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3.8 EVALUATION OF FUEL CONSUMPTION AND HARMFUL SUBSTANCES EMISSIONS BY VEHICLE WITH SPARK IGNITION ENGINE UNDER OPERATION CONDITIONS WITH USING OF FUEL CONTAINING ETHANOL

Mykola Tsiuman

The most prevalent energy source for motor transport, especially for vehicles of M1 and N1 categories, are spark ignition engines. The main part of them is still the liquid fuel engines. In the last years a problem of finding alternative fuels or raw for the fuels production is very actual. This has a goal to replace gradually conventional oil origin fuels with alternative fuels. For natural, climatic and economic conditions of Ukraine plant or animal biological origin components are the most perspective as raw for the alternative fuels production. On legislative level a stimulation strategy of 20 % conventional fuels replacing with the biological components till 2020 has been determined by the Law of Ukraine «About alternative kinds of fuel». In case of conventional petrol it is using of mixtures the petrol and a dehydrated ethanol (bioethanol). Thus, today as a result of using the stimulation strategy (first of all, economic stimulation) some part of fuels for spark ignition engines is the fuels containing ethanol to 30 %.

As known, main vehicle operation performance is the vehicle environmental safety performance. This performance is determined by vehicular engine fuel consumption and harmful emissions. Opportunity evaluation issues of using fuels containing ethanol for spark ignition engines and improvement vehicle performance when using the fuels containing ethanol were studied in works of many scientists [1–4]. In there searches influenced termination issues of additionless than 20 % bioethanol toconventional fuel on carbure torengines fuel economy and environmental performance and improvement methods of this performance were studied. Also a fuel economy and environmental performance of sparkignition engine equipped fuel injection and exhaust gases cleaning systems, using a fuel containing ethanol to 20 % were studied in the researches. However, with advent on the market fuels containing ethanol to 30 % issue of evaluation environmental safety of spark ignition engine and vehicle equipped with the engine powered by fuel with high ethanol content is got actual.

Previously carried out laboratory experimental researches of fuel economy and environmental performance of sparkignition engine equipped a fuel injection and exhaust gases cleaning system susing a fuel containing ethanol more than 20 % have showed that using the fuel containing 25 % ethanol by mass leads to increasing the absolute fuel consumption on 10.8–10.9 % and to decreasing of efficiency nitrogenoxides cleaning [5]. Here with, the engine power performance and efficiency of use the fuel containing ethanol in a energy equivalent seal most sameas the engine performance when using apetrol. Using the research results polynomial dependencies of engine exhaust gases harmful substances concentrations had been got according to the engine speed and load mode, fuel type and air-fuel mixture content, which is going to engine cylinders. The obtained dependencies are a basic of carrying out further evaluation of fuel consumption and harmful emissions from vehicle equipped with spark ignition engine under operating conditions using the fuel containing ethanol.

At the same time, besides solving of issue of engine and vehicle performance evaluation when using the fuel containing ethanol a choosing of the evaluation method needs a special attention. Issues of studying motor vehicles influence on environment and methods of improvement the vehicles environmental performance, development of research and prognostication methods for vehicle environmental performance, and also development of environmental monitoring systems for transport were studied in works of many scientists, suchas Gutarevych Yu.F., Lukanin V.N., Trofimenko Yu.V., Kanylo P.M. [1, 6, 7] and others.

In previously published works with co-authors [8, 9] peculiarities of formation separate elements of intelligent monitoring system for vehicles environmental safety performance, sucha functioning of vehicle on-board system for obtaining the vehicle motion parameters, and also issues of improvement and using of vehicle motion mathematical model for evaluation the vehicle fuel consumption and harmful emissions in a driving cycle taking into account the engine and catalytic converter heating processes have been presented. Using of the vehicle motion mathematical modelwith taking into account the vehicle motion parameters in a real route conditions will enable to solve of actual practical task of influence evaluation of using a fuel containing ethanol on vehicle fuel consumption and harmful emissions under operation conditions.

The purpose of the study is an evaluation of vehicle fuel consumption and harmful emissions with a spark ignition engine equipped a fuel injection and exhaust gases cleaning systems, using a fuel containing ethanol more than 20 %. It is based on the vehicle motion parameters under real route conditions.

The object of evaluation of fuel consumption and harmful emissions when using a fuel containing ethanol under operating conditions isBOGDAN 21101 1.6L equipped with engine VAZ-21114. The Table 1 contains main technical parameters of the vehicle.

Table 1

Technical parameters of BOGDAN 21101 1.6L with engine VAZ-21114

Title	Specification
1	*2*
Weight of the vehicle with a driver and a passenger, kg	1200
Maximum speed, km/h	180
Fuel type	petrol
Number / arrangement of engine cylinders	4 / inline
Engine displacement, l	1.596
Diameter of cylinder / piston stroke, mm	82 / 75.6
Compression ratio	9.8
Engine power, kW/ crankshaft rotation speed, min^{-1}	59 / 5200

Table 1 continue

1	2
Torque, N·m/ crankshaft rotation speed, min^{-1}	120 / 2700
Number of inlet / exhaust valves per cylinder	1 / 1
Exhaust gases cleaning system	three-component catalytic converter
Gearbox ratios	3.636 1.950 1.357 0.941 0.784
Final drive ratio	3.706
Transmission efficiency coefficient	0.941
Wheel rolling radius, m	0.282
Aerodynamic resistance coefficient	0.34
Area of the vehicle frontal section, m^2	1.931

Source: based on manufacturing plant data.

As researched fuels the conventional petroland fuel containing 25 % ethanol (FCEE25) by mass had been used.Physical and chemical characteristics of used fuels are presentedin Table 2.

Table 2

Characteristics of used fuels

Characteristic title	Specifications	
Fuel type	petrol	FCE
Ethanol content by mass in fuel, %	0	25
The heat of fuel combustion, MJ/kg	43.7	39.7
Fuel density for 20 °C, kg/l	0.7325	0.754
Need of air for full fuel combustion, kg/kg	14.82	13.36
Carbon content in fuel, kg C/kg	0.855	0.772
Hydrogen content in fuel, kg H/kg	0.145	0.141
Oxygen content in fuel, kg O/kg	0	0.087
Molar mass, g/mole	115	98

Source: based on fuels laboratory research and reference data

For carrying out of experimental part of the study the on-board system for obtaining vehicle motion parameters is used. The on-board system basedona information device, which connected to On-Board Diagnostic (OBD) connector using a wireless adapter (Fig. 1).For determination of current vehicle location and further obtaining current values of longitudinal road inclination angle, the Global Positioning System (GPS) was used.

