RESEARCH ON HAZARDOUS EFFECT OF PETROL – ETHANOL BLENDS' EMISSIONS IN SPARK INGNITION ENGINES

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Abstract

This paper deals with ecological aspects of using alcohol fuels in spark ignition (SI) engines, determining ecological characteristics of SI engine for various fuels. The dependence of the emission of hazardous material-carbon monoxide (CO), hydrocarbons (HC), carbon dioxide (CO_2) - on the number of crankshaft revolutions n, engine torque M_e and the ignition advance angle Θ was determined in the SI engine bench tests. The toxicity of the emission at idle running of the engine had been also measured.

The purpose of the bench tests is to work out the characteristics of the partial speed, loading and regulation according to the ignition timing advance. The bench tests of SI engine were performed with the Pb-free petrol A-76 and its mixtures with ethanol ester-aldehyde fraction, using fusels as stabilizers. Aldehyde is a colourless liquid produced by oxidation of alcohol. Fusel is a colourless oily alcohol separated in the rectification of ordinary distilled alcohol. The test bench can estimate the torque M_s, when the revolutions of the crankshaft range from 83 s^{-1} to 314 s^{-1} (800-3000 rev/min.), therefore, ecological characteristics of exhaust gases can be determined. The impact of the temperature of the alcohol mixtures' exhaust gases that was lower by 20-30°C on their toxicity was investigated.

Keywords: *internal combustion engines, engine bench tests, petrol-ethanol blends, hazardous emissions, carbon monoxide, hydrocarbons, carbon dioxide.*

1. Introduction

If oil fuels could burn up completely in the internal combustion engines (ICE) their emissions would consist only of carbon dioxide (CO_2), water vapour (H_2O) and nitrogen (N_2). However, in practice, the fuels do not burn up completely in the engine cylinder. When hydrocarbon fuels are burning in the ICE cylinder, about 200 various chemical compounds, most of which being noxious to humans and aggressive to the environment, are formed [1].

ICE emissions contain carbon monoxide (CO), hydrocarbons (C_nH_m), solid particles and aldehydes (R-CHO). When the temperature of ignition is very high (above 1400°C), hazardous nitrogen oxides (NO_x) are formed in the cylinder. When sulphur compounds are burning, the emissions containing sulphur dioxides (SO_2) and sulphur hydrogen (H_2S) can be observed [2].

The content of toxic materials in the emissions of internal combustion engines characterizes the combustion, but it does not assess the toxicity of emissions. For example, the toxicity of benzopyrene of the same concentration as carbon monoxide is by 3 million times higher, while solid particles are 60 times, nitrogen oxides (NO_x) - 35 times and hydrocarbons (C_nH_m) - two times as toxic as carbon monoxide.

The toxicity of the emissions largely depends on the composition of petrol-air mixture described by the air ratio coefficient λ. The lowest amount of (C_nH_m) is found in the emissions at the idle engine's running, when the air ratio coefficient is $\lambda = (0.8\text{-}0.85)$. By leaning the combustible mixture (when$\lambda > 0.9$), the amount of monoxide carbon (CO) is decreased, however, the emission of hydrocarbons (C_nH_m) increases because the ignition of the mixture is not stable.

We know from the literature [3-5] that, using pure ethanol as a fuel for spark ignition (SI) engines, the amount of CO_2 in the emissions of the engine decreases by 35%.

However, despite these advantages, the amount of aldehydes in the emissions largely increases, when engines use petrol-alcohol mixtures or pure alcohol fuels. Aldehyde pollution is highly harmful to the environment (e.g. formaldehyde is considered to be carcinogenic to humans) as well as contributing to engine wearing and diesel oil aging. The content of aldehydes in the emissions is increasing, when the alcohol concentration in the mixture is growing. The amount of aldehydes can be decreased by adding water to alcohols or by heating the air getting into the engine [2, 6].

The amount of the controlled poisonous materials in the emission decreases in case the alcohol is used as engine fuel The lower temperature of combustion in the cylinder (due to the presence of water in alcohol and higher heat of their evaporation) leads to the formation of the lower amount (by 10%.) of nitrogen oxides. The alcohol molecule contains an oxygen atom taking part in the combustion (oxidation) process [7].

