Research on the Possibility of Increasing the Power Output of a High-Speed Diesel Engine by Adding Compressed Natural Gas

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Abstract: The paper presents studies on a high-speed diesel engine driven by added CNG (compressed natural gas) in order to increase its power. The effects of the amount of CNG added on the engine performance have been studied. Throughout the tests the effective performance and pollution emission indicators of ICE (Internal Combustion Engine), the cylinder pressure, etc. were measured. Under all operating conditions the diesel fuel consumption per hour and the rotation speed have remained constant. The amount of CNG added is variable. As a result of the research, relations have been established concerning the overall efficiency, the air to fuel ratio for steady-state performance and smoke opacity. An increase in CO, NOx and H₂ emissions has been recorded and at the same time the amount of CO₂ released has decreased. Both the maximum pressure in the combustion chamber and the pressure rise rate increase which results in rising the engine performance harshness. When CNG has been added in quantity about 47% of the total amount of fuel, the peak value is achieved. The influence of the amount of added gas fuel on the calculated gross heat release rate has been determined. The maximum heat release rate does not change significantly. The nature of the combustion process does not change either. In conclusion, findings validate the possibility to achieve up to 30 % higher maximum rated power by adding 56% CNG mass fraction of the total amount of fuel. Provided the amount of CNG is up to 48% of the total amount of fuel, the ICE ecological indicators have not been deteriorated, furthermore the power has been increased by up to 20%.

1. Introduction
The continuous increase in the specific volume of the modern piston ICE is the result of the investigations conducted by researchers. These investigations are focused on improving engine energy efficiency.
A well-known fact is that diesel engines do not utilize the air introduced to the cylinders efficiently, compared to engines operating with homogeneous fuel-air mixtures [1]. This disadvantage is overcome either by cylinders overfilling or by finding alternative combustion processes.
Another alternative method is adding hydrocarbon gases such as propane-butane, methane and others during the diesel engine operation. Thus a certain homogenization of the mixture has been achieved furthermore there exists the possibility of lowering the smoke opacity limit at air to fuel ratio of $\lambda = 1.05 \div 1.1$. 
This method is mostly used in heavy-duty truck engines, the fleet transportation industry and stationary diesel engines, running in modes close to their full load [2]. On the one hand, from the economics point of view, the engine performance indicators are improved, while on the other hand the CNG method promotes environmental friendliness with lowering the quantities of soot deposited. There are certain advantages of adding gas fuel to the diesel engine: the engine power is increased since more air is being introduced to the cylinder without exceeding the smoke opacity limit.

2. Experimental methodology

A high frequency direct injection diesel engine Prima 65, produced by Perkins Engines Ltd” England is used for the tests. The main technical data are as follows: rated power of 46kW/4500 min-1; the maximum engine torque of 122N.m/2500 min-1 and engine capacity of 1993cm3.

Throughout the tests the following characteristics were measured: engine load; crankshaft rotation speed; diesel engine air consumption; fuel and CNG consumption; exhaust gas temperature; coolant temperature; lube oil temperature; ambient temperature; oil pressure in the lubricating oil system; barometric pressure; air consumption; smoke opacity and ratio of CO; CO2; O2; HC; NOx emissions in the exhaust gases; injector needle movement and mean effective pressure in the combustion chamber. In all modes the diesel fuel consumption per hour remained constant– 4,0 l/h. The quantity of CNG added varied.

The test was carried out at a constant frequency mode of 2500 min-1. Large black markers on the graphs show in comparison the parameter values for both diesel fuel and maximum torque of 122Nm. They are positioned close to the marker at which the same mean effective pressure with CNG added has been achieved.

3. Experimental data and results

By adding 56% of the total amount of CNG, a torque of 153,8Nm and the respective power of 43,3kW were achieved. The torque obtained was 26% bigger than the original one (122Nm) according to the production characteristics of the engine. This limitation was imposed by the smoke opacity ratio, permissible for this type of engine - 55%. Taking into account that the power output was close to the rated power, and the rotational speed was 56% of the rated one, it should be assumed that the absolute amount of soot deposited in the atmosphere led to the same ratio. When the smoke opacity was equal to the smoke opacity caused by diesel fuel (D=33%) only, an increase in the torque was observed by 20%(Fig.1).

The following most important dependencies have been outlined by the research conducted:

- The engine effective efficiency (\(\eta_e\)) is close to the efficiency in the cases when the engine runs only on diesel fuel. A steady-state performance of the engine is obtained with air to fuel ratio of \(\lambda = 1.10\) and smoke opacity D=55%. A certain increase in the percentage ratio of the CO and HC emissions is observed. The quantity of the carbon dioxide (CO2) released is less under similar operating conditions and same power due to the change of the fuel composition. The nitrogen oxides are at higher levels and eventually they are reduced to the original specification levels due to the lower concentration of free oxygen in the cylinder during the combustion process, caused by lowering of the fuel to air ratio.

- Indicator parameters show that with the increase in the percentage of CNG and load respectively, the engine experiences an increase in harshness as well. The maximum pressure in the combustion chamber (\(p_{\text{max}}\)) increases and reaches its maximum point when 47% CNG of the total amount of fuel is added. The maximum rate of pressure increase (\(dp/d\phi_{\text{max}}\)) is raised considerably (up to 1,93MPa/deg) which in turn causes an increase in the noise levels under operating conditions. The maximum cylinder temperature with a maximum of 56% CNG added is in linear relationship and is higher by about 20°C of the temperature under maximum load conditions.
Figure 1. Influence of the part of gaseous fuel on the parameters of the engine

- \( p_e \) – mean effective pressure, MPa;
- \( \eta_e \) – overall efficient;
- \( \lambda \) – Relative air/fuel ratio;
- \( D \) - Opacity of exhaust gas, %;
- \( CO_2 \) - carbon dioxide of exhaust gas, %;
- \( HC \) - hydrocarbons of exhaust gas, ppm;
- \( NO_x \) - nitrogen oxides of exhaust gas, ppm;
- \( (dp/d\phi)_{max} \) - Rate of pressure increase, MPa/deg;
- \( p_{max} \) - Maximal cylinder pressure, MPa;
- \( T_{max} \) – Maximal temperature of burned gas, °K

Figure 2 shows the influence of the quantity of gas fuel added on the heat release rate. It is observed that the maximum heat release rate does not change significantly when the quantity of 48% CNG of the total amount of fuel is added. The heat release rate is higher in the case when 56%CNG of the total amount of fuel is added than when the engine runs only on diesel fuel. The beginning of the visible combustion does not alter significantly (only within 1° of the crankshaft). The end of the process of visible combustion does not change considerably either. The nature of the combustion process does not change, only the instantaneous maximum combustion rates increase.
4. Conclusion
The following conclusions can be drawn from the present study:

- It is possible to achieve almost 30% of higher power coupled with economics characteristics by adding up to 56 % CNG of the total amount of fuel, complying with the smoke opacity limit permissible;
- Adding up to 48% CNG of the overall amount of fuel used, does not deteriorate the ICE ecological indicators, furthermore the power has been increased by up to 20%.
- Declining the amount of soot deposited in the atmosphere by up to 40% mass fraction at maximum load.

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