At measuring of the vehicle motion parameters using the on-board system for data obtaining the following parameters are determined: coolant temperature t_{COOL}, throttle position φ_{thr}, engine crankshaft rotation speed n_e, ignition timing angle θ, vehicle speed V_a, oxygen sensor voltage and status, fuel injection time, mass air consumption, diagnostic trouble codes, vehicle geographic location coordinates.

Based on the obtained parameters with using the vehicle motion mathematical model the following parameters are determined: vehicle passed way S, fuel consumption persecond g_{FUEL}, total fuel consumption $_{FUEL\_\Sigma}$, catalytic converter efficiency according to excess air coefficient λ

and catalytic converter temperature t_{CAT}, carbon monoxide emission persecond g_{CO}, total carbon monoxide emission g_{CO_Σ}, hydrocarbons emission persecond g_{CmHn}, total hydrocarbons emission g_{CmHn_Σ}, nitrogen oxides emission persecond g_{NOx}, total nitrogen oxides emission g_{NOx_Σ}.

(*a*) (*b*)

Fig. 1. On-board system elements for data obtaining in vehicle motion: (*a*) informationdevice; (*b*) adapter with connector for OBD connection
Source: developed by author

A calculating unit of the mathematical model determines engine operating cycle parameters, air and fuel consumption, harmful substances concentrations in exhaust gases and exhaust gases cleaning efficiency according to necessary value of engine torque during the vehicle motion, which depend on excess air coefficient, ignition timing angle, inlet and exhaust systems characteristics, fuel type, number, bore size and capacity of engine cylinders, engine compression ratio and other parameters. The calculating unit is based on the volume balance method suggested by Professor M. Glagolyev and modified in scientific works of V. Dyachenko [10], M. Shokotov and others, principles of the theory of mechanisms and machines.

Determinations of harmful substances emissions persecond and total emissions are based on current engine fuel and air consumption during vehicle motion, exhaust gases harmful substances concentrations and exhaust gases cleaning efficiency.

The carbon monoxide concentration (C_{CO}, %) is described by the equation:

$$C_{CO} = \begin{pmatrix} 6.999 \cdot 10^{-4} \cdot n_e \cdot \eta_v + 1.281 \cdot \eta_v^{\,2} - 2.504 \cdot \eta_v + \\ + 2.542 - 1.378 \cdot 10^{-3} \cdot n_e + 2.474 \cdot 10^{-7} \cdot n_e^{\,2} \end{pmatrix} \cdot (21 - 20 \cdot \lambda) \cdot k_{fuel}^{CO} \quad (1)$$

,

where η_v is cylinder volume efficiency coefficient; k_{fuel}^{CO} is fuel type influence coefficient on *CO* concentration.

The hydrocarbons concentration (C_{CmHn}, ppm) is described by the equation:

$$C_{CmHn} = \begin{pmatrix} 0.036 \cdot n_e \cdot \eta_v + 423.4 \cdot \eta_v^{\,2} - 442.4 \cdot \eta_v + \\ + 270.66 - 0.047 \cdot n_e + 7.371 \cdot 10^{-6} \cdot n_e^{\,2} \end{pmatrix} \cdot (5 - 4 \cdot \lambda) \cdot k_{fuel}^{CmHn} \quad (2)$$

,

where k_{fuel}^{CmHn} is fuel type influence coefficient on C_mH_n concentration.

The nitrogen oxides concentration (C_{NOx}, ppm) is described by the equation:

$$C_{NOx} = \begin{pmatrix} 0.373 \cdot n_e \cdot \eta_v - 9271 \cdot \eta_v^{\,2} + 9208 \cdot \eta_v - \\ -1685 + 0.238 \cdot n_e + 5.543 \cdot 10^{-5} \cdot n_e^{\,2} \end{pmatrix} \cdot \left(3.85 \cdot \lambda - 2.85\right) \cdot k_{fuel}^{NOx}, \qquad (3)$$

where k_{fuel}^{NOx} is fuel type influence coefficient on NO_x concentration.

The exhaust gases harmful substances concentrations have been determined using results of carried out laboratory experimental researches of the engine.

Exhaust gases cleaning efficiency depends on a catalytic converter temperature state, an air-fuel mixture content, which is going to engine cylinders during an inletprocess, the degree of catalytic converter active coataging. The peculiarities of the exhaust gases cleaning efficiency determination were described in detailin [6, 9].

Experimental part of the study contained the obtaining and further processing the following data: the vehicle motion parameters, the engine modes and control parameters, the temperature state of the engine and the catalytic converter, the fuel and air consumption, the harmful emissions during the vehicle motion in Kyiv centre using the conventional petrol and fuel containing ethanol. The routes scheme, obtained with GPS technology, is show in Fig. 2. Both routes coincideal most for 80 %, but have some different parts.

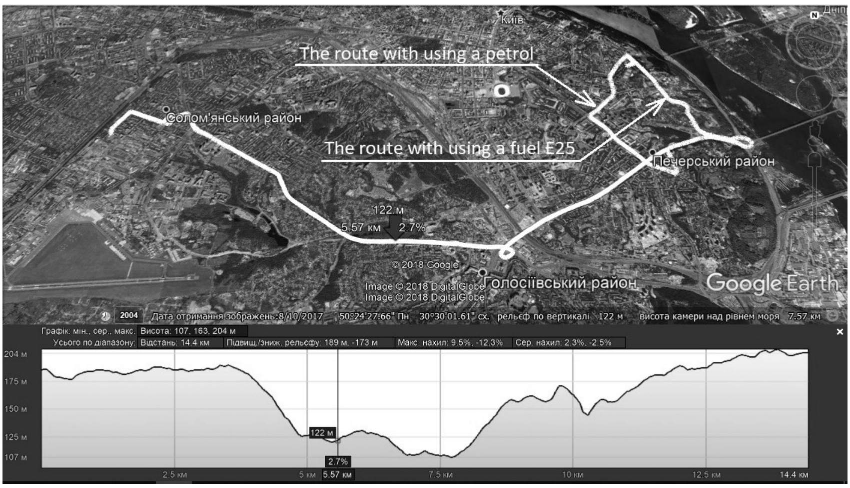

Fig. 2. The vehicle routes during using the studied fuels
Source: developed by author

The experimental studies were carried out inreal traffic conditions the sameas daily operation. Anambient temperature during the vehicle motion is 19 °C when using the petrol and 15 °C using the fuel E25.

Using the obtained current vehicle location coordinates and Google Earthe levation tool the vehicle routes characteristics by the value of longitudinal road in clination angle α for studied fuels had been obtained (Fig. 3). The obtained routes characteristics are used for vehicle fuel consumption and harmful emissions prognostication in different road conditions.

