EXPERIMENTAL STUDIES OF IMPACT OF EXHAUST GAS RECIRCULATION ON THE EFFECTIVE OPERATION IN HEAVY AUGMENTED DIESEL ENGINE

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ABSTRACT

This paper considers the problem of reducing the nitrogen oxides emissions in exhaust gases (EG) of diesel engine by exhaust gas recirculation (EGR). Based on the carried out study the influence of EGR on technical-and-economic and environmental performance of a diesel engine was found as well as main directions of improving a working process of diesel engines with EGR system were formulated.

Keywords: diesel engine, warm-up mode, exhaust toxicity, exhaust gas recirculation, nitrogen oxides (NO_x), heat exchanger of system exhaust gas recirculation.

INTRODUCTION

The problem of increase the efficiency and operational reliability of the internal combustion engine (ICE) is a priority subject for the engine design in the coming decades in accordance with the requirements of environmental law. An extreme increase commercial and passenger vehicles equipped with the ICE leads to a periodic tightening of regulatory restrictions to emissions. Therefore, the main stream in the ICE studies is given by the requirements to the exhaust emissions. These requirements and consumer demands for fuel economy as well initiate the research activities in area of ICE design. It should be noted that a problem of efficiency increasing and a problem of concentration reducing for toxic components of the EG (nitrogen oxides (NOx), hydrocarbons (   ), carbon monoxide (   ) and dispersed particles Pt) in accordance with the rules   24 and 49 of the ECE UN are contradictory.

The complexity of solving this problem lies in the fact that the transport engine exploited in wide range of load and rotation speed. Usually, the terms of reducing emissions NOx, CH and Pt in the exhaust gas and specific fuel consumption BSFC are opposite. Traditional methods of the emission control, such as changing settings of the fuel injection system (for example, reducing the angle of the fuel with simultaneous increase of fuel feeding pressure) allows to move to a higher environmental level of emissions of normalized components, but it reduces fuel economy or require the installation of additional systems for exhaust emission neutralization (catalysts, particle filters, EGR system, etc.), which in turn requires additional work to adapt these systems to the operation conditions of the engine.

Traditional approach of reducing EG toxicity is to change the fuel-injection equipment (FIE) settings. Reducing the onset angel of fuel supply allows passing to a higher environmental level on emissions of normalized components but it reduces fuel efficiency. Alternatively, it is necessary to install additional purification and neutralization systems (catalysts, particulate filters, EGR system and etc.) it, in turn, requires additional finishing work on the adaptation of these systems with engine operation.

Regularity of influence of EGR on behavior of intra cylinder processes in ICE lies in reducing the maximum temperature in the cylinder combustion zones by adding the inert gases (CO_2 and N_2) to the air supplied in the cylinder [1, 2].

Study goal is to evaluate the influence of EGR on technical-and-economic and environmental performance of high-uprated diesel engine under conditions of engine test bench. The studies were carried out at the regimes $n = 1250$; 1500 and 1750 rpm at a load 25; 50; 75 and 100 %. Recycle rate   was calculated by the formula

$$= 100 \cdot CO_{2\_inl}/CO_{2\_exh},$$

where CO_{2_inl} – % of carbon dioxide according to measurements in the inlet manifold after charge air cooler; CO_{2_ehx} – % of carbon dioxide according to the measurements in EG.

The study subject is a reciprocating four-stroke eight-cylinder V diesel with working volume iV_h=11.76 l, piston stroke S=130 mm, cylinder diameter D=120 mm, equipped with turbocharging, aftercooling and accumulator system of fuel supply of «Common Rail» type and a rated power $N_e = 338.5$ kW at crankshaft speed $n = 1900$ rpm.

