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DUAL FUELLING CI ENGINE WITH METHANOL AND DIESEL OIL

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Abstract

Dual fuel compression ignition engine can be run on diverse fuels, both gaseous and liquid ones. Alternative fuels to the Diesel oil feature, as a rule, low cetane number and high temperature of self-ignition. Due to this, such fuels can not be ignited spontaneously and require ignition from small dose of the Diesel oil. In the dual fuel system, as the main fuel can be considered a liquid fuels, which can be supplied to the cylinder in form of vapours, or injected be to the suction manifold. Methyl and ethyl alcohols, or their esters, can be counted among future fuels. Such alcohols can be either the main fuels or small additions improving combustion of the Diesel oil. In the paper are presented test results of the SW 680 engine run on methanol and Diesel oil. Methanol was supplied to the suction manifold in form of methanol-air aerosol. Energetic fraction of the methanol amounted to 12-50%, depending on engine load. Performed tests have shown advantageous effect of the methanol on performance of the engine. One confirmed considerable growth of overall efficiency of the engine in area of higher loads (3-6%), reduction of smokiness of exhaust gases achieved as early as with small additives of the methanol (2-3 times), reduction of CO and CO_2 emissions, reduction of exhaust gases temperature. Small addition of the methanol affects advantageously on combustion of the Diesel oil, shortening time if its combustion. Addition of the methanol enables maintaining effective power of the engine fuelled traditionally, and even its slight growth. Cost of adaptation to dual fuel supply with alcohol are low, and such type of fuelling can be easy implemented in already operated compression ignition engines.

Keywords: *dual fuel, alcohol, methanol, thermal efficiency, toxity*

1. Introduction

Diesel engine fuelled simultaneously with two fuels: fuel with low cetane number, being the main fuel, and the Diesel oil initiating ignition, was assumed to be called as dual fuel engine. Concept of the dual fuel engine was developed at the end of nineteenth century by Rudolf Diesel. Initiation of combustion of homogenous combustible mixture by small dose of the Diesel oil, injected in final phase of compression stroke, belongs to characteristic features of the dual fuel engine. Owing to high energy released from combustion of the initial dose and spatial range of liquid fuel's stream is obtained reliable ignition of the mixture in broad range of air excess number. Due to spatial nature of the stream, such type of the ignition was assumed to be called as stream ignition [14].

Depending on type of the engine, are used the following sizes of the initial dose, referenced to unit dose of energy supplied to the cylinder in nominal conditions Q_{jzn} [18]:

- 15-25%Q_{jzn} – with use of mass production injection system and piston pumps,
- 10-15%Q_{jzn} – with use of mass production high pressure systems of *common rail* type,
- about 5%Q_{jzn} – with use of additional pumps and injectors for the unit dose,
- 1.0-1.5%Q_{jzn} – with use of a special apparatus for the unit dose injected to pre-combustion chambers.

Dual fuel compression ignition engine can be run on diverse fuels, both gaseous and liquid ones, what is schematically presented in the Fig. 1.

