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A New Concept of Dual Fuelled SI Engines Run on Gasoline and Alcohol

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Abstract

The paper discusses tests results of dual-fuel spark ignition engine with multipoint injection of alcohol and gasoline, injected in area of inlet valve. Fuelling of the engine was accomplished via prototype inlet system comprising duplex injectors controlled electronically. Implemented system enables feeding of the engine with gasoline only or alcohol only, and simultaneous combustion of a mixture of the both fuels with any fraction of alcohol. The tests were performed on four cylinders, spark ignition engine of Fiat 1100 MPI type. The paper presents comparative results of dual-fuel engine test when the engine runs on changing fraction of methyl alcohol. The tests have demonstrated an advantageous effect of alcohol additive on efficiency and TCH and NOx emission of the engine, especially in case of bigger shares of the alcohol and higher engine loads.

Keywords: SI engine, dual fuel, thermal efficiency, toxicity, alcohol share

1. Introduction

Ethyl and methyl alcohols have been used as fuels to SI piston engines for many years [1-6]. Owing to high knocking resistance and high heat of evaporation they were used as additives to hydrocarbon fuels. Owing to such features it was possible to increase compression ratio and performance of the engine, what was of a significant importance in heavy loads sports engines. Renewed interest in the alcohols has been seen since seventies of the twentieth century [2, 7]. Such interest was caused by gradual reduction of lead content in gasoline, fuels crisis and improvements in exploitation of crude oil resources. The main issue connected with alcohol additives in fuels, however, is a phenomenon of stratification of the mixtures in low tempera-

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tures and in presence of water. Because of it, there were used a ternary mixtures of gasoline-alcohol-benzyl or gasoline-alcohol-ether. Despite additives of stabilizers in the mixtures, content of alcohol in conditions of European climate did not exceed 8÷12%.

Usage of alcohol as a self-contained fuel is more advantageous, because it allows taking full advantage of high knocking resistance of alcohol, enabling increase of combustion ratio and growth of overall efficiency and unit power output of the engine [2, 3, 7, 11]. Such tendency is especially developed in Brazil with fleet of about 2 million cars run on ethyl alcohol produced from cavassa and sugar cane [12]. Comparison of relative parameters of gasoline and alcohols is shown in the Fig. 1. From this diagram is seen that usage of ethyl and methyl alcohol should result in more than 5% growth of standard engine performance, what is an effect of higher calorific value of the stoichiometric mixture. Additional growth of the parameters can be attained via more rapid process of combustion of alcohol mixtures and reduction of pumping loss due to reduction of temperature of aspirated charge. Another growth of the parameters can be obtained by increase of compression ratio, but it is connected with modification of engine design what disables, as a rule, operation on gasoline only.