In recent years, the main goal of the environment protection programmes of the most states in the world has become the reduction of carbon dioxide (CO_2) content in the emissions because the exhaust gases cause a greenhouse effect. This can be achieved only by decreasing the absolute consumption of oil fuels, i.e. using more energy-efficient vehicles (e.g. in transport) [8].

2. Research methods and the equipment used

The bench tests are aimed at working out the characteristics of partial speed loading and adjusting of the engine according to the ignition timing advance. Based on these characteristics, the dependence of the engine power, torque M_s and the emission of pollutants (CO, CO_2 and C_nH_m) on the fuel used can be determined.

Bench tests were performed with the 4-cylinder engine of 46 kW power. The ignition angle was adjusted to comply with technical specifications.

The engine was loaded by STE-28 type bench brake. The bench consists of an asynchronous three-phase electric motor, reduction gear and liquid rheostat to load and start the internal combustion engine. You can observe the stator response which is equal to the resistance of the rotating shaft via the balance mechanism.

A measuring device of the type AVL DiGas 465 (Austria) was used for determining the dependence of the amount of toxic materials, i.e. carbon monoxide (CO), hydrocarbons (C_nH_m), carbon dioxide (CO_2) in the exhaust gases and the air ratio coefficient λ on the number of revolutions of the crankshaft n, engine load M_s and angle of ignition advance Θ [4-5] .

Thermocouples were used to measure the temperature of the sucked air in the mixing chamber of the carburettor and the manifold of fuel-air mixture. The temperature of engine emissions in the exhaust pipe was measured at a distance of 1.5 m from the suction manifold. To determine the octane number of the fuel, a universal one-cylinder device UIT-85 was used [4].

3. Composition of petrol-alcohol mixtures used in testing

The bench tests of SI engine were conducted with Pb-free petrol A-76 and its mixtures with ethanol ester-aldehyde fracture, using fusels as stabilizers. The composition of these mixtures is shown in Tab. 1.

Tab. 1 Composition of fuels used in the bench test of SI engine

Fuel grade	Composition, %	Alcohol content (percent by volume)	Octane number of fuel
A - 76	Petrol	0	82.9
M_1	(74B+16E+10F)*	26	109
M_2	75B+15E+10F	25	108
M_3	86B+8E+6F	14	87.5

*B - petrol, F - fusel, E - ethanol ester - aldehyde.

Ester-aldehyde fracture consists of ethanol (92% by volume) and oxygen compounds with high octane number - dicarboxylic acids, their aldehydes, esters, high alcohols and methanol (8% by volume). This fracture (alcohol admixture in the fuel mixture being tested) is a waste product of the rectified technical ethanol obtained from molasses. A mixture of high octane number oxygen compounds contains dicarboxylic acids (concentration of 1.0 g/l), their aldehydes (35 g/l) and esters (30 g/l), as well as methanol (0.5%) and higher alcohols.

4. Investigation of ecological characteristics of the engine tested

4. 1. The dependence of SI engine's emission toxicity on its loading

When the loading of SI engine (with n = const.) using various kinds of fuel is growing, the amount of the released carbon monoxide (CO) is decreasing. In the mode of medium loading M_s = (50-100) Nm, the lowest CO concentration was found in petrol emissions, while, in the mode of highest loading M_s = (120-140) Nm, it was the lowest in the emissions of the mixture M_2. At the same time, CO concentration made only 0.06% by volume of emissions. This is shown in the graph presented in Fig. 1.

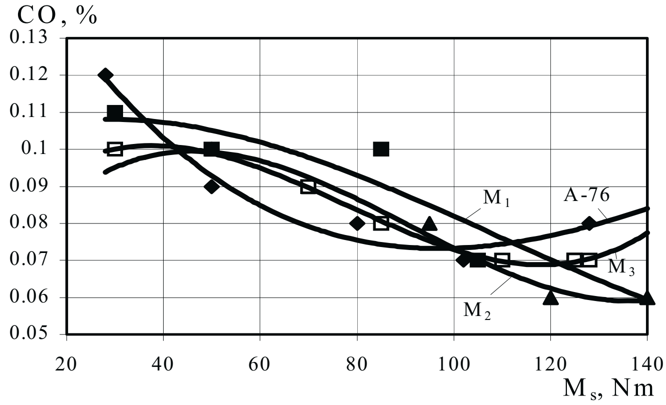

Fig. 1. The dependence of carbon monoxide (CO) concentration in SI engine emission on the engine's torque M_s, when n = 2100 rev/min