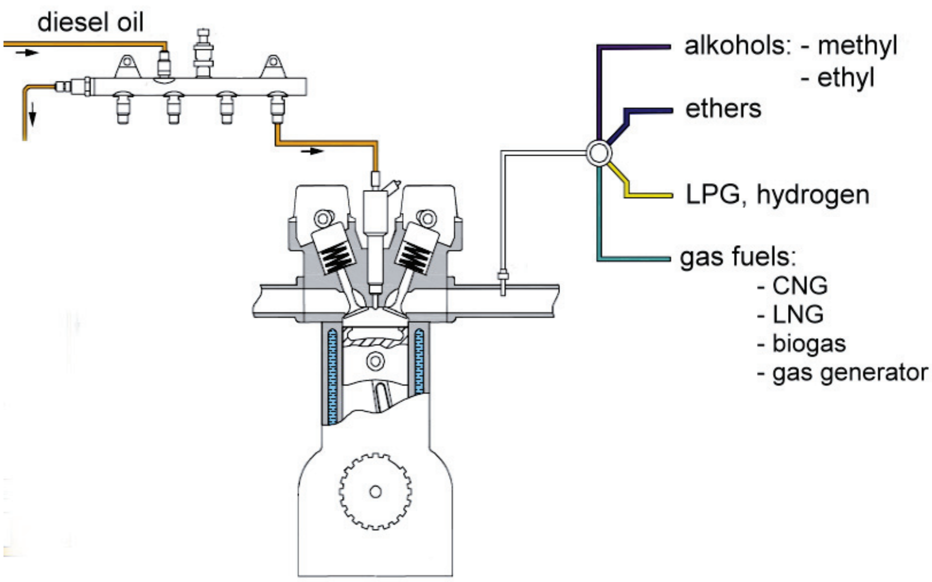

Fig. 1. Possibilities of dual fuel supply of compression ignition engine

All the fuels specified in the Fig. 1, which are assumed to be the main source of energy supplied to the engine, are characterized by high temperature of self-ignition and low cetane number, what disables controlled self-ignition in conditions of engine operation [1-9, 14, 18]. Due to it, it is necessary to incorporate external source of ignition (spark ignition engines) [3, 4, 15-17], or initial dose of the Diesel oil (compression ignition engine) [2, 5, 7-9]. In the dual fuel engine, various liquid fuels can be used also as the main fuel, supplied to the cylinder in form of vapours, or injected to the suction manifold. To a future fuels can be included ethyl and methyl alcohols and their ethers. The alcohols can be used both as the main fuels, and as a small additions improving combustion of the Diesel oil [5, 6, 10-12]. Issue of usage of alcohols in dual fuel compression engines was investigated in the past in the Radom University of Technology (studies of Luft [2, 9] and Kowalewicz [3-7]) and in Bielsko-Biala branch of the Lodz University of Technology with participation of the author [18].

Below are presented some test results of the SW 680 dual fuel engine run on Diesel oil and methanol, supplied to the cylinder with use of mixing system in form of methanol-air emulsion.

2. Experimental engine

The tests were performed on 6 cylinders compression ignition engine of the SW 680 type and direct injection, produced by WSK Mielec. Design of this engine is based on license granted by Leyland Company. Technical data of the engine are presented in the Table 1.

To fuelling of the engine was used a mixing system located in the suction manifold, supplying to the cylinders a mixture comprising emulsion of the methanol-air. Composition of the emulsion was dependent on vacuum pressure in choke of the mixing device of the methanol. In result, at constant rotational speed of the engine, mass of suctioned methanol was constant, whereas composition of the methanol-air mixture was determined by the air excess number $\lambda_o \approx$ const.

Change of engine load was accomplished through change of unit dose of the Diesel oil.

Implemented control system of the engine caused that energetic fraction of the methanol in total dose of energy supplied to the engine increased together with reduction of engine load.

Due to high heat of vaporization of the methanol (r = 1101,13 kJ/kg), parameters of the charge decreased during compression, what had effect on process of self-ignition delay of the Diesel oil.

Tab. 1. Technical data of engine SW 680

Parameter	Size parameter
Type	SW 680/79/1
Number of cylinders	6 circuit line, vertical
Bore	127 mm
Stroke	146 mm
Displacement	11.1 dcm^3
Compression ratio	1:15.8
Rated power	141-148 kW
Engine speed of rated power	2200 rpm
Maximum torque	711.2 N·m
Engine speed of maximum torque	1450 rpm
Type of combustion chamber	toroidal in the piston direct injection symmetric
The order of injection	1-5-3-6-2-4
Injection pump	six-sectional, pistons self-propelled, type: P56-01A
Injector	W18-01
Atomizer	D1LMK 140/2
Injection pressure	17.0-17.5 MPa
Injection timing	$26^o + 2^o$ for TDC

3. Analysis of test results

Addition of the methanol results in growth of overall efficiency of the SW 680 engine operating at maximal load in range of 3-6%, comparing to the engine fuelled traditionally (Fig. 2a). It is connected with higher combustion rate of the methanol-air mixture, comparing to combustion of the Diesel oil. Although fraction of energy supplied with the methanol wasn't high, 8-18% of total energy supplied to the engine at maximal load, however, rapid release of the energy also increases combustion rate of the Diesel oil, shortening time of complete combustion of the charge. Shift of maximal dynamics of the combustion in direction of the TDC, and growth of overall efficiency of the engine are results of such interaction.

Shortening of combustion time effects in reduction of exhaust gases temperature downstream the exhaust valve (Fig. 2b). Reduction of the temperature amounted to 90-100^{o}C, while differences between traditional fuel supply and dual fuel supply increased together with growth of engine's rotational speed. In the investigated engine, this fact confirms positive interaction of combustion of the methanol on combustion of the Diesel oil.