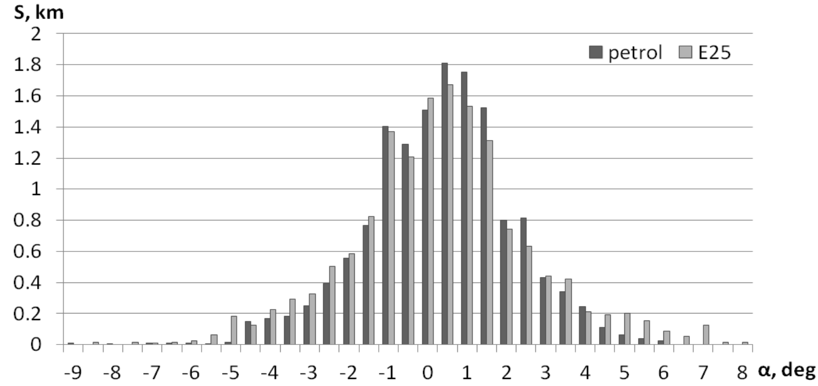

Fig. 3. The routes characteristics by the value of longitudinal road in clination angle
Source: developed by author

Based on the vehicle OBD data, the current vehicle speed, passed way and motion time have been determined for both fuels. As it shown on presented dependencies (Fig. 4), the vehicle speed mode is the almost same for both fuels. But, when FCE E25 is used, areas with speed lowered to 10 km/h have a place. This is traffic conditions influence, which is characterized by a traffic flow density and intensity. This is external random factors, which leads to increasing the total motion time from 1635 s when using the conventional petrol to 1863 s when using the E25 fuel. The total vehicle passedway is 14.705 km with using the petrol and 15.197 km with using the E25 fuel.

Asitshown at the vehicle motion time *τ*and passedway *S*partition by engine modes (Fig. 5), the engine has a more big time for partial load and idling modes when using the E25 fuel than when using the petrol. But, engine operation in for ceidling mode with out fuel supply when using the petrol has a more big time than when using the E25 fuel. Here with, the vehicle passed way with using both fuels is almost same for partial load mode. But, the vehicle passed way with using the E25 fuel is bigger for idling mode. Correlations of passed way and motion time for different engine modes enable to determine an average motion speed for the modes when using the petrol and E25 fuel. They are 41.4 km/hand 37.8 km/h for partial load, 55.8 km/h and 62.5 km/h for forceidling mode, 17.8 km/h and 17.5 km/h for idling mode. Thus, the average vehicle speed modes for different engine modes when using different fuels are also similar.

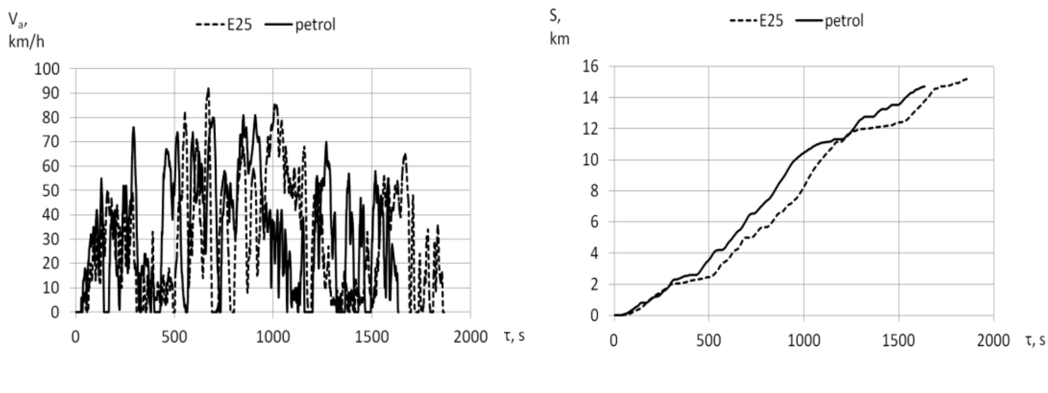

Fig. 4. Dependencies of the current vehicle speed V_a and passed way S from motion time when using the studied fuels
Source: developed by author

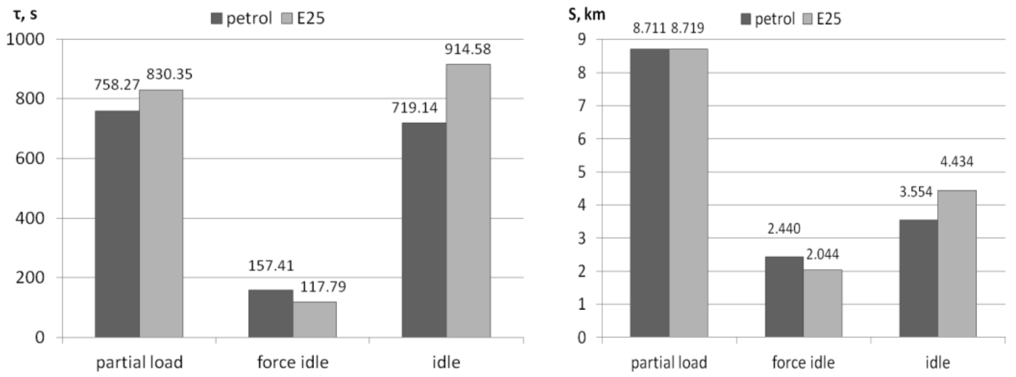

Fig. 5. The vehicle motion time *τ*and passed way *S*partition by engine modes when using the studied fuels
Source: developed by author

Dependencies of coolant t_{COOL} and catalytic converter t_{CAT} temperatures from the vehicle motion time when using the studied fuels are shown on Fig. 6. The dependencies show, that heating time of coolant to the operating temperature of 90 °C is 350 s when using the petrol and 435 s when using the E25 fuel. The heating time of catalytic converter to the temperature of exhaust gases effective cleaning is 132 s when using the petrol and 301 s when using the E25 fuel.

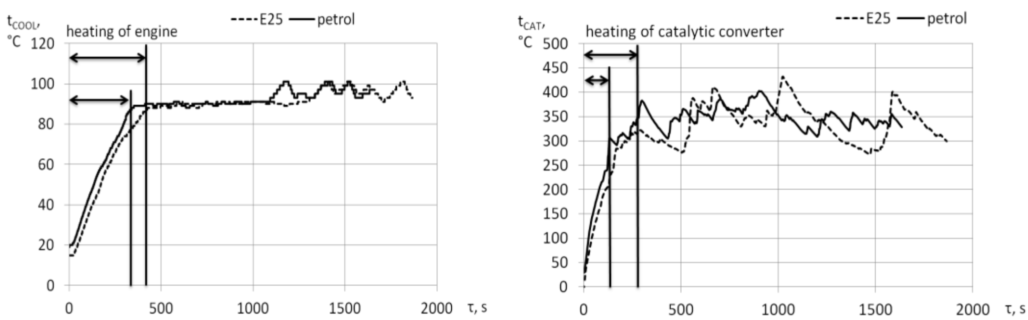

Fig. 6. Dependencies of coolant t_{COOL} and catalytic converter t_{CAT} temperatures from the vehicle motion time when using the studied fuels
Source: developed by author

The different time of operating temperatures achieving for coolant and catalytic converter when using the different fuels has been caused by common influence of anambient temperature and speed and load engine modes (Fig. 7). Fig. 7 shows, that engines modes have been shifted to higher values of crankshaft rotation speed n_e and throttle position φ_{thr} when using conventional petrol comparatively with using the E25 fuel.

