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Optimization of injection and spark timing in direct injection stratified charge (DISC) engine fueled with gasoline-ethanol blend

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Abstract - Direct injection stratified charge (DISC) engine is a hybrid concept between compression ignition and spark ignition engines. DISC engine incorporates some best features of both CI and SI engine with its additional own advantage. Multi-fuels can be used in this engine with improvement in thermal efficiency and reduction in harmful emissions like NOx. This includes multi-fuel capability, high thermal efficiency and low NOx emission production. Fuel is injected just before TDC position in this engine and the spark is used for the initiation of the combustion process. Throttling pressure drop losses are eliminated in this engine; as the engine power output is varied by regulating the fuel supply by keeping the air supply same. The present paper describes optimization of injection and spark timing, performance and emission characteristics of DISC engine using gasoline-ethanol blend. On the basis of experimentation, DISC engine runs well with ethanol and ethanol-gasoline blends. E50 (50% ethanol + 50% gasoline) is found to be more suitable blend with significantly reduced HC, CO, NOx emissions and with marginal reduction in brake thermal efficiency compared to pure gasoline.

Index Terms - Brake thermal efficiency, compression ratio, Disc engine, Ethanol, Emissions,

1. INTRODUCTION

Worldwide growing concern for environmental degradation due to harmful emissions coming from engine exhaust and energy security has put immense pressure on the engine researchers for modification of the engine technology [1,2]. SI engines operates at stoichiometric air fuel ratio, which provides clean burn and negligible emissions, while their performance is limited due to lower compression ratio and throttling losses [1,2]. Whereas, diesel engines are lean combustion engines giving lower concentration of CO and HC in exhaust emission but NOX and smoke are major pollutants due to high combustion temperature. Besides these, the diesel engines can emit a little amount of SO2 if the fuel contains sulphates. It is difficult to manage with compression ignition (CI) engine to satisfy forthcoming emission regulations [3,4]. The direct injection stratified charge (DISC) engine utilizes the features of both DI compression ignition and PFI spark ignition engine. Theoretically, this lean burn combustion are fuel efficient at partial load condition and better engine performance over port fuel injection at full load condition [5,6]. It can reduce the fuel consumption by 40% during idling and by 35% at mid load and speed over the conventional SI engine [7]. It can be operated over a wide range of load and the fuel supply can be varied from lean to rich. In-cylinder direct injection of fuel creates partial fuel stratification where fuel rich zone forms near the region of spark plug this demonstrates improved combustion in ultra-lean zones provide good combustion ignition stability [8]. The in-cylinder DI during the compression stroke produces the cooling effects due to the fuel evaporation that helps to avoid engine knock. The stratified mixture is also beneficial in avoiding scavenging losses during the gas exchange process. This allows engine downsizing mainly with intake pressure boost to achieve very high load with higher fuel efficiency [9]. DISC minimizes the challenges in the PFI, such as pumping losses, heat losses, cold start problem, improves volumetric efficiency and reduce carbon dioxide emissions, even with using lower octane fuel [10–12]. The early DI injection, requires lower injection pressure for improved mixing without thin film formation on the cylinder wall, however, such early injection may also lead to harsh engine operation. However, in the lean stratified charge engine combustion, the NOX and Particulate matter emissions are the major challenges.

Many studies had shown the performance of DISC engine by using renewable fuels like ethanol and shown satisfactory results without any engine modification, this has open a new era for the utilization of biofuel in DISC engine and is proving a good solution to limit energy crises and reduce emissions. In this study, the conventional diesel engine was converted into DISC engine and studied its performance and emissions using gasoline, ethanol and gasoline-ethanol blends. DISC engine technology can be implemented to the diesel engine with few modifications regarding the benefits of valve overlapping to minimize pumping losses [13–15]. Modification was done in cylinder head for spark plug mounting. The fuel injection system was modified for injecting gasoline directly into the engine cylinder at its compression stroke. The fuel injection during compression stroke was chosen to avoid cold start and wall wetting problem. A 3-hole fuel injector with injection pressure 200 bar was employed to produce the stratified charge before the start of combustion.

2. METHODOLOGY

2.1 Engine Modifications

The single cylinder naturally aspirated four stroke CI engine was modified to DISC engine operation. The compression was reduced to 10.5 from 16.5 for DISC engine operation. Figure 1 shows modified DISC engine. The specifications of modified DISC and CI Engine are given in table 1.

