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INFLUENCE OF SPLIT INJECTION MASS AND INJECTION PRESSURE ON METHANOL/DIESEL RCCI COMBUSTION IN A COMPRESSION IGNITION ENGINE

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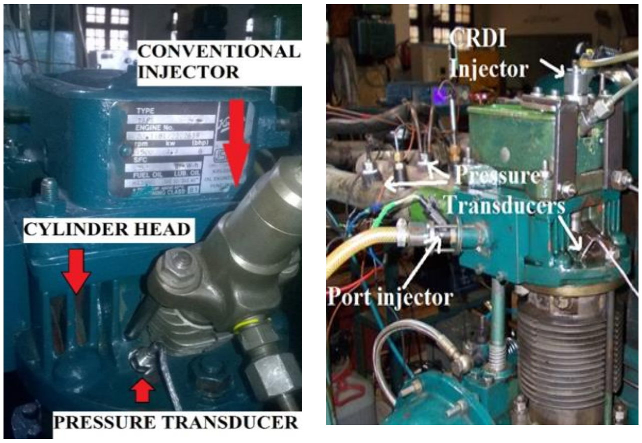
ABSTRACT

Application of electronic fuel injection lead to rate shaping of fuel at different injection pressures on internal combustion engines. In the present study, an experimental investigation was performed to study the influence of multiple injections on a modified single cylinder air-cooled diesel engine operating in reactivity controlled compression ignition combustion mode-a clean combustion mode with higher thermal efficiency, in which extensive research is being performed now a days to meet emission norms. One of the key characteristics of this combustion mode is combustion phasing control, by varying fuel reactivity distributions prior to start of ignition that greatly influences combustion process. Diesel injection pressure and the split diesel fuel mass has a vast impact on fuel reactivity. Methanol has been injected at port (a low reactivity fuel) and diesel has been injected directly into the cylinder. The RCCI combustion strategy was realized at no load by varying high reactivity diesel injection pressure from 400 bar to 600 bar and start of injection mass variation from 40% to 80%. It was found from the investigation that increasing the injection pressure from 400 bar to 600 bar had a better effect on combustion parameters and emissions. At 60% fuel injection mass, the indicated thermal efficiency and emissions showed a better result than other combinations.

Keywords: Fuel Injection timing, Injection pressure, Fuel reactivity, Compression ignition, Methanol, Low reactive fuel

NONMENCLATURE

Abbreviations	
AHRR	Apparent heat release rate
aTDC	After top dead center
BMEP	Break mean effective pressure
CHRR	Cumulative heat release rate
DI	Direct injection
DPF	Diesel particulate filter
ECU	Electronic control unit
HCCI	Homogeneous charge compression ignition
IMEP	Indicated mean effective pressure
ITE	Indicated thermal efficiency
LTHR	Low temperature heat release
PCI	Premixed compression ignition
PCCI	Premixed charge compression ignition
PRR	Pressure rise rate
RoPR	Rate of pressure rise
R_{max}	Maximum pressure rise (bar/degree)
SCR	Selective catalytic reduction
SOI1	Start of injection 1
SOI2	Start of injection 2



Before Modification **After modification**

Figure 1. Cylinder Head [22]

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1. INTRODUCTION

Pollution is one of the major concern in today's modern environment. The majority of pollution is by the transportation industry due to emissions from the automobiles. Diesel engines are widely used for transportation and power generation applications because of their high fuel efficiency. However, diesel engine causes environmental pollution owing to their high NO_x and soot emissions. Considerable effort has thus been devoted towards reducing these pollutant emissions as these emissions has adverse effects on the environment and human health. So reducing emissions from diesel engine is an important aspect in diesel engine research. Reactivity controlled compression ignition (RCCI) is used in direct injection diesel engines to overcome the drawback of higher emissions. High pressure injections of high reactive fuel increases the combustion efficiency, economic performance of the diesel engines and achieved lower engine out emissions [1]. So it is significant to investigate the properties of direct injection parameters in diesel engines equipped with high pressure common rail injections. Automotive engines have state of the art emission control techniques which are not found on non-road stationary engines. As they are a significant source of pollution [2-7] and emits hazardous pollutants into the atmosphere, use of advanced combustion techniques in diesel engines become a solution to solve the environmental problems such as emissions, fossil fuel depletion etc. Accordingly, the injection strategy, reactivity controlled compression ignition (RCCI) [10-11] provides better control of combustion. The implementation of RCCI combustion with diesel fuel needs control of injection parameters and fuel properties.

