THE INFLUENCE OF DIESEL ENGINE'S THERMAL CONDITION ON FUEL CONSUMPTION AND SMOKE OF EXHAUST GASES

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Abstract

The number of vehicles in the world is growing rapidly. Therefore, the global consumption of crude oil is increasing and its natural resources are being depleted. It causes the rise of oil fuel cost. Constantly rising energy prices and environmental concerns have made energy saving the highest priority for transportation operators. The main goal of vehicles' operation is economy. The fuel consumption of the most popular internal combustion engines depends on various factors, and one of the most important of them is thermal condition. Energy or fuel saving is the main way to reduce operational expenses of vehicles.

This paper aims to investigate fuel consumption of 1.9 liter volume direct injection diesel engine and to construct a diagram of the dependence of the amount of smoke in exhaust on the temperature of engine's operation. The temperature was fixed in the engine's crankcase, while the temperature of cooling liquid was measured at four points as well as during the engine's bench testing. Unexpected test results are obtained: when the temperature of exhaust gases rises above 70-75°C, the amount of smoke increases by a few times. Finally, basic conclusions and recommendations are given.

Keywords: *diesel engines fuel consumption, engine's thermal condition, temperature of engine's cooling liquid, smoke in exhaust*

1. Introduction

The growing number of vehicles in the world increases the consumption of crude oil, while the depletion of its natural resources causes the rise of oil cost [2, 5]. Therefore, saving of fuel is becoming a significant problem in transport. The increasing number of vehicles in the world also results in the increase of environmental pollution [2]. Any car manufacturer seeks to reduce the amount of exhaust gases released by a vehicles as well as its fuel consumption.

In recent years, the number of tractors, trucks and cars with diesel engines has increased considerably. This causes the increase of the environment pollution and the so-called 'greenhouse effect', which is harmful for the environment and human beings. Smoky exhaust of diesel engines makes a serious problem [3]. There are various ways of reducing the amount of soot in the exhaust [1, 4], therefore, the efforts are made to enhance the operation of diesel engines and to reduce smoke in exhaust, as well as the emission of toxic materials by vehicles

The research performed is closely connected with all these problems, including the environmental effects of vehicles. The problem of the dependence of fuel consumption and smoke in exhaust on temperature (thermal) condition of an engine is also investigated.

2. The method and the equipment used in the experiment

The main goal of the current experimental research is to perform the comparative analysis in testing a diesel engine under the varying temperature and to determine the effect of the engine's thermal condition on fuel consumption and smoke in exhaust, when a particular range of loading and revolutions is selected.

Four-stroke, four-cylinder *1Z*-type diesel engine of the car *Audi-80* manufactured in 1992 was used in testing. The engine with a solid, direct injection combustion chamber, provided with a turbocompressor (drawing in air), a recirculation system for burnt gases and electronic control unit (ECU) of engine's operation was tested. Technical characteristics of the manufactured *1Z*-type engine are given in Tab. 1. By removing the thermostat from its cooling system, a large cooling circle was forcibly opened, and the operating temperature of an engine could be achieved slower. In this way, the time of testing from its beginning until the end, when the main cooling system's fans start working, is prolonged. Thus, favourable conditions for collecting more information are created.

Tab. 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

An additional 5 kW electric fan is installed for engine cooling. In testing, this fan is connected to the source of power and placed in front of the engine to direct the air flow to the engine and cooling radiator. The air flow created by the additional fan prevents the heating of an operating diesel engine.

An electric engine test bed *КИ-5543* with a weighing electrodynamometer was used to determine the torque of the internal combustion engine.

An Austrian exhaust smoke analyser *AVĻDiSmoke 4000* was employed to determine smoke in exhaust of the engine. For this purpose, it is provided with a special camera operating on the principle of photometric absorption. This camera allows smoke D and light absorption coefficient k to be determined.

The consumed fuel was weighed by electronic balance *SK-5000*.

The engine operating in the modes presented in Tab. 2 was tested.

Tab. 2. Testing conditions

Nr.	Engine speed, min^{-1}	Torque, Nm
1	2000	37
2	2000	75
4	2500	37
5	2500	75

To determine the operating temperature of the engine, four thermocouples were installed into the coolant hoses and one of them was inserted into the hole for checking the level of diesel oil. The data on the temperature of the liquids were registered by *AVL DiScope 865* device.