TABLE I

ENGINE SPECIFICATIONS

Parameters	DISC Engine	CI Engine
Bore	80mm	80 mm
Stroke	110mm	110 mm
Displacement	553 CC	553 CC
Compression ratio	10.5	16.5
Engine speed (RPM)	1350	1500

The mechanically operated fuel injection system was modified such as to inject fuel during the suction stroke of engine cycle. The camshaft was attached with a pulley for working of fuel injection pump in the speed ratio of 1:1. The pump pulley is having the arrangement to vary the fuel injection timing. The timing for fuel injection was set by timer pulley adjustment with respect to marking noted for end of injection (EOI) and TDC marker on the engine. The ball type governor was mounted on the engine to regulate the speed of the engine at 1350 RPM. The governor was having arrangement to regulate the fuel supply to the engine to maintain desired speed. At high load condition the fuel was injected directly in the cylinder early in the suction stroke for forming homogeneous mixture.

The experimental set-up is shown in Figure 1. An eddy current dynamometer was coupled to the engine output shaft for the measurement of engine torque. M111A22 quartz crystal dynamic pressure transducer was used to measure in-cylinder pressure with built-in amplifier having 1mV/psi sensitivity. The crankshaft position was obtained using an encoder having 1degree resolution to determine the in-cylinder pressure as a function of crank angle. The exhaust emissions were measured with AVL Di-TEST GMBH A-8020 Graz exhaust gas analyzer.

1. Engine 2. Eddy current dynamometer 3. Shaft encoder 4. Pressure transducer 5. DISC Fuel injection component 6. Air throttle 7. Data acquisition system 8. Air manometer 9. Fuel manometer 10. Regulator 11. RPM display 12. Temperature display 13. Air tank 14. Fuel tank 15. Spark plug 16. Electronic spark ignition system 17. Fuel injector 18. Gas analyzer 19. To exhaust, 20. Belt transmission.

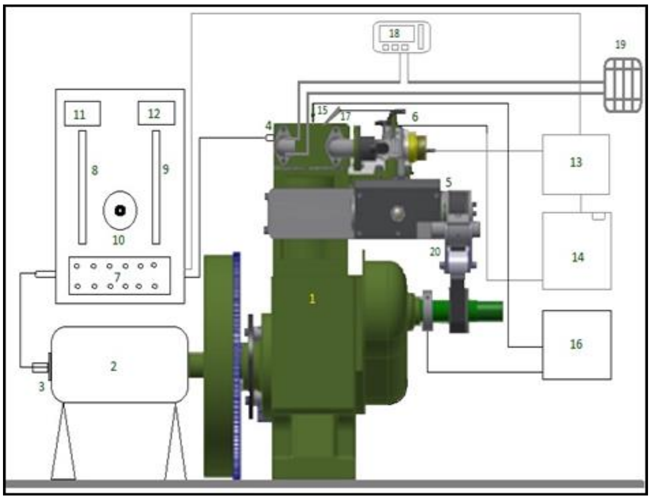

FIGURE 1

SCHEMATIC LAYOUT OF EXPERIMENTAL SET-UP

Gasoline and Ethanol were used as the test fuels and the fuel properties are given in the following table 2. To improve the cold start, and avoid engine knock the fuel injection timing was chosen during the compression stroke while SI timing was chosen near the TDC. For the engine warm-up, it was run on idle conditions on gasoline mode for 30 minutes. The coolant and lubricant temperature were maintained at 85°C to achieve stable combustion even using pure ethanol.

TABLE II

FUEL PROPERTIES

Fuels	Gasoline	Ethanol
Cetane	0–5	5–8
Antiknock Index	87.1	98
A/F Stoichiometric	14.66	9
Lower heating value [MJ/kg]	44.5	26.8
Latent heat of vaporization (kJ/kg)	350	919

3. RESULTS AND DISCUSSION

The experimental investigations were carried out on modified gasoline DISC engine. The DISC engine performance and emissions were investigated at different injection timings. The experimentations were also carried out with ethanol and ethanol-gasoline blends on modified DISC engine. To improve the cold start problem the injection timing was preferred during the compression stroke. The engine speed 1350 rpm, fuel injection pressure 200 bar and 7 bar BMEP were fixed. To determine the optimize spark timing and optimize fuel injection timing. The Fuel injection timing changed with the interval of 5° CA over 35 to 55° BTDC and spark timing changed with the interval of 3° CA over 14 to 26° CA BTDC during the compression stroke for investigation.