It seems that much bigger benefits can be attained in highly supercharged compression ignition engines by intermediate injection of the methanol to area near the inlet valve, what would allow to take advantage of high heat of vaporization of the methanol to cooling of sucked air [9, 17, 18].

To adverse phenomena connected with usage of the methanol can be counted growth of concentration of hydrocarbons and nitrogen oxides in the exhaust gases, comparing to the engine fuelled traditionally (Fig. 3b and 3c).

Growth of THC concentrations results from, similarly like in case of fuelling with gas, valve overlapping, causing what part of the methanol-air mixture penetrates to the exhaust gases and is purged to atmosphere. Such phenomenon is extremely adverse, because the methanol unlike methane, the main component of majority of gaseous fuels, is highly toxic, and in consequence results in pollution of natural environment. Therefore, systems of direct or indirect injection of the methanol are more advantageous, because in such case it is possible to correlate opening time of injector of the methanol with closing time of the exhaust valve, what restricts scavenge of fuel to the exhaust system. Such investigations were performed by prof. Kowalewicz in the Radom University of Technology [5, 6].

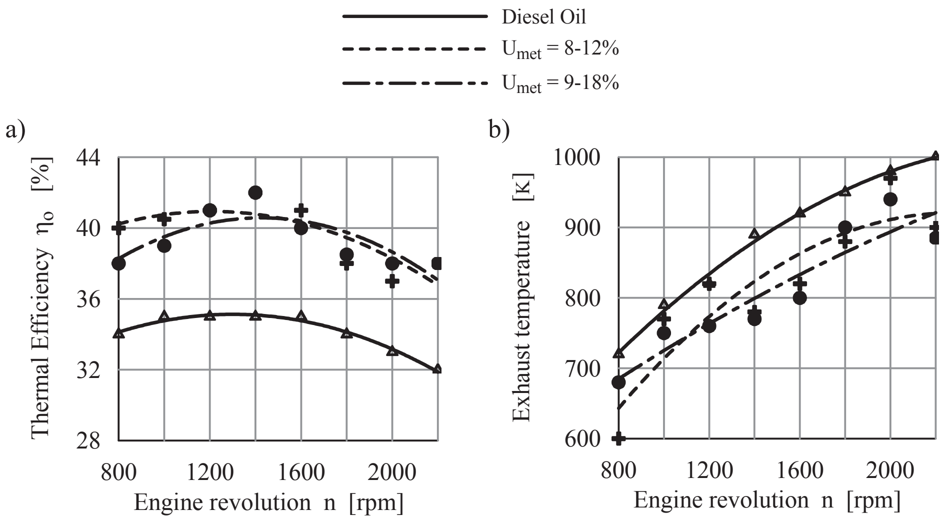

Fig. 2. Effect of rotational speed on overall efficiency and temperature of exhaust gases of the SW 680 engine operated on Diesel oil and run in dual fuel system, fuelled with Diesel oil and methanol: maximal engine load

Growth of combustion rate in the engine fuelled with methanol and Diesel oil results in growth of NO_x concentration in exhaust gases at full load of the engine (Fig. 3c).

The highest differences in the NO_x concentration are present in area of lower rotational speeds (growth with 30%) and decrease together with increase of the speed, while in range of 2000-2200 rpm are even smaller than the concentrations in case of traditional fuelling.

Additive of the methanol have also advantageous effect on smokiness of exhaust gases (Fig. 3d). Reduction of the smokiness depends on fraction of the methanol in total dose of energy. For a smaller fraction U_{met}, nearly twice reduction of the smokiness occurs in complete range of

