Indian Journal of Engineering & Materials Sciences
Vol. 19, December 2012, pp. 411-416

# Effect of two-springs split injection on the performance and emission characteristics of diesel-oxygenated blends in a DI diesel engine

M Kumaresan[a]* & G Devaradjane[b]

[a]Department of Automobile Engineering, SACS M AV M M Engineering College, Kidaripatty, Madurai 625 301, India

[b]Department of Automobile Engineering, Anna University, MIT Campus, Chennai 6000 025, India

*Received 7 March 2012; accepted 16 October 2012*

This paper attempts to find the use of two-springs split injection with an oxygenated compound blended with diesel to address the environmental pollution issue especially in smoke and oxides of nitrogen emission reduction besides retaining the performance. Experimental investigation has been carried out to study the performance, and emission characteristics of diesel and diesel-diethyl carbonate oxygenated compounds blend in the proportions of 10% by volume in a direct injection (DI) single cylinder diesel engine using the standard single-spring injection and two-springs split injection. From the investigation it has been observed that with two-springs split injection at an injection timings of 27° before top dead center (BTDC) the brake thermal efficiency is found as 29.3%, oxides of nitrogen emission as 1.32 g/kWh and smoke level as 36% opacity with 10% diethyl carbonate-diesel oxygenated blend.

**Keywords:** Diesel engine, single-spring injection, two-springs split injection, oxygenated compound blend, emission parameters

Diesel engines are efficient prime movers for heavy duty vehicles, so they have attracted many automobile and research institutions for their use as main prime movers of vehicles. Considerable research has been carried out on the applicability of such engines to light duty vehicles and small engines. The most serious problems facing the diesel engines developments are control of diesel knock, idle stability, engine speed hunting in case of small engines and control of nitric oxide emission. In pilot injection, a small amount of fuel injected during the ignition delay period is a means of reducing diesel knock and the pilot injection is used to shorten the ignition delay and to control the rapid pressure rise. Thus pilot injection controls NOx emission to some extent. This principle is achieved by the use of two-spring split injector. The two spring split injector has two control springs within it, each having a different set force to provide injector needle valve to open at two different opening pressures for two stages of injection, i.e., pilot injection and main injection.

Ishida *et al.*[1] studied the development status of a small, direct-injection diesel engine at Isuzu for the stabilization of idle speed, control of HC and noise reduction by the use of two spring injector.

*Corresponding author (E-mail: phdkumar@yahoo.com)

Study conducted by Litzinger and Stoner[2] shows that several oxygenated compounds including ethers, alcohols, carbonates, acetals and esters are showing potential promise to reduce smoke and particulate matter. The cited references report, a correlation between fuel oxygen content and smoke as well as particulate emissions.

The studies carried out by Liotta and Montalvo[3], indicated that an oxygen content of 7% by volume in fuel results in 40% reduction in smoke and particulate emissions. Oxygenates were selected on the basis of their characteristics for satisfactory application in diesel engines. The emissions of oxygenated fuel blends are analyzed by incorporating exhaust gas recirculation and common rail fuel injection systems.

Choi and Reitzl[4] conducted an experimental study on the effects of oxygenated fuel blends and multiple injection strategies on DI diesel engine emissions. At high loads, a significant beneficial effect of oxygenated fuels was seen as reduced soot emissions with little or no penalty on NOx emissions. Also, at high loads split injection had an additional favorable effect on soot emissions as compared to single injections, but the soot reducing influence by the oxygenates was not as marked as that seen with the single injection cases. Li *et al.*[5] investigated the effects of cetane number and cetane improver such as nitrate type additives and peroxide type additives on exhaust emissions. An increase in Cetane number results in a shorter ignition delay which causes a longer mixing controlled combustion. There is an increase in PM emission when the Cetane number yields lower combustion pressure in later part of combustion period. This means lower combustion temperatures resulting in lower soot oxidation rates and thus higher PM levels.

The main objective is to investigate the performance and emission characteristics of diesel and diesel-DEC oxygenated compounds blend in the proportions of 10% by volume in a direct injection single cylinder diesel engine using the standard single spring injection and two spring split injection.

