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Performance Indicators of a Passenger Car with a Spark Ignition Engine Functioning With Different Engine Fuels

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Abstract: The article presents the results of analytical and experimental studies of the performance of a passenger car with a spark-ignition internal combustion engine running on liquefied petroleum gas (LPG) with the addition of dimethyl ether (DME). Comparative results obtained for the base (gasoline, LPG) and composite gas (DME concentration 5 ± 1, 10 ± 1, 15 ± 1% in LPG) fuels are presented.

Keywords: Carbon dioxide emissions, dimethyl ether, liquefied petroleum gas, passenger car, performance indicators

1. Introduction

At present, in world practice, dimethyl ether (DME) is used as a substitute for petroleum motor fuels, as a complete or partial substitute for diesel fuel. DME is considered not only an environmentally friendly fuel, including the reduction of greenhouse gas emissions - carbonate anhydride but also a renewable energy source due to the possibility of obtaining it from biomass. However, low values of viscosity and calorific value of DME are the main reasons for the emergence of several technological and production difficulties for its wide distribution as an environmentally friendly substitute for diesel fuel. On the other hand, some of its identical properties with liquefied petroleum gas (LPG/LPG) suggest the possibility of its use as an additive to LPG, and the resulting composite gas mixture as a motor fuel for internal combustion engines with spark ignition. Distinctive flammability properties (flash point, flammability concentration limits, cetane number, etc.)

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DME can improve the engineering properties of LPG and thereby increase the operational properties (dynamism, fuel efficiency, environmental friendliness) of a vehicle or a car, which are characterized by such indicators as maximum speed, acceleration time, fuel consumption per mileage, and emissions of harmful substances.

1.1. Aim and objectives

It is known that the operational properties of a car include: traction and speed, braking, fuel efficiency, environmental friendliness, controllability, understeer, manoeuvrability, stability, ride, etc. On the other hand, the types of motor fuels used can mainly affect those indicators characterizing the traction-speed, fuel-economic and environmental properties of the vehicle.

In this regard, the goal of the research was set - to study the possibility of improving the performance of a passenger car with a spark-ignition engine using a composite gas motor fuel - liquefied petroleum gas (LPG) with the addition of dimethyl ether (DME).

2. Materials and methods

Please The search for rational solutions to modern problems associated with replacing petroleum motor fuels with environmentally friendly alternative fuels for stationary and transport vehicles are the main scientific and technical areas of leading companies, centres, scientists and specialists [1-4].

Analysis of the use of various types of alternative fuels in the leading countries of the world shows that currently, the most common substitutes for petroleum motor fuels or energy sources are: liquefied petroleum gas (LPG/LPG), compressed natural gas (CNG), liquefied natural gas (LNG/LNG), biodiesel, gasoline-ethanol mixture (E10, E20, E85), hydrogen and electric vehicles, for example, there is an intensive development of the use of these types of alternative motor fuels (Table 1) in the USA [5].

Table 1. Number of US vehicles and gas stations running on alternative fuels

	Number of cars / filling stations, thousand units/unit							
	Types of alternative motor fuels							
Years	LPG	CNG	LNG	Biodiesel	Ethanol, (E85)	Methanol, (M85)	Hydrogen	Electriccar
1995	173/3299	50/1065	0.6/-	-/-	1,7/37	19/82	-/-	3/188
2000	182/3268	101/1217	2/44	27*/2	87,5/113	13/3	-/-	12/558
2005	174/2995	118/787	2,8/40	90*/304	246/436	0/0	74/14	52/588
2010	143/2647	116/841	3,3/39	260*/644	619/2142	0/0	64/58	58/541
2015	2248/3594	8744/1563	7,0/111	1263*/721	1881/2990	0/0	2/39	118/30945
2018	2837/3341	5939/1659	10/137	1857*/681	1150/3617	0/0	29/60	258/61067

Note: * Production in the mill. gallons (1 gallon = 3.785 liters).

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Problems of the development and use of alternative fuels and energy in general and for transport in particular form the basis of the policy documents of many developed countries. For example, according to the US Biomass Act, by 2025 the volume of produced energy sources from renewable resources will be increased to 25%. Currently, bioethanol, biodiesel, obtained from various resources (including plants, algae, etc.) are most widely used as a motor fuel in the USA, the European Union and Latin America. In many countries, there is a functioning production facility for the production of up to 800 million litres of biofuels per year and various forms of tax incentives are in effect [6-9].

However, in recent years, due to the critical situation with global warming, the importance of the use of low-carbon technology in all spheres of the economy, including road transport, has significantly increased. In this regard, the use of motor fuels and other various energy sources in road transport with a relatively lower carbon content compared to petroleum fuels has become an important scientific and technical problem requiring comprehensive study. In order to solve this problem, Danish, American and Austrian researchers, based on the results of their work, proposed using dimethyl ether (DME) as a substitute for diesel fuel, which is known and used in perfumery to create pressure in cylinders with varnishes and deodorants instead of harmful gases - freons, butane and propane, as well as a refrigerant and solvent.