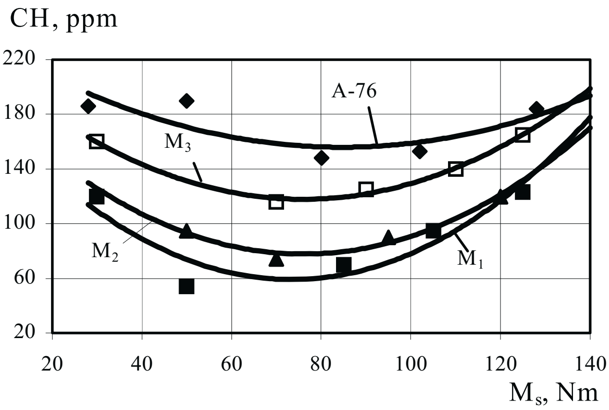

Fig. 2. The dependence of hydrocarbons (C_nH_m) concentration on the torque M_s of the engine using petrol-alcohol mixtures, when n = 2100 min^{-1}

As shown in the diagrams presented in Fig. 2, when the engine was using alcohol mixtures, the content of hydrocarbons (C_nH_m) in the emissions was several times lower. All the minimums of the fuel curves can be observed when the engine was working in the medium loading mode M_s = (50-95) Nm. The best results were obtained when the mixture M_1 was used because the content of hydrocarbons (C_nH_m) in the emissions made only one fourth of that found when petrol was used.

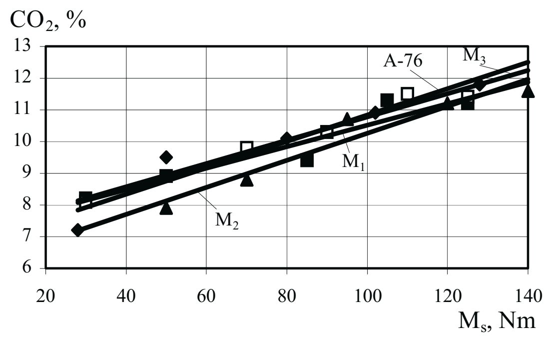

Fig. 3. The dependence of carbon dioxide (CO_2) concentration in SI engine emission on the engine's torque M_e, when n = 2100 rev/min

As shown in the diagrams presented in Fig. 3, the use of alcohol mixtures led to the reduction of the amount of carbon dioxide in the emissions of the engine working in the medium loading mode M_s = (50-80)Nm by about 12% compared to that found when clear petrol was used. The best result from the perspective of the environment protection was obtained when the mixture M_2 was used. In this case, the concentration of CO_2 was by 17% lower than its content in the emissions of the engine working in the medium loading mode.

4. 2. The dependence of emission toxicity on the crankshaft revolutions of the engine

In this case, the toxicity of emissions was measured in testing the engine based on the revolutions. The throttle valve was completely open and fixed, while the data were obtained by varying the loading.

As shown in the graphs presented in Fig. 4, the content of carbon monoxide (CO) in the emissions of the engine using alcohol mixtures made only one fifth - one tenth of the amount found when petrol was used. This indicates that alcohol mixtures are burnt more effectively in the cylinder. Since the pass valves of the carburettor had not been changed when these mixtures were used, the inlet manifold was not heated, and the above phenomenon could be attributed to the fact that alcohol fuels evaporated slower and the engine used a leaner mixture.

