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SEARCH FOR ALTERNATIVE FUELS FOR COMBUSTION ENGINES

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Summary. The ongoing difficulties with fuel and energy are the reason for continuous search for new energy carriers and trials to limit the energy consumption, which will result in reduction of harmful impact on the environment**.** The article presents some ways to find new types of fuels and some technical methods to arrange this process.

Key words: alternative fuels, engine, oils of vegetable origin.

INTRODUCTION

A continuous increase in the number of motor vehicles moving on public roads creates specific hazards for the environment that surrounds us. Generally, in the majority of considerations it is assumed that – as far as the harmful impact on the environment is concerned – the engine is the most adverse unit of a vehicle

Tempestuous development of motorization has caused the necessity to limit its harmful impact on the environment. This is related to stricter and stricter requirements as to the protection of the natural environment. The necessity has arisen to apply solutions that have not been taken into consideration so far or have been ignored and astonishingly good results have been obtained through their application . The ongoing difficulties with fuel and energy are the reason for continuous search for new energy carriers and trials to limit the energy consumption, which will result in the reduction of harmful impact on the environment.

The requirements imposed on the modern engines are very often opposing, which can be clearly seen when taking into account the continuously growing number of vehicles and difficulties in the traffic reffered to here, and – on the other hand – there is a necessity to reduce the quantity of consumed fuel and harmful components of toxic exhaust gases emitted into the environment [4,9]. As far as the engines driving both the cars and the lorries are concerned, this comes down to taking into account the three most essential factors:

- Low fuel consumption (cost-effectiveness of operation),
- Low toxicity of exhaust gases,
- High engine response (good dynamic properties).

This problem was noticed at earliest in relation to the engines of lorries of high carrying capacities, where the cost-effectiveness of transport is of fundamental importance.

In order to solve the problem of the cost-effectiveness improvement and in order to reduce the toxicity in case of these engines, it was also necessary to apply a new approach, different from the traditional solutions. As far as the lorry engines are concerned, they have been more susceptible to meeting the stricter requirements for years, and there has been significant progress achieved in their construction forced by restrictive regulation on the one hand, and the necessity to reduce the fuel consumption related costs on the other hand.

Simply speaking, the lower the fuel consumption by an engine, the lower the global quantity of toxic components emitted by this engine into the atmosphere. In this way, the key problem allowing for meeting of these two first demands is to reduce the fuel consumption by the engine.

According to these demands, Scania and Volvo [10] companies try to reduce the fuel consumption in the next versions of engines launched to the market. The factor that unambiguously allows for an assessment of cost-effectiveness of the engine operation is the specific fuel consumption.

FUEL OF RAPE ORIGIN

These fuels in the form of rape oil or methyl ester of fatty acid of rape oil were creating hopes for significant improvement of certain parameters of the engine operation with their simultaneous availability (numerous fallow lands in the West Pomeranian Province waiting for reclaiming) despite the fact that the rape is a capricious plant. Combustion of pure rape oil has turned out to be a complex issue and required changes in the construction of engines. Attention was focused on esters despite the fact that bringing their physical and chemical parameters close to those of the diesel oil required additional treatments. The psychological and economic aspects have been omitted in this paper. From the technical point of view, the products of combustion of rape fuels are much less toxic as these fuels do not contain sulphur, and additional oxygen bonds allow for a significant reduction of the exhaust gases smokiness, the proof of which are the executed tests on the STAR 350 [2,6,7] diesel engine presented in Fig. 1.

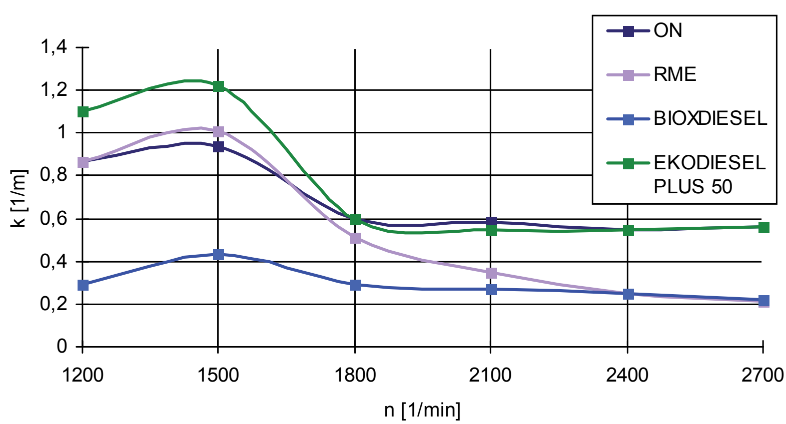

Fig.1. Characteristics of the 359 engine smokiness at powering with different fuels
ON – diesel oil, RME – methyl ester of fatty acid of rape oil,
BIOXDIESEL – diesel oil with ester admixture,
EKODIESEL PLUS 50 – diesel oil with ester admixture

