FUEL EFFICIENCY OF CONVENTIONAL DESIGN TRACTORS DIESEL ENGINES IN RELATION TO NEW DESIGN

by

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Total consumption of all types of energies is rather high nowadays with constant tendency of increasing.
Transport section is one of the highest consumers of energy obtained from fossil fuels.
It is absolutely clear that the reduction of energy consumption and the protection of environment – exhaust emission reduction, i. e. cleaner air, will be one of the main tasks of automotive industry in the first decades of the 21st century.
In spite of its superiority over the petrol engine in respect of the fuel consumption, a diesel engine "suffers" from the increased exhaust emission, particles and NO_x first of all and also from the noise and vibrations.
The paper gives a review of fuel efficiency of conventional design tractors diesel engines in relation to new design.

Introduction

Throughout mankind's history, energy consumption has changed substantially due to the growth of world's population and the great changes in human activities. Energy is the blood of human activity and its expansion provides new possibilities, for increased energy consumption.One of the characteristics feature of our time is a common viewpoint charred by the public community that our society is very unrational user of energy. Total consumption of all forms of energy is very high at present time and that is increasing simultaneity. It follows from this that human activities must be geared towards minimum energy use in order to help protect energy resources and minimize ecological and economic disadvantages.

Due to globalization of national economies, very significant growth will take place in the transportation sector, which is going to be the most important consumer of energy. For example, in 2004 EU's diesel and gasoline consumption amounted to 270 million tons, compared to 180 million tons in 1985, and it is forecast to reach 325 million in 2020.

Efficiency is generally defined as the ratio of benefit to cost, of output to input.

Since the beginning of the seventies, two outstanding features of the automotive industry is in the limelight, energy saving and environmental protection, in order to reduce the global greenhouse effect accomplish clean air conditions.

Energy consumption in the transport sector in general, can be reduced by reducing engine power used and increasing fuel efficiency.

The fuel consumption of gasoline and heavy-duty diesel engines is of great important, since it account for up 30% of operating costs.

Rising fuel costs and the need to conserve fossil fuel led to an increased interest in the role of lubricants in improving fuel economy. Lubricant formulation can have a beneficial reduction of engine friction, this improving fuel economy. For example, friction losses in a car engine may account for more than 10% of the total fuel energy [1].

In Japan, by the year 2010, the fuel consumption of automobiles must be reduced by an average of 22,8% compared to 1995 [2].

This trend to improve fuel economy has led to the introduction of lower oil viscosity grades such as 5W30 and 10W30 grades that are now commonplace in the heavy-duty engines.

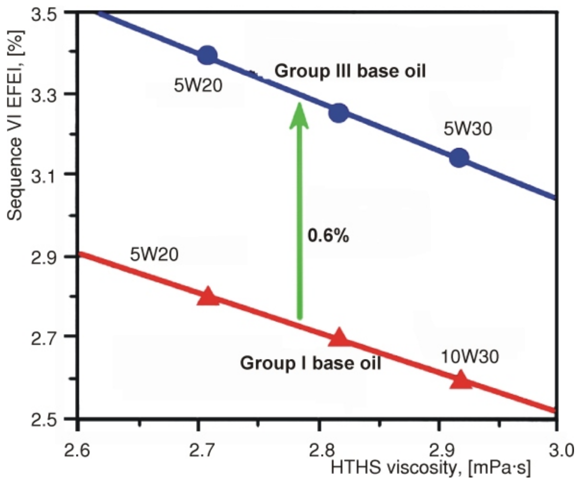

Figure 1. Fuel economy benefits obtained from VHVI Group III base oil

Figure 1 shows fuel economy benefits as result of the lower elastohydrodynamic lubrication (EHL) friction of the very high viscosity index (VHVI) Group 3 in compare with Group 1 base lubricant oils [3]

Typically, PAO (polyalpholefins) based engine oils have a fuel consumption benefit of up to 3.4% relative to comparable mineral oils. In automotive transmissions the benefit is of the order of 10% of the power transmitted through the unit resulting in a fuel economy benefit of up to 2% in the driveline of a vehicle. This results in on overall benefit of up to 5.4% in a vehicle [4]. In industrial transmissions, it is a possible to achieve a 10% reduction in energy consumption by replacing mineral oil with equiviscous PAO based oils [2, 5].