Dependencies of total fuel consumption g_{FUEL_Σ} on the vehicle motion time and their partition by the engine modes when using studied fuels are shown on Fig. 8. As it shown on Fig. 8, the total fuel consumption per route is 891 g when using the petrol and 1098 g when using the E25 fuel. Thus, the total fuel consumption of E25 is on 23.2 % more than total petrol consumption. Herewith, the E25 fuel consumption is more than petrol consumption on 20 % for engine partial load mode and on 33.5 % for engine idling mode. This difference is caused by much bigger vehicle motion time for these engine modes when using the E25 fuel.

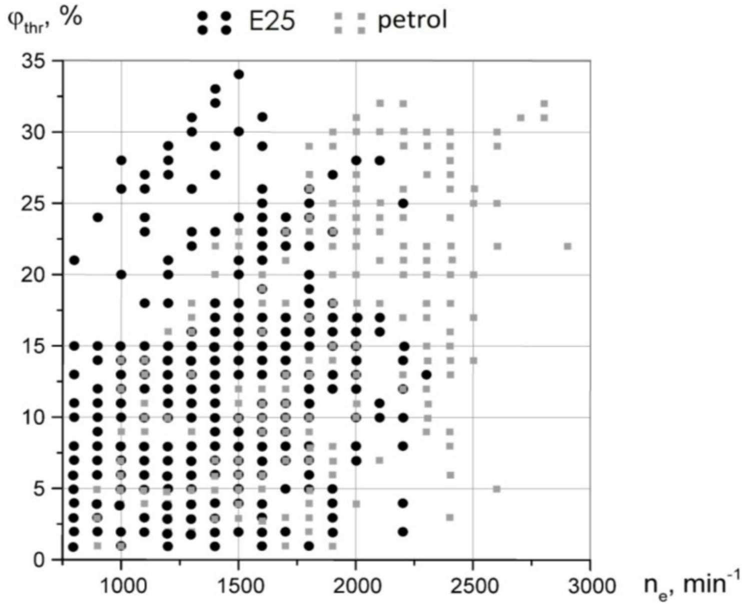

Fig. 7. Partition of the engine speed and load modes during the coolant and catalytic converter heating
Source: developed by author

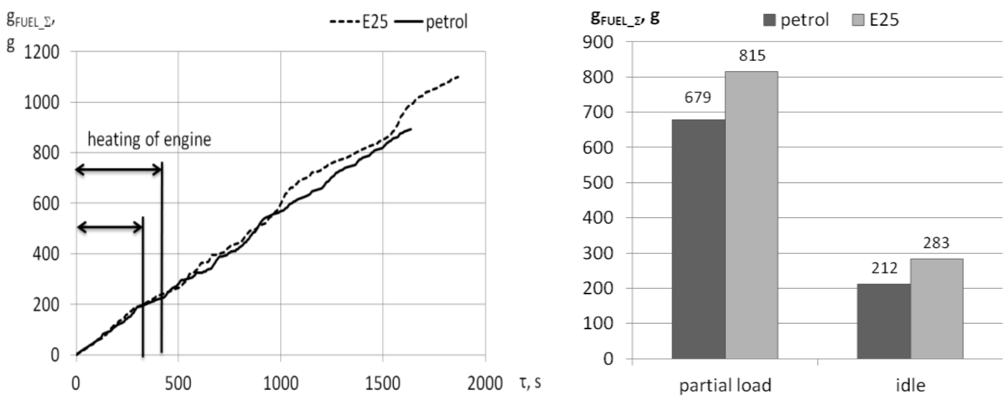

Fig. 8. Dependencies of total fuel consumption on the vehicle motion time and their partition by the engine modes when using studied fuels
Source: developed by author

Dependencies of total carbon monoxide emission g_{CO_Σ} on the vehicle motion time and their partition by the engine modes when using studied fuels are show non Fig. 9. As it shown on Fig. 9, the total carbon monoxide emission per route is 38.864 g when using the petrol and 63.935 g when using the E25 fuel. Thus, the total carbon monoxide emission when using the E25 fuel is on 64.5 % more than when using the petrol. Herewith, the carbon monoxide emission when using the E25 fuel is more than when using the petrol on 85.1 % for engine partial load mode and on 6.2 % for engine idling mode. This difference is caused by much bigger catalytic converter heating time to the temperature of exhaust gases effective cleaning when using the E25 fuel. This factor influences significantly on the total value of carbon monoxide emission and other harmful substances. It has a place because emission of carbon monoxide, which is emitted for catalytic converter heating period, is near 14 g or 36 % from his total emission when using the petrol and 32 g or 50.1 % from his total emission when using the E25 fuel. Relative increasing of the carbon monoxide emission for catalytic converter heating period is 128 % when using the E25 fuel comparatively with when using the petrol. Thus, the much higher value of carbon monoxide emission when using the E25 fuel is caused by the catalytic converter heating duration, which is influence result of engine modes during heating.

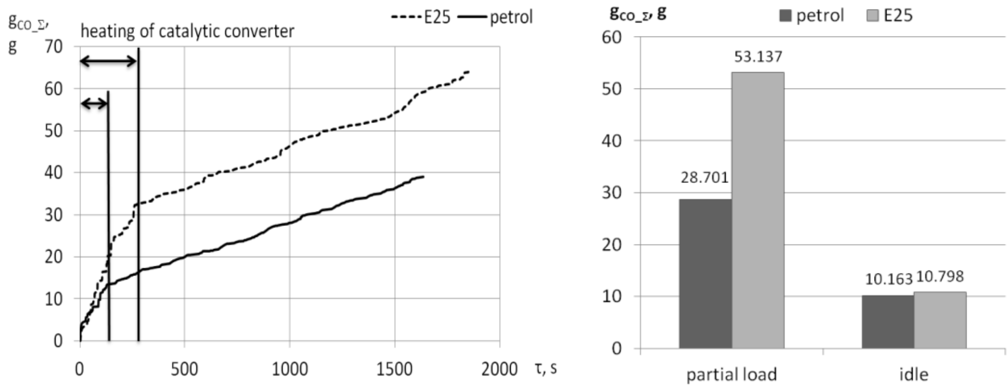

Fig. 9. Dependencies of total carbon monoxide emission on the vehicle motion time and their partition by the engine modes when using studied fuels
Source: developed by author

