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INFLUENCE OF THE DISTANCE BETWEEN GAS INJECTOR AND INTAKE VALVE ON COMBUSTION INDICATORS AND NO_x EMISSION IN DUAL FUEL CI ENGINE

The use of alternative energy sources for internal combustion (IC) engines is being raised. The most promising fuel in such application is natural gas in gaseous state, which mainly consists methane. It is mainly being used as an engine fuel for both monofuel and dual fuel configuration. Many investigations confirmed the benefits of application of dual fuel compression ignition engine fuelled with natural gas. The aim of this paper is analysis of engine operation parameters and emissions for two different locations of gas injector in the inlet duct. The operation parameters and NO_x emission from this research are presented and compared for different natural gas shares in total energy delivered to the cylinder with fuel. The parameters are compared to monofuel operated engine.

Keywords: dual fuel engine, compressed natural gas, injector, performance

1. INTRODUCTION

Compressed natural gas is currently third growth energy source in the world. Total consumption of this fuel is raising constantly. This fuel is being used mostly to spark ignition engines due to very high octane number and required high knock-resistance. However, significant share in the European market have got currently compression ignition (CI) engines, which can be operated both in monofuel and in dual fuel mode with diesel oil and NG (natural gas).

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The literature review indicated many confirmed advantages of engines operating in discussed configuration. In the investigations reported in [Louinici 2014] lower in-cylinder pressures were noticed up to 40% of maximal engine load. It can effect quieter combustion noise and lower vibration level. Lower brake specific fuel consumption was observed at high loads in whole investigated range of engine speed. Work parameters and emissions of heavy duty dual fuel CI engine operated in transient conditions have been investigated [Barroso et al. 2013]. Significant reduction of PM emission was observed simultaneously with reduction of CO_2 emission. Higher NO_x emission was noticed during operation of CI engine in the dual fuel mode with NG, which can be although reduced with exhaust gas recirculation (EGR). In the investigations presented in [Abdelaal et al. 2012] the dual fuel CI engine was operated with 5%, 10%, 15% and 20% of EGR. In whole investigated load range the significant reductions of NO_x and CO_2 emissions were noticed.

Important problem combined with usage of CNG as an engine fuel, is irregular composition for different distribution regions. The heating value can vary for ca. 10% what impacts in-cylinder temperatures, overall engine efficiency and therefore energy produced from unit mass of fuel [Farzaneh-Gord 2012]. The distribution region must be also considered for final calibration of combustion system.

The conversion of monofuel CI engine to dual fuel requires change of regulation parameters [Mikulski et al. 2016]. Different injection strategies of CI engine and indicated significant differences in early flame propagation under change of diesel injection parameters have been analysed [Pielecha et al. 2012]. In discussed combustion system the pilot diesel injection ignites mixture of air and gaseous fuel, so the choice of pilot injection configuration will impact combustion of main fuel dose. Some investigations indicated significant increase of carbon monoxide emissions after conversion to dual fuelling, which can be reduced on the way of advanced timing of diesel fuel [Nwafor 2007]. The timing of GF injection influence also engine operational indicators and one has to consider the distance between gas injector and combustion chamber. This parameter influence significantly the mixture formation and requires further detailed analysis.

2. RESEARCH PROBLEM AND SCOPE OF INVESTIGATIONS

The compression ignition engines are being still very popular and their further development is strongly expected. In dual-fuel CI engines diesel fuel can be partially substituted with natural gas, as it was mentioned in the chapter 1. The substitution rate i.e. share of CNG (U_{GF}) depends on few factors e.g. load [Cummins Dual Fuel Engines–brochure] and can be described as the relation of heating values of gaseous E_{GF} and liquid fuels E_{DF} (1):

$$U_{GF} = \frac{E_{GF}}{E_{DF}} \tag{1}$$

From the literature review can be concluded that injection of the gaseous fuel changes the conditions of mixture formation. Volumetric efficiency is being dropped due to gas expansion [Aslam et al. 2005]. The proper preparation of mixture has got crucial impact on combustion process and its products, so this aspect for the dual fuel combustion system requires analysis.

The constructional parameters of dual fuel system effects also engine operational indicators. One of the parameters is the distance between injector and intake valve, which is the main field of this study. The scope of research was to evaluate the combustion parameters for two different locations of CNG injector placed in the inlet port. The investigations were conducted using comparative method of engine performance and emissions for two injector locations presented in the fig. 1.