Pressure to improve the fuel economy of motor vehicles is getting stronger due to necessity of preventing global atmospheric warming, and on the other hand, saving energy.

Diesel engines provide high thermal efficiency and high CO_2 reduction effects. With today's direct injection diesel vehicles, a fuel economy improvement of at least 30% over comparable vehicles with SI (spark ignition) engines is achieved.

For that reason, the diesel engine is at least in Europe, seen as the best solution for reducing fuel consumption and these reducing CO_2 emissions.

It is estimated that diesel engines could emit 28% fewer green house gasses in the total energy cycle including refining and vehicles use.

The testing has been performed from that point of view, energy efficiency of three-cylinder tractors engines older design and diesel engines of new design.

Experimental

Testing of fuel efficiency has been performed on three cylinders tractors engines with indirect fuel injection (Perkins 3.152 – M 33/T) and direct fuel injection (Perkins D3.152 – DM 33/T).

These engines are older design (production technology). The criterion for choice of these engines was theirs large production as well as representative in exploitation in Serbia and wide area of Balkan's peninsula.

These engines are compared to equally of European engines, which are newer design.

The criterion for choice of representative European tractor's engines (W3 and E3) was theirs market share, the same class as domestic representative engines and as the first theirs performance (power, torque) and fulfillness of European provisions with regard to the emissions of pollutants by the engine.

The tab. 1 shows the technical characteristics of engines, older and newer design.

From tab. 1 it can be seen that European modern tractor diesel engines (W3 and E3) have higher compression ratio (10-15%), higher injection pressure (15-30%), lower specific fuel consumption, larger piston diameter and smaller stroke, lower swept volume, and considerable higher (8-19%) volume power related to M33/T and DM33/T older design diesel engines.

Moreover, there are significant differences in injection equipment. Modern European's engines have fuel pump for every cylinder while older design engines have rotational high-pressure pump.

Specific fuel consumption measuring has been performed on a test stand using direct method [6, 7].

Specific effective fuel consumption is presented by diagram as (1) brake performances and (2) over universal diagram, finding economical point, *i. e.* minimum fuel consumption pole.

Results

Figure 2 shows comparative results of testing brake performances on three-cylinder tractor's diesel engines (M33/T and DM33/T) older design.

It can be seen that the direct injection engines (DM33/T) have larger power approx. 15%, and lower specific fuel consumption approx. 5% from the same engine displacement. These differences are result in design of these two engines. Namely, engine

Table 1. Characteristics of tested engines

Item	Data \ Engines	M33/T	DM33/T	W3	E3
1	Fuel injection system	IDI	DI	DI	DI
2	Total swept volume, V [l]	2.5	2.5	2.1	2.33
3	No. of cylinder in line	3	3	3	3
4	Compression ratio, ε	17.4:1	16.5:1	18:1	19:1
5	Bore, D [mm]	91.4	91.4	94	94
6	Stroke, S [mm]	127	127	100	112
7	Rated power ISO 2288 [kW]	30.2	34.8	35	35
8	Rated speed, n [rpm]	2200	2250	2500	2800
9	Max. torque, M [Nm/rpm]	150/1400	163/1800	145/1250	138/1800
10	Injection pump	Rotational	Rotational	Unit	Unit
11	Volume power [kW/l]	12,08	13.92	16.7	15.02
12	Start of injection (degrees before TDC)	20	20	–	–
13	Injection pressure [bar]	118	200	230	–
14	Spec. fuel consumption – g_{eo} [g/kWh]	258	246	242	225