## Two-Springs Injector

The two-spring nozzle holder is a development of the standard nozzle holder. At first, only one of these springs has an influence on the nozzle needle and as such defines the initial opening pressure.

The second spring is in contact with as top sleeve which limits the needle's initial stroke. When strokes take place in excess of the initial stroke, the stop sleeve lifts and both springs have an effect upon the nozzle needle during the actual injection process, the nozzle needle first of all opens an initial amount so that only a small volume of fuel is injected into the combustion chamber. Subsequently as the injection pressure increases further in the nozzle holder, the nozzle needle opens completely and the main quantity is injected .This 2-stage rate of discharge curve leads to softer combustion and reduced noise.

First spring opening pressure is 195 bars and the second spring opening pressure is 255 bars. Figure 1 shows the view of two-springs Injector. Figure 2 shows comparison of needle lift curve for standard and two-springs injector.

## Oxygenated Compounds

It was observed from the literature survey (Mani Natarajan *et al*.[6] that among 71 oxygenates , only the diethyl carbonate (DEC) is used for the experiment based on the properties of diesel and oxygenates and also considering many aspects like, cost, oxygen content, flash point, solubility, availability, toxicity, lubricity, and biodegradability. The selected oxygenates are blended with diesel fuel in proportion of 10% by volume and experimental study is conducted in a single cylinder naturally aspirated direct injection diesel engine. The blending levels are restricted due to reduction of calorific value, corrosion and lubricity problems

The structure of, diethyl carbonate is as : ($C_5H_{10}O_3$)

$CH_3CH_2O[C{=}O]OCH_2CH_3$

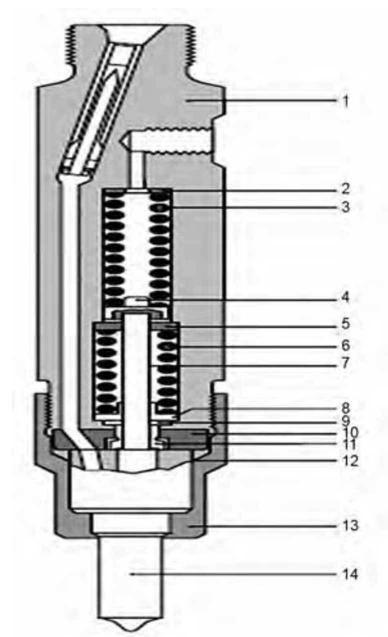


Fig. 1—Two-springs injector [1 – nozzle-holder body, 2 – shim, 3 – spring, 4 – pressure pin, 5 – guide element, 6 – spring 2, 7 – pressure pin, 8 – spring seat, 9 – shim, 10 – intermediate element, 11 – stop sleeve, 12 – nozzle needle, 13 – nozzle-retaining nut, 14 – nozzle body]

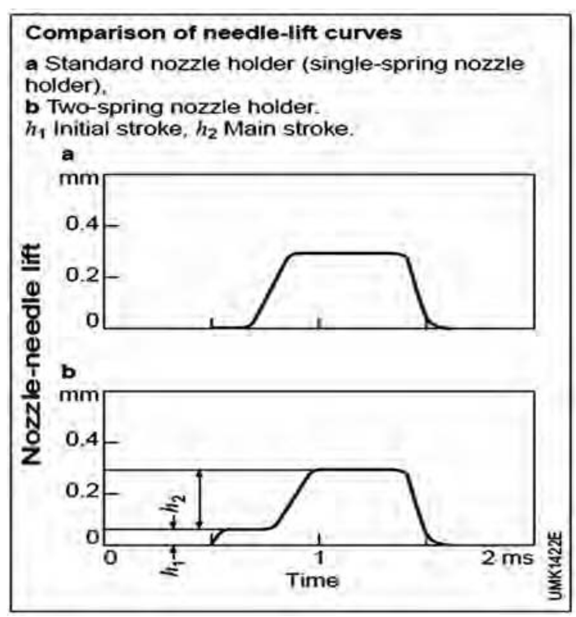


Fig. 2—Comparison of needle lift

The important properties of diesel and oxygenate are listed for comparison in Table 1. It can be seen from Table 1, that the properties of the diesel and selected oxygenates vary very little.