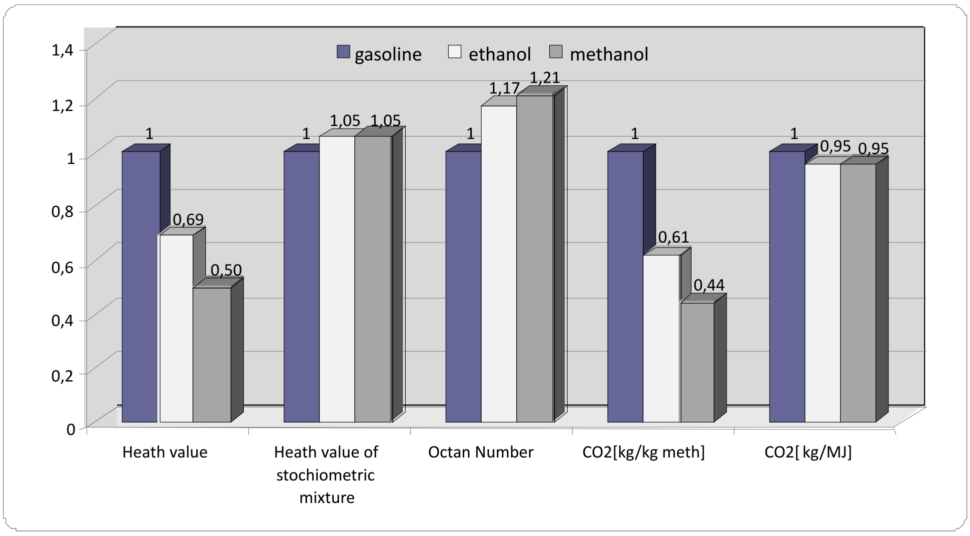

Fig. 1. Comparison of relative parameters of gasoline, ethanol and methanol

Common implementation of multipoint injection of light fuels creates a possibility in range of fraction volume of added alcohols in gasoline. Design solution described in the paper implements additional injectors in each cylinder, factory-new injectors are destined to injection of alcohol whereas additional ones to injection of gasoline. Such system enables simultaneous fuelling of the engine with gasoline and alcohol, whereas fraction of alcohol can change within limits of 0÷100%, depending on engine load and rotational speed [7-9]. Feeding of the engine at low loads with gasoline only or with a mixture having small additive of alcohol constituted assumption to the performed research. Share of alcohol increased with increase of engine load. Correct composition of the combusted mixture was controlled by opening time of gasoline and alcohol injectors. As a final stage of the research work is planned to increase compression ratio up to value restricted by knocking combustion at fuelling with alcohol only. It will enable to increase efficiency of the engine at partial loads, when the engine shall be run on gasoline mainly. It should be underlined that such direction of the feeding is currently investigated by Volvo and Ford, what can be proved by announcements in literature [13].

2. System of Dual-Fuel Feeding of the Engine

The substance of proposed feeding system is usage of duplex injectors in each cylinder to injection of gasoline and injection of alcohol. Scheme of prototype suction manifold is shown in the Figure 2. Additional injectors are located in frontal part of the manifold, Figure 3. Such configuration required modification of the manifold to enable assembly of the injectors and production of new fuel rail for the additional injectors. To assembly of the injectors there were implemented a steel sleeves bonded to the manifold with epoxy glue. Necessity of production of the prototype fuel rail resulted from different spacing of the injectors, which amounted to 37 mm. Alcohol was injected through factory injector of standard engine, gasoline through additional injector. More detailed description of the engine and the test bed is presented in the work [7, 8].

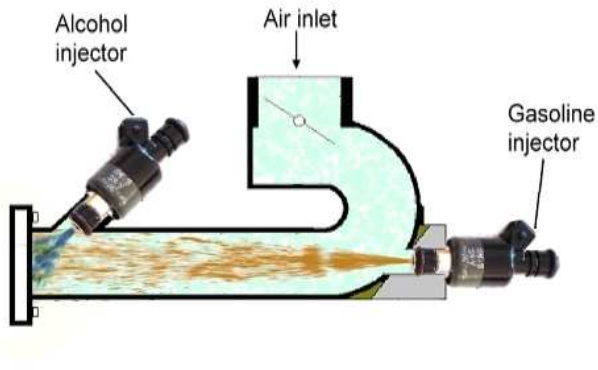

Fig. 2. Scheme of prototype suction manifold of Fiat 1100 MPI engine

Fig. 3. Factory suction manifold of Fiat 1100 MPI engine: 1 – location of additional injectors were assembled

The tests were performed on four cylinders, SI engine with multipoint injection of Fiat 1100 MPI type. Technical data of the engine are specified in the Table 1, whereas view of the test bed in the Figure 4.

Table 1

Technical data of Fiat 1100 MPI engine

Engine type	Fiat 1100 MPI
Bore×stroke	70×72 mm
Swept capacity	1108 ccm
Compression ratio	9,6
Rated power/engine speed	40 kW/5000 rpm
Torque/engine speed	88 Nm/3000 rpm

3. Analysis of the Test Results

Problem of dual fuelling of the engine can be considered from two points of view: run on gasoline only or on alcohol only, and simultaneous feeding with mixture of gasoline and alcohol. In the first case, compression ratio should remain the same as in factory-new engine. In the second case, at low loads the engine should be run on gasoline only and as engine load increases one should add alcohol. Portion of alcohol can be increased up to 100% at maximal loads. In this case it is possible to increase compression ratio of the engine with 1,5÷2,0 units.