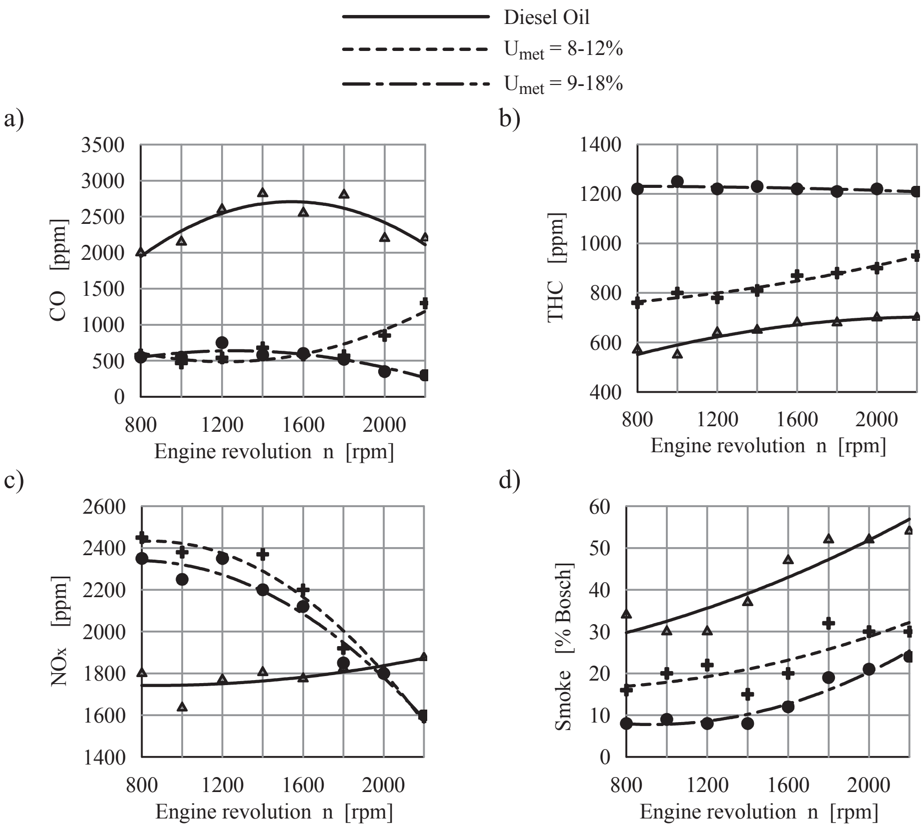

Fig. 3. Comparison of concentrations of exhaust gases components of the SW 680 engine fuelled with Diesel oil and methanol

change of rotational speed. At increased fraction U_{met} one obtained 2.6-3.0 times reduction of the smokiness. It points at possibility of considerable reduction of solid particulates emission, PM, of the engine at full loads through slight additive of the methyl or ethyl alcohol. This is very important feature of dual fuel engine, which can be implemented in bus engines, operated in center of cities with heavy traffic. Costs of adaptation to dual fuel supply with the alcohols are small, what should encourage users to implement dual fuel systems.

Reduction of the smokiness enables growth of maximal power output and torque of the engine run on the methanol. It can be obtained through reduction of average air excess number for entire charge calculated from the following formula:

$$\lambda = \frac{\dot{V}_p}{\dot{m}_{on} \cdot L_{on} + \dot{m}_{met} \cdot L_{met}}, \tag{1}$$

where:

$\dot{V}_p$ – flow rate of the air sucked by the engine [nm^3/s],

$\dot{m}_{on}$, $\dot{m}_{met}$ – deliveries of the Diesel oil and methanol [kg/s],

L_{on}, L_{met} – theoretical demand of air for the Diesel oil and methanol [nm^3/kg].

However, assumption to performed comparative tests was obtainment of identical power output like in case of traditional fuelling (Fig. 4). This condition was reached through limitation of maximal dose of the Diesel oil injected to the engine.

In course of the tests described in this paper, change of engine load was accomplished through decrease of dose of the Diesel oil. Implemented system of methanol supply assured constant output of the methanol at steady rotational speed. In result, together with reduction of engine load, fraction of the methanol increased to a value of about 40-48%, depending on the rotational speed (Fig. 5a).

Comparison of overall efficiency of the engine fuelled in dual fuel system and the engine fuelled traditionally shows that addition of the methanol have advantageous effect on overall efficiency of the engine run in dual fuel system only in area of average and maximal loads (Fig. 5b-5d). In area of minimal loads, overall efficiencies of the dual fuel engine were slightly lower than overall efficiency of the engine fuelled traditionally. Explanation of this phenomenon is not easy, because in complete range of changing engine loads, the methanol-air mixture featured nearly constant composition λ_o=const. At small fraction of the methanol (about 12% of energy in nominal conditions), the methanol-air mixture was so lean that at decreasing dose of the Diesel oil, conditions of its combustion deteriorated. In such case, smaller range of the stream and decreasing ignition energy are of essential meaning. In result, thermal efficiency decreases more rapid than in the engine fuelled traditionally. It can be also assumed, that decreased temperature of the charge, due to evaporation of the methanol, and smaller concentration of oxygen in the charge, have adverse effect on combustion of the Diesel oil, what additionally effects in reduction of the efficiency.

