Efficiency of Alternative Fuel in Internal Combustion Engines

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Abstract

Experimental work was carried out which allowed us to analyze the ways of solving the problems of simultaneous decrease in the consumption of conventional fuel, emission of toxic and greenhouse gases within a short time. It was shown that upgrading of internal combustion engines (ICE) operating with the conventional fuel makes it possible to meet the requirement 140 g/km CO_2; the use of alternative kinds of fuel broadens the possibility to decrease CO_2 emission and increase performance index; ICE performance with a thinned homogeneous mixture allows a substantial increase in performance index. Investigation of the operation process in ICE showed the possibility of its performance with a thin homogeneous mixtures; the performance index increases under the rated conditions from 23 to 32–34 % as a mean. It was established that power installations operating with hydrogen are able to provide zero CO_2 emission. A concept of the transition to hydrogen as a fuel in the most efficient manner is formulated.

The necessity to decrease atmospheric pollution and consumption of nonrenewable kinds of fuel compels restrictions of the emission of toxic gases and carbon dioxide and stimulates efforts aimed at an increase in the performance index of power installations. Since vehicles are the main consumers of oil products and the sources of toxic (CO, CH, NO_x) and greenhouse (CO_2) gases, the countries of the European Union introduce limitations on CO_2 emission for vehicles [1–3], which is equal to a decrease in the consumption of hydrocarbon fuel (Table 1).

The limitations require search for optimal ways to solve the problems of simultaneous decrease in the consumption of conventional fuel, emission of toxic and greenhouse gases within a short time. The AVTOVAZ JSC organized and carried out experimental work which allowed us to analyze the ways of solving the mentioned problems. The results of this analysis demonstrated the following.

The existing average level of CO_2 emission in tests over the mixed European cycle for all the automobiles sold in the countries of the European Union is about 180 g/km, which is

TABLE 1

Limitations on CO_2 emission for motor transport, according to the Directives of the European Union

Directives of the European Union and their effective dates	CO_2 emission, g/km	Equivalent petrol consumption, l/100 km	Decrease in consumption, % (equivalent performance index of ICE, %)
Directives of Eurocomission:			
starting with 2008	140	5.87	22 (29)
starting with 2012	120	5	33 (34)
Directives of Europarliament:			
staring from 2008	140	5.87	22 (29)
starting from 2015	90	3.87	50 (46)

TABLE 2

Requirements to toxicity of exhaust gases, g/km [4, 5]

European standards for toxic components	CO	CH	NO_x
Euro-3 (since 2000)	2.3	0.2	0.15
Euro-4 (since 2005)	1	0.1	0.08
Euro-5 (starting from 2010)	0.5	0.04	0.04

close to the level of emission by the automobiles of compact class (mass during tests: 1350 kg), corresponds to the emission level of VAZ-2110 automobile and petrol consumption 7.5 l per 100 km.

The performance index of an engine in automobile tests according to the European drive cycle with petroleum consumption 7.5 l/100 km and CO_2 emission 180 g/km is 23 %/ To decrease CO_2 emission to 140, 120 and 90 g/km, it will be necessary to increase the mean performance index to 29, 34 and 46 %, respectively. One can hardly achieve the performance index of 34 % with the operation mode under consideration, and the performance index of 46 % is impossible for the existing technological level. The problem is complicated due to rigid requirements limiting the toxicity of exhaust gases (Table 2) [4, 5] which are provided nowadays for the operation of petrol engines with the stoichiometric mixture using three-component (CO, CH, NO_x) neutralizers, which limits the possibility to increase the performance index.

According to our estimations, upgrading of petrol ICE involving the most efficient developments will allow one to increase the performance efficiency of the engines by 12–17 % of the initial level, that is, to bring it to a value of 27 %. The performance efficiency of modern supercharged diesel engines in the regime under consideration is about 32 %. The necessity to decrease the emission of nitrogen oxides and soot formed in the cylinders of a diesel engine during its operation with a thin non-homogeneous mixture to the level required by Euro-4 and below will require the use of neutralizers decreasing the performance efficiency to 30 %.

A decrease in the mass of an automobile to 800 kg, accompanied by the use of upgraded ICE, allows one to decrease fuel consumption to 3.5 l/100 km and CO_2 emission to 84 g/km. Organization of partial production of these automobiles and the use of upgraded ICE in other vehicles will allow one to decrease total CO_2 emission to 140, 120 and 90 g/km, provided that the fraction of small cars 18, 47 and 90 % of the total number, respectively. However, it is necessary to keep in mind that the demand for the cars of especially small class is limited. Engine shutdown at stops of a car with automatic start after pressing the throttle pedal allows one to increase the performance index of a petrol engine from 27 to 29 % and the performance index of a diesel engine with a neutralizer to 30 %. So, upgrading ICE using the conventional fuel one may reach the standard for CO_2 (140 g/km). The use of a hybrid power unit with a modern diesel engine, with turbo-supercharging and a maximal performance index of 42 % will allow one to decrease CO_2 emission to 120 g/km but would not be able to provide 90 g/km. It should be

TABLE 3

CO_2 emission depending on the hydrocarbon composition of fuel

Fuel, chemical formulas	Caloric value, MJ/kg	CO_2 emission			Decrease in CO_2 emission, %
		kg/kg of fuel	g/MJ	g/km	
Petrol, $CH_{1,855}$	44.5	3.1757	71.36	180	0
Natural gas, CH_4	50	2.75	55	138	23
Propane, C_3H_8	46.6	3	64.37	162	10
Butane, C_4H_{10}	46.1	3.0345	65.8	165	8
Dimethyl ether, C_2H_6O	31.57	1.913	60.59	125*	15
Hydrogen, H_2	120	0	0	0	100

* For the performance index of a diesel engine under rated conditions equal to 28 %.

noted that additional expenses per one car with a hybrid power unit may be 3500 to 15 000 Euro, per a diesel car with a neutralizer 3000 to 8000 Euro, per a car with upgraded petrol engine meeting the requirement 140 g of CO_2 per 1 km from 600 to 1000 Euro, which may finally have a negative effect on automobile sales.