Fig.1 demonstrates different constructive schemes of the EGR system installed on the test engine.
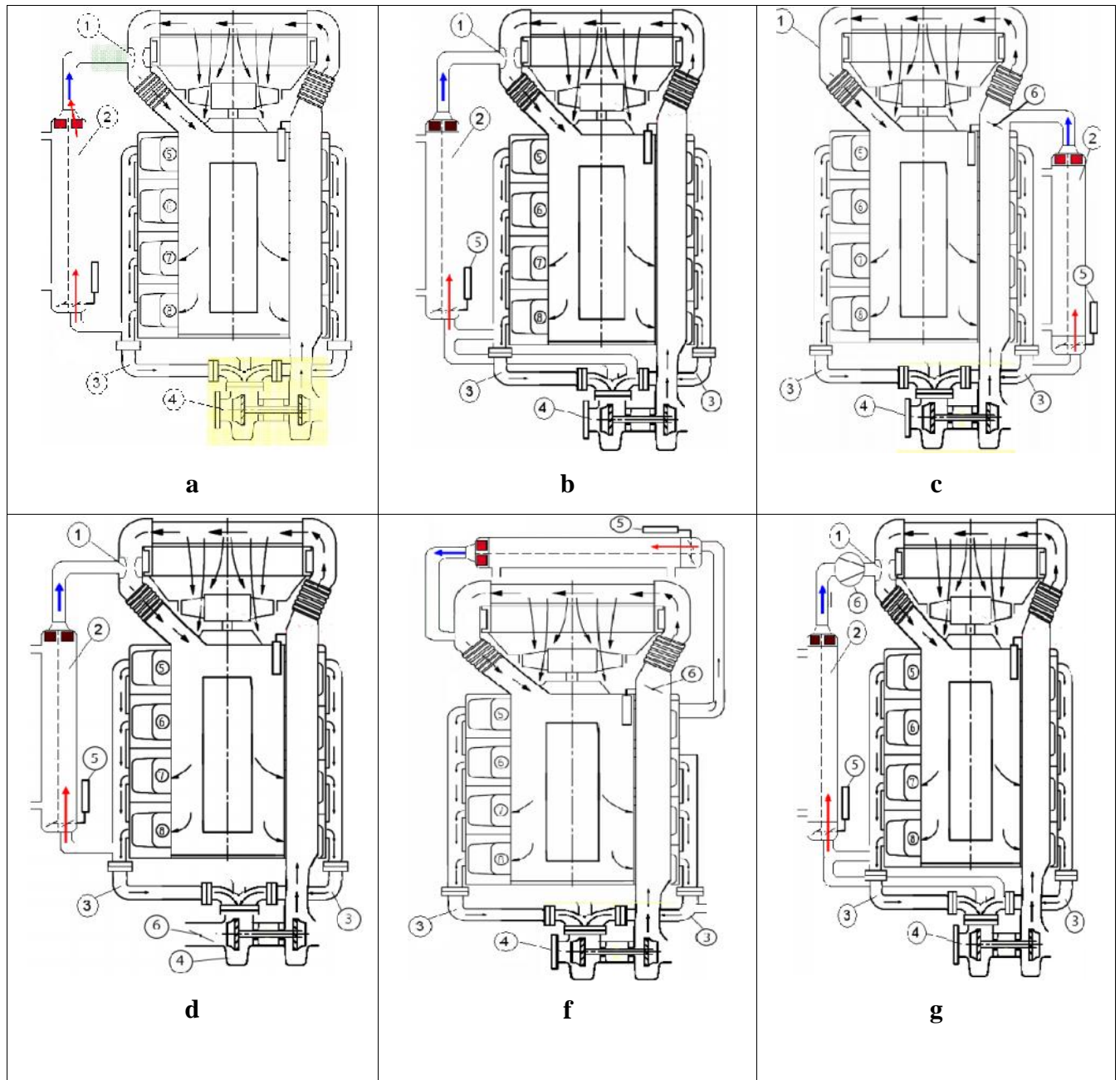
Fig 1. Schemes of EGR system for configuration of test engine

1-mixer; 2-heat exchanger; 3-exhaust manifold; 4-turbocharger; 5-valve ; 6-throttle valve on c,d,f and compression on g

Fig. 1a shows structural scheme of EGR system on the engine under study. This scheme is optimal with regard to layout and simplicity of alternate design. In the selected scheme bleeding of EG was carried out from right exhaust manifold and subsequent cooling in a heat exchanger. The EG supply in the inlet manifold was carried out after charge air cooler using a special mixer. The coolant fed to the heat exchanger of the internal circuit of the engine cooling system, and the heated water is sent back into the cooling system (fig. 2). The main

advantage of the chosen design solution is the possibility of a more rapid warming of the coolant in the cooling system of the engine warm-up mode, which in turn will allow for faster go to a more economical engine operation and to ensure efficient operation of heating, ventilation and air-conditioning the cabin interior. It should be noted that this is a problem for vehicles operated in different climatic zones.