Alternate fuels are a better option as fuel for several reasons. The research by Hashimoto [13] has demonstrated that ethanol/n-heptane mixtures exhibit significantly different low temperature chemistry. The injection pressure was reduced from 800 to 400 bar to account for the volatility differences of gasoline and diesel fuel that produce larger, less easily vaporized droplets, as discussed by Shi et al. [14]. It is known fact that, ethanol and methanol have very similar physical and chemical properties. Li et al. [18-21] investigated the effect of methanol fraction, SOI and intake temperature on RCCI combustion. Also, the analysis of RCCI combustion to be performed at the optimal values of various operating parameters. These optimal values to be determined according to engine load and speed. It motivates the present research to conduct a study at diesel injection pressure of 400 bar to 600 bar and the start of injection mass from 40% to 80%. Based on the literature review, it is clear that RCCI with alternative fuels are better promising combustion strategy to achieve lower oxides of nitrogen and smoke emissions without compromising fuel economy. However, it suffers from poor thermal efficiency at low load conditions, and higher unburned hydrocarbon emissions. Ganesh et al [22] in their study documented that RCCI is implemented in a small, single cylinder, air-cooled stationary diesel engine widely used in agricultural and small utility power generation applications which are not tested with RCCI combustion. Different bio fuels such as untreated rape seed oil (RSO) [23], wood based renewable fuel [24] and methanol [25] are tested using conventional combustion methods on the non-road multi cylinder diesel engines and single cylinder diesel engines [26] to meet the emission standards. The present study discusses the effect of high reactivity fuel mass and injection pressure variations on a stationary diesel engine using methanol as low reactive fuel to achieve RCCI combustion to meet emission standards which has become essential today and without compromising thermal efficiency.

2. TEST ENGINE DETAILS AND EXPERIMENTAL PROCEDURE

An existing single cylinder, naturally aspirated, air-cooled direct injection (DI) compression ignition (CI) engine was modified to run the engine in RCCI mode of operation.

The modifications are shown in Fig 1. The engine specifications are given in Table 1. The low reactive fuel is injected in port at 3 bar and high reactive fuel (commercially available diesel) is injected directly with split injection. SOI-1 mass has been varied from 40% to 80% at injection pressure 400 bar to 600 bar.

Table 1. Test engine specifications

Make	Kirloskar
Bore x stroke	87.5 x110 mm
Compression ratio	17.5:1
Connecting rod length	231 mm
Piston	Stock piston
Inlet valve opening	4.5 deg bTDC
Inlet valve closing	144.5deg bTDC
Exhaust valve opening	-144.5 deg bTDC
Exhaust valve closing	-355.5 deg bTDC

The SOI-1 and SOI-2 injection angles are maintained at 34 deg bTDC and 25 deg bTDC respectively.

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3. RESULTS AND DISCUSSION:

3.1. Effect of injection pressure on combustion characteristic at 40% pilot mass fraction:

The effect of injection pressure on the combustion characteristic at no load condition with 40% of pilot mass fraction of diesel and 45% port fuel fraction is shown in the Fig 2. The in cylinder pressure and the rate of heat release is reduced with increase in injection pressure of diesel. This is due to the better atomization achieved at higher injection pressure that leads to attain more homogeneity inside the cylinder. It results with better fuel stratification inside the cylinder so the spontaneous combustion is occurred. By increasing the injection pressure from 400 bar to 600 bar the CA50 is achieved closer to TDC. For 400 bar injection pressure the CA50 is attained at 7deg CA bTDC and for 600 bar injection pressure CA50 is attained at 4deg CA bTDC. For higher injection pressure the combustion duration is reduced. This is due to the fact the fuel distribution and mixing is better at higher injection pressure it helps to reduce the delay period so the SOC gets advanced and the EOC gets retarded towards TDC which results in lesser combustion duration at 600 bar injection pressure compare to 400 bar injection pressure.