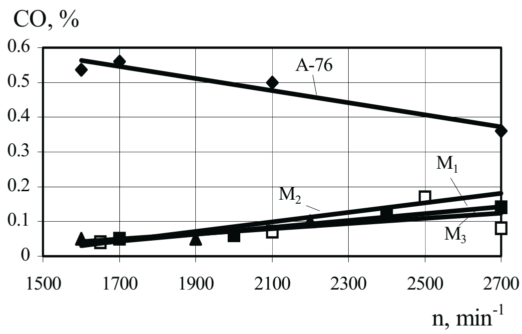

Fig. 4. The dependence of carbon monoxide (CO) concentration in SI engine emission on crankshaft revolutions n, when various kinds of fuel are used

The lowest concentration K_{CH} = (80-150) ppm of the exhausted hydrocarbons (C_nH_m) was observed when the mixture M_3 (14% of alcohol) was used. When other alcohol mixtures (i.e. M_1 and M_2) were used, the pollution was similar to that produced by petrol, while when the number of revolutions was larger (n = 2300-2700 min^{-1}), the emissions increased by (3-4) times (Fig. 5). This may be accounted for by a considerably higher content of alcohol in the mixtures M_1 and M_2. In this case, the crankshaft of the engine is revolving at a higher rate, the alcohol cannot evaporate in time and the fresh combustible mixture gets cooler. This, in turn, results in the formation of the condensate and not uniform distribution of the mixture in the cylinders.

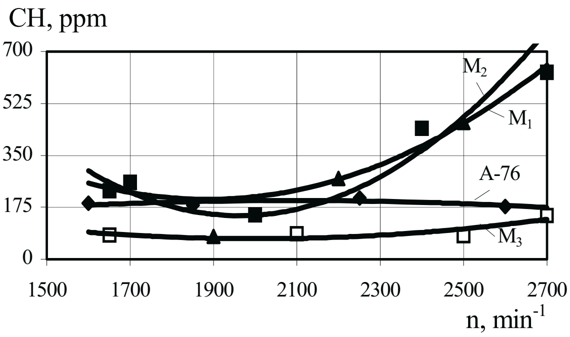

Fig. 5. The dependence of hydrocarbons (C_nH_m) concentration in SI engine emission on the crankshaft revolutions n when various kinds of fuel are used

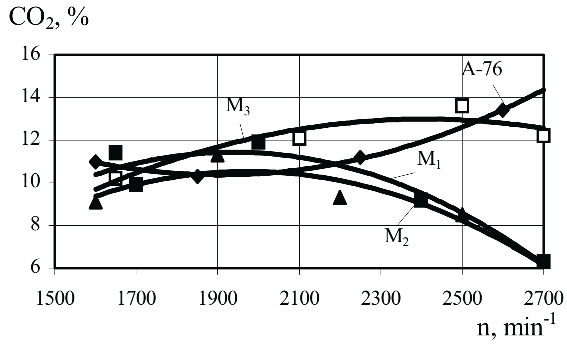

Fig. 6. The dependence of carbon dioxide (CO_2) concentration in SI engine emission on crankshaft revolutions n for various fuels

The analysis of the curves presented in Fig. 6 shows that the highest concentration of CO_2 in the emissions can be observed when the revolutions of the engine is $n = (1600\text{-}2000)$ rev/min.$^{-1}$ and it is using the mixture M_1, while at the rate of $n = (2200\text{-}2700)$ rev/min.$^{-1}$, the highest content of CO_2 is found when petrol and the mixture M_3 are used. When the number of the crankshaft revolutions *n* increases in the engine using alcohol mixtures M_1 and M_2, the concentration of carbon dioxide decreases, while when petrol and mixture M_3 (containing the lowest amount of alcohol) are used, the content of CO_2 in the emissions increases. The concentration of CO_2 in the emissions produced by using the mixtures M1 and M_2 decreases because, when the revolutions are high $n = (2300\text{-}2700)$ rev/min.$^{-1}$, great amounts of unburnt ethanol are released in the air.

4. 3. The influence of the ignition advance angle *Θ* on the toxicity of engine's emissions

The test was performed with the engine loaded up to 40-50%, with the revolutions of the crankshaft are $n = 2000 \pm 100$ rev/min.$^{-1}$. The ignition advance angle was gradually increased, while the throttle position remained unchanged.