During the experimental studies in this case the coolant temperature was 80 - 85 ° C.
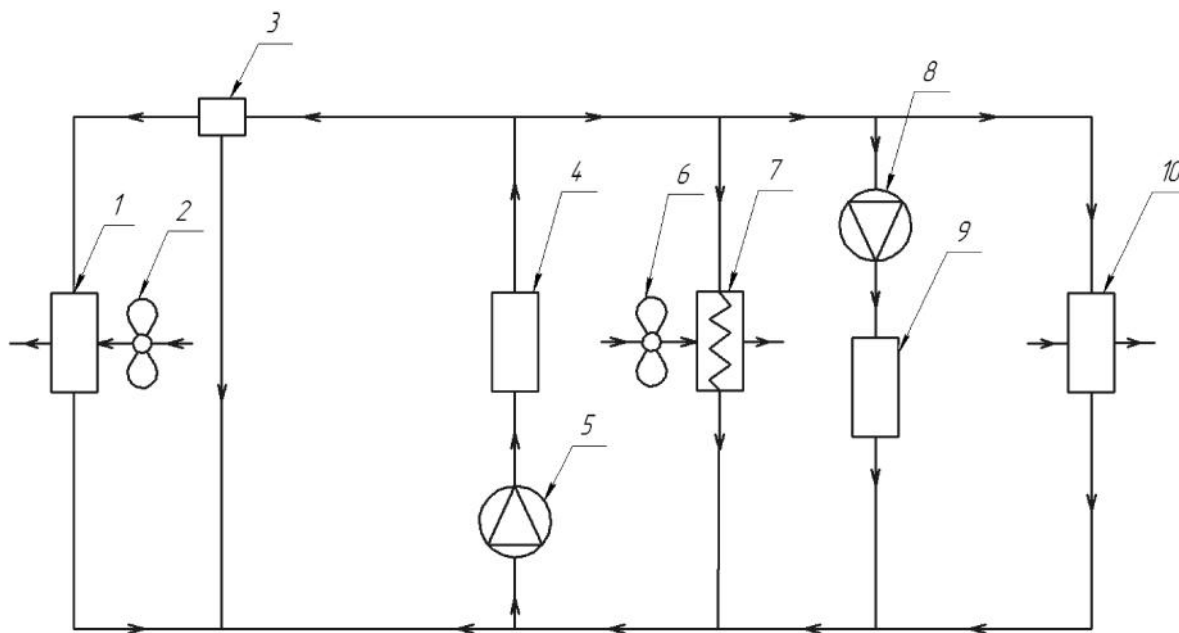
Fig. 2. Hydraulic scheme of the engine cooling system and heating the vehicle cabin

1 - heat exchanger of engine cooling system; 2 - fan of engine cooling system; 3 - thermostat; 4 - internal combustion engine; 5 - pump of engine cooling system;

6 - fan of air conditioner; 7 - heat exchanger of air conditioner; 8 - pump of auxiliary heat exchanger of cabin interior; 9 - auxiliary heat exchanger of cabin interior; 10 - heat exchanger of exhaust gas recirculation.

