ДВИГАТЕЛИ И ЭНЕРГЕТИЧЕСКИЕ УСТАНОВКИ

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THE PECULIARITIES OF HEAT LOSSES SIMULATION OF AUTOMOTIVE GASOLINE ENGINE IN OPERATIONAL CONDITIONS

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Abstract. *The heat balance of gasoline engine is analyzed and the losses of received energy from fuel are simulated. It's based on the using the experimental diagram of engine operating cycle. The power balance of automotive engine for the appropriate modes of the moving vehicle is evaluated. The driving cycleis used in accordance with the UNECE Regulations № 83-05.*

Key words: *automotive gasoline engine, energy of fuel, heat losses, heat balance, driving cycle.*

ОСОБЕННОСТИ МОДЕЛИРОВАНИЯ ТЕПЛОВЫХ ПОТЕРЬ АВТОМОБИЛЬНОГО БЕНЗИНОВОГО ДВИГАТЕЛЯ В ЭКСПЛУАТАЦИОННЫХ РЕЖИМАХ

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Аннотация. *Проанализирован тепловой баланс бензинового двигателя и смоделированы потери внесенной с топливом энергии на основании экспериментальных индикаторных диаграмм рабочего цикла. Оценен баланс мощностей автомобильного двигателя в соответствующих режимах движения автомобиля в ездовом цикле согласно Правилам ЕЭК ООН № 83-05.*

Ключевые слова: *автомобильный бензиновый двигатель, энергия топлива, тепловые потери, тепловой баланс, ездовой цикл.*

ОСОБЛИВОСТІ МОДЕЛЮВАННЯ ТЕПЛОВИХ ВТРАТ АВТОМОБІЛЬНОГО БЕНЗИНОВОГО ДВИГУНА В ЕКСПЛУАТАЦІЙНИХ РЕЖИМАХ

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Анотація. *Проаналізовано тепловий баланс бензинового двигуна та змодельовані втрати внесеної з паливом енергії на основі експериментальних індикаторних діаграм робочого циклу. Оцінено баланс потужностей автомобільного двигуна у відповідних режимах руху автомобіля в їздовому циклі згідно з Правилами ЄЕК ООН № 83-05.*

Ключові слова: *автомобільний бензиновий двигун, енергія палива, теплові втрати, тепловий баланс, їздовий цикл.*

Introduction

The efficiency of the internal combustion engine (ICE) is largely determined by its ability to transform the energy of fuel for useful work. Analysis of designs of modern engines shows a steady development of these. It contributes for improvement the efficiency of fuel using and reduction of heat losses, in particular, reduction of mechanical losses; improvement the quality of the combustion process, utilization of exhaust gases energy. The quality of conversion the energy of fuel for useful work can be evaluated by determining the components of the heat balance, that describes the distribution of heat energy in the engine.

As is known, the energy of fuel distributes in the engine for the effective work, the mechanical losses and the heat losses, such as losses of exhaust gases energy, losses in the lubrication and cooling systems and losses because of incomplete combustion. Thus, the heat balance already has been formed definitely on quality.

Therefore, for improvement the efficiency of using the fuel energy, at the present stage of ICE development the utilization of the heat emitting into the environment is actual. However, without quantitative evaluation of heat balance components for different operating modes of the automotive engine, it's impossible to develop the general concept and the constructive implementation of ICE heat utilization system.

Analysis of the Publications

Qualitative and quantitative analysis of ICE heat balance components is closely linked with researches of engine operating cycle. Fundamental researches in this area are the scientific works on the analysis of the peculiarirties and the simulation of engine operating cycle written by famous scientists, such as V.I. Hrynevetskyi [1], G.R. Rikardo [2], M.M. Hlaholiev [3], the works on the simulation of the combustion process written by I.I. Vibe [4] and the works on the simulation the processes of heat transfer from the working body to the cylinder walls written by G. Woschni [5].