## Experimental Procedure

A single cylinder, water cooled, four stroke direct injection compression ignition engine with, compression ratio of 15.6:1, developing 5.9 kW (8 bhp) at 1500 rpm was used for the present study. Variable load tests are conducted from no load, 0.785, 1.57, 2.57, 3.54, 3.9, 4.7, 5.6 kW power output at a constant rated speed of 1500 rpm with fuel injection pressure of 200 bars and cooling water exit temperature at 60°C. The injection timing recommended by the manufacturer was 27° bTDC. The governor was used to maintain constant speed under varying load conditions which control the fuel flow as load changes over engine. The performance characteristics of the engine are evaluated in terms of brake thermal efficiency, emission characteristics in terms of smoke, HC, CO, NOx and smoke are compared using the standard single spring and two-springs split injection with diesel and 10% DEC oxygenated diesel blends. Observations such as the time for 50 cc of fuel consumption measurement of CO, HC, and NOx using crypton gas analyzer and measurement of smoke using AVL smoke meter are obtained. The eddy current dynamometer was used. The engine specifications given in Table 2.

Table 1—Properties of diesel and oxygenate

| Properties | Diesel | Diethyl carbonate |
|---|---|---|
| Density, g/cc | 0.826 | 0.980 |
| $O_2$ Content, (wt %) | - | 40.36 |
| Cetane number | 45 | 58 |
| Boiling point, °C | 199/317 | 126 |
| Flash point, °C | 50 | 25 |
| Heat of combustion, kJ/kg | 44,320 | 22,065 |
| Self Ignition Temp., °C | 255 | 445 |
| State | clear liquid | clear liquid |

Table 2—The engine specification

| | |
|---|---|
| Bore (mm) | 88 |
| Stroke (mm) | 110 |
| Connecting rod length (mm) | 230 |
| Compression ratio | 15.6:1 |
| Speed (rpm) | 1500 |
| Injection timing ( BTDC deg) | 27 |
| Rated power ( kW) | 5.8 |

## Results and Discussion

The experimental study is conducted in a single cylinder naturally aspirated direct injection diesel engine, with standard single spring and two-springs injector using diesel and 10% diesel DEC oxygenated blends with injection timings of 27° bTDC. The performance, emission and combustion parameters are measured.

### Comparison between standard single-spring injection and two-springs split injection

The comparison of performance and emission parameters of 10%DEC oxygenated blend between standard single-spring injection and two-springs split injection are measured and shown in Figs 3-8.

*Brake thermal efficiency*

Figure 3 show the comparison of brake thermal efficiency of oxygenated blend 10%DEC between standard single-spring injection and two-springs split injection.

The brake thermal efficiency indicates the ability of the combustion system to accept the experimental fuel and provides comparable means of assesing how

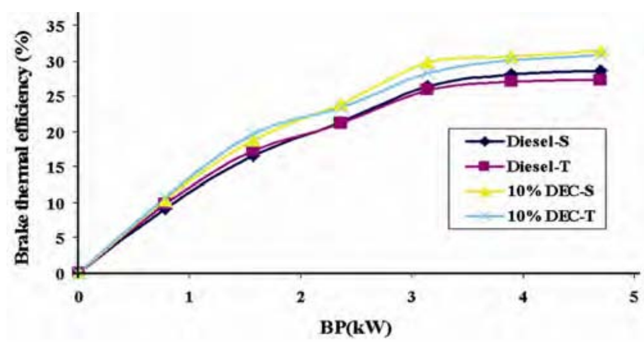


Fig. 3—Comparison-of brake thermal efficency of 10%DEC oxygenated diesel blend between standard single-spring injection and two-springs split injection