Table 1 presents the characteristics of EGR system and its influence on the pressure and temperature in the inlet P_s, Ts and exhaust P_t, Tt manifolds at the studied regimes. Application of EGR led to a reduction of the engine air flow because of the decreasing pressure and increasing temperature T_s of the air in the inlet manifold. Also it should be noted that EG temperature T_t slightly increases before a turbine but in this case EG pressure significantly decreases from 5.7 to 17.5%. High efficiency of EGR heat exchanger (E) on all regimes and low EG recycle rate that significantly decreases with an increase of load should be noted. Analysis of the obtained data showed that maximum value of EGR rate is reached on all regimes at 25% load and is in the range 10 – 14 % since at this load P_t/P_s ratio has a

maximum value which, in turn, is a determining factor of   value in the EGR system design under study. The high degree of EGR on engine operating conditions at low loads will reduce the time it takes to warm up the coolant.

Table 1. Characteristics of the EGR system and a change of temperature and pressure in the inlet and exhaust manifolds on regimes of ESC cycle

| Load	Crankshaft speed	E	R	Ts	Ps	Pt	Tt
%	rpm	, %		, %			
25	1250	100,00	10,60	3,40	10,50	12,50	-3,90
	1500	99,20	10,00	2,10	12,10	14,30	-4,20
	1750	98,30	12,20	1,20	11,50	17,50	-3,60
50	1250	100,00	4,30	3,40	6,00	9,30	-4,00
	1500	99,40	6,80	1,80	8,00	12,00	-4,20
	1750	98,10	8,30	0,50	6,00	13,50	-2,40
75	1250	100,00	3,10	0,70	3,50	5,70	-3,40
	1500	99,30	5,10	1,50	5,40	10,30	-3,10
	1750	97,60	7,60	1,00	2,90	11,90	-0,60
100	1250	100,00	2,50	-1,10	2,50	5,20	-3,40
	1500	99,10	4,50	0,80	2,90	9,10	-2,00
	1750	97,10	7,10	2,70	0,00	10,40	0,50

Fig.3 shows the dependencies of   and P_t/P_s ratios related to the value of engine load at n = 1250, 1500 and 1750 rpm.

a   *b*
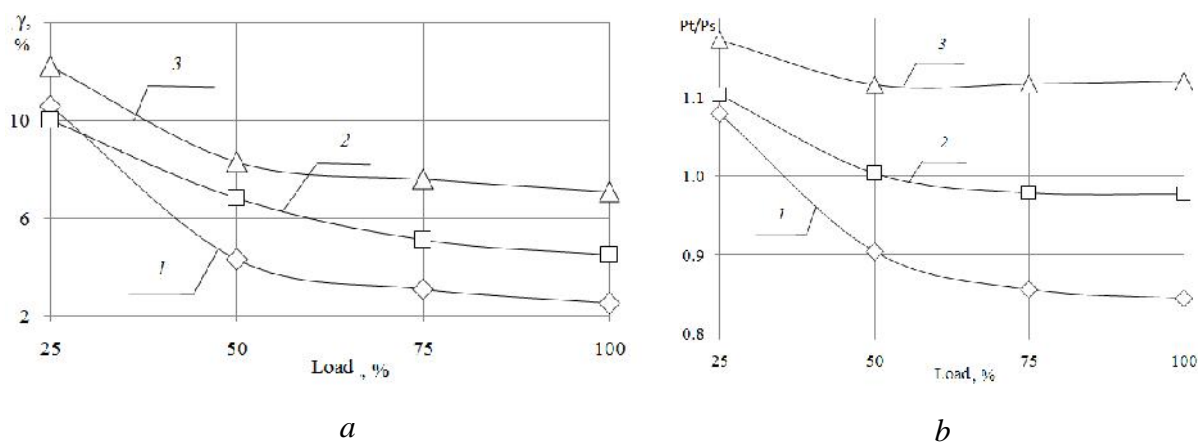
Fig. 3. Dependence of EGR rate and P_t/P_s ratio when engine operates on regimes of ESC

cycle:

1 – 1250 rpm[1]; 2 – 1500 rpm; 3 – 1750 rpm

Fig. 4 shows the influence results of EGR on specific effective flow rate of fuel g_e and engine air mass flow G_{air} coming from compressor stage of the turbocompressor according to the load characteristics at crankshaft speed 1250, 1500 and 1750 rpm. It should be noted that application of EGR led to a slight change in fuel economy at a load of 25 % at all studied crankshaft speeds and at $n = 1250$ rpm value of specific effective flow rate of fuel decreased by 1 %. Increase of load from 50 to 100% resulted in a decrease of the engine fuel efficiency at $n = 1250$ rpm from 1 to 2.7%, at $n = 1500$ rpm increase did not exceed 0.5% and at $n = 1750$ rpm decrease from 0.2 to 0.5% (fig. 5, *a*). Engine air mass flow reduced at decrease of load on all studied frequencies by 4 – 13% depending on the regime. The resulting dependence of G_{air} reduction versus load is caused by the increase of   value with a decrease of load that, in turn, influences on the turbocompressor working regime, pressure and temperature of the air in the inlet manifold (fig. 5, *b*)

a

b
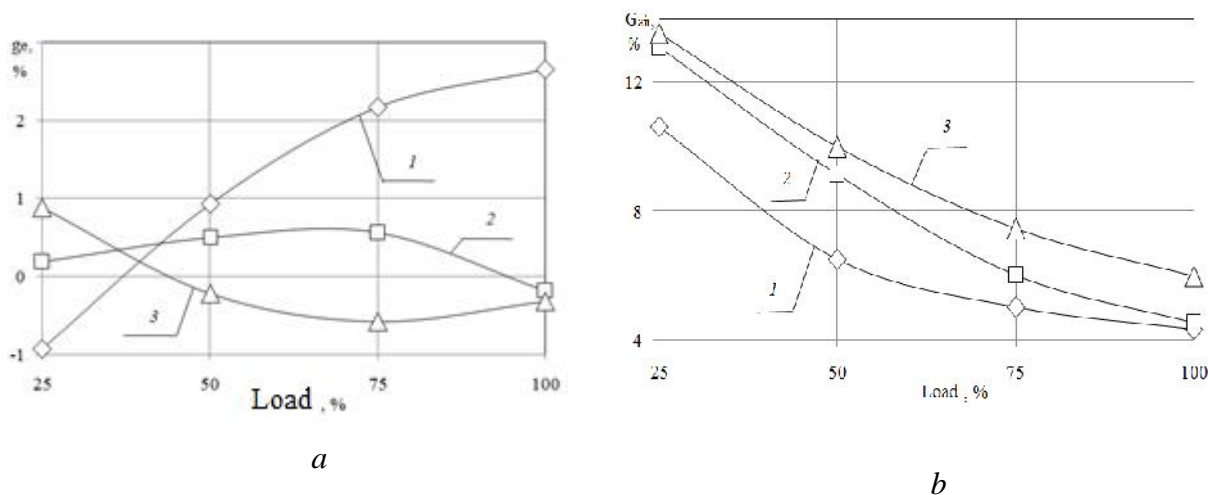
Fig. 4. Influence of EGR when operating on regimes of ESC cycle:

1 – 1250 rpm; 2 – 1500 rpm; 3 – 1750 rpm; Load, %

– specific effective fuel flow rate g_e; *b* – engine air flow *G*air coming from

turbocompressor.

Fig. 4 presents results of reducing NO_x concentration in EG when diesel engine operates with EGR system under load at crankshaft speeds *n* 1250; 1500 and 1750 rpm. It is seen from the analysis that the intensity of decreasing NO_x concentration in EG increases with higher crankshaft speed to a greater degree at medium and high loads.
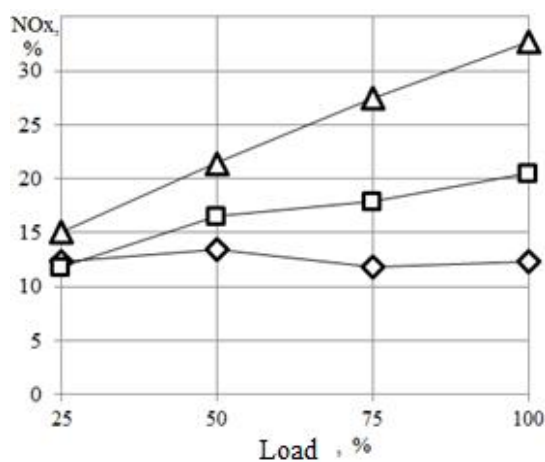

Fig. 5. Reduction of NOx concentration when applying EGR on the regimes:

1 – 1250 rpm; 2 – 1500 rpm; 3 – 1750 rpm.