Recent researches of engine operating cycle made at the National Transport University, are devoted to the questions of the mathematical description of ICE heat release and the development of the combustion process algorithm calculating [6], the simulation the engine mechanical losses components [7] and the determination the effect of exhaust gases recirculation for the engine performance [8]. The issue of utilization the heat energy of the automotive engine exhaust gases is described in the works of V.G. Kuz [9]. However, in the mentioned works, the problems of quantitative evaluation of heat balance components of automotive ICE for the appropriate operating modes of vehicle movement have not been shown, but that is required for effective utilization of engine heat energy.

The Purpose and the Task

The purpose and the task of this work is development the methods of simulation and quantitative evaluation the heat losses of the automotive gasoline engine for the appropriate operating modes of vehicle movement.

General Method of the Study

The basis of method the heat losses simulation for the operating modes of automotive ICE is represented the mathematical model of engine operating cycle [10]. When the specific engine operating modes are being determined for the quantitative evaluation the heat balance components, it was assumed that the real set of these modes mainly corresponds to vehicle driving cycle standardized.

Quantitative evaluation of heat balance components for the particular engine mode was being carried out on basis of the appropriate experimental diagram of the engine operating cycle. The determination of engine operating cycle indicators had been carried out previously for this diagram with using the specialized calculation software [11]. These resulting values of the heat balance components have been described by the appropriate polynomial equations for the full set of engine operating modes. On the basis of these equations the quantitative evaluation of heat losses for the automotive gasoline engine has been carried out for the appropriate operating modes of moving vehicle.

The Object of Study

The object of study is Volkswagen BBY automotive gasoline engine installed on Scoda Fabia vehicle. The technical characteristics of the engine, vehicle and the parameters required for the simulation are shown in tabl. 1 and 2.

Table 1 Technical parameters of VW BBY engine

Parameter name	Value
Engine power, kW	55
Engine displacement, cm^3	1390
Number of cylinders	4
Number of valves	16
Diametr of cylinder, mm	76,5
Stroke, mm	75,6
Compression ratio	10,5

Table 2 Technical parameters of Scoda Fabia vehicle

Parameter name	Value
Vehicle weight (with driver), kg	1100
Vehicle front area, m^2	1,9
Coefficient of aerodynamic drag	0,31
Dynamic wheel radius, m	0,265
1st gear ratio	3,455
2nd gear ratio	2,095
3rd gear ratio	1,387
4th gear ratio	1,026
5th gear ratio	0,813
Main gear ratio	3,882
Transmission efficiency	0,9

The Simulation of Engine Heat Balance Components

For the purpose of quantitative evaluation the engine heat balance components for engine particular modes the experimental researches data of VW BBY engine have been used. These experimental researches have been made at the Department of engines and heating engineering of the National transport University [6, 8]. In the process of experimental researches the set of engine load characteristics for all its speed modes have been defined. It has been made with the registration of operating pressure signal and ignition moment for the fourth engine cylinder. For further analysis in each engine mode the representative diagram of engine operating cycle is identified.

On the basis of these data and software for calculation of engine operating cycle indicators and heat release characteristics [11] and mathematical model of engine operating cycle [10] the energy of fuel and the heat balance components for particular engine modes have been defined. In particular, it is the equivalent heat for effective work q_e, work of mechanical losses q_m, heat transfer from the working body to the cylinder walls q_{cs}, exhaust gases energy q_{eg} and incomplete combustion of the fuel energy q_{ic}.