The same situation in the form of the time density characteristics was presented in Fig. 2.

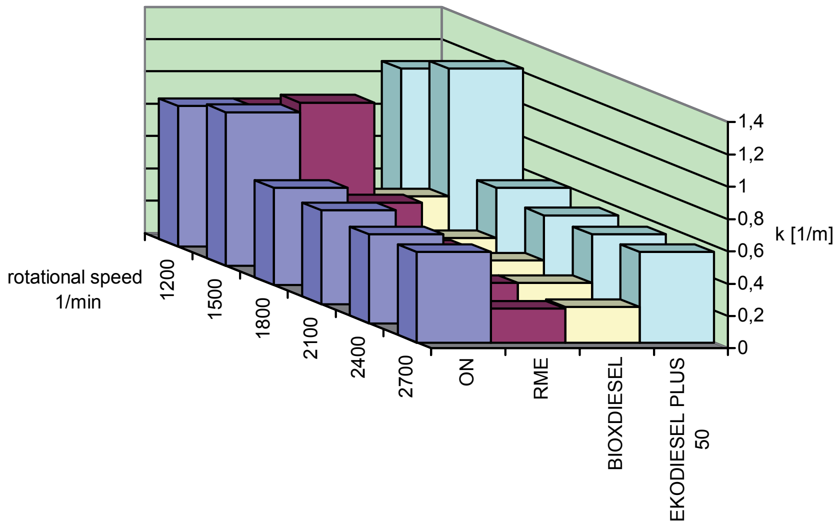

Fig. 2. Characteristics of time density of exhaust gases smokiness of the 359 engine

In order to enable comparison of smokiness in Bosch scale (jB) and in the presently used units of exhaust gases opacity 1/m, their comparison was presented in Fig. 3 [6].

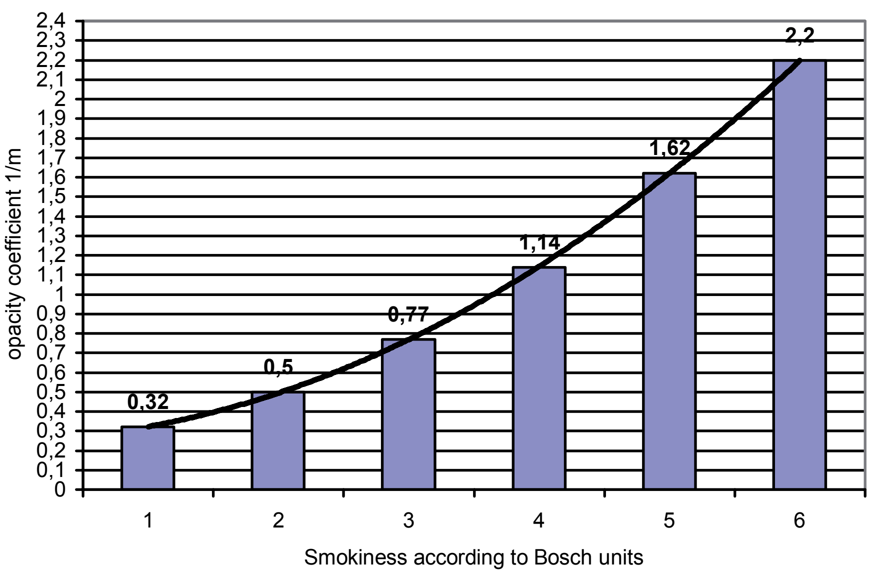

Fig. 3. Comparison of units of exhaust gases smokiness

STARTING THE ENGINE POWERED WITH OILS OF VEGETABLE ORIGIN

Research carried out in the country on the operation of diesel engines powered with oils of vegetable origin and mixtures of diesel oil and oils of vegetable origin has shown that the operational parameters of the engine supplied in such a way are subject to improvement in relation to the engine powered with pure diesel oil or pure rape oil [7].