Dependencies of total hydrocarbons emission g_{CmHn_Σ} on the vehicle motion time and their partition by the engine modes when using studied fuels are show nonFig. 10. As it shown on Fig. 10, the totalhydrocarbons emission per route is 1.161 g when using the petrol and 1.530 g when using the E25 fuel. Thus, the total hydrocarbons emission when using the E25 fuel is on 31.8 % more than when using the petrol. Herewith, the hydrocarbons emission when using the E25 fuel is more than when using the petrol on 36.9 % for engine partial load mode and on 17.7 % for engine idling mode. Main reason of higher hydrocarbons emission when using the E25 fuel is also caused by catalytic converter heating time. The hydrocarbons emission, which is emitted for catalytic converter heating period, is near 0.25 g or 21.5 % from their total emission when using the petrol and 0.5 g or 32.7 % from their total emission when using the E25 fuel. Relative increasing of the hydrocarbons emission for catalytic converter heating period is 100 % when using the E25 fuel comparatively with when using the petrol. Thus, influence of the catalytic converter heating time on the hydrocarbons emission when using the E25 fuel is significant, but it is less than for the carbon monoxide emission.

Dependencies of total nitrogen oxides emission $_{NOx\_\Sigma}$ on the vehicle motion time and their partition by the engine modes when using studied fuels are show non Fig. 11. As it shown on Fig. 11, the totalnitrogen oxides emission per route is 1.774 g when using the petrol and 1.838 g when using the E25 fuel. Thus, the total nitrogen oxides emission when using the E25 fuel is on 3.6 % more than when using the petrol. Herewith, the nitrogen oxides emission when using the E25 fuel is more than when using the petrol on 4.9 % for engine partial load mode and less than when using the petrol on 13.1 % for engine idling mode. This data is due to the fact that nitrogen oxides emission significantly depends on the engine modes. The nitrogen oxides emission is significantly increased with increasing of the engine load and crankshaft rotation speed. The catalytic converter heating period influence on the nitrogen oxides emission is not same significant as for other harmful substances emissions. It is due to the factthat engine load and crankshaft rotation speed are not high at this period. The nitrogen oxides emission increasing when using the E25 fuel is mostly caused by the bigger vehicle motion time. This is external factors influence.

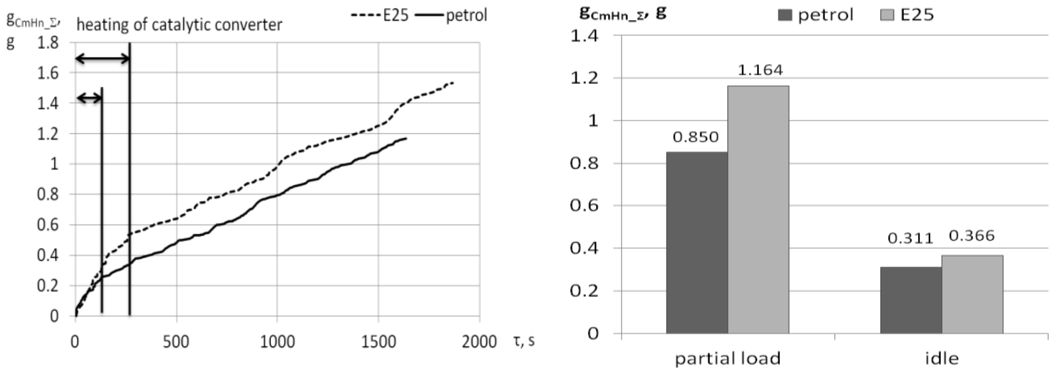

Fig. 10. Dependencies of total hydrocarbons emission on the vehicle motion time and their partition by the engine modes when using studied fuels
Source: developed by author

The obtained data evidences about ambiguous influence of different operating factors on the vehicle fuel consumption and harmful emissions when using the fuel containing ethanol. For objective evaluation of the influence of the fuel containing ethanol using on vehicle performance the more detailed partition of the obtained fuels consumption and emissions by engine speed and load modes must be done.

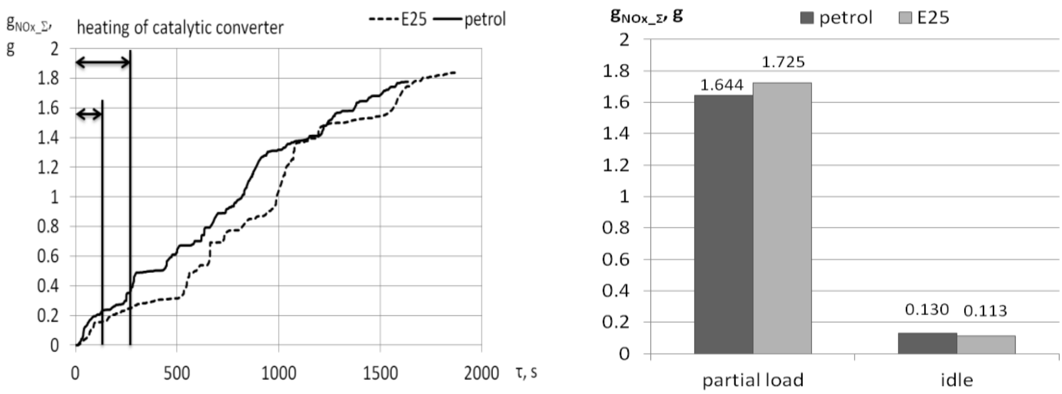

Fig. 11. Dependencies of total nitrogen oxides emission on the vehicle motion time and their partition by the engine modes when using studied fuels
Source: developed by author

Herewith, peculiarities of engine control system operating for steady state and transient modes should be taken into account. The modes with constant values of crankshaft rotation speed and throttle position or their slowly changing for heated engine are the steady state modes. Other engine modes and heating modes are transientones.Thus, correct comparison of engine performance when using different fuel sispossibleonlyforthe same modes of engine operation. For example, dependencies of the engine fuel consumption per second for the engine steady state modes when using the conventional petrol and fuel containing ethanol are presented on Fig. 12.