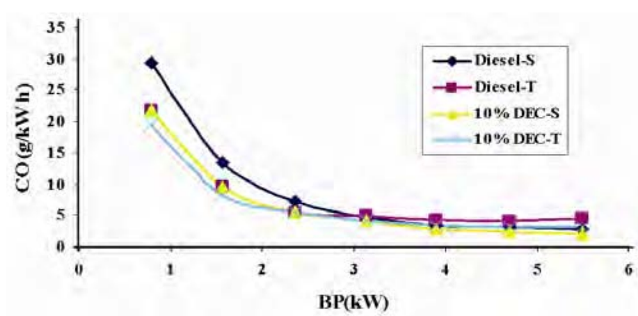


Fig. 4—Comparison of carbon monoxide (CO) of 10%DEC oxygenated diesel blend between standard single-spring injection and two-springs split injection

effectively the energy in the fuel was converted into mechanical output. It is observed that brake thermal efficiency is slightly higher for standard single-spring injection compared to two-springs split injection method at higher loads. A slight drop to 26.4% brake thermal efficiency is obtained for two-spring split injection of diesel compared to 27.4% for standard single-spring injection. A drop in peak temperature takes place as some heat liberated by pilot injected fuel is being taken by main injected fuel for latent heat of vaporization. This drop is responsible for decreasing the brake thermal efficiency of the engine with the two-spring split injection. With oxygenated diesel blend, an increase in the brake thermal efficiency is observed. This is due to the presence of higher oxygen content in the blends which promotes combustion characteristics of the blends. The enhancement of premixed combustion phase, due to the oxygenate addition result in high combustion pressure and subsequently a higher power output, while the improvement of diffusive combustion phase result in a more rapid and complete combustion, which is also beneficial to the increase in power output.

From Fig.3, it is observed that the brake thermal efficiency of 10%DEC for standard single-spring injection is about 31% and 29.3% for two-springs split injection, thus an increase of 3.6% and 3% is observed. This increase is because of higher Cetane number. The effect of reduced calorific value of the 10% blend on power is offset by better combustion of the blended diesel. Better combustion is possible due to the presence of oxygen molecules inside the micro air-fuel parcels in the combustion chamber.

*Emission of CO, HC, NOx, smoke of 10%DEC oxygenated diesel blend*

Figures 4-7 show the comparison of the emission of CO, HC, NOx and smoke emissions of 10%DEC oxygenated blend between standard single spring injection and two-springs split injection.

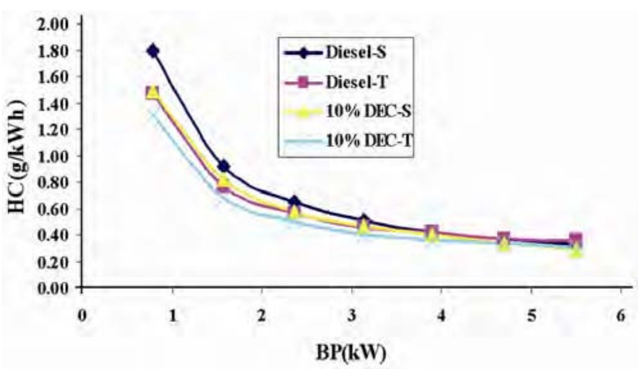


Fig. 5—Comparison of hydrocarbon (HC) of 10%DEC oxygenated diesel blend between standard single-spring injection and two-springs split injection

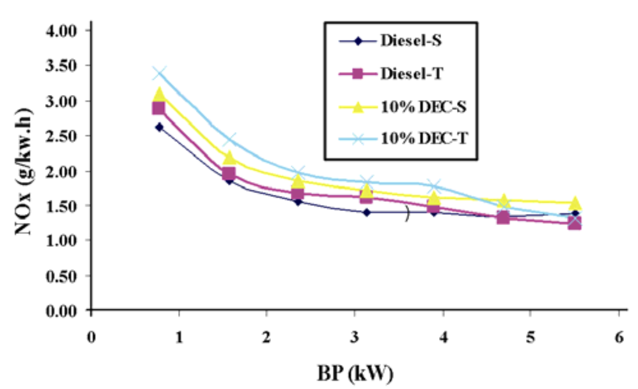


Fig. 6—Comparison of oxide of nitrogen (NOx) of 10%DEC oxygenated diesel blend between standard single-spring injection and two-springs split injection