The density of both fuels is similar and they mix well in different proportions. With the specified proportion of rape oil to the diesel oil, such a state is obtained that the newly formed fuel has still got a relatively high calorific value, close to the calorific value of the diesel oil, and at the same time contains oxygen bonded in hydroxyl groups of the rape oil. Thus, this fuel is combusted more completely than pure diesel oil, and the quantity of heat produced in this process exceeds the quantity of heat produced during combustion of pure diesel oil. As a result the total quantity of combusted fuel is lower, therefore the fuel consumption is reduced, and indirectly – also the emission of toxic compounds.

Therefore a question arises, whether the engine maintains such positive properties also in the conditions of its starting at low ambient temperatures. At the same time it is known that in supercharged engines, even when powered with diesel oil, there are difficulties occurring during starting at low ambient temperatures.

Influence of addition of diesel oil to the fuel of vegetable origin on the limit temperature of starting of a diesel engine with direct injection was presented in Fig. 4.

One can clearly see that the addition of the diesel oil amounting to 70% of the whole volume of fuel improves the starting properties of the engine at a relatively low cost [7]. Whereas the problems with starting with the ecological fuel available in our country do not encourage its use, normal operation of an engine, including also a supercharged engine, does not pose difficulties as this fuel evaporates better at high temperatures, which is advantageous for forming of homogenous fuel mixture with air, similarly as in the case of the diesel oil.

In 1995, instructions of proceeding during starting of a tractor engine powered with mixtures of diesel oil and acid esters of rape oil were prepared at the Academy of Agriculture in Szczecin [5].

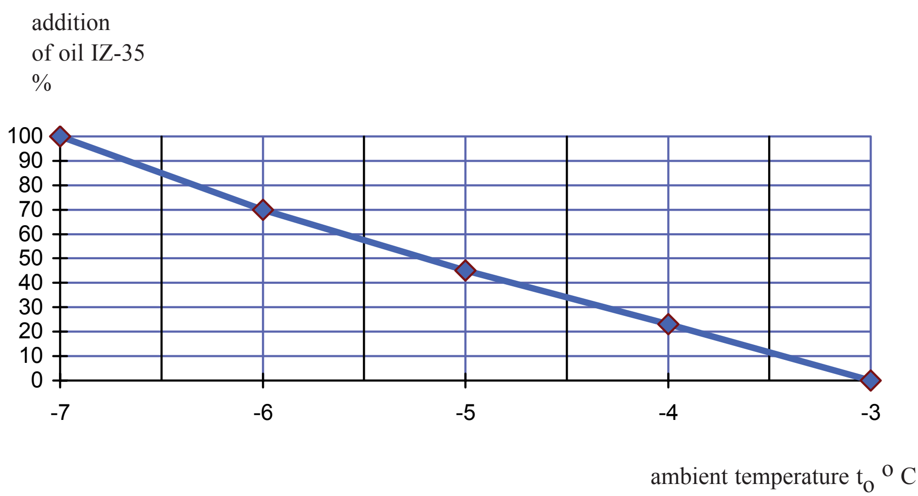

Fig. 4. Influence of addition of diesel oil on starting properties of an engine powered with the fuel of vegetable origin [5]

APPLICATION OF NATURAL GAS AND ENGINE FUEL

The natural gas is a fuel that does not require chemical processing apart from purification and sulphur removal. High-methane gas, due to its physical and chemical properties is defined as a good and ecological engine fuel. It is so widely available that there is no need to store it. It is cheaper than liquid fuels, after treatment it is free of corrosive substances, which decides about the engine lifetime. This fuel is lighter than the air – the proportion of its density in relation to the air is 0.55 – 0.58, depending on the chemical composition. In case of leakages in the supply system it escapes to the atmosphere, whereas a liquid fuel spills over the surface, and the mixture of propane-butane (heavier that the air) accumulates over the ground surface.

The natural gas as an engine fuel is used in the form of:
- CNG (Compressed Natural Gas),
- LNG (Liquefied Natural Gas).