Due to the above mentioned reasons, comparative tests were performed with feeding of the engine with gasoline only or alcohol only and injection of the fuels via

Fig. 4. View of the test bed: 1 – prototype fuel rail, 2 – additional injector, 3 – assembled original, factory fuel rail

factory-made injector, and with dual-fuel feeding with changing fraction of methyl alcohol. Share of methyl alcohol, calculated energetically amounted to 20, 40, 60, 80 and 100%. Ignition timing was identical as in case of feeding with gasoline. In case of dual-fuel feeding, gasoline was injected via additional injector whereas alcohol via factory injector. It should be underlined, that at low shares of alcohol big quantity of gasoline is injected via additional injector in distant location from inlet valve, what impairs conditions of gasoline-air mixture formation and can have an effect on engine parameters. Comparison of dual-fuel engine parameters was referenced to the values obtained in case of run on gasoline only, injected via factory injector of standard engine.

It is worth to emphasize that in case of feeding with methanol only the engine developed torque bigger with about 5% with respect to gasoline feeding. Such result was obtained without any optimization of ignition advance angle, and therefore it can be assumed that engine performance in case of such feeding and optimization of engine tuning can be still better. In course of the analysis presented in this paper one restricted himself to operational points for the same engine loads only. With such assumption, operational points of the engine operated at higher torque with respect to gasoline feeding were omitted.

Comparison of overall efficiency of the engine, presented in the Figure 5 shows that the engine run on methanol operates with higher thermal efficiency in complete range of engine loads and speeds. Simultaneously, differences in the efficiency increase together with growth of engine load and in range of medium and maximal loads absolute differences amount to 3÷5%, what results a relative increase of the efficiency in scope of 10÷16%. The relative increase of the efficiency decides about operational consumption of energy.

Usage of methanol advantageously effects on concentration of hydrocarbons and nitrogen oxides in exhaust gases, Figure 6. In complete range of engine loads there was observed nearly 2÷3 fold reduction of hydrocarbons concentration comparing to gasoline feeding. Such significant changes can be explained by different chemical composition of the methanol, CH_3OH, comparing to mixture of different hydrocarbons having complex chemical constitution and being a components of gasoline. Oxidation time of hydrocarbon increases as quantity of carbon and hydrogen increases, what in high-speed spark ignition engines effects on concentration of hydrocarbons in exhaust gases. Not without a meaning is also a fact that molecule of methanol contains oxygen, which when released in combustion process, speeds-up oxidation of carbon and hydrogen atoms. Additional factor which is conductive to fast oxidation of methanol are higher temperatures during combustion, with respect to temperatures present during gasoline feeding.