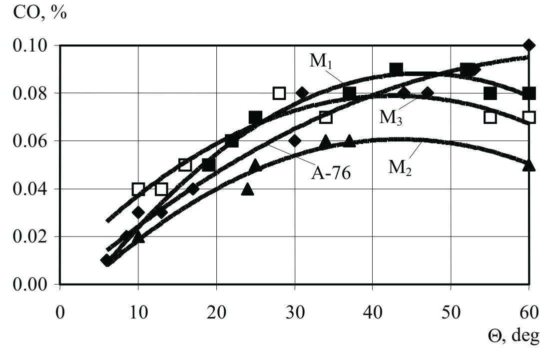

Fig. 7. The dependence of carbon monoxide (CO) concentration in SI engine exhaust gases on ignition advance angle Θ for various fuels

As shown by the curves presented in Fig. 7, the lowest CO concentration was found, when the ignition advance angle was $\Theta = 5\text{-}20°$. When $\Theta = (25\text{-}55)°$, the content of carbon monoxide increases by 3-5 times. When Θ is further increased, the operation of the engine becomes unstable. The combustible mixture is not ignited; therefore, the reduction of CO content indicates poor mixture ignition rather than more effective burning reaction.

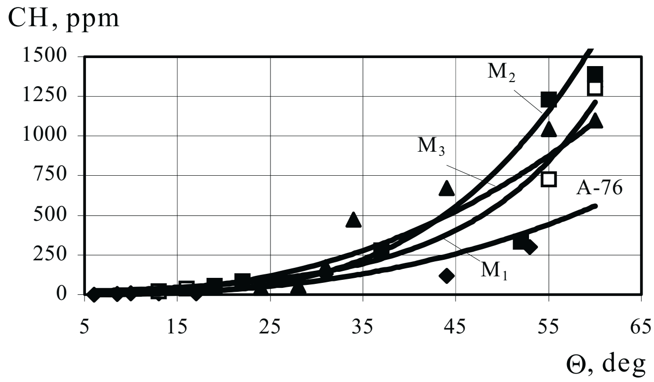

Fig. 8. The dependence of hydrocarbons (C_nH_m) concentration in SI engine exhaust gases on the ignition advance angle Θ for various fuels

The curves in Fig. 8 show that adjusting of the ignition advance angle Θ from 6° to 20° does not affect much the emission of hydrocarbons (C_nH_m). However, if Θ exceeds 25°, the curves $K_{CH} = f(\Theta)$ start to rise rapidly. When $\Theta = (55\text{-}60)°$, the amount of hydrocarbons in the emissions is by 10 times higher because the combustible mixture is not always ignited. The analysis of the graphs revealed that the petrol curve $K_{CH} = f(\Theta)$ was the last to start rising (when $\Theta = 50°$). The curves reflecting the use of the mixtures M_1 and M_2 begin to rise early, when $\Theta = 35°$.

As shown in Fig. 9, by adjusting the ignition advance angle Θ, the highest amount of carbon dioxide (CO_2) was obtained when petrol was used, while the lowest amount could be observed when the mixture M_2 was used. The increasing of Θ results in the decrease of CO_2 for both kinds of fuel used was fixed. This can be accounted for by the fact that, when the ignition advance angle is large, the combustible mixture is not always ignited. In this case, the amount of complete combustion products (CO_2) is small and more unburnt fuels are released in the atmosphere.

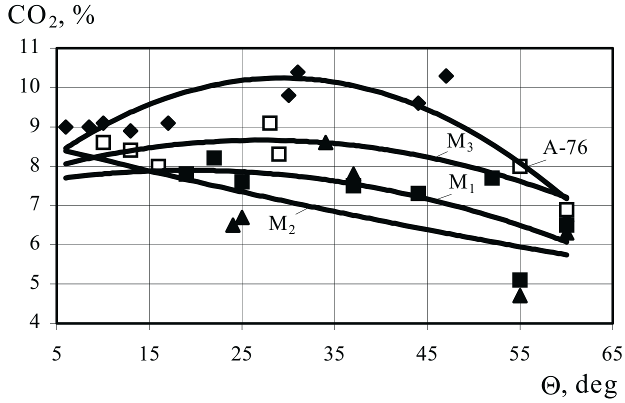

Fig. 9. The dependence of carbon dioxide (CO_2) concentration in SI engine exhaust gases on ignition advance angle Θ for various fuels

4. 4. The toxicity of emissions of the engine at idle running

As shown by the diagrams in Fig. 10-11, the lowest amount of incomplete combustion products (CO and C_nH_m) is found when the engine uses alcohol mixtures M_1 and M_2 at idle running.