3.1 Fuel injection and spark timing effect on bsfc

The least BSFC was observed at fuel injection timing of 45° BTDC and at spark timing of 20°BTDC as shown in figure 2. The fuel injection timing 45° BTDC and spark timing 20° BTDC indicates the best combination of the fuel vaporization, mixture homogeneity, combustion chamber pressure, temperature and finally physical and chemical readiness of the fuel to ignite.

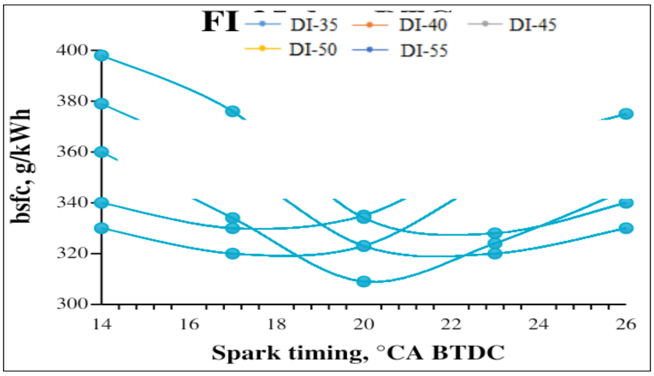

FIGURE 2 EFFECT OF SPARK TIMING AND FUEL INJECTION TIMING ON BSFC

3.2 Effect on exhaust emissions

The CO, HC and NOx emissions were observed at different injection timing and spark timing. At DI-45 where the HC emissions were lower by 18, 7.4, 13.8 and 26% than that of DI timing at 35, 40, 50 and 55° CA BTDC respectively. Similarly, CO emissions were reduced by 45, 21, 10 and by 25% at DI-45 over the DI timing at 35, 40, 50 and 55° CA BTDC. The early injection at DI-50 and DI-55° CA BTDC may cause cylinder wall wetting due to high injection pressure and over penetration in low dense air, this increases the fuel consumption. While later injection timing at DI-35, DI-40° CA BTDC increases the fuel burn duration due to insufficient time for mixing/ time overcome its autoignition delay at the time of start of combustion. The combustion efficiency was comparatively poor due to the deficiency of oxygen where high load operation uses rich equivalence ratio ϕ. The NOX emissions were observed maximum at DI-45 for slight leaner mixture and improved combustion at this injection point. The NOX can be lower by increasing the level of fuel stratification by means of retarding the DI timing to 35° CA BTDC where the NOX reduction was observed by 15.4%.

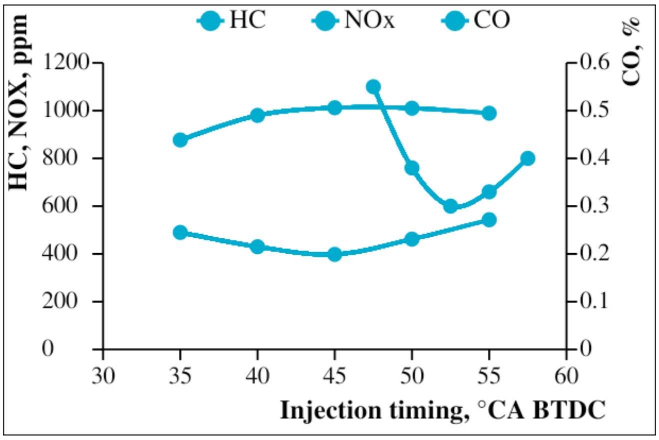

FIGURE 3

EFFECT OF SPARK TIMING AND FUEL INJECTION TIMING ON BSFC

3.3 Effects on in-cylinder pressure and heat release rate

The maximum peak pressure was found for DI at 45° BTDC and spark timing 20° BTDC because of the most favorable stratified mixture formation and best combustion location for the 200 bar injection pressure as shown in figure 4.