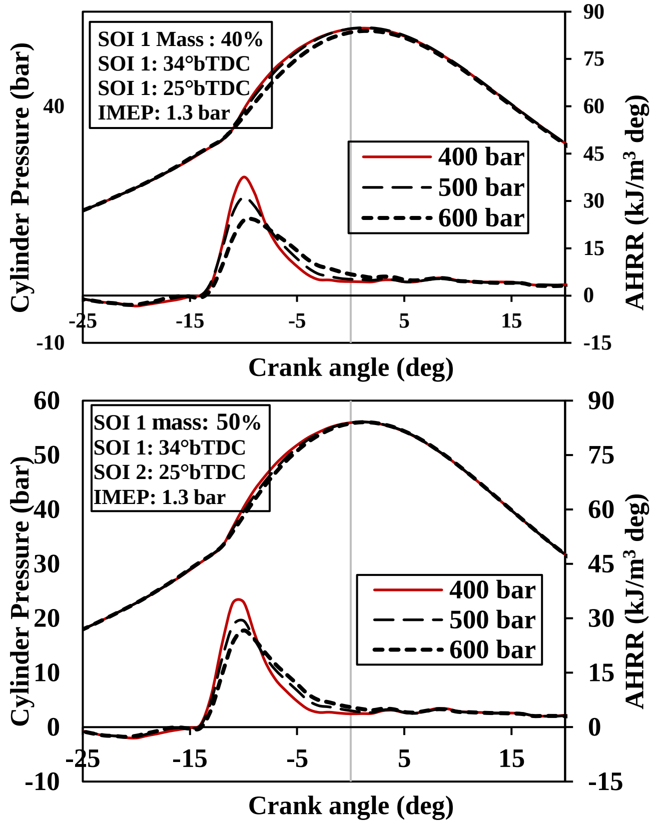

Figure 2: Effect of injection pressure of 40% & 50% pilot fraction on cylinder pressure & heat release rate

3.2 Effect of injection pressure on combustion characteristic at 50% pilot mass fraction:

The combustion parameters are estimated by varying the injection pressure at 50% of pilot mass fraction and 45% of methanol is injected in the port. By increasing the pilot mass fraction from 40% to 50 %, the delay period gets increased and the SOC also gets retarded towards TDC. So the low and high reactivity fuel mix well inside the cylinder and more homogeneity is attained. This helps to achieve a smooth pattern of heat release rate and in cylinder pressure. At 50% of pilot fuel fraction, cylinder pressure and rate of heat release follows the same trends as of 40%. As increase in injection pressure the in cylinder pressure and rate of heat release is decreased. By increasing the pilot mass fraction from 40% to 50% that the SOC is retarded towards TDC. This is due to the 50% of high reactivity fuel is injected in the first injection so it takes more time to mix with the low reactivity fuel and supports the combustion. Combustion duration also less due to more delay period.

3.3. Effect of injection pressure on combustion characteristic at 60% pilot mass fraction:

In cylinder pressure and rate of heat release at 60% pilot mass fraction and 49% of methanol for different injection pressures are shown in the figure 3. This shows that an increase in pilot mass fraction of diesel, fewer amount of fuels gets burned in low temperature region and the remaining fuel gets burned in the high temperature region. This would result in the in cylinder pressure and heat release rate and is lower than 40% and 50% pilot fuel injection cases. By increasing the low temperature region the fuel stratification can be easily achieved. So the more spontaneous combustion is occurred inside the cylinder it leads to more smooth combustion inside the cylinder throughout the engine operation.

3.4. Effect of injection pressure on combustion characteristic at 70% pilot mass fraction:

The combustion parameters for various injection pressure at 70% of pilot mass fraction of diesel and 45% mass fraction of methanol is shown in the Fig 3. With increase in mass fraction of pilot injection, the amount of fuel gets participated in the low temperature region gets increased. This is due to the fact 70% of high reactivity fuel is injected well advance in the compression stroke so it has more time to mix well with the low reactivity fuel

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and releases simultaneously some amount of energy in the compression stroke. Because of this event, a more spontaneous combustion that takes place inside the cylinder and the rate of heat release and the in cylinder pressure range is low and smooth. When more amount of fuel injected in the pilot it delayed the start of combustion. Once the fuel gets ignited based on the readiness of the mixture, the heat release rate varies. So the CA50 is reached close to the TDC. The CA50 for 600 bar injection pressure is reached at 1 deg CA bTDC . At the same time when increase in mass fraction of the pilot fuel, combustion duration gets decreased.