The CNG natural gas, as a fuel for vehicles, does not require any technological treatment apart from compressing and drying. The disadvantage of this system is the low density of accumulated energy in a volume unit (despite significant compression of gas up to the pressure of approximately 20 MPa), which is followed by use of tanks of large volumes and weights. It may be used for any spark-ignition engines and diesel engines after adequate constructional changes. Single refuelling enables mileage of approximately 300 km.

Application of the LNG liquefied natural gas that, apart from hydrogen, is mentioned as the future alternative fuel, allows for the elimination of disadvantages related to the density of accumulated energy, weight of tanks and problems with high pressure.

The natural gas during liquefaction is cooled down to the temperature of – 161.15 ^{0} C. During such process, the volume of gas is reduced 630 times. Thanks to that, the ‘density of energy’ of liquefied natural gas is very high. The liquefaction process is associated with very careful purifying of the gas of carbon dioxide, nitrogen, propane-butane and humidity. It is already a very clean fuel with the octane number of 130. After repeated change into the gaseous state there are not many impurities left, and the gas is dry and free of humidity. Due to low liquefaction temperatures, it requires a cryogenic tank, and refuelling takes place similarly as in case of traditional fuels [9].

Further to the statements contained in the introduction, the toxicity of exhaust gases of engines supplied with the CNG natural gas and with the diesel oil has been assessed, which is presented in Fig. 5.

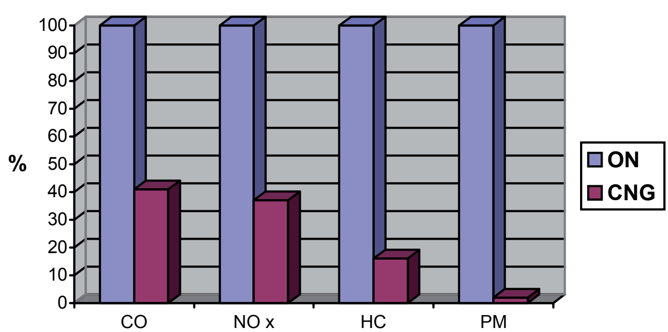

Fig. 5. Comparison of emissions from bus engines powered with diesel oil and CNG [1]
CO – carbon monoxide, NO_x – nitric oxides, HC – hydrocarbons , PM – particulate matter

As it results from Fig. 5, at powering with the natural gas the emission of toxic compounds was significantly reduced in the engines of the tested buses, and so, for CO it was 41% in relation to the diesel oil, for NO_x 37 % , for HC 16 % and for PM only 2 %.

In this aspect, one can clearly see the advantages resulting from application of the natural gas as a fuel.

This is the main advantage in comparison to liquid oil derivative fuels, however one has to remember that the emission level is significantly dependant on the engine's construction, its combustion chamber, characteristics of the supply system, adjustment parameters and general technical condition. As far as the aspect of harmful impact of combustion engines on the environment is concerned, use of buses driven with engines powered with the natural gas in the public transport is a very promising solution.

Generally speaking, the advantages of the CNG compressed natural gas as a fuel are as follows [4]:

- sulphur content close to zero,
- very low emission of particulate matter,
- very low emission of fuel vapour,
- reduced emission of carbon dioxide (greenhouse effect),
- reduced emission of toxic compounds after cold start of an engine,
- high octane number of fuel (possibility to use higher compression ratios),
- extended limits of inflammability,
- reduced emissions of nitric oxides thanks to lower combustion temperature,
- higher ignition temperature (lower hazard of self-ignition),
- fuel components are not directly toxic,
- lower emissions of aldehydes (30-80 %), almost complete elimination of benzene and 1-3 butadiene,
- lower level of engine noise,
- low impact on smog creation.

Disadvantages:

- more difficult storage due to low energy density,
- gas compression is necessary,
- limited range of vehicle movement,
- significant tank weight,
- hindered catalytic afterburning of methane,
- negative impact of methane emission (this gas causes the greenhouse effect),
- necessity to dry,
- longer refuelling time,
- deterioration of dynamic performance of engine,
- possibility of occurrence of flame backflow.

The research carried out in the country forecast that the share of the natural gas as an engine fuel can reach several percent in the near future. The ENGVA (European Natural Gas Vehicles Association) assumes that in the year of 2020, 20% of the European vehicles will be powered with the natural gas coming from renewable sources of energy [9]. This means that 24 million NGV vehicles will be served by approximately 30 thousand refuelling stations, and the significant part should consist of public transport buses and public utility vehicles.