As a result the analysis of quantitative values of the heat balance components of the engine for all its possible modes (fig. 1) the polynomial equations for heat balance components have been obtained as dependent on the engine speed n and the engine load M for:

– the effective work:

$$q_e = -27,8718 + 0,05746 \cdot n - 4,3178 \cdot 10^{-5} \cdot n^2 + 1,6345 \cdot 10^{-8} \cdot n^3 - 3,13904 \cdot 10^{-12} \cdot n^4 + 2,4142 \cdot 10^{-16} \cdot n^5 + 1,18409 \cdot M - 0,02825 \cdot M^2 + 4,27942 \cdot 10^{-4} \cdot M^3 - 3,39818 \cdot 10^{-6} \cdot M^4 + 1,03368 \cdot 10^{-8} \cdot M^5; \qquad (1)$$

– the mechanical losses:

$$q_m = -15,23938 + 0,00161 \cdot n + 9,65899 \cdot 10^{-5} \cdot n^2 - 8,05102 \cdot 10^{-8} \cdot n^3 + 2,39565 \cdot 10^{-11} \cdot n^4 - 2,43407 \cdot 10^{-15} \cdot n^5 - 1,43118 \cdot M + 0,03808 \cdot M^2 - 5,51367 \cdot 10^{-4} \cdot M^3 + 4,04622 \cdot 10^{-6} \cdot M^4 - 1,18422 \cdot 10^{-8} \cdot M^5; \qquad (2)$$

– the losses in the cooling system:

$$q_{cs} = 122,27437 + 0,02021 \cdot n - 2,16929 \cdot 10^{-4} \cdot n^2 + 1,71029 \cdot 10^{-7} \cdot n^3 - 4,98689 \cdot 10^{-11} \cdot n^4 + 5,02 \cdot 10^{-15} \cdot n^5 + 1,02058 \cdot M - 0,03716 \cdot M^2 + 5,19415 \cdot 10^{-4} \cdot M^3 - 3,37921 \cdot 10^{-6} \cdot M^4 + 8,50064 \cdot 10^{-9} \cdot M^5; \qquad (3)$$

– the losses of exhaust gases energy:

$$q_{eg} = -72,70822 + 0,14927 \cdot n - 5,25776 \cdot 10^{-5} \cdot n^2 - 9,2387 \cdot 10^{-9} \cdot n^3 + 7,92783 \cdot 10^{-12} \cdot n^4 - 1,0706 \cdot 10^{-15} \cdot n^5 - 0,55685 \cdot M + 0,01656 \cdot M^2 - 1,76314 \cdot 10^{-4} \cdot M^3 + 8,01525 \cdot 10^{-7} \cdot M^4 - 1,11471 \cdot 10^{-9} \cdot M^5; \qquad (4)$$

Analysis of the obtained data (Fig. 1) shows that when the engine load increases the percentage of heat lost to the exhaust system increases too, but the percentage of heat lost to the cooling system decreases.

It is explained that the cylinder charge is reduced for the low engine load and consequently the exhaust gas mass is reduced too, that as a result reduces the quantity of heat exhaust gases. In addition, when the engine speed is $n = 2400$ min^{-1} and $n = 3100$ min^{-1} and the engine load is reduced, the total percentage of the heat equivalent for the effective work and mechanical losses is reduced too, that additionally results to the increase of losses in the cooling system. If engine speed is $n = 3800$ min^{-1} this peculiarity is not observed.

Comparison the experimental values of heat balance components (fig. 1, a, c, e) and its values described by polynomial equations (1–4) (fig. 1, b, d, f) indicates the sufficient accuracy degree of this performances simulated.

The adequacy of results of heat balance simulating for particular engine modes is also confirmed by the comparison with results obtained in other studies [12, 13].