The use of alternative kinds of fuel broadens the possibilities to decrease CO_2 emission and increase performance index. The calculated data on changes in CO_2 emission due to variations of the hydrocarbon composition of fuel (without taking into account the possibility to improve the performance index of ICE) are shown in Table 3.

It follows from Table 3 that the most suitable kinds of fuel for use in the nearest future are natural gas and liquefied oil gas (for ICE with forced ignition) and dimethyl ether (for diesel engines). At the same time, gaseous fuel possesses low calorific value per unit volume, which causes the necessity to increase the volume of fuel tanks and decrease the run per one refueling.

It is known that ICE operation with thin homogeneous mixture allows one to increase the performance index of the engine substantially. Widely used three-component neutralizers are unable to provide a decrease in NO_x emission. The problem of decreasing the emission of nitrogen oxides, along with the simultaneous increase in the performance index of an ICE can be solved with the help of combustion at low temperature, which is possible if fuel with low inflammability is present in the combustible mixture, for example free hydrogen. Hydrogen-containing synthesis gas obtained on board the

TABLE 4

Estimation of the efficiency and outlooks of the use of different kinds of fuel in motor transport

ICE characteristics, fuel	Performance index, mean over Eurocycle, %	Energy consumption, MJ/100 km	CO_2 emission, g/km	Run according to Eurocycle per single refueling, km	Increase in expenses per one car, Euro
Petrol ICE, ε = 9.5, tank 40 l, three-component neutralizer	23	250	180	530	0
The same, with upgraded ICE and car	29	194	140	680	1000
ICE, ε = 9.5, petrol 23 l, hydrogen 90 l, 40 MPa	32	180	85	540	300
ICE on hydrogen, balloons 90 l, 40 MPa	34	170	0	165	300
ICE on natural gas, ε = 12, balloons 90 l, 35 MPa	23	250	137	450	300
The same, with SGG	30	192	105	590	500
ICE, ε = 12.5, propane + butane (50 %) balloon 40 l, 0.16 MPa	25	230	150	540	250
The same, with SGG	28	205	134	605	450
Diesel, ε = 18, supercharging, diesel oil, tank 40 l, neutralizer	30	192	138	650	4000–8000
The same, on dimethyl ether	30	192	116	490	4000–8000

Note. ε is the ratio of combustible mixture compression in ICE.

car can be used instead of hydrogen. For instance, investigations carried out in 1973–1975 in the USA with Chevrolet car with an engine (5.75 l in volume) equipped with synthesis gas generator (SGG) demonstrated a decrease in petrol consumption by 26 % when driving according to the Federal drive cycle CVS-3 [6]. Synthesis gas generator was operated with petrol. The composition of synthesis gas, mol. %: H_2 0.216, CO 0.236, CH_4 0.01, CO_2 0.0123, H_2O 0.012, N_2 0.5125.

The results of investigations of the performance process of an ICE using petrol with hydrogen added and using hydrogen alone showed the possibility for an engine to operate with thin homogeneous mixtures with an increase in performance index under the rated conditions from 23 to 32–34 % as a mean. Tests of VAZ-2110 vehicle with the engine using a thin mixture demonstrated the possibility to decrease toxic emissions to the level of Euro-5 standards without using a three-component neutralizer. Similar results were obtained in the investigation of ICE using petrol with hydrogen-containing synthesis gas added. Taking into account the performance index of SGG which is 80 % as a mean (on the basis of caloric value of the initial substance and conversion product) and fuel consumption through the SGG, the performance index of ICE under the rated conditions was about 30 %. The work performed allowed one to carry out a complex estimation of the efficiency and outlooks of the use of the indicated kinds of fuel for motor transport.

The experimental and calculated data on changes in CO_2 emission taking into account changes in the performance index of ICE and on estimated increase in expenses per one car for different methods used to decrease CO_2 emission are shown in Table 4. This analysis shows the possibility to decrease CO_2 emission to 140 g/km by increasing the performance index of petrol ICE working with the stoichiometric mixture, by using diesel engines and exchanging petrol for natural gas.

Fulfillment of the requirement of 120 g/km for CO_2 emission accompanied by a slight increase in the car price provides combustion of a thin homogeneous mixture using synthesis gas or hydrogen, 90 g/km may be achieved with ICE using a mixture of hydrocarbon fuel with hydrogen. Zero CO_2 emission with increased performance index of the power installation (to 45–50 % as a mean) could be provided by power installations using hydrogen. However, in order to create the infrastructure for their production, hydrogen generation and transportation to the consumers, substantial financial resources and time are necessary. In this situation, stage-by-stage upgrading of the conventional ICE for operation using mixtures of liquid or gaseous fuel with hydrogen-containing synthesis gas, hydrogen and then for operation using hydrogen will allow one to solve urgent problems of energy saving and pass to hydrogen power engineering with minimal consumption of time and expenses. The work performed allowed us to formulate the concept of stage-by-stage transition to the use of alternative kinds of motor fuel (finally hydrogen) by the most efficient way, in the opinion of authors.

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