At the end of 2002, there were 450 thousand NGV vehicles moving in Europe, and – in order to reach 24 million in 2020 – the annual increment at the level of 8-9 % is required.

Zakłady Samochodowe JELCZ SA [*Automobile Factory "JELCZ" JSC]* is the manufacturer of city CNG gas buses. The AUTOSAN SA factory is prepared for the production of the A1010 M CNG commuter bus. The factory version of the JELCZ 120M/1 bus has been prepared with the MD 111M6 engine manufactured by the Wytwórnia Silników MIELEC-DIESEL, Spółka MIELEC-DIESEL GAZ and NGV AUTOGAS companies. These buses have been granted certifications of approvals (EURO-3) and are currently in operation. Works are being carried out at the moment to develop a low-decker version of the JELCZ bus with the MAN engine. Also other renown companies are preparing their offers for gas buses [3], however launching them onto the domestic market is stopped by the unsolved issue of certification of approval and protection of patent rights for the proposed solutions.

Taking into account the above-mentioned advantages and disadvantages of powering with gas, one should more precisely look at the dynamic properties of vehicles powered in this way. According to the available data, they are by 10% worse (10% power drop) [3], which does not always have to correspond to the dynamic properties that mainly depend on the run of the torque curve. Such properties are particularly essential in relation to public transport buses as the ability of manoeuvring in the streets full of traffic and fuel consumption depend on that. The data concerning this issue are increased to the limits for the best tour coaches [10] powered with the diesel oil. The total engine response ratio informing about the ability of adapting to variable loads and rotational speeds is 2.34 for the MAN D2876 engine up to 2.60 for the DAF XE 315C engine respectively, and it is very high as far as this group of engines with direct injection is concerned. However, the recent MAN bus engine denoted as E2866 DUH03 powered with compressed natural gas has got the engine response ratio equal to 2.3, comparable to the lower range of capabilities of engines powered with diesel oil.

It seems, however, that it will be hard for the engines powered with the natural gas to reach such values, therefore the cleanliness of combustion gases remains their main role, which is of particular importance in the conditions of city traffic.

As long as the government does not clearly specify comprehensive principles of financing related to the gasification of engines designed for driving of buses, one should not expect increase in the interest of hauliers with such energy carrier.

An example that confirms this thesis may be the fact that the town of Gorzów Wielkopolski has purchased a certain number of buses from KAPENA Słupsk factory but driven with traditional engines, which is in contradiction to the statements contained at the beginning of the paper.

DIESEL ENGINE POWERED WITH ETHANOL

Scania, in search for ecological engines for driving of buses, has applied a diesel engine powered with light fuel with the octane number of 95. This fuel, with the commercial denotation of E95 is manufactured by SvenskEtanolkemiAB and has the following composition:

1. Ethanol 95% –92.2% m/m (93.3% v/v)
2. Ignition activator –5% m/m
3. Ether MTBE –2.3% m/m
4. Isobutanol–0.5 % m/m
5. Corrosion inhibitor – 90 ppm m/m

It is designed for powering of the Scania DS19 01 engine with the cubic capacity of $V_s = 8.7$ dm^3 and the rated power of Ne = 169 kW (230KM) at 1800÷2000 1/min, being a variation of the

DSC9 11 engine. In the engine designed to be powered with ethanol, the compression ratio ε has been increased from 18 into 24, and also the controlling of the fuel dosing has been changed, the fuel pump output has been increased, the diameters of the openings of the spraying nozzles have been enlarged, gaskets, filters and cooler of the supercharging air have been changed. One of the buses with such an engine is already in operation in the town of Słupsk, and another one will be used in Warsaw as from September this year.

ENGINE SUPERCHARGING

Supercharging is the commonly used method aiming at an improvement of the operational parameters of an engine and at a reduction of its harmful impact on the environment. In the most modern generation of high-speed diesel engines that meet all the very strict requirements, turbo-charged engines of direct injection with cooling of the supercharging air (TDI) are used. Application of direct injection enables meeting the two demands as this is the most economical method of combustion, which results in the fact that the engine emits the lowest quantity of exhaust gases per unit of produced power, and thus the engine emits lower quantity of harmful compounds emitted into the atmosphere. Turbo-charging through increase of the mass of air supplied to the engine with its significant turbulence allows for a better preparation of combustible air-fuel mixture and thus for better combustion process. Additional cooling of the supercharging air improves filling of the cylinder and thus creates better conditions for preparation of the fuel mixture.