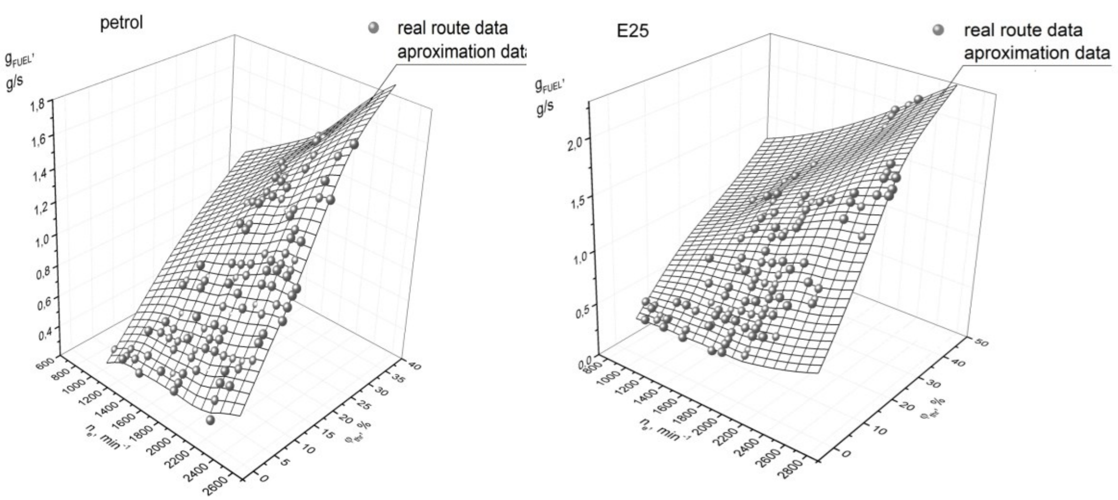

Fig. 12. Dependencies of the engine fuel consumption persecond for the engine steady state modes when using the petrol and E25 fuel containing ethanol
Source: developed by author

The dependencies have been obtained using the fuel consumption and operation time for appropriative engine mode during the vehicle motion on real route. The experimental data approximation has been carried out using the specialized soft ware. The obtained dependencies describe the engine fuel consumption under the operating conditions. These dependencies are the engine operating characteristics, which can beused for vehicle technical condition monitoring.

An approximation error (δ_{appr}, %) is evaluated by weighted average relative error value:

$$\delta_{appr} = \sum_{i=1}^{n} \frac{\tau_i}{\tau_\Sigma} \cdot \delta_i \qquad (4)$$

where n is total quantity of the engine modes, which are characterized by combination of the crankshaft rotation speed n_e value and the throttle position φ_{thr} value; τ_i is the engine operation time for i-th mode, s; τ_Σ is the total time of the vehicle motion on the route, s; δ_i is relative approximationerror of the engine performance for i-th mode, %.

The approximation errors of the fuel consumption persecond, carbonmon oxide emission persecond, hydrocarbons emission persecond and nitrogen oxides emission persecond are 2 %, 3.68 %, 2.38 %, 4.81 % accordingly when using the petrol and 1.9 %, 4.43 %, 2.15 %, 5.09 % accordingly when using the E25 fuel.

The comparative operating characteristics of the fuel consumption per second (g_{FUEL}, g/s), carbon monoxide emission per second (g_{CO}, g/s), hydrocarbons emission per second (g_{CmHn}, g/s) and nitrogen oxides emission per second (g_{NOx}, g/s) when using the studied fuels are shown on Fig. 13.

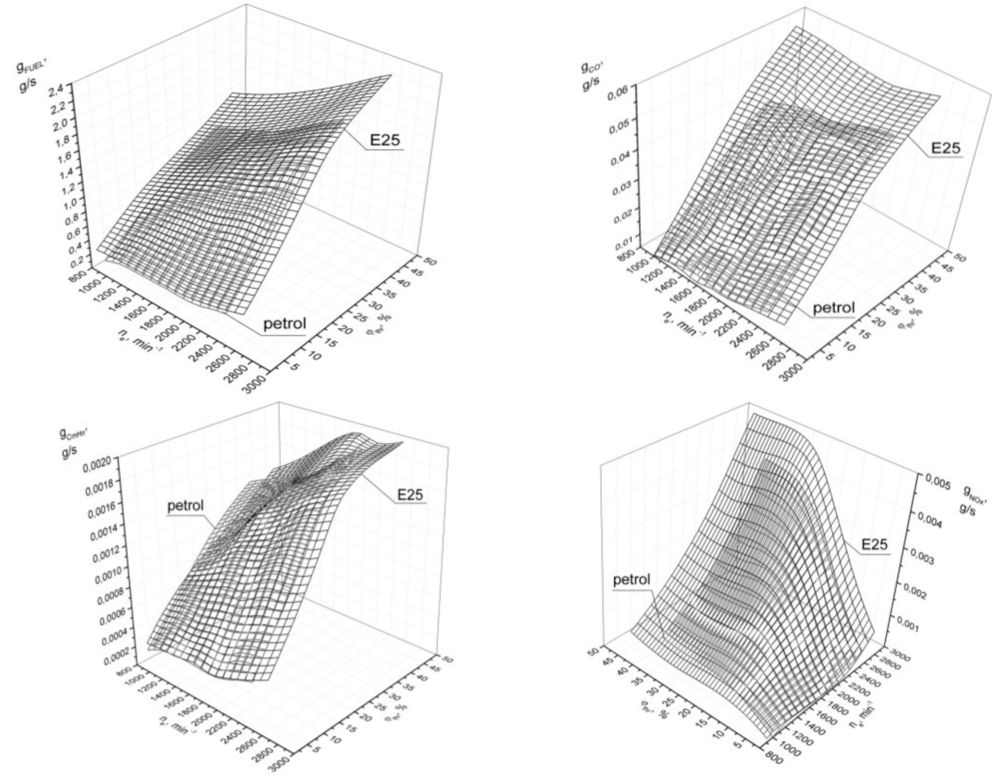

Fig. 13. The comparative operating characteristics of the fuel consumption per second (g_{FUEL}, g/s), carbon monoxide emission per second (g_{CO}, g/s), hydrocarbons emission per second (g_{CmHn}, g/s) and nitrogen oxides emission per second (g_{NOx}, g/s) when using the studied fuels
Source: developed by author

Using the operating characteristics the most common engine mode range for the vehicle motion in city traffic conditions has been determined. An idling mode and partial load modes with values of crankshaft rotation speed from 1500 to 2500 min^{-1} and throttle position from 5 to 20 % compose the range. For these modes with using the engine operating characteristics for the petrol and fuel containing ethanol the vehicle fuel consumption per second and harmful emissions per second have been determined. The obtained data and relative difference (*diff.*, %) of the data for studied fuels are given in Table 3.