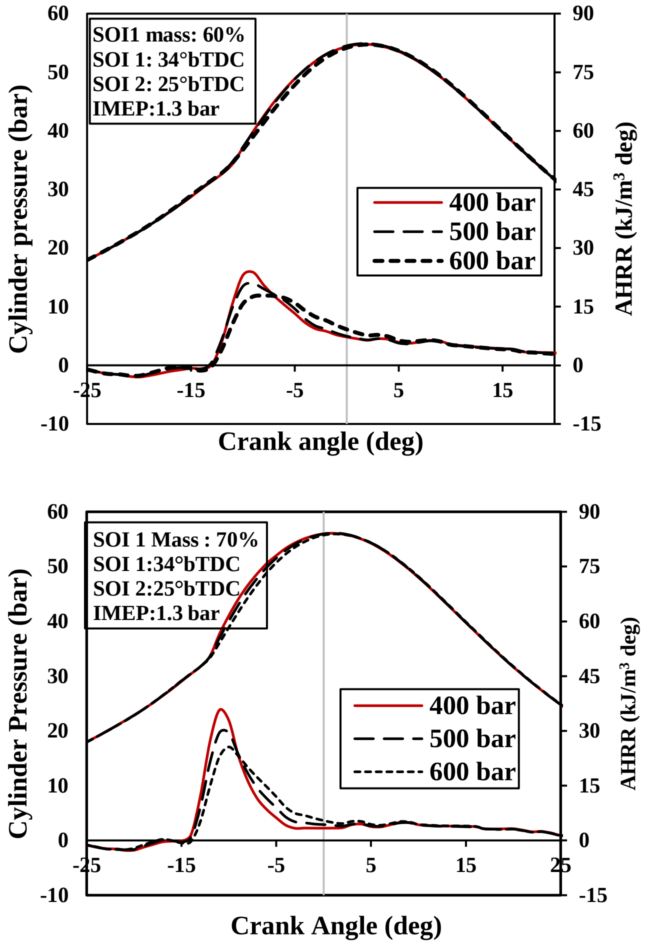

Figure 3: Effect of injection pressure on 60% and 70% pilot fraction on cylinder pressure & heat release rate

3.5 Effect of injection pressure on combustion characteristic at 80% pilot mass fraction:

The cylinder pressure and heat release traces clearly shows the low temperature region. This is due to fact as 80% of fuel is injected at 34 deg CA bTDC so it take some time to reach its auto ignition temperature. Before the SOC some amount of fuel in the low temperature reaction and it releases a tiny amount of energy, once this fuel combines with main injection fuel it gets ignited and the fuel starts burning gradually. At 600 bar injection pressure the rate of heat release and the in cylinder pressure is lower compare to 300 bar injection pressure and the combustion also phased closure to the TDC. From the above results it indicates that as increase in pilot mass fraction and the injection pressure, CA50 reached closer to the TDC and the fuel burns quickly when methanol is used as low reactivity fuel.

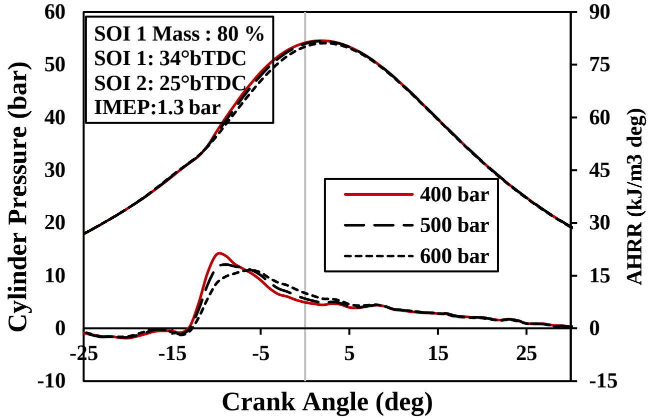

Figure 4: Effect of injection pressure of 80% pilot mass fraction on cylinder pressure and heat release rate.