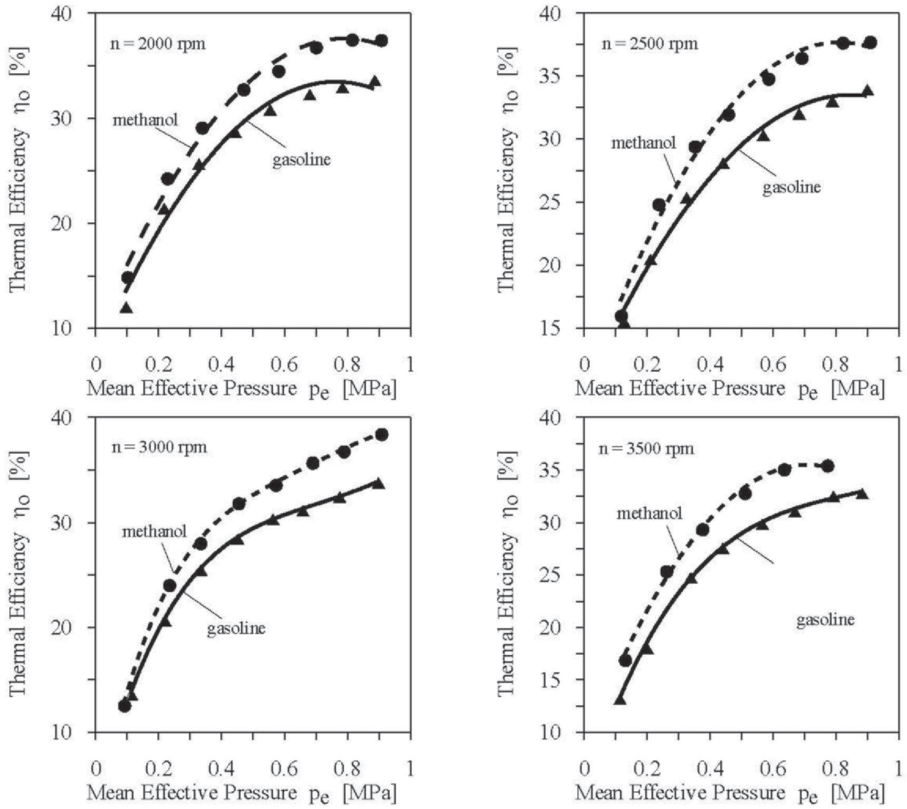

Fig. 5. Comparison of efficiency of Fiat 1100 MPI engine runs on gasoline and methanol

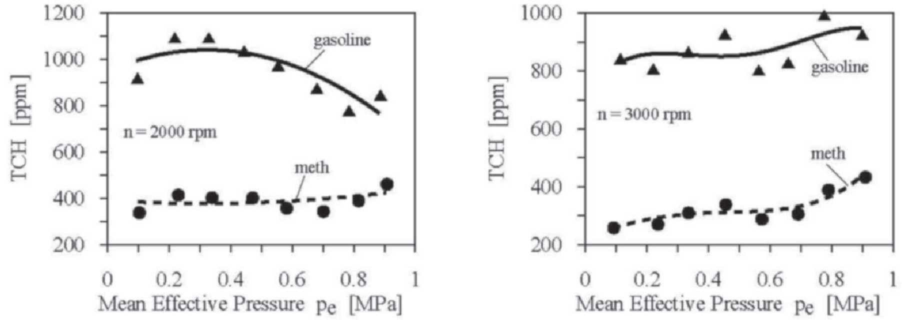

Fig. 6. Comparison of TCH hydrocarbons concentration in exhaust emissions of Fiat 1100 MPI engine run on gasoline and methanol

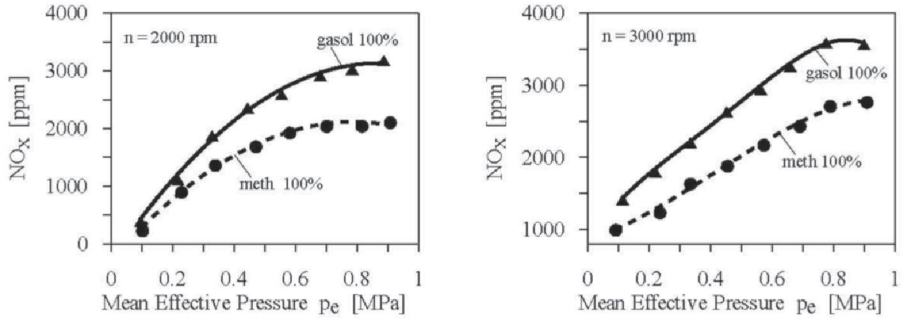

Fig. 7. Comparison of NOx nitrogen oxides concentration in exhaust emissions of Fiat 1100 MPI engine run on gasoline and methanol

From ecology point of view reduction of NOx concentration in exhaust gases present in complete range of engine load, Figure 7, is especially important. Differences in the NOx concentrations are growing as engine load grows, and in range of medium and maximal loads they amount to 40÷60%. Fact of reduction of NOx emission when feeding with methanol was also announced in earlier announcements in literature [7, 10, 11], while analysis of obtained test results points at significant extent of such phenomenon. Due to big difficulties connected with reduction of nitrogen oxide by catalytic converters, described advantageous feature of methanol combustion requires a special underlining.