The following cases were investigated:

- the temperature is lower than the optimal operating temperature. The data obtained at this stage should provide the information about fuel consumption by the engine when it has not been heated, i.e. has not reached its operating temperature yet,

- the temperature is normal operating temperature of an engine. The results obtained at this stage could show the actual fuel consumption by the considered engine, i.e. that which is specified by technical documentation,
- the temperature is higher than the optimal operating temperature. The results obtained at this stage will show fuel consumption when a diesel engine is overloaded.

3 Testing results

During the first test, when the engine has not yet reached its operating temperature, specific fuel consumption was about 336 g/kWh, while the cooling system's temperature rose only up to 30°C. The analysis of Fig. 1 shows that specific fuel consumption remained actually unchanged, while the engine's temperature rose by 10 degrees (from 35°C to 45°C). When the engine was getting hotter, fuel consumption was uniformly decreasing. At the temperatures of 70°C and 85°C, respectively, specific fuel consumption of diesel engine was 313 g/kWh. When the engine was heated to the maximum temperature and the fans had not been switched yet, specific fuel consumption of the engine tested dropped to 278 g/kWh.

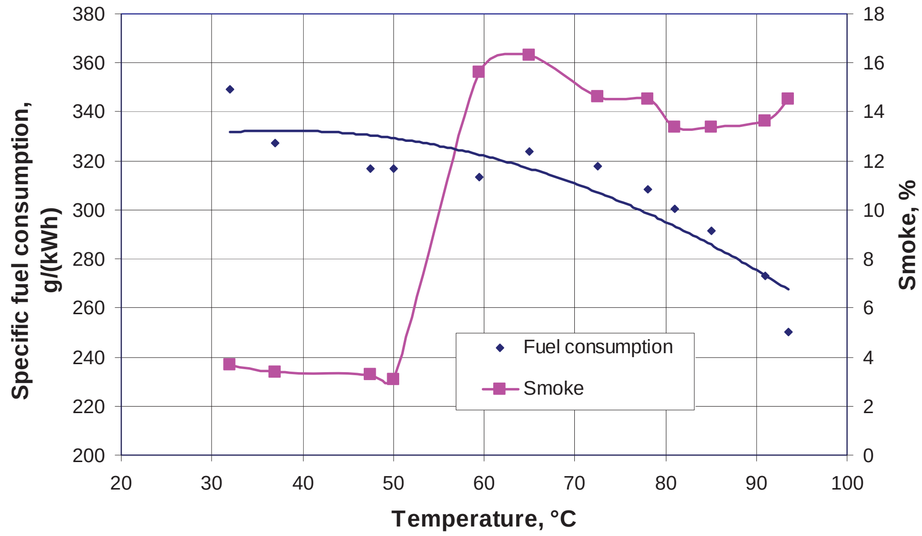

Fig. 1. The dependence of fuel consumption and smoke content in exhaust on the operating temperature of an engine, working at 2000 revolutions/min and 37 Nm loading

The graph in Fig. 1 shows that, when the coolant's temperature rose from 34°C to 66°C, smoke in exhaust decreased from 4.2% to 3.1%. When the coolant's temperature reached 66°C, smoke in exhaust increased up to 19.6%, i.e. by about 5-6 times. Later, when the coolant's temperature was rising up to 100°C, smoke in exhaust was irregularly decreasing.

During the second test, the engine's power reached 15.6 kW. The initial diesel oil temperature was 16°C. At the beginning of the test, specific fuel consumption slightly exceeded 303 g/kWh, while the coolant's temperature reached 21°C and diesel oil temperature was 16°C. In the middle of testing, specific fuel consumption dropped to 250 g/kWh, while the coolant's and diesel oil temperature was 65°C and 64°C, respectively. When the engine tested was heated to the temperature when fans were switched on, fuel consumption reached 230 g/kWh, while the temperature of the coolant and diesel oil was 100°C and 102°C, respectively (Fig. 2). During this test, fuel consumption was uniformly decreasing by about 3.7% with respect to 10ºC increase of the coolant's temperature.

As shown in the graph (Fig. 2), when the coolant's temperature is rising from 23°C to 75°C, smoke content is decreasing from 7.4% to 3.6–4.0%. At the temperature of 75°C, smoke increases up to 30%, or, later, up to 36.6% (94,4°C), i.e. grows by 5-8 times. In the temperature range from 95°C to 100°C, smoke content begins to decrease.