DYNAMIC, MECHANICAL AND COMPREX SUPERCHARGING

Application of supercharging without compressor (dynamic supercharging) does not cause any results within the range of rotational speeds corresponding to the engine starting as the inlet system is adapted to causing wave phenomena at the rotational speeds within the area of torque to the rated power. During starting, the engine behaves the same as normal unsupercharged engine. At present, this is commonly used in the spark ignition engines with petrol injection as well as in the diesel engines of cars and lorries as combined supercharging in conjunction with turbo-charging. Mechanical turbo-charging also does not cause significant changes in the engine operation at starting speeds and does not cause undesired results.

The compressor supplies, however, a slightly greater quantity of air to the engine but this can be compensated by greater dose of fuel and starting will take place faster.

Thanks to that, the negative effects of starting consisting in increased emission of toxic compounds into the atmosphere can be reduced. It is similar with supercharging of the Comprex type that combines the features of both these discussed methods of supercharging.

TURBO CHARGING

The most common method of supercharging is turbo-charging. In this solution, the useless energy of escaping exhaust gases is used for powering of a turbine connected by means of shaft with a compressor. Despite significant technical maturity of engines and turbochargers, this supercharging is characterised by deterioration of starting parameters of the engine as the result of increase in the air flow resistance in the inlet system. Such resistance is increased due to the fact that the inflowing air must flow through the rotor of the compressor, unmoving as the engine so far does not produce exhaust gases powering the turbine. At the same time, reduction of the compression ratio in the turbo-charged engines, essential for these engines to obtain high efficiency within the area of medium and high loads influences the deterioration of the starting properties of the engine that one must be aware of. An improvement of such situation can be obtained through the application of the above-mentioned combined supercharging.

RESULTS OF APPLICATION OF DYNAMIC SUPERCHARGING

Its influence on the ecological parameters can be presented on the basis of testing of the SW 680 engine manufactured by the above-mentioned Wytwórnia MIELEC-DIESEL factory. The results of tests of the smokiness of exhaust gases of this engine have been presented in Fig. 6.

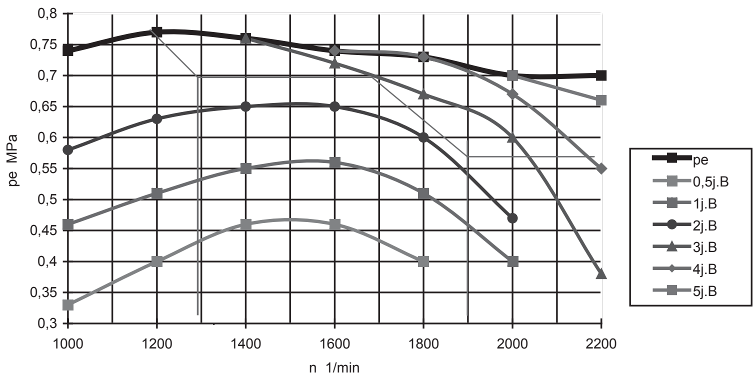

Fig. 6. Universal characteristics of smoking of the SW 680 engine in an unsupercharged version