Seems that explanation of the reasons of reduction of NOx quantities generated in process of methanol combustion is not easy and requires additional detailed analyses. Indeed, duration of combustion of methanol-air mixture is shorter, but simultaneously average temperatures of working medium during combustion are higher. Effect of time on quantities of generated NO, the main constituent of nitrogen oxides in exhaust emissions of spark ignition engines, is linear while effect of temperature is mainly of exponential character. Therefore, growth of temperature should effect more significantly on quantities of generated NO than reduction of the time, and in consequence should lead to growth to NOx concentration in exhaust gases. It seems, anyhow, that in such case a significant role can be played by considerable quantity of oxygen contained in molecules of methanol, which mainly take part in oxidation of the fuel. With the same coefficient of excess air for methanol and gasoline, quantity of oxygen supplied with aspirated air is smaller at feeding with methanol, what can have effect on reduction of quantity of generated NOx.

Changes observed on course of combustion at feeding with alcohol have an effect on changes of pressure run in cylinder bore, what is shown in the Figure 8. Alcohol-air mixture is combusted faster than gasoline, and maximal pressures in cylinder bore are generated earlier. It is especially visible at partial engine loads. This phenomenon is a one of reasons of growth of overall efficiency of the engine.

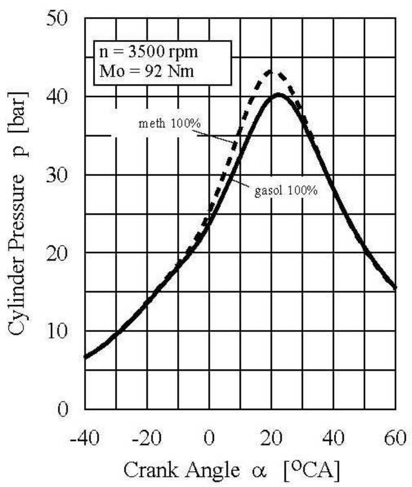

Fig. 8. Comparison of course of cylinder's pressure during combustion in Fiat 1100 MPI engine run on gasoline and alcohol

Comparison of thermal efficiency of the engine in function of engine load for various shares of methanol is presented in the Figure 9. Additive of methanol results in growth of thermal efficiency of the engine as methanol portion and engine load increase. For higher shares of methanol the efficiencies were higher than observed in case of gasoline feeding. Especially big differences are present at feeding with methanol only (share of 100%). In case of small additive of methanol (share of 20%) at low engine load the efficiency at dual-fuel feeding was smaller than in case of traditional feeding. It doesn't undermine, however, the fact of advantageous effect of methanol additive on the efficiency; because the results were probably affected by fact that at dual-fuel feeding the gasoline was injected via additional injector in distant location from inlet valve. It had an effect on conditions of gasoline-air mixture creation and in case of supremacy of gasoline's share and low engine loads it had decisive effect on generated efficiency. In discussed conditions of engine operation, advantageous effect of methanol, proportional to its share in the charge, did not compensate loss of the efficiency caused by worsening of conditions of evaporation and blending of gasoline with air. It should be stressed that as early as in stage of initial tests performed after assembly of the prototype manifold, one pointed at unfavorable effect of changed location of gasoline injection point on efficiency of the engine. Seems that more advantageous conditions could be obtained with use of initial mixer of alcohol with gasoline, and injection of prepared earlier mixture via factory injectors. It is planned to devote a future tests to this issue.