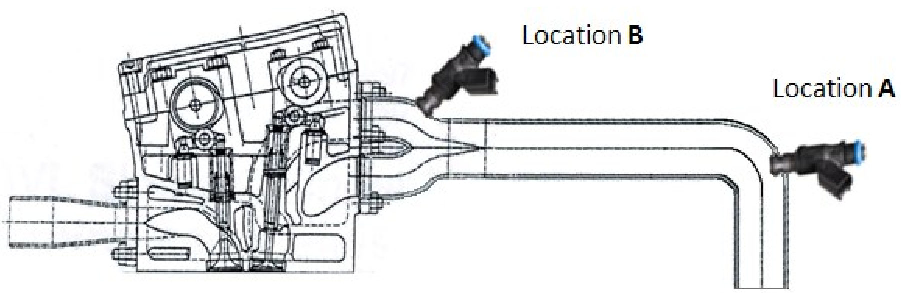

Fig. 1. The investigated injector positions; A – 60 cm away from intake valve, B – 10 cm from intake valve

Location A took place 60 cm from intake valves to enable better mixture homogenization due to longer mixing time. In version B the injector was located in the helical swirl channel. The analysis consist comparison of important combustion and emission parameters. Indicated mean effective pressure (IMEP) was calculated from the in-cylinder pressure traces. The indicated specific fuel consumption (ISFC) was evaluated concerning consumption of both fuels and indicated power. As a factors to evaluation of combustion process both heat release and indicated thermal efficiency were used.

3. METHODOLOGY

3.1. Research equipment

The tests were carried out on the engine test-bench with AVL5804 one-cylinder compression ignition research engine. The main parameters are collected in Tab. 1.

Table 1

Technical parameters of AVL 5804 research engine

Parameter	Unit	Value/Data
Cylinder number	–	1
Cylinder displacement	cm^3	510.7
Number of valves	–	4
Type of valve train	–	OHC
Compression ratio	–	16.2
Type of injection system	–	Common rail
Maximal injection pressure	bar	2000

The engine is coupled with dynamometer and controlled with test rig control system. The configuration of test-bench is presented in the Fig. 2.

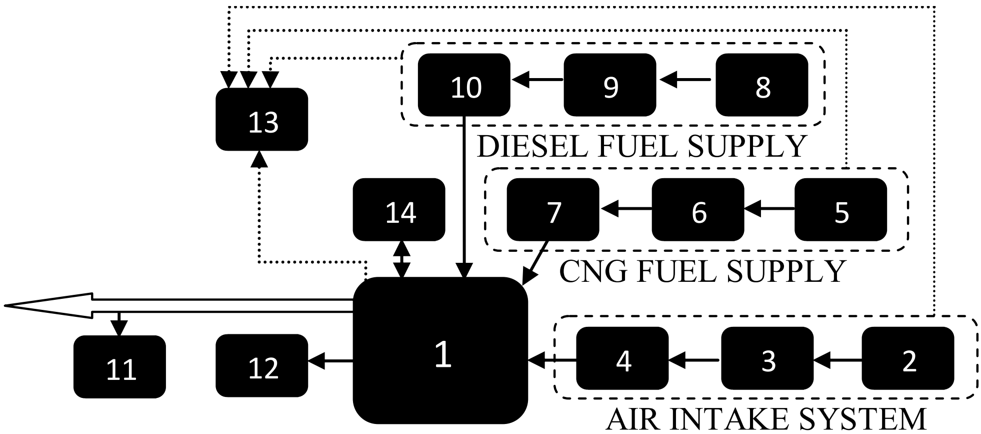

Fig. 2. Engine test stand with measurement equipment; 1 – AVL 5804 engine, 2 – air filter, 3 – air mass flow meter, 4 – full-variable supercharging system, 5 – CNG vessel, 6 – CNG mass flow meter, 7 – injector, 8 – diesel tank, 9 – gravimetric diesel fuel mass flow meter, 10 – common-rail diesel injection system, 11 – Horiba Mexa exhaust gas analyser, 12 – engine indicating system, 13 – temperatures and pressures monitoring system, 14 – engine control system

AVL IndiCom 621 hardware delivered information about in-cylinder pressure. The intake pressure was regulated using variable supercharging system coupled with air mass flow meter. Pilot injection was realized with common rail system with piezoelectric injector.

As a gaseous fuel a 99.95% methane from pressure vessel was used and expanded in two pressure reducers. NG was injected 35 deg CA aTDC during intake stroke. Gas mass flow was measured with Micro Motion Coriolis Elite Sensor CMFS010M300 calibrated for methane. CNG fuel was being injected into intake channels by means of electromagnetic gas injector actuated with independent controller. The concentrations of THC, CO and NO_x in the exhaust gases were measured by means of Horiba Mexa 7100D analyser.

