the manufacturers are very sparing in giving information as to its curve run on the external characteristics of the engine, as is the case with the torque or engine power, not to mention the universal characteristics. Such data would allow for unambiguous determination as to which of the engines is more economical. The only possibility of obtaining this information is, therefore, to carry out simulation tests using data provided by manufacturers.

Accurate and quick determination of the specific fuel consumption and hence the parameter, on which the economy of the engine depends as well as its harmful impact on the environment are very important issues. This allows the user to plan the operating costs. A comprehensive picture of the specific fuel consumption at different engine operating conditions can be presented on the universal characteristics, where under the maximum torque curve there is a field of its supply [1, 9, 10, 16, 19]. Drawing the fields of operation on the universal characteristics, with constant load and speed for a specified gear, forms a time density characteristics of the engine operation, which enables a precise determination of the value of the specific fuel consumption [33,75,107,]. This gives the opportunity to assess the engine performance characteristics in the light of the requirements set.

TIME DENSITY CHARACTERISTICS OF SPECIFIC FUEL CONSUMPTION

The time density characteristics of the engine can be prepared using the results of road tests or field tests of a vehicle, drawing the operating ranges at a given load and engine speed on the universal characteristics of its engine or assuming in advance the model of the engine and properly dividing its universal characteristics [4, 6, 7, 9, 10].

For trucks of high load capacity moving on motorways or expressways, Scania company offers an universal division of the area of the universal characteristics into four fields according to the scheme assuming that the percentage share of the time density of the engine depends on the load capacity of the vehicle, and distinguishes two categories of vehicles [9, 10, 11, 13, 18]:

vehicles with the weight of 30 ÷ 40 tonnes	vehicles with the weight of 50 ÷ 60 tonnes
a) **I** - 9 %, **II** - 60 %, **III** - 6 %, **IV** - 25 %	b) - 9 % - 50 % - 6 % - 35 %

This way of dividing the universal characteristics has been shown in the Figure 2, where such division has been based on the following criteria:
- total engine operating time,
- engine operating time at various ranges of loads,
- time of driving in particular gears,
- number of clutch engagements.

A part of the set of measuring equipment designed for counting the engine operating time within specified ranges of its characteristics has been made in a simplified system of logic - running time meters.

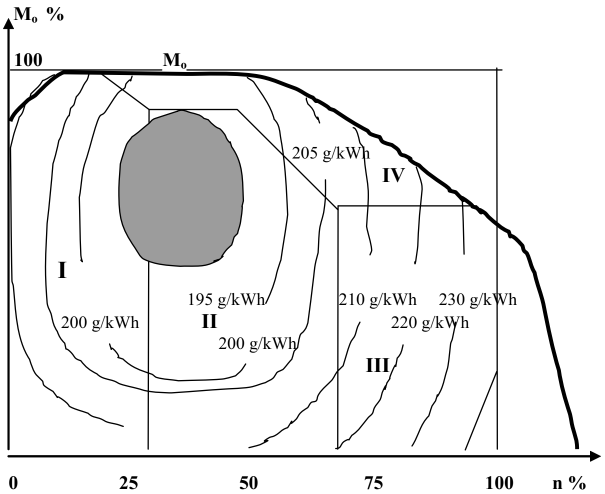

Fig. 2. Time density characteristics of the Scania DC 11 01 340 engine - grey colour denotes the minimum fuel consumption field

One should also bear in mind the fact that the field that in the assumption was based on the area of a rectangle of $M_o - n$ ($0 \div n_z$) did not fully match the universal characteristics of the engine, limited from the top by the maximum torque curve and, in relation to the theoretical assumption, one could take into account only the specified percentage of the field of the mentioned rectangle. A part of the field above the maximum torque line has been subtracted at the speed corresponding to the idle speed and the speed above 75% of engine speed.

The time density characteristics prepared on the basis of the characteristics (Fig. 2) in the bar system (Fig. 3) considers only the fields actually used on the universal characteristics and thanks to that it can be seen what part of the universal characteristics does not coincide with the rectangle with the dimensions of $M_{omax} - n$.