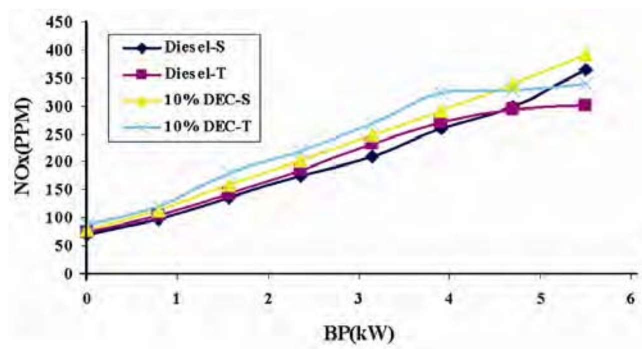


Fig. 7—Comparison of oxide of nitrogen (NOx) (ppm) of 10%DEC oxygenated diesel blend between standard single-spring injection and two-springs split injection

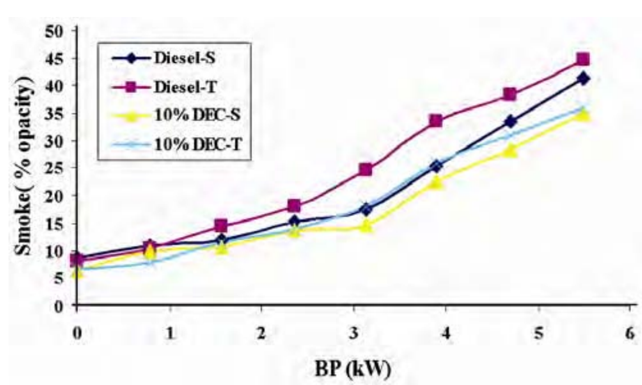


Fig. 8—Comparison of smoke opacity of 10%DEC oxygenated diesel blend between standard single-spring injection and two-springs split injection

*Carbon monoxide emission*

Diesel engines always operate on the lean side of the stoichiometrics, therefore CO emission from diesel engine is not much significant, but the local air/fuel ratio prevailing during droplet evoporation is important in CO generation . CO emissions are due to freezing of CO chemistry, as the burned gases got cooled and availability of less time for CO to become $CO_2$[7].

From Fig. 4, it is observed that the CO emission from diesel fuel for standard single-spring injection is 2.65 g/kWh and 4.52g/kWh for two-springs injection. However, with the 10%DEC blends performs better in reducing CO emission to 1.95 g/kWh for standard single-spring injection and 3.10 g/kWh for two-springs split injection as oxygenate liberate oxygen quickly

*Hydro carbon emission*

Hydrocarbons (HC), more appropriately organic emissions, are the consequence of incomplete combustion of the hydrocarbon fuel. The level of unburned hydrocarbon in the exhaust gases is generally specified in terms of the total hydrocarbon concentration expressed in ppm carbon atoms. While total hydrocarbon emission is a useful measure of combustion inefficiency, it is not necessarily a significant index of pollutant emissions. Fuel composition can significantly influence the composition and magnitude of the HC emission. HC formation mechanisms are likely to be most important at different operating modes. Engine idling and high load operation produce significantly higher HC emission than full load operation. However, when the engine was overloaded, HC emission increased very substantly.

From Fig. 5, it is seen that the emission of HC for diesel as 0.33 g/kWh with standard single-spring injection and 0.36 g/kWh for two-springs split injector. It is also observed that for low to medium loads, the HC emission is found to be reducing with two spring injector because of very small quantity being injected at low loads. The HC emission for 10%DEC blends is 0.29 g/kWh for standard single-spring injection and 0.30 g/kWh for two-springs split injection.

*NOx emission*

The effect of oxygenated fuel blends on NOx emission is complex and is not conclusive. The cetane number and fuel density can influence NOx emissions. Local rich combustion and high tempareture are important for NOx formation.