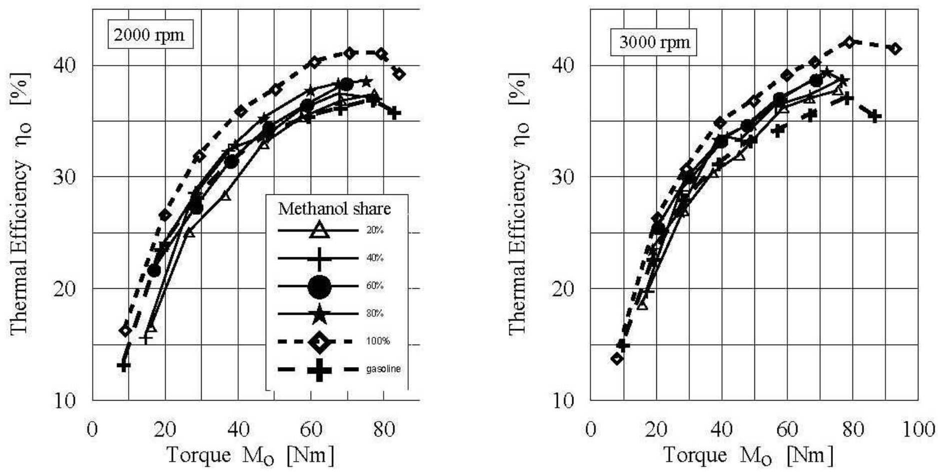

Fig. 9. Comparison of thermal efficiency of Fiat 1100 MPI engine run on gasoline only and in dual-fuel feeding with different shares of methanol

Absolute change of thermal efficiency of the engine in measuring points was determined as a difference of the efficiency at dual-fuel feeding and in traditional feeding, at the same load and rotational speed:

$$\Delta\eta_o = \eta_d - \eta_b \tag{1}$$

where: $\Delta\eta_o$ – change of thermal efficiency of the engine [%],
η_d – efficiency of the engine at dual-fuel feeding [%],
η_b – efficiency of the engine at gasoline feeding [%].

Effect of dual-fuel feeding on operational consumption of energy can be determined as a relative change of the thermal efficiency calculated from the following formula:

$$\delta_o = \frac{\Delta\eta_o}{\eta_b} \cdot 100\% \tag{2}$$

Runs of relative values of engine's effectiveness change in function of engine load for different shares of methanol shown in the Figure 10 point at considerable improvement of engine efficiency in range of medium and maximal engine loads, especially for bigger shares of methanol. Relative changes of the efficiency above 10% should contribute to reduction of operational fuel consumption and improvement of its ecological features.

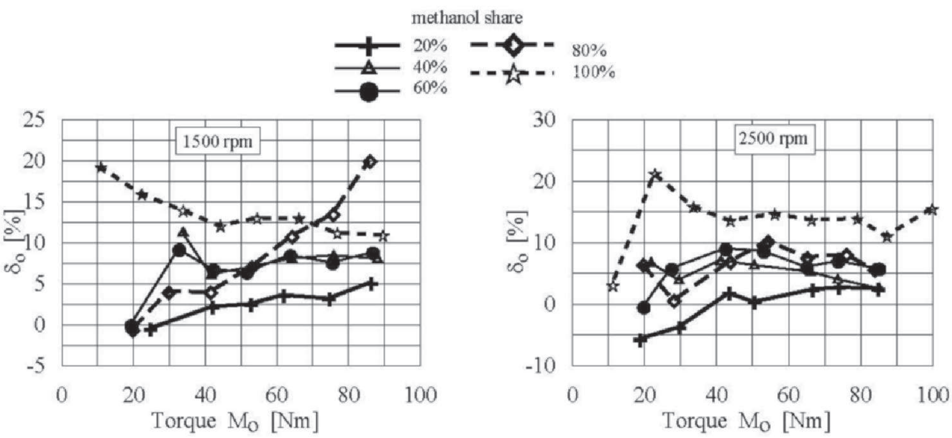

Fig. 10. Relative changes of thermal efficiency of dual-fuelled engine for various methanol share