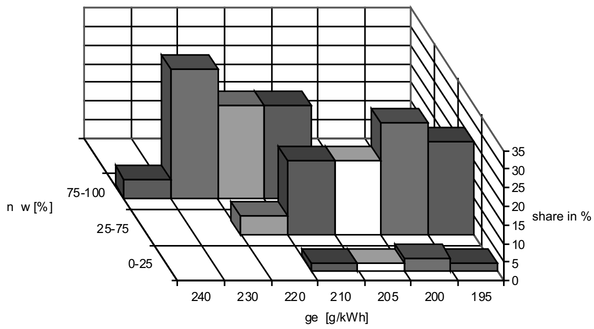

Fig. 3. Time density characteristics of the Scania DC 11 01 340 engine in the bar system

EQUIVALENT SPECIFIC FUEL CONSUMPTION

Due to the sought savings achievable thanks to the determination of precise fuel consumption by the engine, the desired information for the dispatchers of transport companies is to determine the quantity of fuel used by the engine of a truck driving a long way with a cargo. Hence the search for Scandinavian companies [2,8,10,18], the vehicles of which for example, drive a route from Gothenburg to Istanbul. The calculation of the likely fuel consumption is therefore an important issue. After the analysing this problem, the author has proposed application of a new measure of the economy of the engine operation in the form of ***equivalent specific fuel consumption*** as its equivalent value resulting from the time density characteristics of the engine load [18]. Assuming the engine model proposed by Scania, such calculation can be made using the weighted arithmetic mean with use of the time density characteristics [20]. For the Scania DC 11 01 340 engine, the characteristic of which in the bar system has been shown in the Figure 4, it looks as follows:

$$g_{ez} = \frac{\Sigma g_{ein} u_i}{\Sigma u_i}, \qquad (1)$$

where:

$g_{ei\,n}$ - value of specific fuel consumption in i –field of the time density characteristics defined by the speed of the engine,

u_i - percentage share of the i –field in the time density characteristics.

For the Scania DC 11 01 340 engine, the value of the specific fuel consumption calculated with this method is:

Engine speed range 0−25% n_N

g_{ez} = (195×0.03+200×0.27+205×0.25+210×0.25+220×0.2):0.907 = 228.86 g/kWh.

Engine speed range 25-75% n_N

g_{ez} = 223.51 g/(kW×h).

Engine speed range 75-100% n_N

g_{ez} = 234.97 g/(kW×h).

Since the area under the torque curve (torque supply field) is 0.907 of the area of the rectangle with the dimensions of M_o - n_N, particular fields of the constant specific fuel consumption had to be referred to the actual field of torque supply. Thus, the equivalent specific fuel consumption for the whole area of the universal engine characteristics is:

$$g_{ez} = \Sigma\, g_{ez} : 3 = 687.34:3 = 229.11 \text{ g/(kW×h)}.$$

In order to determine what is the influence of the specific fuel consumption on the equivalent fuel consumption, for the Scania DC 11 01 340 engines, calculation of the hourly fuel consumption has been carried out based on the equivalent fuel consumption and the specific fuel consumption, obtaining the following results:

– for the equivalent fuel consumption and the engine power of 250 kW (340 HP):

$$G_h = \frac{g_e \cdot N_e}{1000} = \frac{229.11 \cdot 250}{1000} = 57.27 \text{kg/ h}, \quad (2)$$

$$\text{i.e. } 57.27 kg / h \cdot \frac{1}{0.82 dm^3 / kg} = 69.85 dm^3 / h,$$

– for the minimum specific fuel consumption and the engine power of 250 kW (340 HP):

$$G_h = \frac{192 \cdot 250}{1000} = 48 \text{kg/h}, \quad (3)$$

$$\text{i.e. } 48.0 kg / h \cdot \frac{1}{0.82 dm^3 / kg} = 58.53 dm^3 / h.$$

The difference is 11.32 dm^3, which at 10-hours operation of the vehicle during the driver's working day gives more than 113.2 dm^3 per day and is a significant quantity.

This calculation shows how much closer to the reality is to use, as the measure of economy of the engine operation, the equivalent specific fuel consumption, and not the minimum specific fuel consumption normally given in the descriptions of engines. In a similar way, the equivalent fuel consumption has been determined for 21 engines of the Scania and Volvo companies, obtaining:

– the average value of the minimum specific fuel consumption of 190.93 g/kWh, according to the manufacturer's data [2,8,11,13],
– the average value of the equivalent fuel consumption of 226.35 g/kWh, obtained from simulation tests. The difference between these two values tells about the method of use of the torque supply field of the engine during its operation and is the measure of economy of the engine operation. These were direct-injection engines, turbo-charged with the power of 180 to 486 kW at the rated speed of 1800 to 2400 1/min, and 71.5% of the engines fell within the range from 1800 to 1900 1/min. The maximum torque values ranged from 903 to 3895 Nm at the average engine speed of 1081 1/min (from 1000 to 1100 1/min). The curves of the value of the equivalent specific fuel consumption in ascending order have been shown in the Figure 4, where the trend line and the equation describing it have been given. The values of the maximum torque and the torque corresponding to the rated power have been given in ascending order in Fig. 5.