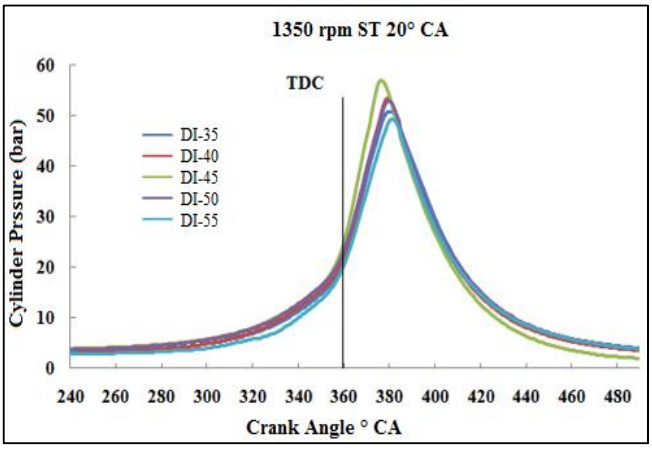

FIGURE 4

EFFECTS OF FUEL INJECTION TIMING ON CYLINDER PRESSURE

The Peak HRR was also found higher for DI at 45° BTDC; figure 5 shows the maximum burn occurred when the piston passed TDC and shorter burn duration in case of DI at 45° BTDC. This indicates the maximum power output without knock and higher cyclic efficiency. Therefore the DI at 45° BTDC and ST 20° BTDC was implemented for gasoline-ethanol blends and pure ethanol for further performance and emissions study.

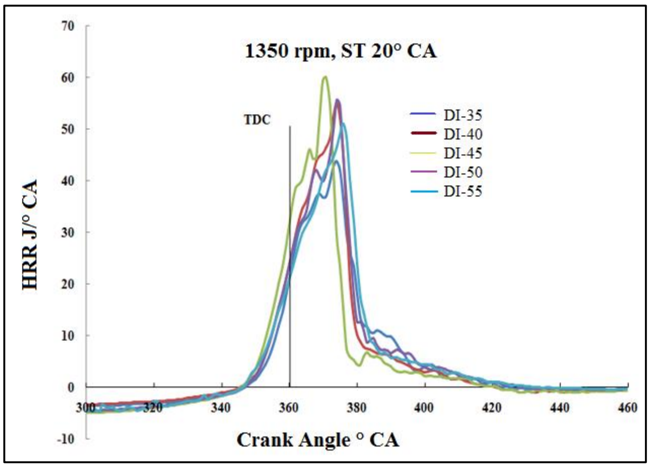

Figure 5

EFFECTS OF FUEL INJECTION TIMING ON HRR

3.4 Effects of brake thermal efficiency

For the same operating conditions gasoline fuel delivered maximum thermal efficiency for Injection of fuel 45°CA BTDC. Blending ethanol with gasoline decreases the energy density and increases the heat of vaporization. Therefore for the same operating conditions ethanol requires higher fuel supply over gasoline. As a result lower brake thermal efficiency and higher BSEC for the increased volume of ethanol in blends.

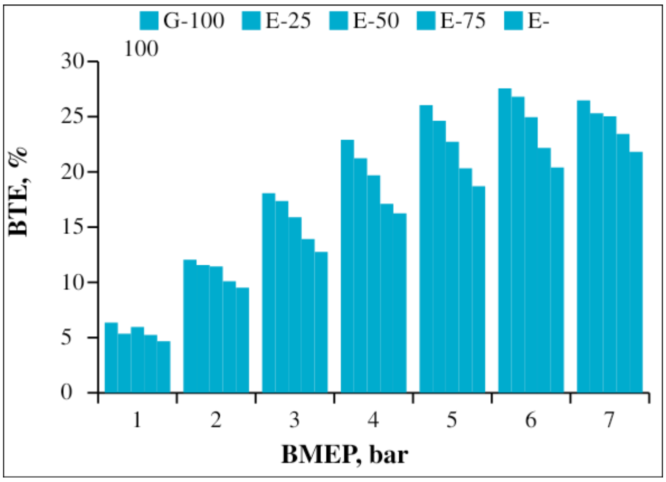

FIGURE 6

VARIATION OF BTE WITH BMEP

The BTE was dropped down for pure gasoline and E-25 when the load was increased from 6 bar to 7 bar BMEP. Gasoline stratified combustion for higher fuel supply is subjected to loss of combustion efficiency due to inadequate mixture preparation at the time of combustion. On the other hand, the BTE was continuously increased for E-75 and pure ethanol under increased loading conditions. This can be possible because the ethanol has a higher laminar flow velocity than the gasoline at stoichiometric equivalence ratio [16]. Higher laminar flow velocity increases the flame speed and tends to advance the start of combustion and reduce the burn duration with considering the effects of high latent heat of vaporization of ethanol [17].