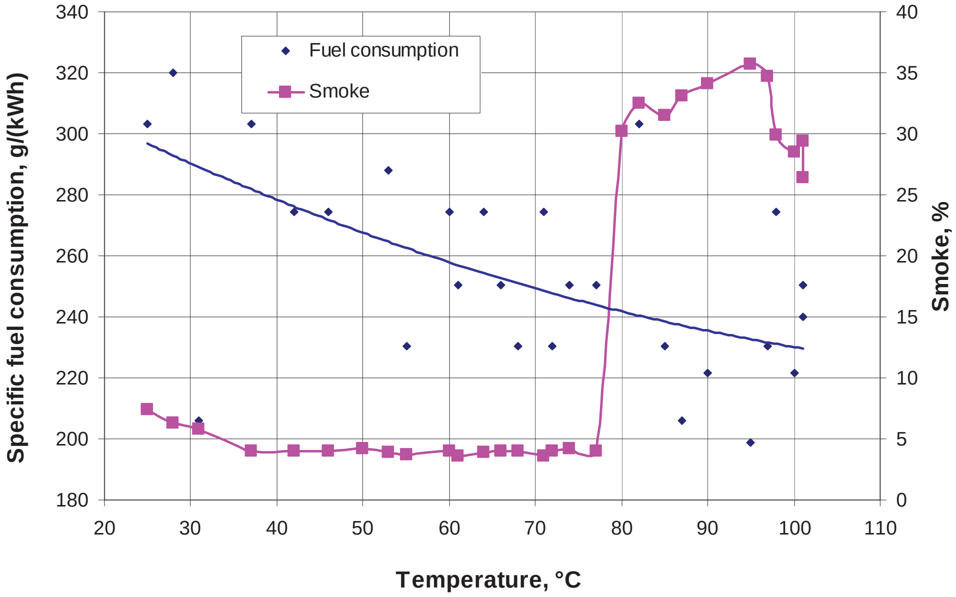

Fig. 2. The dependence of fuel consumption and smoke content in exhaust on the operating temperature of an engine, working at 2000 revolutions/min and 75 Nm loading

During the third test, the engine power reached 9.76 kW. The initial temperature of diesel oil was 14°C. At the beginning of testing, fuel consumption was 358 g/kWh, while the temperature of the coolant and diesel oil was 20°C and 22°C, respectively. When the considered engine was uniformly heated and the coolant's temperature reached 53°C, specific fuel consumption reached 348 g/kWh. At the end of testing, the lowest fuel consumption of 324 g/kWh was reached, while the temperature of diesel oil and the coolant was 98°C and 93°C, respectively (Fig. 3).

During this test, smoke content in exhaust has increased by 1-2% compared to the first and second tests. One can see that, when the temperature of the coolant increases from 20°C to 70°C, smoke content increases from 5.8% to 3.3%, while, at the temperature of 74°C, smoke content increases up to 17.9%. When the coolant's temperature is rising up to 98°C, it is changing in the range of 16.9-19.6%.

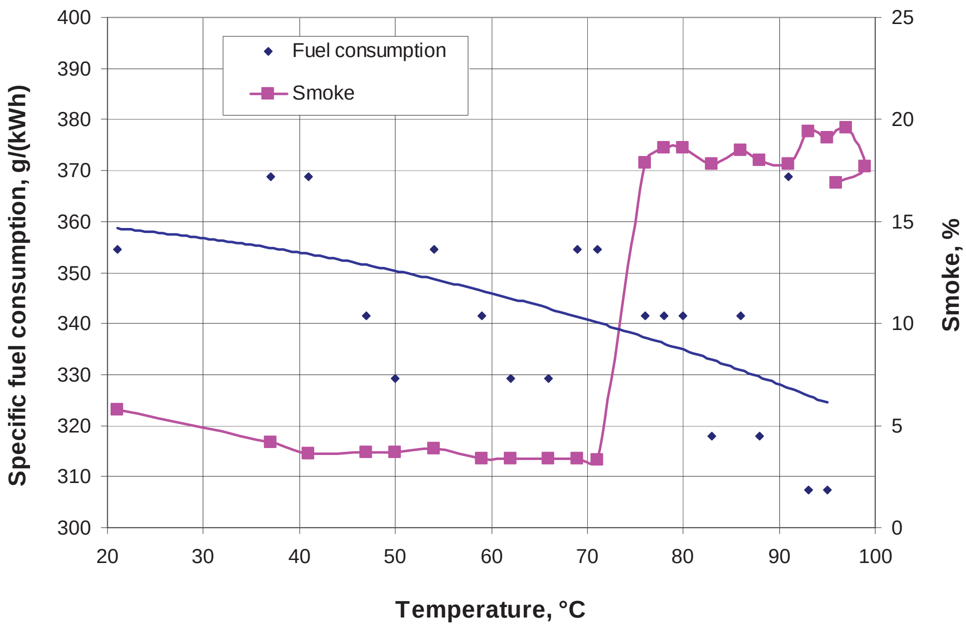

Fig 3. The dependence of fuel consumption and smoke content in exhaust on the operating temperature of an engine, working at 2500 revolutions/min and 37 Nm loading

During the fourth test, the power of the engine reached 19.5 kW, while the initial diesel oil temperature was 15°C.