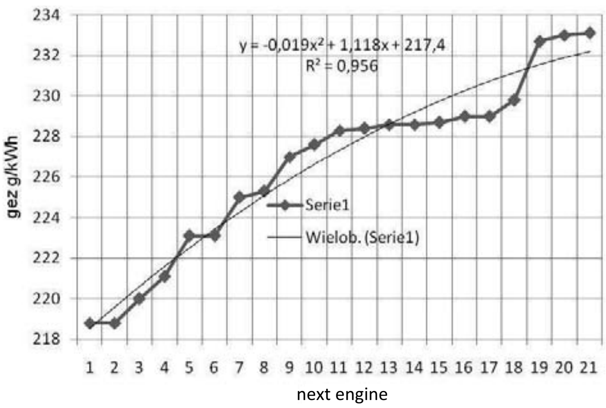

Fig. 4. Values of equivalent specific fuel consumption in ascending order

The trend line of the presented g_{ez} values is described by the equation:

$$y = - 0.019\, x^2 + 1.118\, x + 217.4. \quad (4)$$

The values of maximum torque (series 1) are described by the equation:

$$y = 2.468\, x^2 + 74.78\, x + 977.1, \quad (5)$$

and the torque values corresponding to the rated power (series 2) with the equation:

$$y = - 0.963\, x^2 + 108.5\, x + 617.2. \quad (6)$$

The equivalent specific fuel consumption is strongly related to both values of torque as the correlation coefficient between g_{ez} and Mo is 0.9535, and between g_{ez} and Mnz it is 0.9523. Given the fact that the engines of trucks should have the universal characteristics chosen in such a way that the field of their economic operation was at 75% of the rated load and at 75% of the rated engine speed for the tested engine group, these results were as follows:

– the average value of torque according to the manufacturers' data: 1657.95 Nm
– the average value of torque according to the simulation tests: 1266.022 Nm, hence the 1657.95 x 0.75 = 1243.46. The difference is 1.8% and therefore the engines assessed as a group are constructed in accordance with the adopted principles.

As for the average engine speed, at which there was a minimum fuel consumption according to the theoretical assumptions outlined above, it amounted to 1450 1/min, while from the simulation test it resulted in 1081 1/min, and so the difference corresponds to 34%.

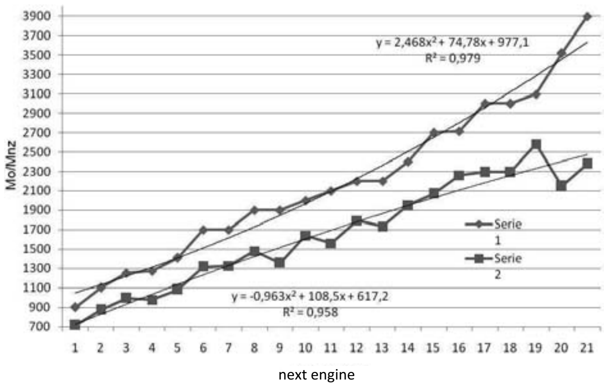

Fig. 5. Torque values of tested engines

The situation is the more advantageous that the maximum torque value occurs at lower engine speeds, which is desirable for operational reasons.

CONCLUSIONS

The presented results of research and tests support the assumption that the equivalent specific fuel consumption based on the universal characteristics (general) is a better rate of economy of the engine operation than the specific fuel consumption given on the external characteristics of the engine. After examining a greater number of engines it will be possible to make an attempt to generalise the obtained results.

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EKWIWALENTNE ZUŻYCIE PALIWA W SILNIKACH POJAZDÓW SZWEDZKICH FIRM

S t r e s z c z e n i e . Przedstawiono problemy zużycia paliwa jako parametr wykorzystywany do oceny wykorzystania zasilania momentu obrotowego silnika używanego do napędu samochodu ciężarowego o dużej ładowności. Nowy sposób tej oceny został zaproponowany w formie równoważnego zużycia paliwa i został on przetestowany dla silników Scania i Volvo Trucks.

S ł o w a k l u c z o w e : silnik, zużycie paliwa, ładowność.