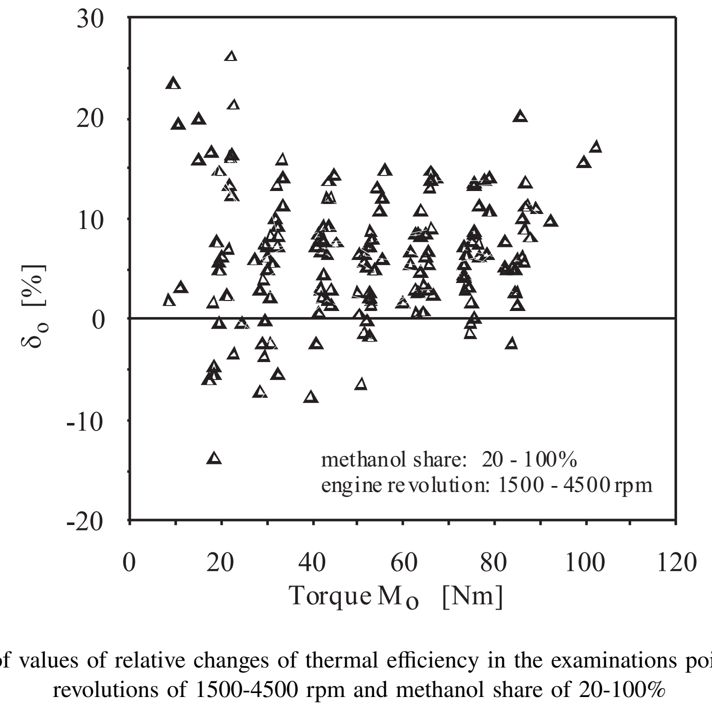

Fig. 11. Set of values of relative changes of thermal efficiency in the examinations points for engine revolutions of 1500-4500 rpm and methanol share of 20-100%

Set of projections of all values of relative change of the effectiveness on the δ_o-M_o plane for engine revolution of 1500-4500 rpm and 20-100% shares of methanol is presented in the Figure 11. From location of the points in the Figure 11 comes that in prevailing number of engine operational states dual-fuel feeding effects advantageously on the thermal efficiency, causing its growth. Reduction of the efficiency in some measuring points, in range of small and slight shares of methanol mainly, can be connected with different injection of gasoline comparing with injection in standard engine.

Additive of methanol also effects advantageously on ecological properties of the engine, causing reduction of hydrocarbons and nitrogen oxides concentration in exhaust gases, what is presented in the Figs. 12÷13. Concentration of hydrocarbons in range of medium and maximal engine loads decreases with growth of methanol share in the mixture. However, in range of low engine loads and additive of methanol below 40%, concentrations of hydrocarbon can be higher what is probably connected with worsening of conditions of homogenous gasoline-air mixture generation, what was signaled earlier.