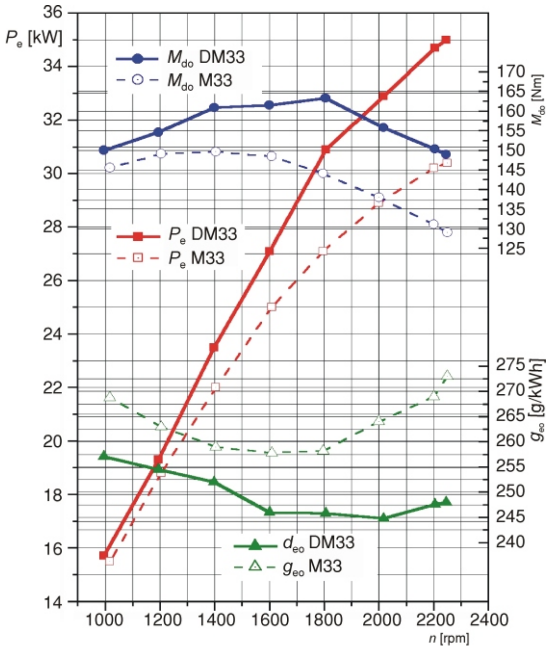

Figure 2. Brake performances of M33/T and DM 33/T engine

M33/T has indirect fuel injection in a swirl chamber in a cylinder head. Nozzle has two holes; the injection pressure is relatively low compared to modern tractor's diesel engines.

The engine DM33/T has direct fuel injection in cylinders at considerably higher fuel pressure (1.7), thus better energy efficiency. The nozzles have four holes (0.28 mm) that the fuel spray makes better mixture with rotating air.

The fig. 3a and 3b shows universal specific effective fuel consumption of M33/T and DM33/T diesel engines. It can be noticed that the minimum fuel consumption pole these two engines (M33/T and DM33/T) are differ, namely they include different section of working regime. They are 250 g/kWh and 233 g/kWh, respectively, *i. e*. the difference is 7%.

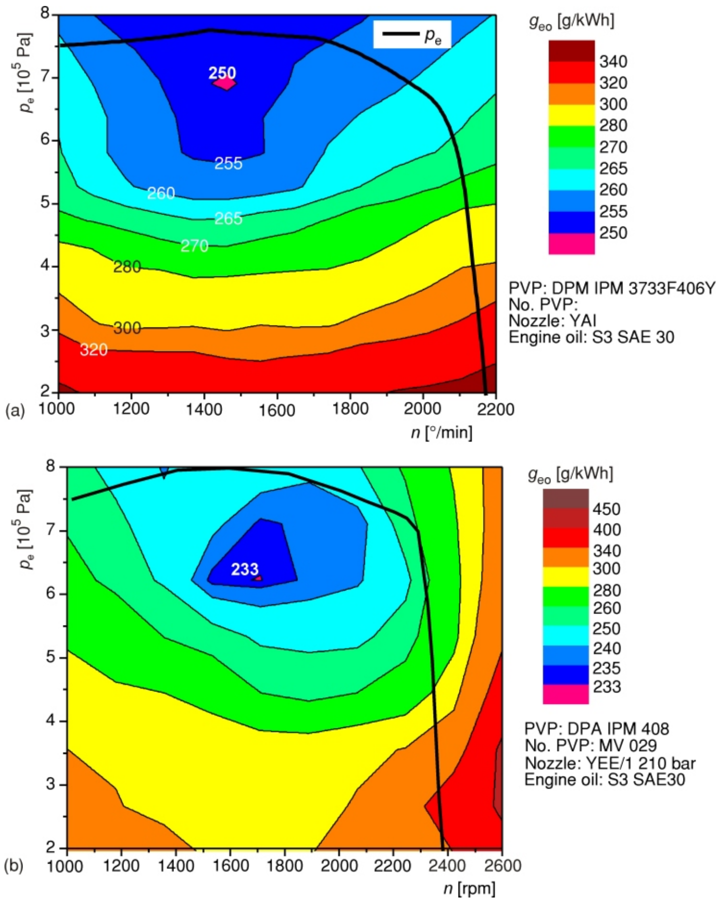

Figure 3. Universal specific effective fuel consumption diagrams of (a) M33/T and (b) DM33/T engine

The minimum specific fuel consumption pole of DM33/T engine, related to one of M33/T engine is slightly shifted to right and down, thus it is approx. 300 rpm right of max. torque and at approx. 80% of full load.

Relatively low position of minimum fuel consumption pole of DM33/T engine shows that if it would be readjusted to declared power of M33/T engine 29 kW at 2000 rpm, instead of 34 kW at 2250 rpm (tab. 1), the minimum fuel consumption pole will be again inside the working area of engine.