3.5 Variation of brake specific energy consumption

The brake specific energy consumption increases for the increased volume of ethanol in the blend. Figure 7 shows the variation of brake specific energy consumption with BMEP for ethanol, gasoline and ethanol-gasoline blends.

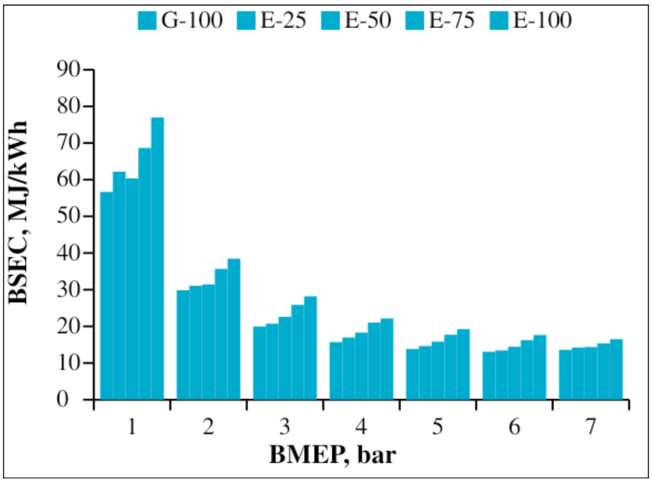

FIGURE 7

VARIATION OF BSEC WITH BMEP

3.6 Variation of HC and CO emissions with BMEP

DISC engine delivers higher combustion efficiency at part load conditions. When operated low load conditions, the lean stratified combustion produces higher HC emissions. For lean combustion fuel do no releases such chemical energy to attain complete combustion. At high load conditions where fuel supply is higher and inadequate oxygen availability lead to insufficient oxidation of HC and CO. Figure 8 and 9 shows variation of HC and CO emissions. Light chain oxygenated ethanol fuel allows the better oxidation of HC and CO at increased loading conditions hence reduced HC and CO emissions. At high load 7 bar BMEP, the percentage reduction in HC emissions relative to G100 were 18, 43, 72, and 74 % for E25, E50, E75, and E100 respectively. The reduction in CO emissions percentage relative to pure gasoline were observed as 20, 33, 36 and 40% for fuels E25, E50, E75, and E100 respectively.