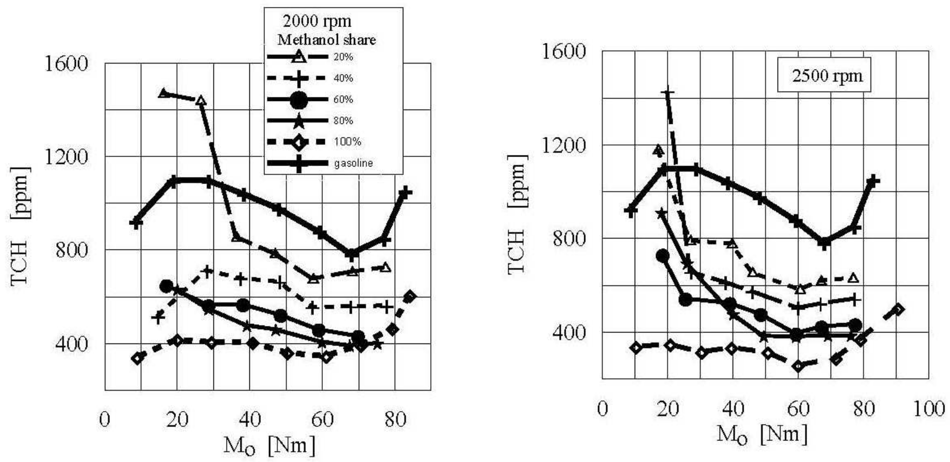

Fig. 12. Comparison of concentration of total TCH hydrocarbons in Fiat 1100 MPI engine fed with gasoline and in dual-fuel system at different shares of methanol

4. Conclusions

On base of the performed tests it is possible to draw the following general character conclusions:

- Dual-fuel feeding with gasoline and alcohol has advantageous effect on external parameters of the engine, such as overall efficiency, maximal power output, and

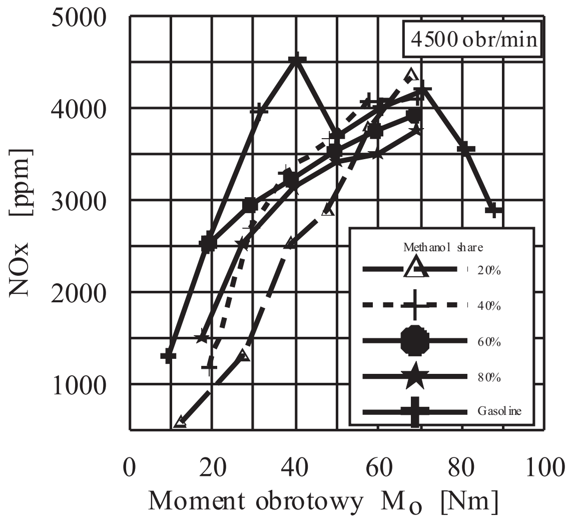

Fig. 13. Comparison of nitrogen oxides NOx concentration in Fiat 1100 MPI engine fed with gasoline and in dual-fuel system at different shares of methanol

maximal torque. Max power output and torque can be increased with about 5%, maintaining compression ratio of the standard engine.

- Growth of overall efficiency of the engine increases with growth of methanol share and engine load. Absolute growth of the efficiency amounted to 2÷5%, while relative growth amounted to 6÷16%. Significant growth of engine efficiency should lead to reduction of operational consumption of energy and improvement of ecological parameters of the engine.
- Worsening of engine efficiency in some investigated points, especially at low engine load and low shares of methanol can be connected with remote distance of gasoline's injection point fare from inlet valve due to incorporation of additional injector. This issue requires additional tests and production of a new aspiration collector.
- Analysis of summary indices of energetic advantages resulted from implementation of dual-fuel feeding shows at fact that implemented prototype feeding system should contribute to considerable reduction of energy consumption by spark ignition traction engines.
- Correct utilization of high knock resistance of ethyl and methyl alcohol requires compression ratio increased with 1,5÷2,0 units, what should contribute to growth of overall efficiency of the engine, especially at low loads.
- Implementation of additional alcohol fuel should lead to reduction of emission of basic components of exhaust gases, especially THC and NOx, as well as carbon dioxide, CO_2.
- Developed feeding system can be characterized by many advantages, substantial

for dual-fuel feeding of spark ignition engine. Among the advantages one can specify:
- possibility of engine start-up on gasoline only, what enables to maintain its starting capability like in case of traditional feeding;
- possibility of dual-fuel feeding with actively changeable share of alcohol, depending on engine load and rotational speed;
- possibility of usage of a big shares of alcohol without any danger of fuel stratification;
- possibility of increase of compression ratio and automatic shift to feeding with alcohol only at maximal engine loads.

- It seems that due to chemical similarity of methyl and ethyl alcohols, results similar to the ones described here can be obtained by usage ethyl alcohol as additive to gasoline.

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