3.2. Operating conditions and measuring procedure

Measurements were conducted on the engine test-rig in a conditioned engine box, in terms of load characteristic at constant speed (n = 2000 rpm). The base engine load was estimated as approx. 5 bar of IMEP for monofuel diesel operation. Intake pressure was kept approximately constant and equalled 1.1 barA. The air temperature amounted to 25 deg C.

Diesel fuel was injected under pressure of 700 bar and gaseous fuel under 9.1 bar abs. The dose of diesel fuel was representative in both measurement series. The share of gas energy in total fuel energy was varied in the range 0–70%.

4. INVESTIGATION RESULTS

As it was already mentioned in the chapter 2 the substitution of diesel fuel with natural gas impacts engine operational parameters. The measurements were conducted for different shares of CNG energy in total fuel energy. Fig. 3 presents comparison of IMEP and ISFC for both injector locations.

As one can observe, the IMEP value decreases with the rise of gas share in the total energy delivered with both fuels. In comparison to monovalent diesel supply the drop of IMEP for 70% CNG energy equals 45%. The important aspect of engine operation is high λ-value. The lean CNG-air mixture requires relative big energy to initiate combustion process and can cause misfiring [The Cummins Dual Fuel Engines–brochure] and results in lower IMEP.

For the injector placed in the location A lower IMEP values are indicated for all mixture compositions in combination with bigger indicated specific fuel consumption at the same time. Injection in location A took place long distance from intake valve. The portion of rich intake charge can accumulate in the channel, close to the valve, and move to the exhaust system during overlap. Smaller fuel dose can be combusted in the consequence and therefore lower rise of in-cylinder pressure can be expected, what confirm research results presented in the Fig. 3a. Also higher indicated specific fuel consumption is noticed as an effect (compare with Fig. 3b), up to 13% for the highest investigated U_{GF}. The smaller fuel dose closed in the cylinder after charge intake impacts quantity of heat released during combustion process. The estimation of heat released from fuel and engine indicated thermal efficiency are presented in the Fig. 4.

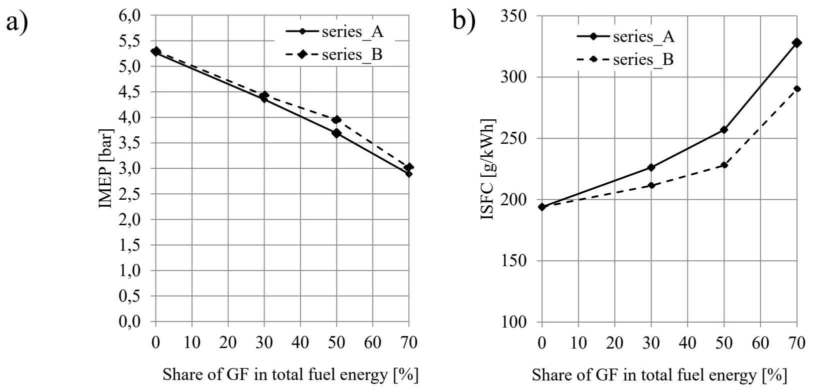

Fig. 3. IMEP (a) and ISFC(b) in series A (full-line) and series B (dashed-line)

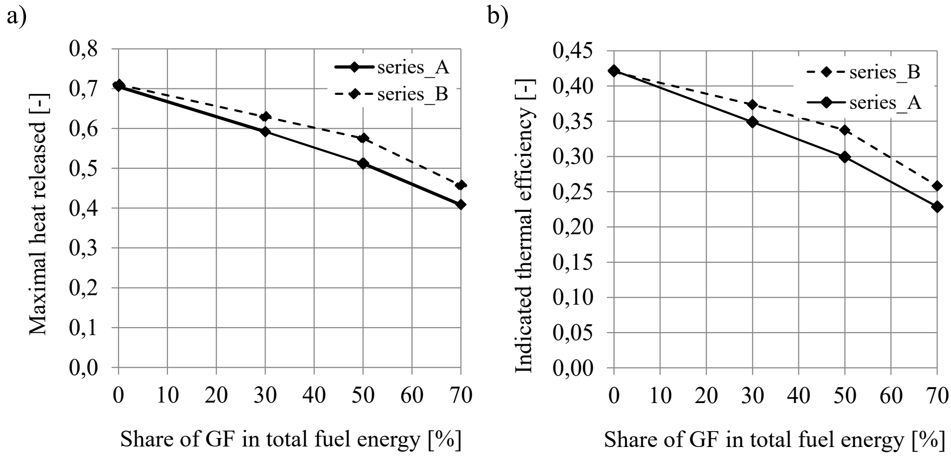

Fig. 4. Maximum heat release (a) and indicated thermal efficiency (b) for location A (full-line) and for location B (dashed-line)