Practically it means that the adjusted engine will have approx. 8% lower fuel consumption. However, the smoke emission and NO_x emission will not be decreased.

Comparative brake performances of examined older design three cylinders tractor engines (M33/T and DM33/T, made in Serbia) and equivalent European diesel engines newer design are presented in fig. 4.

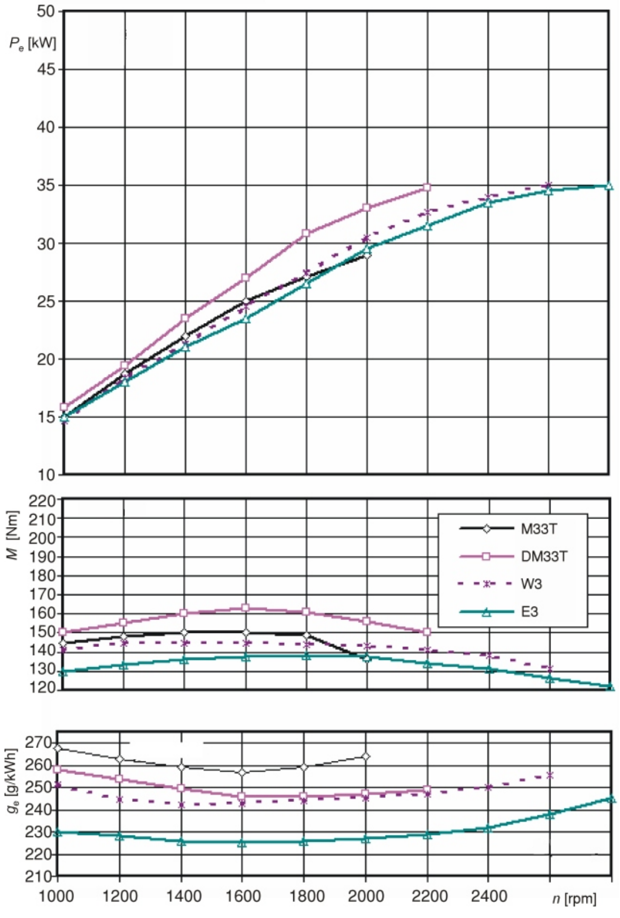

Figure 4. Comparative brake performances of three cylinders tractor engines older and newer design

Figure 4 shows that modern European engines W3 and E3 *vs.* DM33/T have approx. same max. power and smaller swept volume and at the same time better torque back-up.

Second European engine of modern design E3 *vs.* DM33/T has also the approx. same max. power, smaller swept volume of 7%, larger power per unit displacement of 8%, and at the same time better torque back-up.

Fuel consumption of three cylinder tractors diesel engines of older and newer design shows fig. 5.

From fig. 5 it can be seen that the engine with indirect injection (older design) has approx. 5% higher fuel consumption *vs.* DM33/T direct injection engine also older design. However if considering load regimes adapted to the minimum fuel consumption pole (fig. 3) it can be seen that the disposition and size of pole of DI engines fit much better to engine exploi-

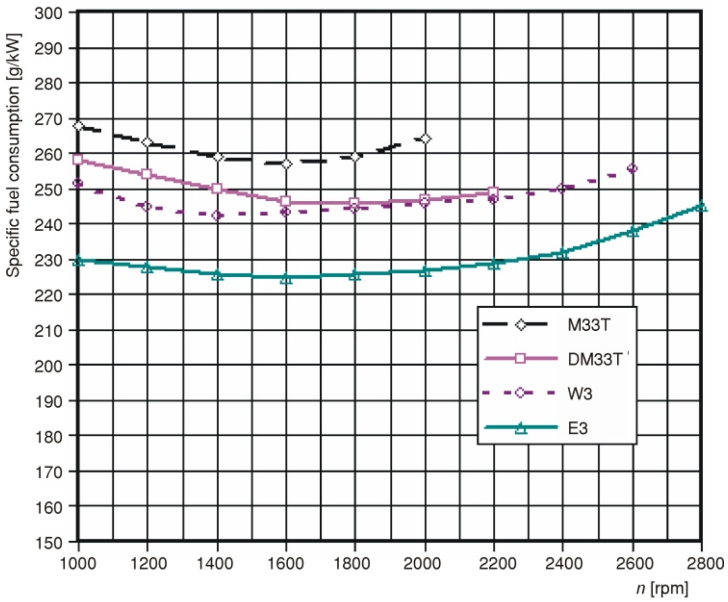

Figure 5. Specific fuel consumption of three-cylinder tractors diesel engines older and newer design