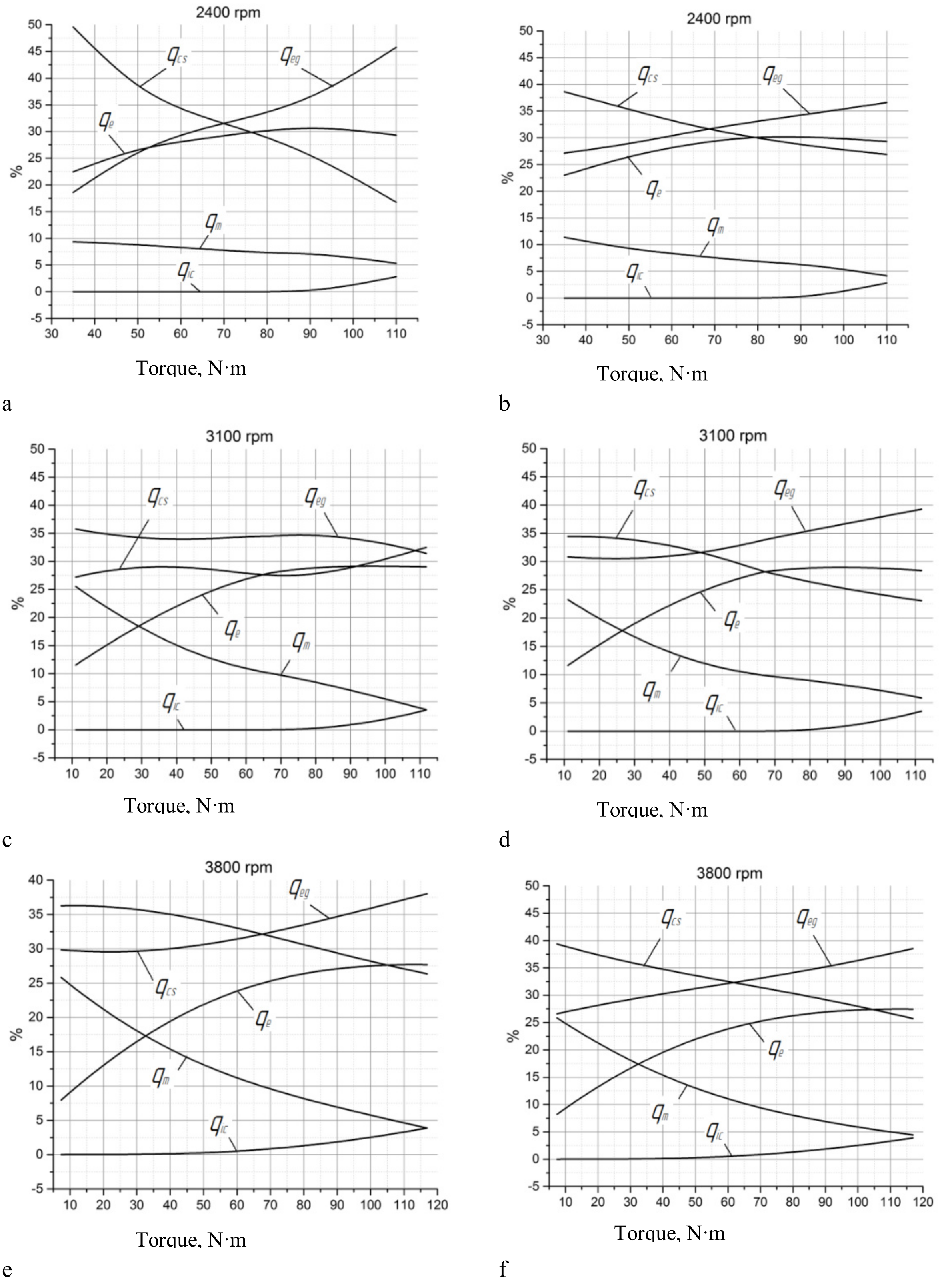


Fig. 1. Relative values of the heat balance components for VW BBY engine: a, c, e – experimental; b, d, f – polynomial

The Simulation of Distribution Engine Heat Energy for Driving Cycle of Vehicle

For determine the possible efficiency of utilization the engine heat energy, it is necessary to estimate the quantity of heat for the basic moving modes of the vehicle. For simulating of the basic moving modes of Scoda Fabia vehicle with VW BBY engine the driving cycle according to UN ECE Regulations No. 83-05 has been selected. It contains the four consecutive sectors of urban cycle and the extra-urban cycle (fig. 2).