It seems that influence of stream of liquid fuel plays a crucial role in case of combustion of lean mixtures of the methanol. It can be confirmed by studies of the Luft [2, 9], in which the engine was supplied with methanol vapours from a special evaporator located outside the inlet system. Moreover, in these investigations one confirmed reduction of overall efficiency of the dual fuel engine at small initial doses.

4. Summary

On the base of performed tests it is possible to formulate some observations of a general nature, connected with fuelling of the dual fuel engine with alcohols. To advantageous phenomena can be included:

- meaningful growth of overall efficiency of the engine in area of a higher loads, with use of big doses of the Diesel oil,

- possibility to maintain the same, or even slightly better, power output as in case of the engine fuelled traditionally,
- considerable reduction of smokiness of exhaust gases achieved even in case of low additions of the methanol,
- reduction of carbon dioxide emissions due to smaller fraction of carbon in particle of the methanol, comparing to traditional fuels,
- reduction of temperature of exhaust gases,
- low adaptation costs to dual fuel feeding with the alcohol.

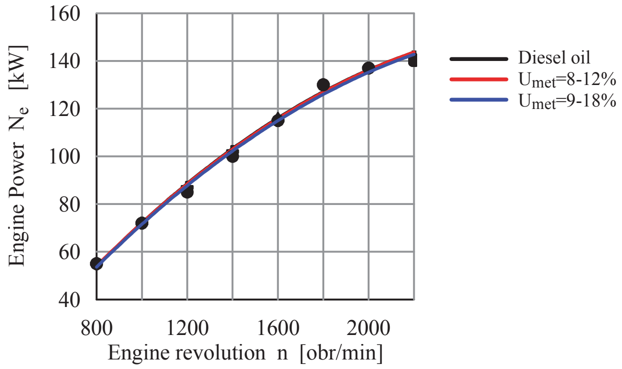

Fig. 4. Comparison of maximal power output of the SW 680 engine run in dual fuel system – fuelled with Diesel oil and methanol

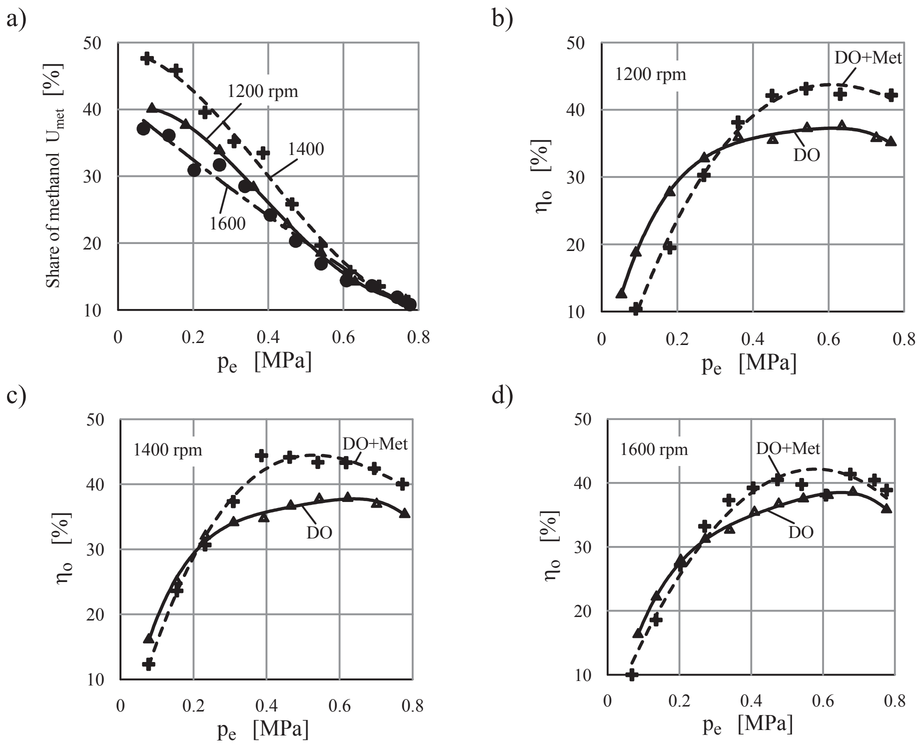

Fig. 5. Comparison of energetic fraction of the methanol and overall efficiency of the SW 680 engine fuelled with Diesel oil and run in dual fuel system – fuelled with Diesel oil and methanol: different rotational speeds

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