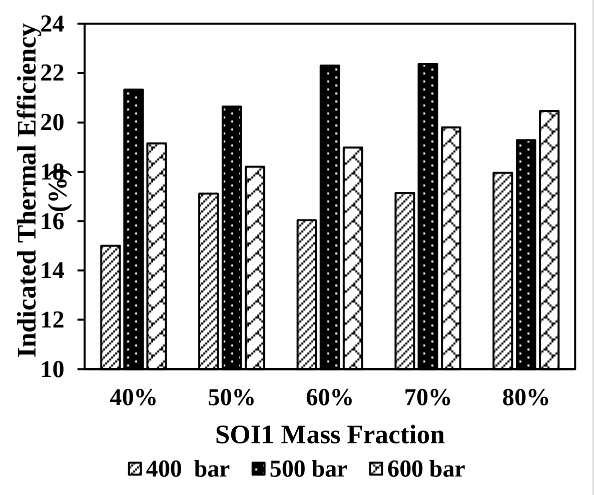

Figure 5: Indicated thermal efficiency of pilot mass and injection pressure variations

The objective of the present study is to identify the effects of pilot mass and injection pressure with methanol as low reactive fuel. The results indicated that combustion, performance and emission characteristics (Figure 6) are influenced by injection pressure and pilot mass. But the CA50 to be between 0 deg TDC and 5 deg TDC which will give maximum thermal efficiency and lesser emissions. Since the study was conducted at no load conditions there is not much significance in emissions due to the low reactive fuel property. Experiments are further to be explored at all loads to find

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the optimal operating conditions that will give better efficiency and emission results.