Table 3

The vehicle fuel consumption per second and harmful emissions per second whenusingthepetrolandthe fuel containing ethanol

	Performance	g_{fuel}, g/s			g_{CO}, g/s		
	Fuel type	petrol	FCE	*diff.*, %	petrol	FCE	*diff.*, %
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Engine mode	Idling mode	0.262	0.288	9.92	0.00707	0.00646	-8.63
	n_e = 1500 min^{-1}; φ_{thr} = 5 %	0.461	0.534	15.84	0.0119	0.0110	-7.56
	n_e = 1500 min^{-1}; φ_{thr} = 10 %	0.681	0.778	14.24	0.0173	0.0172	-0.58
	n_e = 1500 min^{-1}; φ_{thr} = 20 %	1.068	1.191	11.52	0.0299	0.0352	17.73

Table 3 continue

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
	n_e = 2000 min^{-1}; φ_{thr} = 5 %	0.513	0.583	13.65	0.0135	0.0131	-2.96
	n_e = 2000 min^{-1}; φ_{thr} = 10 %	0.792	0.856	8.08	0.0203	0.0193	-4.93
	n_e = 2000 min^{-1}; φ_{thr} = 20 %	1.274	1.413	10.91	0.0340	0.0344	1.18
	n_e = 2500 min^{-1}; φ_{thr} = 5 %	0.653	0.705	7.96	0.0184	0.0163	-11.41
	n_e = 2500 min^{-1}; φ_{thr} = 10 %	0.895	0.987	10.28	0.0244	0.0230	-5.74
	n_e = 2500 min^{-1}; φ_{thr} = 20 %	1.463	1.638	11.96	0.0374	0.0381	1.87
	Idling mode	0.000279	0.000273	-2.15	0.000069	0.000065	-5.80
	n_e = 1500 min^{-1}; φ_{thr} = 5 %	0.000491	0.000496	1.02	0.000459	0.000545	18.74
	n_e = 1500 min^{-1}; φ_{thr} = 10 %	0.000722	0.000739	2.35	0.00109	0.00111	1.83
	n_e = 1500 min^{-1}; φ_{thr} = 20 %	0.00122	0.00120	-1.64	0.00158	0.00163	3.16
	n_e = 2000 min^{-1}; φ_{thr} = 5 %	0.000545	0.000552	1.28	0.000578	0.000623	7.79
	n_e = 2000 min^{-1}; φ_{thr} = 10 %	0.000843	0.000830	-1.54	0.00139	0.00142	2.16
	n_e = 2000 min^{-1}; φ_{thr} = 20 %	0.00137	0.00139	1.46	0.00264	0.00273	3.41
	n_e = 2500 min^{-1}; φ_{thr} = 5 %	0.000704	0.000698	-0.85	0.000978	0.00103	5.32
	n_e = 2500 min^{-1}; φ_{thr} = 10 %	0.000963	0.000973	1.04	0.00178	0.00189	6.18
Engine mode	n_e = 2500 min^{-1}; φ_{thr} = 20 %	0.00155	0.00160	3.23	0.00369	0.00389	5.42

Source: developed by author

As it seen from Table 3, relative value of the fuel consumption in creasing when using the E25 fuel is from 7.96 % to 15.84 % comparatively with when using the petrol. Here with, influence of used fuel type on the carbon monoxide emission is ambiguous. For more part of engine modes the carbon monoxide emission is decreased from 0.58 to 11.41 % when using the E25 fuel comparatively with when using the petrol. Butfor n_e = 1500 min^{-1}; φ_{thr} = 20 % mode the carbon monoxide emission is increased on 17.73 % when using the E25 fuel. The value of fuel type influence on hydrocarbons emission is insignificant. This value does not exceed 2.5 % for more part of engine modes. This is as approximation error level. The nitrogen oxides emission is also increased from 1.83 to 6.18 % when usingtheE25 fuel for all engine modes besides idling mode and n_e = 1500 min^{-1}; φ_{thr} = 5 % mode. In idling mode the nitrogen oxides emission is decreased on 5.8 % when using the E25 fuel. In n_e = 1500 min^{-1}; φ_{thr} = 5 % mode the nitrogen oxides emission is increased on 18.74 % when using the E25 fuel.

Taking in to account the ambiguous influence of used fuel type on the vehicle fuel consumption and harmful emissions, it is expedient to evaluate the fuel consumption and harmful emissions when using of different fuel types for vehicle motionin 900 sconditional driving cycle with out transient motion modes. The engine modes for the driving cycle appropriate to the engine modes specified in Table 3. The idling mode duration is accepted equalto 450 s. Duration of each of other modes is 50 s.

The total fuel consumption (g_{FUEL_Σ}, g) in the driving cycleis

$$g_{FUEL\_\Sigma} = \sum_{i=1}^{n} g_{FUEL\ i} \cdot \tau_i , \tag{5}$$

where n is quantity of the engine modes, n = 9; τ_i is the engine operation time for i-th mode, s; $g_{FUEL\ i}$ is the engine fuel consumption per second for i-th mode, g/s.

The total carbon monoxide emission (g_{CO_Σ}, g) in the driving cycle is

$$g_{CO\_\Sigma} = \sum_{i=1}^{n} g_{CO\,i} \cdot \tau_i , \tag{6}$$

where $g_{CO\,i}$ is the engine carbon monoxide emission per second for i-th mode, g/s.

The total hydrocarbons emission (g_{CmHn_Σ}, g) in the driving cycle is

$$g_{CmHn\_\Sigma} = \sum_{i=1}^{n} g_{CmHn\,i} \cdot \tau_i , \qquad (7)$$

where $g_{CmHn\,i}$ is the engine hydrocarbons emission per second for i-th mode, g/s.

The total nitrogen oxides emission (g_{NOx_Σ}, g) in the driving cycleis

$$g_{NOx\_\Sigma} = \sum_{i=1}^{n} g_{NOx\,i} \cdot \tau_i , \qquad (8)$$

where $g_{NOx\,i}$ is the engine nitrogen oxides emission per second for i-th mode, g/s.

Using the values of fuel consumption per second and harmful substances emissions per second from Table 3 and the equations (5–8) it is done the calculation of the vehicle total fuel consumption and harmful emissions per driving cycle when using the conventional petrol and the E25 fuel containing ethanol. Based on the calculation results it is found that the total vehicle fuel consumption per driving cycle, carbon monoxide emission per driving cycle, hydrocarbons emission per driving cycle, nitrogen oxides emission per driving cycle are 508 g, 13.537 g, 0.546 g, 0.740 g accordingly when using the petrol and 564 g, 13.287 g, 0.547 g, 0.773 g accordingly when using the E25 fuel. The relative increasing of fuel consumption is 11 % when using the E25 fuel. The relative decreasing of carbon monoxide emission is 1.8 % when using the E25 fuel. The relative increasing of hydrocarbons emission is 0.2 % when using the E25 fuel. The relative increasing of nitrogen oxides emission is 4.5 % when using the E25 fuel. Thus, the using of the E25 fuel containing ethanol leads to some decreasing of the carbon monoxide emission and insignificant increasing of the nitrogen oxides emission.