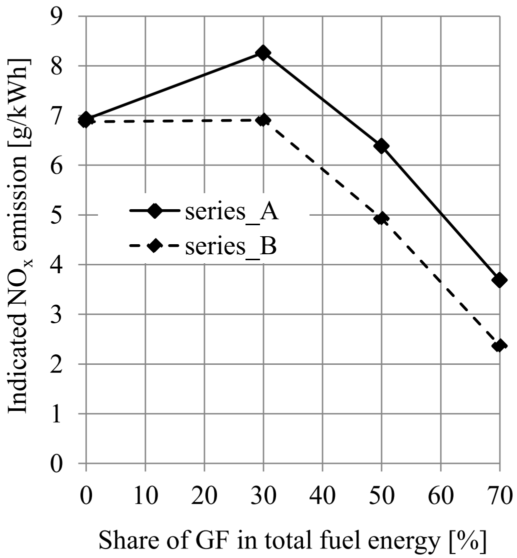

Fig. 5. The comparison of NO_x emissions in location A (full-line) and location B (dashed-line)

In the location A a bigger total fuel energy was delivered to the cylinder with fuel (up to about 6%). According to above mentioned loss of CNG amount during valve overlap, approx. 5% lower value of heat released was indicated. Highest drop both observed indicators was noticed for the 50% substitution of gaseous fuel. Also lower value of indicated thermal efficiency was noticed in the whole U_{GF} range (Fig. 4b).

The NO_x emission was also investigated in the scope of that research. In the Fig. 5 the NO_x emission was presented for both injector locations as a function of CNG substitution percentage. For the injector location A higher NO_x emission was indicated in every measurement point. Lower λ-value in the combination with higher fuel energy results in higher combustion peak temperature and in higher NO_x content formed on the way of Zeldovich mechanism.

5. SUMMARY AND CONCLUSIONS

Concerning research results the distance between gas injector and combustion chamber impacts engine indicators. Two locations of gas injector in dual fuel combustion system were examined in terms of load characteristic, according to the Fig. 1. For the injection in the location A some portion of fuel was being move into the exhaust during valve overlap, what resulted in lower IMEP and also higher ISFC for about 13% in the whole investigated range of gas share. The confirmation is the value of heat released from the fuel combustion. For the location B approx. 5% more heat was being released. That change resulted also in higher indicated thermal efficiency in achieved for location B. Finally, the influence of injector location on the exhaust emissions according to investigations is slight. Higher NO_x emission was indicated for the location A; perhaps the reason for that could be placed in the inconsiderably lower air excess ratio.

Concluding, the closer location of injector to inlet valve results in better (for few percent of value) combustion indicators.

NOMENCLATURE

CI	Compression ignition
CNG	Compressed natural gas
CO_2	Carbon dioxide
EGR	Exhaust gas recirculation
GF	Gaseous fuel
IMEP	Indicated mean effective pressure
ISFC	Indicated specific fuel consumption
NG	Natural gas
NO_x	Nitrogen oxides
PM	Particulate matter
THC	Total hydrocarbons
λ	Air excess ratio

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WPŁYW UMIESZCZENIA WTRYSKIWACZA GAZU NA WSKAŹNIKI PROCESU SPALANIA I EMISJĘ NO_x DWUPALIWOWEGO SILNIKA O ZAPŁONIE SAMOCZYNNYM

Summary

Użycie alternatywnych źródeł energii w silnikach spalinowych systematycznie rośnie. Za najbardziej obiecujące uważa się paliwa gazowe bogate w metan, które mogą służyć do zasilania silników jedno- i dwupaliwowych. Udział w rynku silników spalinowych o zapłonie samoczynnym jest znaczący, natomiast wiele badań wykazało również szereg zalet takich silników pracujących w konfiguracji dwupaliwowej z CNG.

Celem artykułu jest analiza wskaźników pracy i emisji silnika o zapłonie samoczynnym z wtryskiem CNG w dwóch punktach układu dolotowego o różnym oddaleniu wtryskiwacza od zaworu dolotowego. Przedstawiono szereg parametrów pracy oraz emisję NO_x zmierzoną przy różnych udziałach paliwa gazowego w całkowitej energii dostarczanej do cylindra wraz z paliwem. Parametry odniesiono do silnika zasilanego wyłącznie olejem napędowym.

Słowa kluczowe: silnik dwupaliwowy, CNG, wtrysk paliwa, spalanie