Therefore, in recent years, DME has become an efficient and environmentally friendly motor fuel, a substitute for diesel fuel.

This motor fuel, obtained from natural gas, biomass, coal, carbon-containing products (bitumen), from pulp and paper production waste and other sources, does not contain aromatic hydrocarbons, sulphur and is characterized by complete combustion, has a high cetane number (55-60) and the absence of soot and nitrogen oxides in the exhaust gases. Moreover, at the same time, greenhouse gas emissions are sharply reduced due to the low-carbon content [9-14].

Analysis of the data obtained shows that DME is undoubtedly a promising substitute for diesel fuel from the standpoint of low-carbon technology. However, taking into account the real operational data, it is necessary to expand the scientific search directions for various options for using DME as a substitute for other types of motor fuels and energy sources, including those aimed at improving the performance of a passenger car with a spark-ignition engine.

In this case, it should be taken into account that DME is close to liquefied petroleum gas in terms of its physicochemical properties and is easily stored and transported, and in specific cases, it can be used as an additive to liquefied petroleum gas (LPG). They carried out scientific work related to the use of a mixture of LPG and DME as a motor fuel for an internal combustion engine with spark-ignition revealed several issues related to detonation during combustion, and the authors developed recommendations for changing the shape of the piston combustion chamber. Although these scientific solutions allow the use of DME with a high concentration, this requires, as already noted, the implementation of several constructive and technological changes [15-17].

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3. Fundamental approaches

The concept of these studies is to increase the energy and environmental performance indicators (Fig. 1) of a passenger car with a spark-ignition engine running on a mixture of LPG and DME or composite gas fuels) without changing the basic adjustment parameters.

Figure 1. Performance properties of motor vehicles

The object of research was a passenger car NEXIA 3 DONC (Manufacturer - Uzbekistan, sedan body, class B, engine - A15MF DOHC 4 stroke with a volume of 1.5 litres, 5-speed manual transmission). The different contents of DME in the LPG composition were determined based on the invariability of the basic adjustment data of the engine and were established based on the results of the thermal calculation. In experimental studies, the following basic and composite gas motor fuels with injection power systems were adopted:

1. Compared base fuel - Gasoline AI-91
2. Main base fuel - LPG (LPG100)
3. Composite gas fuel - LPG + 4 ... 6% DME (LPG95 + DME05)
4. Composite gas fuel - LPG + 8 ... 10% DME (LPG90 + DME10)
5. Composite gas fuel - LPG + 14 ... 16% DME (LPG85 + DME15)

Bench tests of the engine were carried out on the basis of an inductor brake test bench "Schenk WS-230", and field studies were carried out at the Pskent auto-testing ground, the former South Range of NAMI (Fig. 2).

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Figure 2. Fragments from bench and polygon studies

In the process of experimental studies, the KORSUS-DATRON test complex, the MEXA-584L gas analyzer and other test installations, instrumentation were used.

4. Results

The establishment of the permissible concentration of DME in the LPG composition was carried out taking into account the flammability (octane number, density, the heat of combustion, concentration limits of flammability, the temperature of ignition and self-ignition, etc.) of the resulting gas mixture. In this case, the octane number or anti-knock resistance of the composite gas fuel is an indicator that should be justified. In accordance with the World Fuel Charter [18], the following requirements are imposed on the octane number of automobile motor fuels (Table 2.)

Table 2. Limit values of octane numbers of modern motor gasolines

Indicatorname	Petrolbrand	Limitvalues	
		Min.	Min.
ResearchOctaneNumber (RON)	91	91	-
Motoroctanenumber (MON)	91	82	-
ResearchOctaneNumber (RON)	95	95	-
Motoroctanenumber (MON)	95	85	-
ResearchOctaneNumber (RON)	98	98	-
Motoroctanenumber (MON)	98	88	-

It is known that DME has a rather high (more than 55) cetane number (CN), which is related to the octane number (ON) of gasoline or other motor fuels for internal combustion engines with spark ignition according to the following formula:

$$ON = 120 - 2CN \quad (1)$$

The results of the performed analytical calculations of changes in the RON of composite gas fuels are presented in the form of a table (tab. 3)

Table 3.The octane number of various motor fuels

Fuel	Octanenumber	Changingthe	ActualMON	Note

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	(MON)	ON value		
LPG	100-105	-	100	Norm
DME	10	-	10	-
LPG95 + DME05	96	4	96	Norm
LPG90 + DME10	91	9	91	Norm
LPG85 + DME15	86,5	13,5	86,5	Limitation

Thus, the limiting concentration of DME in the LPG composition according to the permissible RON value or according to the antiknock resistance of the composite gas fuel is no more than 10%. In this case, the regression equation obtained by the least-squares method by calculating the RON of the composite gas fuel depending on the concentration of DME in the LPG (K_{DME}), as well as a graphic explanation of this result (Fig. 3).

$$ON = -1.18K_{DME} + 100.6 \qquad (2)$$

Assuming that the obtained results of bench studies should be confirmed by the results of field studies in accordance with the methodology for conducting these studies, the maximum speed of movement, acceleration time to 100 km/h, as well as emissions of harmful substances (CO, CH, NO_x, CO_2) of exhaust gases of a passenger car were measured operating on various fuels, which characterize its comparative energy and environmental performance on one or another type of motor fuel.