For each elementary section of the driving cycle the parameters of the automotive engine mode have been defined, which depends on the vehicle speed, selected gear and the external resistance forces for vehicle movement.

The results showed (fig. 2) that the average efficiency of the engine reaches only 19,65 % and the heat losses in the cooling system dominate and reach the value 41,03 %, when the vehicle is moving in the urban cycle. When the vehicle is moving in the extra-urban cycle, the average heat losses of exhaust gases are increased and reach the values of losses in the cooling system – 30,49 %. Thus, when the vehicle is moving in the extra-urban cycle, the significant percentage of the heat losses falls on the heat of exhaust gases, which increases the possibility of utilization the engine heat losses.

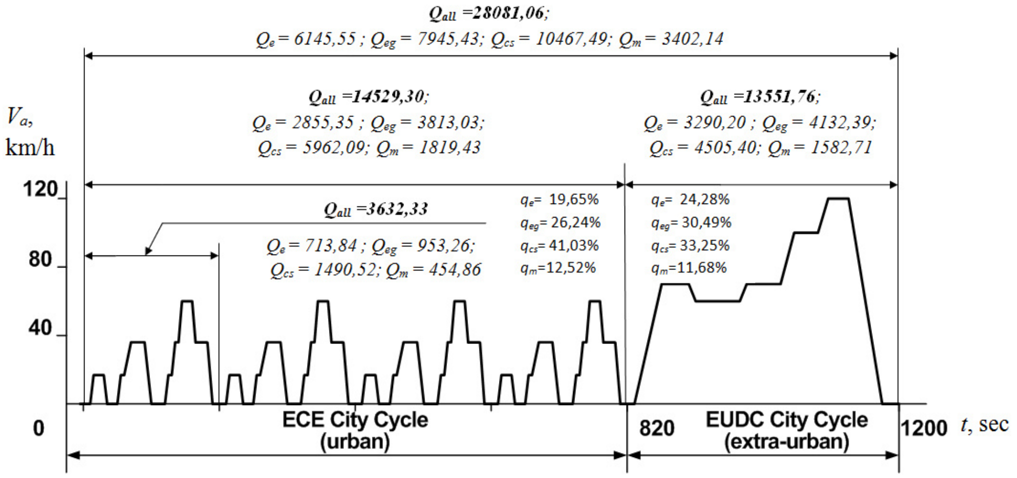
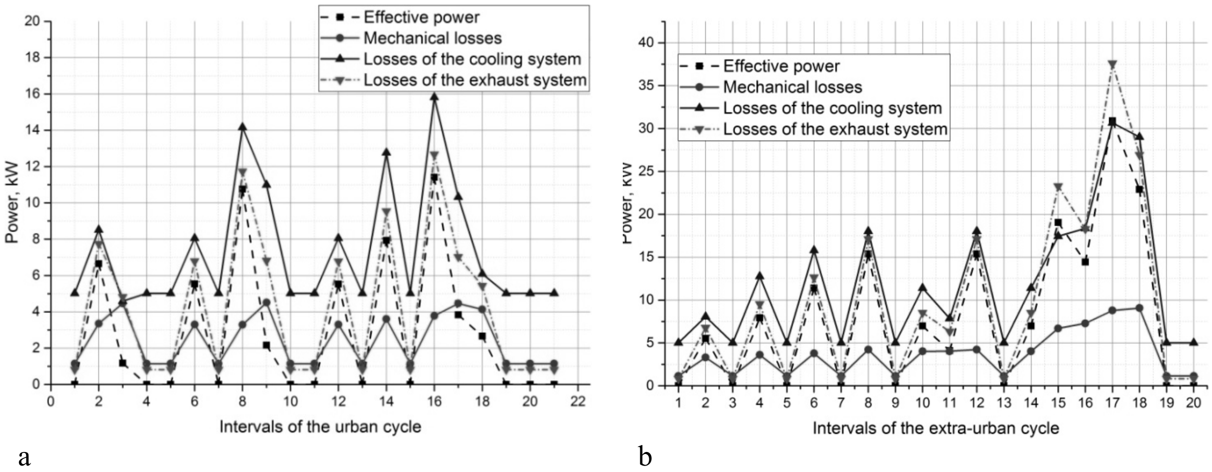