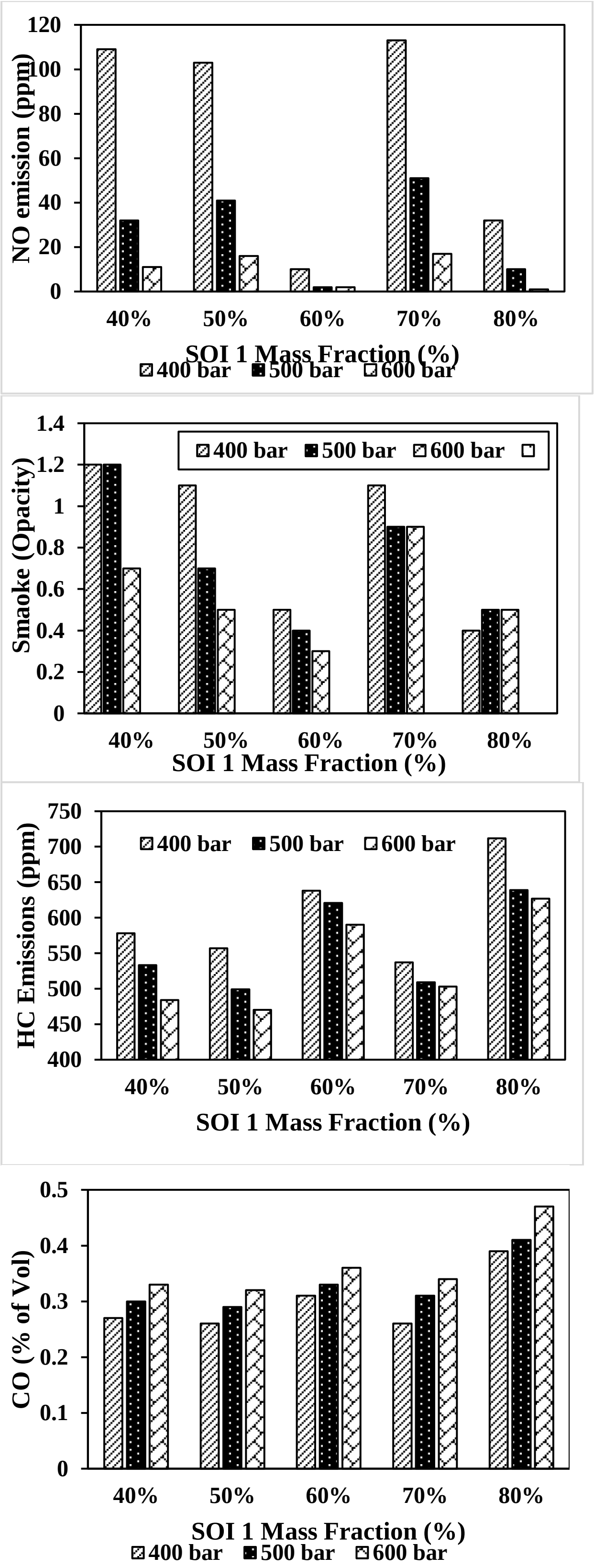

Figure 6: Emission characteristics of pilot mass and injection pressure variation

4. CONCLUSIONS

1. The performance and emissions for varying injection pressures and pilot mass fraction at 45% of PFI quantity showed that indicated thermal efficiency is higher at 60% pilot fraction compared to other pilot fractions. At 60% pilot fraction particularly at 600 bar injection pressure the ITE is much higher.

2. Figure 6 shows the NO emission for injection pressure and pilot fraction variations. 60% pilot fraction resulted in lesser NOX emission than the other pilot fraction variations. At higher injection pressure the fuel gets atomized well inside the cylinder with the methanol and it reduces the in cylinder temperature due to higher specific heat capacity. For all the pilot fraction NOX is higher at lower injection pressures due to poor atomization and mixing, that leads to a sudden combustion occurs inside the cylinder, which results in higher NOX emission.

3. Smoke emission for different injection pressure and different SOI 1 mass fraction at 45% methanol mass fraction are discussed in Figure 6. From the figure, it is known that at 600 bar injection pressure and 60% SOI 1 mass fraction, smoke emission is lower than other condition. Because at higher injection pressure the degree of atomization is higher and more homogeneity is present inside the cylinder so the smoke emission is lower at 600 bar injection pressure compare to 400 bar injection pressure.

4. HC emissions at 45% fraction of methanol in the mixture resulted in higher HC emissions throughout the engine operation because methanol is having higher latten heat of vaporization. It absorbs more amount of heat inside the cylinder so it fails to oxidize the fuel completely it results with higher HC emission at lower loads.

5. With an increase in mass fraction of SOI 1 the CO emissions gets increased from 0.21% of Vol to 0.45% of Vol. This is due to the fact the temperature inside the cylinder fails to support the combustion. By increasing the injection pressure from 400 bar to 600 bar the CO emission also gets increased due to poor air utilization. The oxidation of CO is less due to insufficient oxygen and low temperature so the CO emission is higher at 600 bar injection pressure.

6. Overall, the indicated thermal efficiency and NO emissions are comparable at 500 bar injection pressure and at 60% pilot mass fraction.

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References

[1].Reitz.R.D. Directions in internal combustion engine research.Combustion and flame.Vol 160.pp 1-8, 2013

[2].Reducing Emissions from Non-road Diesel Engines., An information report prepared for the NSWEPA. https://www.epa.nsw.gov.au/.Retrieved18 Dec 2018

[3].https://en.wikipedia.org/wiki/Nonroad_engine#cite_ref-au_6-1, Retrieved 30 April 2019

[4].International Council on Clean Transportation, India Bharat Stage IV and V Non-Road Emission Standards, 2018, Retrieved 30 April 2019

[5].https://www.dieselnet.com/standards/in/nonroad.php, Retrieved 30 April 2019

[6].Pradeep Agrawal, India's Petroleum Demand: Empirical Estimations and Projections for the Future. IEG Working Paper No. 319, 2012.