The results obtained when engine was operating according to altitude-speed performances show that applying EGR leads to increase of g_e from 2 to 17 g/(kW·h) at a crankshaft speed in

the range 900 – 1700 rpm and to decrease from 1 to 3.5 g/(kW·h) with increasing crankshaft speed from 1700 to 1900 rpm (fig. 6, *a*). EGR influence on NO_x concentration in EG when engine operates according to altitude-speed performances is shown in fig. 6, *b*.

a

b
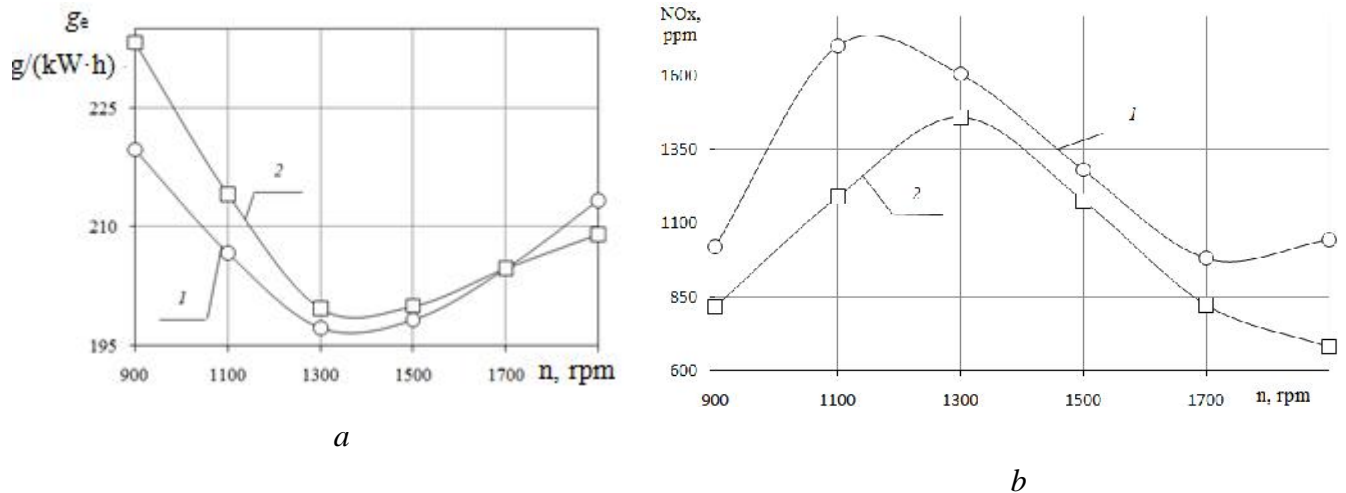
Fig.6. EGR influence when engine operates according to altitude-speed performances:

1 – without EGR system; 2 – with EGR system; n, rpm g_e, g/(kW·h)

a – specific effective fuel flow rate g_e; *b* – NO_x concentration in EG.

CONCLUSIONS

Analysis of the study results in general showed the presence of EGR influence on NO_x concentration in EG and fuel efficiency of high-uprated diesel engine. Application of EGR system allowed reducing the NO_x emissions by 10 – 35% on the studied regimes.

2. In order to improve effective and environmental performance of the studied diesel engine it is necessary to carry out further research in the following directions:

- adjustment of fuel-injection equipment (maximum pressure of fuel supply, number of stages, proportion of fuel in each portion, fuel supply angle and angular interval between stages);

- selection of turbocompressor (determination of optimal characteristics of compressor and turbine wheels) and methods for its adjustment.

3. Hydraulic cooling scheme of the engine and the heating of the vehicle cabin researched in this work will significantly reduce the time required to warm up the engine and cabin interior.

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