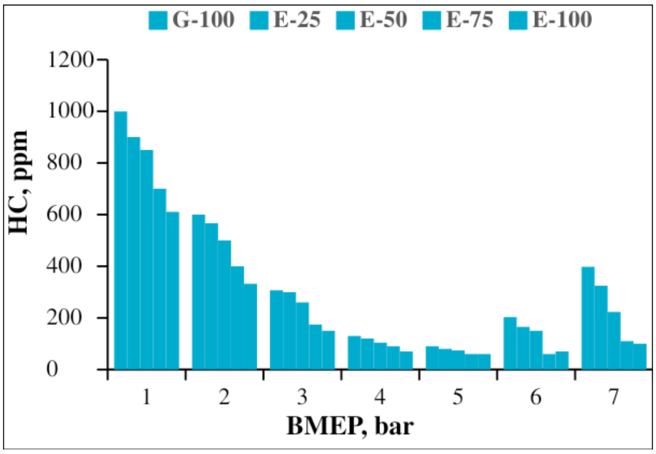

FIGURE 8

VARIATION OF HC WITH BMEP

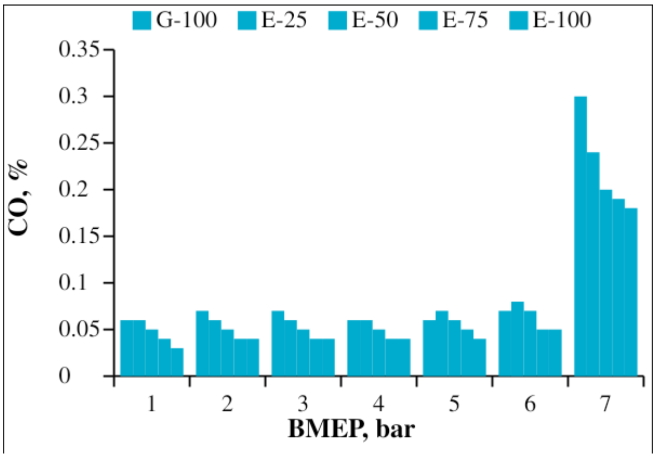

FIGURE 9

Variation of HC with BMEP

3.7 Variation of NOx emissions with BMEP

For low load conditions, the NOX emissions were low, as the NOX is a function of combustion temperature. The ethanol and ethanol- gasoline blends has the leaning effect due to more oxygen present in ethanol. Addition of ethanol to gasoline fuel decreases the NOX level at higher loading, the NOX reduction was significant at high load for pure ethanol. Ethanol stratified combustion produces low-temperature combustion mainly because of its high latent heat of vaporization, which creates the cooling effect in the combustion process. The percentage reduction in NOX at 6 bar BMEP were found to be 17.6, 20, 27 and 50.3% for E25, E50, E75, and E100 respectively.

. 4. CONCLUSIONS

DISC engine performance and emissions are influenced by the Spark ignition timing and Fuel injection timing. The engine was tuned at ST 20° CA BTDC and DI at 45° CA BTDC for stratified combustion where the best performance and lesser emissions were achieved.

DISC engines allow effective utilization of renewable and biodegradable pure ethanol for higher loading conditions. Ethanol has lower thermal efficiency, higher brake specific energy consumption and lower exhaust gas temperature than that of gasoline.

The combustion of oxygenated ethanol fuel produces lower HC and CO emissions when compared to gasoline for all loading conditions and the significant reduction in NOX was observed particularly at higher loading conditions.

Ethanol DISC engine can be more effective and efficient than gasoline for higher loading conditions in terms of performance and emissions.

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REFERENCES

[1] Heywood J. B., *Internal Combustion Engine Fundamentals,* McGraw-Hill, 1988.

[2] Costa M, Sorge U, Allocca L, *CFD optimization for GDI spray model tuning and enhancement of engine performance,* Advances in Engineering Software. 49 (2012) 43–53.

[3] Drake M. C.,. Haworth D.C, *Advanced gasoline engine development using optical diagnostics and numerical modeling,* Proceedings of the Combustion Institute. 31 (2007) 99–124.

[4] Luján J. M., Climent H., Novella R.. Rivas-Perea, *Influence of a low pressure EGR loop on a gasoline turbocharged direct injection engine*, Applied Thermal Engineering. 89 (2015) 432–443.

[5] Bhiogade G. E and Suryawanshi J. G., *A comparative experimental study on engine operating on premixed charge compression ignition and compression ignition mode*, Thermal science. 21 (2017) 441–449.

[6] Zhao F.. Harrington D.L, *Automotive spark-ignited direct-injection gasoline engines,* Progress in Energy and Combustion Science. 25 (1999) 437–562.

[7] Sendyka B., Cygnar M., *Theoretical Analysis of the Fuel Stream in the Gasoline Direct Injection Engine,* SAE Technical Paper, 2002.

[8] Reynolds C.C.O., Evans R.L. et al., *The effect of varying the injected charge stoichiometry in a partially stratified charge natural gas engine,* SAE Technical Paper, 2005.

[9] Lecointe B., Monnier G., *Downsizing a gasoline engine using turbocharging with direct injection,* SAE Technical Paper, 2003.

[10] Kume T., Iwamoto Y. et al., *Combustion control technologies for direct injection SI engine*, SAE Transactions. (1996) 704–717.

[11] Kono S., *Study of the stratified charge and stable combustion in DI gasoline engines*, JSAE Review. 16 (1995) 363–368.

[12] Harada J., Tomita T. et al., Ito, *Development of direct injection gasoline engine*, SAE Transactions. (1997) 767–776.

[13] Rotondi R., Bella G., *Gasoline direct injection spray simulation,* International Journal of Thermal Sciences. 45 (2006) 168–179.

[14] Li J., Chae J.O. et al., *Preliminary Investigation of A Diffusing-Oriented Spray Stratified Combustion System for DI Gasoline Engines*, SAE Paper, 1998.

[15] Li J., et al., *Effect of injection and ignition timings on performance and emissions from a spark-ignition engine fueled with methanol*, Fuel. 89 (2010) 3919–3925.

[16] Hara T. Tanoue K, *Laminar flame speed of ethanol, n-heptane, iso-octane air mixtures*, JSAE Paper. 20068518 (2006).

[17] Turner D, et al., *Combustion performance of bio-ethanol at various blend ratios in a gasoline direct injection engine,* Fuel. 90 (2011) 1999–2006.