The NOx emission shows increasing trends (in ppm) for both standard single-spring injection and two-springs split injection. It is also observed that NOx emission is lower for two-springs split injection compared to standard single-injection from the low to higher loads due to two stages of fuel injection. NOx emissions are due to the effect of temperature and oxygen content. At high temperatures both nitrogen and oxygen attain atomic state from molecular state. At the atomic state both the oxygen and nitrogen has affinity towards each other. This results in formation of nitric oxide (prompted) and again and again various chains of chemical reactions takes place involving atomic oxygen and nitrogen with intermediate products of combustion such as OH and H and also with $O_2$ and $N_2$ molecules etc. NOx mainly consists of NO and $NO_2$ (95%). The remaining 5% consists of other oxides of nitrogen.

Figures 6 and 7 show that the NOx emission for diesel is 1.39 g/kWh with standard single-spring injection and 1.24 g/kWh for two-springs split injector. Two-spring split injection reduces the ignition delay of the second injection. Reducing ignition delay may reduce the quantity of pre-mixed combustion. This will reduce the temperature of high temperature region leading to reduction in NOx concentration. The oxygenate show increase in Nox emission for both cases of standard single-spring injection and two-springs split injection. The increase relates to the oxygen content in the oxygenate. But the increase in the Nox emission is only to 1.32 g/ kWh for 10% DEC blend using two-springs injector compared to 1.53 g/kWh. for standards ingle-spring injection.

*Smoke emission*

The smoke emission for diesel fuel increases quickly at higher loads. Using the oxygenated fuel blends, the smoke emission can be reduced significantly at higher loads. The smoke emission is lower for standard single-spring injection compared to two-springs split injection due to two stages of fuel injection.

Smoke production is mainly during diffusive combustion phase, the addition of oxygenates will supply more oxygen which leads to an improvement

Table 3—Comparison of performance, emission and combustion parameters of 10%DEC oxygenated blend between standard single-spring injection and two-springs split injection

| Parameters | Diesel-S | Diesel-T | 10%DEC-S | 10%DEC-T |
|---|---|---|---|---|
| Brake thermal efficiency (%) | 27.9 | 26.4 | 31.0 | 29.3 |
| CO (g/ kWh) | 2.65 | 4.52 | 1.95 | 3.10 |
| HC (g/ kWh) | 0.33 | 0.36 | 0.29 | 0.30 |
| NOx (g/ kWh) | 1.39 | 1.24 | 1.53 | 1.32 |
| Smoke opacity (%) | 41.4 | 44.6 | 35.0 | 36.0 |

in diffusive combustion. Moreover, the enrichment of oxygen will also promote the oxidation of smoke in the late expansion and exhaust process. From the Fig. 8, it can be seen that the smoke emission for diesel as 41.4% opacity with standard single-spring injection and 44.6% opacity. for two-springs split injector. While split-injection reduces the NOx emission the adverse effect is seen on smoke levels as soot oxidation is reduced in the later part of the expansion stroke only at higher loads.. The smoke emission is only 36% opacity with 10% DEC blend for two-springs injector. Table 3 shows comparison of performance, emission and combustion parameters of 10%DEC oxygenated blend between standard single-spring injection and two-springs split injection.

## Conclusions

Both standard single-spring and two-springs split injection show increase in performance and reduction in smoke, CO and HC with the addition of oxygenate. With two-springs injection the reduction in NOx is more compared to standard single-spring injection with diesel and oxygenated blend.

## References


1 Shiro Ishida, Ryoji Kihara & Manabu Furubayashi, *SAE 850068*, 1985.

2 Litizinger T & Stoner M, *SAE paper 01-1475 (SP-1461)*, 1999.

3 Liotta F J & Montalvo D M, *SAE paper 932734 (SP-994)*, 1993.

4 Choi C Y & Reitz1 R D, *Fuel*, 78 (1999) 1303-1317.

5 Xiaobin Li, Chippior W L & Gulder O L, *SAE paper 972968*, 1997

6 Mani Natrajan Frame E A, Naegeli D W, Tom Asmus, Wendy Clark, John Garbak Manuel A, Gonzalez D, Eleanor Liney Wiliam Piel & Wallace J P III, *SAE paper 2001-01-3631*, 2001.

7 Bosch, *Automobile Handbook*, 3rd ed, (SAE Germany), 1993, pp 75-135.