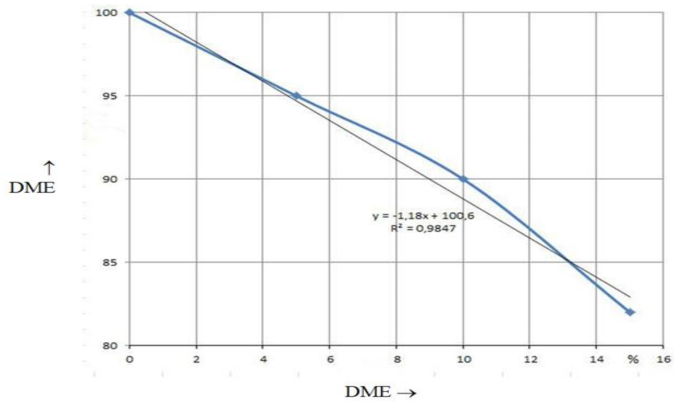

Figure 3. Changes in the MON values of composite gas fuels depending on the concentration of DME in the LPG

The generalized results of these studies are presented in the form of a table (Table 4.).

Table 4. Generalized results of field studies of a passenger car NEXIA 3

Indicators	Fuel				
	Petrol AI-91	LPG	LPG95 +DME05	LPG90 +DME10	LPG85 +DME15
Maximumspeed, km/h (%)	178,5	175,5 (100)	173,5 (99,4)	176,5 (100,6)	166 (94,3)

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Acceleration time to 100 km/h, s (%)	15.23	15.6 (100)	15.6 (100)	15.7 (100,7)	16.5 (94,2)
Fuel (energy) consumption at 90 km/h, l/100 km (MJ/100km)	9,2 (300)	9,65 (247,6)	9,45 (242,5)	9,21 (235.05)	10,03 (257,4)

The methodology for conducting field studies included the determination of the exhaust gas components (CO, CH, NO_x, O_2, CO_2) of an internal combustion engine (Table 5.) operating on various fuels at characteristic speeds (40, 60, 80, 100 km/h). The environmental assessment of the use of composite gas fuels was made based on the reduction of not only harmful emissions (CO, CH, NO_x) and greenhouse gas - carbon dioxide (CO_2).

Table 5. Exhaust gas components of the NEXIA 3

Fuel	Vehiclespeed, km/h	Petrol AI-91	LPG	LPG95+ DME05	LPG90+ DME10
CO, %	40	0.23	0.07	0.55	0.73
	60	0.38	0.17	0.71	0,63
	80	0.35	0.44	0.51	0.72
	100	1.15	0.17	0.47	0.55
CH, ppm	40	29	65	37	49
	60	33	31	38	42
	80	28	50	62	67
	100	41	40	71	69
NO_x, ppm	40	555	136	39	65
	60	397	94	80	74
	80	541	236	106	143
	100	343	580	150	169
CO_2, %	40	1.58	1.20	0.92	1.09
	60	2.04	1.42	0.89	1.05
	80	2.54	2.08	1.08	1.15
	100	2.30	2.30	1.51	1.52

Note:

1. The measurement of the components of the exhaust gases was carried out without active elements of the catalytic converter in order to determine the real values of emissions and to assess the load on the neutralization system depending on the type of fuel used.
2. When comparing emissions of harmful substances, one should take into account the value of the indicator of the relative aggressiveness of the components of the exhaust gases (A_{CO}=1; A_{CH}=3.16; A_{NOx}=41.1)

5. Conclusion

1. The limiting concentration of DME as an additive to LPG is limited by the antiknock resistance of the resulting fuel gas mixture.
2. Composite gas engine made from a mixture of LPG and DME, containing not more than 10% vol. DME is recommended for use, provided that the basic control parameters of the engine are not changed.
3. The results of laboratory, bench and field studies have experimentally substantiated the use of composite gas motor fuel with a DME content of no more than 10% vol. As part of the LPG.
4. As a result of experimental studies of the use of DME as an additive to LPG, there is a sharp decrease in NO_x emissions (by 22-72%) in comparison with the base fuel-LPG. At the same time, reducing CO_2 (by 10-45%) as a greenhouse gas, which confirms the main scientific idea of using DME as a motor fuel.

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