Specific fuel consumption of the cold engine at the beginning of testing was 293 g/kWh, while the temperature of diesel oil and the coolant reached 24°C and 33°C, respectively. When the temperature of an engine was rising, its fuel consumption dropped to 264 g/kWh, while the temperature of the coolant and engine oil was 64°C and 60°C, respectively. Having reached the minimum value, fuel consumption began to increase again, when the operating temperature of the engine exceeded 91°C. In this test, the lowest fuel consumption of 256 g/kWh could be observed when the operating temperature of the engine was 84°C. The test was completed, when the temperature of the engine rose to 100°C, while the fans were switched off. At this moment, specific fuel consumption was 258 g/kWh (Fig. 4).

Since the engine tested was heavily loaded, fuel consumption stopped decreasing and stabilized at the temperature of 84°C. Fuel consumption remained the same until the engine's temperature reached 95°C. Then, it began to increase and was growing gradually until the test was completed.

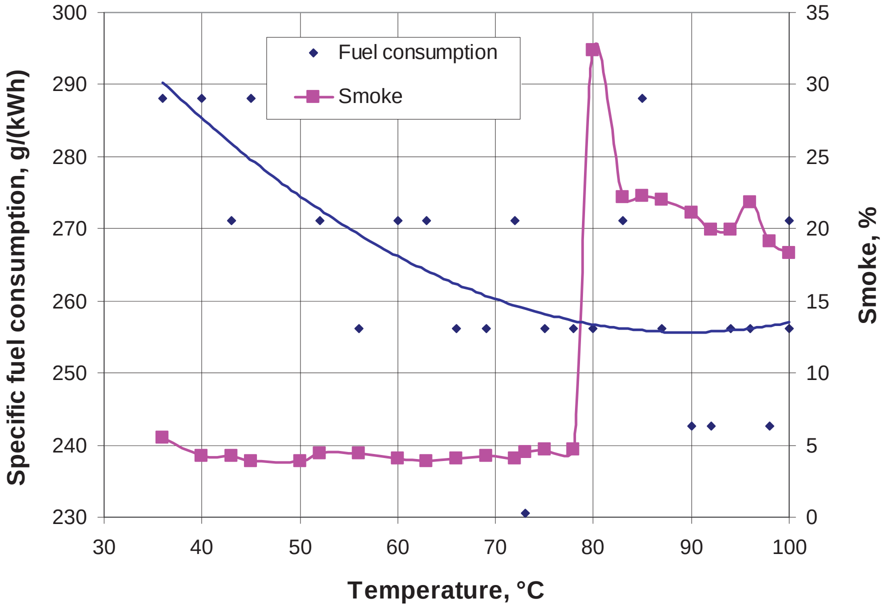

Fig. 4. The dependence of fuel consumption and smoke content in exhaust on the operating temperature of the engine working at 2500 revolutions/min and 75 Nm loading

As shown in the graph (Fig. 4), smoke content in exhaust is in the range of 3.9-5.5%, when the temperature of the coolant of the engine is rising from 33°C to 79°C. When the coolant reaches 80°C, smoke content increases up to 32%. When the temperature of the coolant reaches 99°C, it drops to 18.3%.

4. Conclusions

The following results were obtained in testing a diesel engine and determining the dependence of its fuel consumption and smoke content in exhaust on the temperature condition of this engine:

1. The most economical operation of diesel engine could be observed, when its temperature was in the range of 83-88ºC,
2. When the temperature of the engine was 25-35°C, the increase of diesel oil consumption by >11% could be observed,
3. When the temperature exceeds 95°C, the consumption of diesel oil by the engine begins to grow,
4. In every test, when the temperature of diesel oil reached 70-80°C, smoke content in exhaust usually increased by 3-6 times,

5. Optimal temperature of diesel oil, ensuring the minimum smoke content in exhaust, is in the range of 65-70°C (3.1-4.7%),
6. The largest amount of smoke could be observed when the temperature of diesel oil was 75-100°C (10.4-37.1%).

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