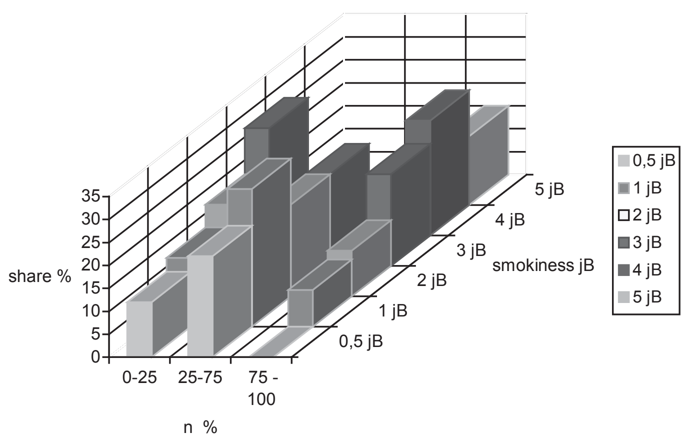

Fig. 7. Time density characteristics of the SW 680 engine without supercharging

It results from the data presented in the graphic form in Fig. 6 that the degree of smokiness of exhaust gases of the tested SW 680 engine in an unsupercharged version is different depending on the speed and loads but generally speaking, it is quite high. It ranges from 0.5 up to 5 in the Bosch scale, whereas the permissible smokiness for this type of engine should not exceed the value of 2.7 up to 3 in the Bosch scale (jB). The next figure presents the characteristics of time density of smokiness for the situation presented in Fig. 6.

This figure shows the percentage share of particular values of smokiness in the whole area of operation and shows under what parameters the engine should operate to obtain the lowest harmful impact on the environment.

The next figure presents the universal characteristics of the smokiness of the exhaust gases of the SW 680 dynamically supercharged engine. When compared to the characteristics presented in Fig. 6, one can clearly see the difference to the advantage of the supercharged engine, hence e.g. the tendency to supercharge the majority of the currently used diesel engines.

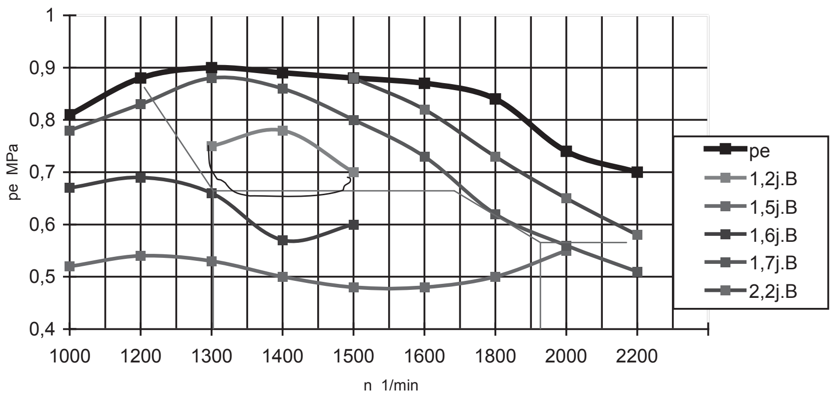

Fig. 8. Universal characteristics of the smokiness of the exhaust gases of the SW 680 dynamically supercharged engine

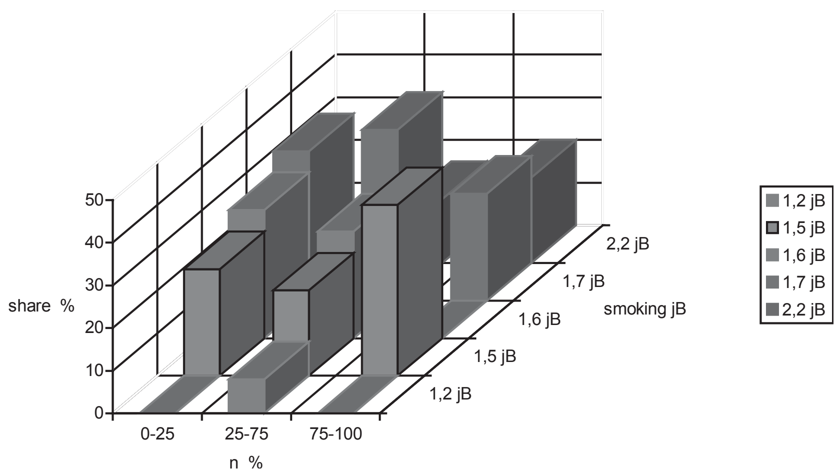

Fig. 9. Time density characteristics of the SW 680 engine with supercharging

The values of the exhaust gases smokiness for the dynamically supercharged engine are definitely lower as they range from 1.2 jB up to 2.2. jB (Bosch units), and the area of the characteristics of relatively low smokiness is significant for particular ranges of speeds. The highest percentage values of the exhaust gases smokiness took place at 1.5 jB and 1.7 jB (Bosch units)

In this way one of the problems of application of renewable fuels for powering of engines of vehicles of high carrying capacity have been briefly presented.

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