tation condition as important tendency of modern designed tractor diesel engines. That means, in condition of engine exploitation *i. e*. tractor, during the basic works, the disposition of point of minimum fuel consumption can influence to absolute *i. e*. fuel consumption per hour which can be considerably lower comparing to one or more discrete points calculated during the laboratory testing.

It is well known that tractor diesel engines in most working operations required operating regime of 1400 to 1600 rpm and load of 60 to 80% as it is at the same time the region of minimum DI fuel consumption.

Analyzing the fuel consumption in that manner, the savings can be higher, to 15%.

Related to modern design engines (W3 and E3) the fuel consumption of M33/T engine is considerably larger for approx. 7% and 15%, respectively.

Comparing direct injection engines older (DM33/T) and newer design (W3 and E 3) it can be seen that engine W3 has approx. 2% lower specific fuel consumption while engine E3 has approx. 9.3% lower specific effective fuel consumption related to DM33/T engine. These differences are mainly results of different injection equipment, injection pressure, distribution systems, compression ratio *etc*. This point out that on the tractor diesel engines of older design must be applied design solutions, which will improve the efficiency related to national long-term interests as well as necessity to fulfill Europeans fuel consumption and emission regulations.

Must be emphasized, but it not shown on fig. 5, that the modern design engines (W3 and E3) have considerably higher power per unit displacement related to older design engines, thus pointing out to development of modern designed engines – increasing power per unit displacement and at the same time decreasing the specific fuel consumption.

Conclusions

Based on obtained results the following conclusions may by make.

(1) Older designed tractor's direct injected diesel engines (DM33/T) have approx. 5% lower specific fuel consumption related indirect injected engines (M33/T).

(2) Modern European tractor's diesel engines (W3 and E3) have approx. 2% and 9,3%, respectively, lower specific fuel consumption related to DM33/T older designed engine.

(3) Modern European tractor's diesel engines (W3) have approx. the same max. power, approx. 19% smaller swept volume, approx. 10% higher compression ratio, approx. 15% higher injection pressure, and approx. 20% higher power per unit displacement related to DM33/T older designed engines.

(4) Modern European tractor's diesel engines (E3) have approx. the same max. power, approx. 7% smaller swept volume, approx. 15% higher compression ratio, and approx. 8% higher power per unit displacement related to DM33/T older designed engine.

(5) Approaching European's fuel consumption regulations it is necessary to apply solutions on older designed engines in order to improve theirs energy efficiency.

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References

[1] Richardson, E., Review of Power Cylinder for Diesel Engines, *Trans.*, *ASME, J., Engineering for Gas Turbines and Power*, *122* (2000), 11, pp. 506-511

[2] Igarashi, J., The Mineral Oil Industry in Japan, *Proceedings*, 13th International Colloq. Tribology, Esslingen, Germany, 2002, pp. 13-17

[3] Bleimschein, I., Brieger, P., PAO Base Oil Reduce Fuel and Energy Consumption, *Proceedings*, 14th International Colloq. Tribology, Esslingen, Germany, 2004, pp. 1561-1568

[4] Esig, G., *et al.*, Diesel Engine Emission Reduction – The Benefits of Low Oil Consumption Design, SAE Paper 90059, 1990

[5] Korcek, S., *et al*., Automotive Lubricants for the Next Millenium, *Proceedings*, 12th International Colloq. Tribology-Plus, Esslingen, Germany, 2000, pp. 43-53
[6] ***, Energy Efficiency Profile: European Union, MURE-Odyssey, MURE-Measures de Utilization rationale de I' Energie, 2004
[7] ***, ECE 84, 120 Regulations

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