Fig. 2. The equivalent heat energy Q (kJ) of engine and its distribution by component for vehicle moving in the driving cycle according to UN ECE Regulations No. 83-05

Definition of the engine power balance for the vehicle moving in the appropriate driving cycle modes allows to evaluate the feasibility of heat losses utilization. At the fig. 3 the power balance components of the automotive engine are presented for the vehicle modes in the driving cycle, which are identified for appropriate speed and acceleration of the vehicle for these modes.

As the presented results show, for vehicle modes in the urban cycle (fig. 3, a) the power of losses in the cooling system has got the highest values. Herewith, for vehicle modes in the extra-urban cycle (fig. 3, b) the power of losses in the exhaust gases approaches or exceeds the power of losses in the cooling system.



a b

Fig. 3. Power balance components of the automotive engine for the elementary sections of the driving cycle of the vehicle: a – urban cycle; b – extra-urban cycle

The average values of the power balance components of the automotive engine for the vehicle modes in the urban and extra-urban driving cycle are shown at fig. 4.

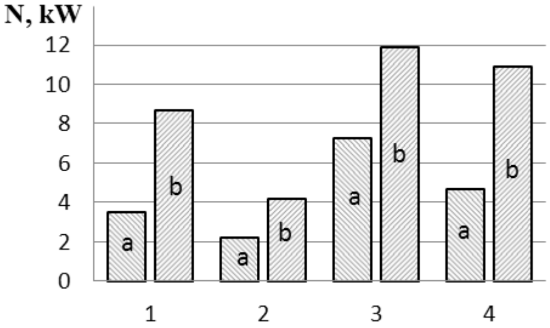


Fig. 4. The average values of the power balance components of the automotive engine for the vehicle modes in the driving cycle: a - urban cycle; b – extra-urban cycle; 1 – effective power; 2 – power of mechanical losses; 3 – power of losses in the cooling system; 4 – power of losses in the exhaust system

The figure shows that the average values of the power of heat losses in the cooling system and exhaust system reach respectively in urban cycle 7,27 and 4,65 kW and in extra-urban cycle 11,86 and 10,87 kW. Herewith, the total values of these heat losses constitute in the urban cycle 67,6 % of the total energy of fuel and in the extra-urban cycle 64 % of its. This indicates that the efficiency of fuel energy usage improves in the extra-urban driving cycle of the vehicle. The obtained values for the power of heat losses constitute the quantity of potential heat energy that can be used in the implementation of the particular method of automotive engine heat utilization. At this ratio of the effective power and power of heat losses, its utilization even on 5-10% can give a significant effect for improvement of fuel economy and environmental performances of the automotive engine.

Conclusions

The method of the heat losses simulation of automotive gasoline engine is developed for the appropriate operating modes vehicle on the basis of the experimental performances of engine operating cycle and total performances of the engine with usage the software for calculation of engine operating cycle indicators and heat release characteristics and mathematical model of engine operating cycle. It allowed to obtain the polynomial equations for the heat balance components of engine which depend on engine speed and engine load.

Using the developed method the effective work and heat losses and engine power balance have been evaluated for the appropriate vehicle modes in the driving cycle according to UN ECE Regulations No. 83-05.

The evaluation found that the efficiency of fuel energy usage improves in the extra-urban driving cycle of the vehicle and herewith, the absolute values the power of heat losses significantly increase, that, in its turn, increases the potential possibility of heat energy utilization, as well as the possible effect of improvement of fuel economy and environmental performances of the automotive engine.

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