Taking into account that the petrol and the fuel containing ethanol have a different density (Table 2), the volume petrol consumption per the driving cycle is 0.694l and the volumeE25 fuel consumption per the driving cycle is 0.748l. Thus, the relative increasing of the E25 fuel consumption comparatively with the petrol consumption is 7.8 % by volume equivalent.

Here with, the engine operation efficiency is also characterized by energy consumption. Taking into account the fuels combustion heat (Table 2), the equivalent petrol consumption per the driving cycle is 22.2 MJ and the equivalent E25 fuel consumption per the driving cycle is 22.39 MJ. The relative increasing of the E25 fuel consumption comparatively with the petrol consumption is 0.9 % by energy equivalent. This evidences about in significant impairment of the engine operation efficiency when using the E25 fuel containing ethanol.

Thus, the using of fuels containing ethanol more than 20 % has significant influence on fuel economy and environmental performance of sparking nition engine because the physical and chemical characteristics of the fuels containing ethanol have significant differences comparatively with conventional petrol.

The operating conditions, which are characterized by complex of road, traffic and atmosphere conditions, have significant influence on vehicle motion modes and vehicular engine operation modes. The operating vehicle fuel consumption and harmful emissions significantly depend on these vehicle and engine modes.The temperature state of engine and catalytic converter, the engine crankshaft rotation speed and load have the highest influence on the vehicle fuel consumption and harmful emissions.Thus, for the correct evaluation of vehicle performance when using the conventional petrol and the fuel containing ethanol, the fuel consumption and harmful emissions determination for separate engine speed and load modes during the vehicle motion is necessary.

Based on the experimental study resultsof fuel consumption and harmful emissions during motion of BOGDAN 21101 1.6 l, which equipped with VAZ-21114 spark ignition engine, in city traffic using the conventional petrol and the E25 fuel containing ethanol, the operating characteristics of the fuel consumption per second, carbon monoxide emission per second, hydrocarbons emission per second and nitrogen oxides emission per second for the range of engine speedandloadmodes are obtained. The weighted average approximation errors of experimental data are 1.9–5.09 %.

Using the obtained operating characteristics, the fuel type influence on the fuel consumption and harmful emissions for separate steady state operating engine modes and conditional driving cycle, which consists the complex of these operating modes, have been found. The results of this study show that the fuel consumption is increased on 11 % bymass, on 7.8 % by volume and on 0.9 % by energy equivalent when using the E25 fuel containing ethanol comparatively with using the conventional petrol. The last value evidences about insignificantimpairmentof the engine operation efficiency when using the E25 fuel containing ethanol. Also the using of the E25 fuel containing ethanol leads to some decreasing of the carbon monoxide emission, insignificant increasing of the nitrogen oxides emission and with practically unchanged hydrocarbons emission.

Fur ther research will beaimed on cause's analysis of engine operation efficiency impairment and nitrogen oxides emission increasing when using fuels containing ethanol more than 20 %, improvement methods determination of these performances.

РЕФЕРАТ

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ОЦІНКА СПОЖИВАННЯ ПАЛИВА ТА ВИКИДІВ ШКІДЛИВИХ РЕЧОВИН МОТОРНИМИ ТРАНСПОРТНИМИ ЗАСОБАМИ З ДВИГУНОМ ВНУТРІШНЬОГО ЗГОРАННЯ ЗА УМОВ ЕКСПЛУАТАЦІЇ З ВИКОРИСТАННЯМ ЕТАНОЛОВМІСНОГО ПАЛИВА

Підвищення паливної економічності та зниження шкідливих викидів транспортних засобів є актуальним для досягнення високого рівня екологічної безпеки транспорту та його сталого розвитку. Метою дослідження є оцінювання витрати палива та викидів шкідливих речовин транспортним засобом з двигуном з іскровим запалюванням, системою впорскування і каталітичною нейтралізацією відпрацьованих газів під час використання спиртовмісного палива з вмістом біоетанолу більше 20 % на основі даних про параметри руху транспортного засобу в умовах реального маршруту. Подальші дослідження буде направлено на аналіз причин погіршення показників транспортного засобу та визначення способів їх поліпшення при використанні спиртовмісних палив.

Ключові слова: витрата палива, шкідливі викиди, транспортний засіб, двигун з іскровим запалюванням, умови експлуатації, спиртовмісне паливо.

РЕФЕРАТ

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ОЦЕНКА ПОТРЕБЛЕНИЯ ТОПЛИВА И ВЫБРОСОВ ВРЕДНЫХ ВЕЩЕСТВ МОТОРНЫМИ ТРАНСПОРТНЫМИ СРЕДСТВАМИ С ДВИГАТЕЛЕМ ВНУТРЕННЕГО СГОРАНИЯ ПРИ ЭКСПЛУАТАЦИИ С ИСПОЛЬЗОВАНИЕМ ЭТАНОЛСОДЕРЖАЩИХ ТОПЛИВ

Повышение топливной экономичности и снижение вредных выбросов транспортных средств актуальны для достижения высокого уровня экологической безопасности транспорта и его устойчивого развития. Целью исследования является оценка расхода топлива и выбросов вредных веществ транспортным средством с двигателем с искровым зажиганием, системой впрыска и каталитической нейтрализацией отработавших газов при использовании спиртосодержащего топлива с содержанием биоэтанола более 20 % на основе данных о параметрах движения транспортного средства в условиях реального маршрута. Дальнейшие исследования будут направлены на анализ причин ухудшения показателей транспортного средства и определения способов их улучшения при использовании спиртосодержащих топлив.

Ключевые слова: расход топлива, вредные выбросы, транспортное средство, двигатель с искровым зажиганием, условия эксплуатации, спиртосодержащее топливо.

ABSTRACT

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EVALUATION OF FUEL CONSUMPTION AND HARMFUL SUBSTANCES EMISSIONS BY VEHICLE WITH SPARK IGNITION ENGINE UNDER OPERATION CONDITIONS WITH USING OF FUEL CONTAINING ETHANOL

Increasing of fuel economy and reducing of harmful emissions of vehicles are actual for achieving a high level of transport environmental safety and sustainable development. The purpose of the study is an evaluation of vehicle fuel consumption and harmful emissions with a spark ignition engine equipped a fuel injection and exhaust gases cleaning systems, using a fuel containing ethanol more than 20 %. It is based on the vehicle motion parameters under real route conditions. Further research will be aimed to analysis of vehicle performance impairment causes and determination of their improvement methods when using fuels containing ethanol.

Key words: fuel consumption, harmful emissions, vehicle, spark ignition engine, operating conditions, fuel containing ethanol.

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