[7].http://pib.nic.in/newsite/PrintRelease.aspx?relid=174919, Retrieved 18 December 2018

[8].Genzale.L.C., Reitz.R.D., Musculus.M.P.B. Optical Diagnostics and Multi-Dimensional Modeling of Spray Targeting Effects in Late-Injection Low-Temperature Diesel Combustion. SAE technical paper. 2009-01-2669

[9].Inagaki.K., Fuyuto.T., Nishikawa.K., Nakakita.K., Sakata.I. Dual-fuel PCI combustion controlled by in-cylinder stratification of ignitability. SAE technical paper. 2006-01-0028

[10].Kokjohn.SL., Hanson.R.M., Splitter.D.A., Reitz.R.D. Experiments and modeling of dual-fuel HCCI and PCCI combustion using In-Cylinder fuel blending. SAE technical paper. 2009-01-2647

[11].Splitter.D.A., Hanson.R., Kokjohn.S.L., Reitz.R.D. Reactivity controlled compression ignition (RCCI) heavy duty engine operation at mid and high loads with conventional and alternative fuels. SAE technical paper. 2011-01-0363

[12].Heywood. J.B. Internal combustion engine fundamentals. 1988. McGraw hill co.

[13].Hashimoto K. Inhibition effect of ethanol on homogeneous charge compression ignition of heptane. SAE Technical Paper. 2008-01-2504.

[14].Shi.Y. Optimization of a compression ignition engine fuelled with diesel and gasoline-like fuels. PhD Thesis. University of Wisconsin-Madison; 2009

[15].Srinivas.P., Woo.Y., Kook.S., Hawkes.ER. Ethanol utilisation in a diesel engine using dual-fuelling technology. Fuel 2013; 109: 597-607.

[16].Hanson.R.M., Curran.S., Wagner.R., Reitz.R.D. Effects of Biofuel Blends on RCCI Combustion in a Light-Duty, Multi-Cylinder Diesel Engine. SAE technical paper. 2013-01-1653

[17].Dempsey.A.B.,Walker.N.R., Reitz.R.D. Effect of Piston Bowl Geometry on Dual Fuel Reactivity Controlled Compression Ignition (RCCI) in a Light-Duty Engine Operated with Gasoline/Diesel and Methanol/Diesel. SAE technical paper. 2013-01-0264

[18].Li.Y,Jia.M.,Liu.Y.,Xie.M.Numerical study on the combustion and emission characteristics of a methanol/diesel reactivity controlled compression ignition(RCCI) engine.Applied Energy.106(2013)184–197

[19].Li.Y., Jia.M., Chang.Y., Liu.Y., Xie.M., Wang.T., Zhou.D. Parametric study and optimization of a RCCI engine fuelled with methanol and diesel. Energy. 65 (2014) 319-332

[20].Li.Y., Jia.M., Chang.Y., Xie.M., Reitz.R.D. Towards a comprehensive understanding of the influence of fuel properties on the combustion characteristics of a RCCI (reactivity controlled compression ignition) engine. Energy. 99 (2016) 69-82

[21].Li.J., Yang.W., Zhou.D. Review on the management of RCCI engines. Renewable and Sustainable Energy Reviews. 69 (2017) 65–79

[22].Duraisamy Ganesh, P.R. Ayyappan, Rangasamy Murugan Experimental investigation of iso-butanol/diesel reactivity controlled compression ignition combustion in a non-road diesel engine. Applied Energy 242 (2019) 1307-1319

[23].Mari Pietikainen, Ari Valiheikki , Kati Oravisjarvi et al, Particle and Nox emissions of a non-road diesel engine with an SCR unit: The effect of fuel, Renewable Energy 77 (2015) 377-385

[24].Seppo Niemi, Ville Vauhkonen, Sari Mannonen et al, Effects of wood-based renewable diesel fuel blends on the performance and emissions of a non-road diesel engine, Fuel 186 (2016) 1–10

[25].Chenyang Fan, Chonglin Song, Gang Lv Evaluation of carbonyl compound emissions from a non-road machinery diesel engine fuelled with a methanol/diesel blend, Applied Thermal Engineering, 129 (2018) 1382–1391

[26].Arkadiusz Jamrozik, Wojciech Tutak, Michał Pyrc, Michał Gruca, Marek Kocisko, Study on co-combustion of diesel fuel with oxygenated alcohols in a compression ignition dual-fuel engine, Fuel 221 (2018) 329–345

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