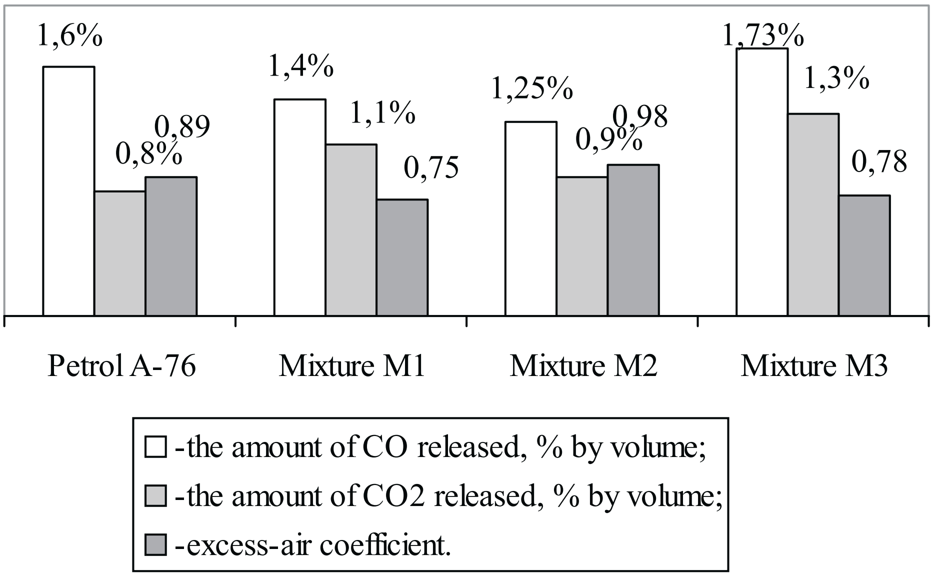

Fig. 10. The concentration of carbon monoxide (CO) and carbon dioxide (CO_2) in SI engine exhaust gases and their air/fuel ratio λ at idle running for various fuels

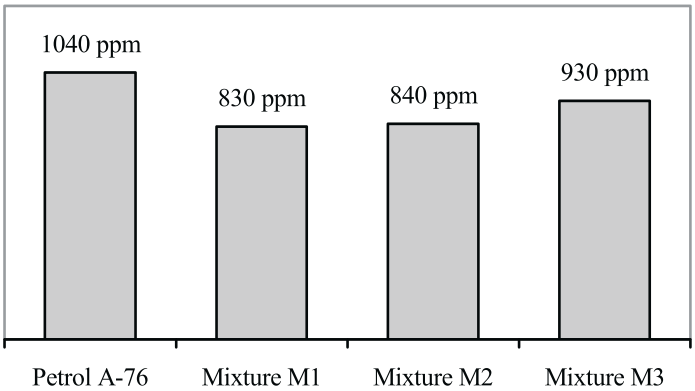

Fig. 11. The concentration of hydrocarbon (C_nH_m) in SI engine exhaust gases at idle running for various fuels

5. Conclusions

1. The analysis of the ecological characteristics has demonstrated that the concentration of carbon monoxide (CO) in emissions is lower by 10-15% as compared with petrol when the revolutions (n = 2100 rev/min) of the engine crankshaft are stable.
2. Concentration of hydrocarbons (HC) in the exhaust of alcohol mixtures is lower by 10-1% as compared to petrol in the full engine load spectrum. When the amount of ethanol is 25-26% by volume of the mixture, HC content in exhaust gases is even by (2-4) times lower as compared to clear petrol.
3. The wide opening of the fuel throttle and variation of the engine torque M_e leads to the formation of the amount of carbon monoxide (CO) in the alcohol mixture exhaust by (3-5) times smaller than its content in the petrol exhaust.
4. The concentration of hydrocarbons, HC, is lower by 0-30% in the exhaust gases of alcohol mixture compared to their content in petrol exhaust gases. When the content of ethanol reaches 5-26% by volume and the engine's rate of revolutions exceed 2200 rev/min, the ignition of the combustible mixture is not stable, and the unburnt fuel emission increases.
5. In the idle mode, the lowest concentration of CO and HC was found for petrol-alcohol mixtures M_1 and M_2.

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