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Prediction of Suitable Ignition Timing and Compression Ratio of Dmf Direct Injection Turbocharged Multi-Cylinder Si Engine with EGR

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Abstract-— **This research article focused on optimising and selected suitable compression ratio, ignition timing and stimulation, experimental study and performance parameters, exhaust gas recirculation, and a heat release rate for a multi-cylinder turbocharge direct injection spark ignition (SI) engine. Simulation results, methodology, combustion models, sub-models were used to find optimised performance parameters for better combustion. Optimum parameters were identified by conducting a test with constant compression ratio (14.4:1) and constant speed mode (2500 rpm) and variable speed mode by varying Exhaust Gas Recirculation (EGR) ratio between 0 to 15%, and emission characteristics were found. Optimised EGR ratio among the variations and predicted suitable ignition timing and duration for DMF of injection timing of SI engine were selected from simulation results. Variation of In-cylinder pressure, heat release rate with Crank angle and Specific Fuel Consumption, Ignition Delay, along with NOx and Particulate Matter emission results were obtained from the simulation and experimental results.**

Index Terms - DMF-Direct injection, Compression ratio optimisation, spark ignition-timing optimisation

I. INTRODUCTION

The climate strategy for land transportation is expected to result in gains in energy production and alternative fuels. SIDI engines are vital in improving gas performance. These engines would certainly operate on renewable energy sources. DMF and iso-butanol are mainly derived from alternative energy sources like sugar cane and used for IC engines. Another problem with the SIDI engines is that the mixture preparation requires high accuracy. This tight spacing is crucial as carburettors are fitted near spark plugs, so a spark ignites the mixture formed near the spark plug. The fuel's physical properties would significantly impact this operation because alcohols appear to have higher heats of vaporisation and less density than gasoline. Thus, local conditions at the time of combustion will be somewhat different from more traditional fuels. DMF and iso-butanol were used to conduct the experiments to research the effects of these fuels to speed. These effects are contrasted to those of something else, iso-octane, a pure chemical widely used for fuel. First, a mapping analysis shows that similar results can be obtained between all three types of fuels. The ignition is the first step that must occur before the combustion. Finally, the evaporation and mixing phase was studied by using high-speed laser-induced fluorescence. Through this method, a greater understanding of them can be obtained.

2. MATERIALS AND METHODOLOGY

The direct injection system allows work with injection techniques in order to achieve better fuel economy. DMF characteristics such as high octane, latent heat of vaporisation, and quicker laminar speed make DMF a very attractive biofuel. These improvements help to achieve very reliable and efficient knock suppression in SI engines. Several tests have shown that DMF has a positive effect of suppressing soot development indirect injection engines. DMF use helps in the elimination of harmful emissions and toxic substances (CO). The lower air-fuel ratio (AFR) and lower heating value (LHV) in contrast to DMF means that it would increase the brake specific fuel consumption (BSFC) and CO_2 specific emissions. This study looks at stratified DMF injection. The experiments were conducted at 1000 RPM with the lambda of 1.00, 1.10, 1.20 and 1.30. Flare characteristics were analysed from photographs taken during the torch-lighting ceremony. In a further development of DMF-directed injection strategies, the authors believe the findings based on this study and fuel properties are shown in Table No 1.

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Table 1
Test fuel properties.

	DMF	Gasoline
Chemical formula	C_6H_8O	$C_{6.62}$–$C_{11.88}$
H/C ratio	1.333	1.795
O/C ratio	0.167	0
Gravimetric oxygen content (%)	16.67	0
Density @ 20 °C (kg/m^3)	889.7[a]	744.6
Research octane number (RON)	101.3[b]	96.8
Motor octane number (MON)	88.1[b]	85.7
Octane index ([RON + MON]/2)	94.7	91.25
Stoichiometric air fuel ratio	10.72	14.46
LCV (MJ/kg)	32.89[a]	42.9
LCV (MJ/L)	29.26[a]	31.9
Flash point (°C)	1	−40
Heat of vaporization (kJ/kg)	332	373
Stoichiometric heat of vaporization (kJ/kg$_{air}$)	31	25.8
Initial boiling point (°C)	92	32.8

2.1 Methodology and Experimental setup

Alkylating furan can be produced with biomass, such as 2,5-dimethylfuran and 2-methyl furan, with desirable properties to fuel blending blocks with the spark-ignition. Their high volume of octane, relatively high energy density, low water solubility and minimal effect on the volatility of the gasoline mix are potentially essential benefits for combustible sources based on alcohol. However, previous studies have reported poor oxidative stability and potential for the formation of dangerous organic peroxides for furanic compound gasoline fusion mixes. We show that the oxidative stability of alkylated furans is shallow about conventional fuel.

Multi-cylinder turbocharged SI engine combustion simulation methodology has one of the significant phases of the in-cylinder model and predicts the engine parameters[15].

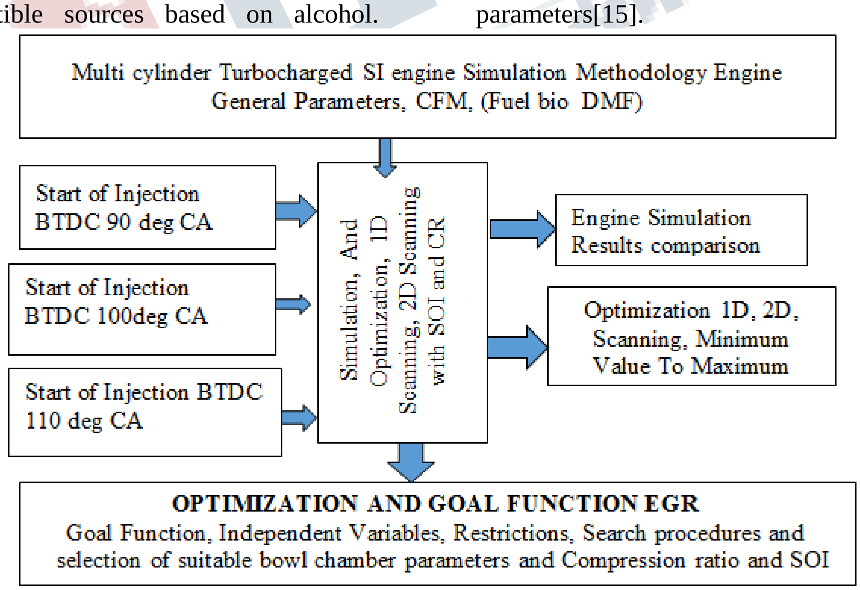

Figure 2.1 Diesel RK simulation methodology for Multi-cylinder DMF engine

It deals with creating three different EGR ratio and constant swirl ratio piston bowls and a selection of suitable EGR Bowl chambers[16]. Based on the methodology, the EGR ratio, bowl chambers parameters created with constant swirl ratio and same compression ratio 16.5:1 for multi-cylinder precooled turbocharged

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diesel DI engine[17]. The second is to select suitable multi-hole injectors, which varies from 3 to 7 holes and three different piston bowls with different swirl ratios with the same compression ratio 28.54:1 for a multi-cylinder turbocharged DMF HCI engine.

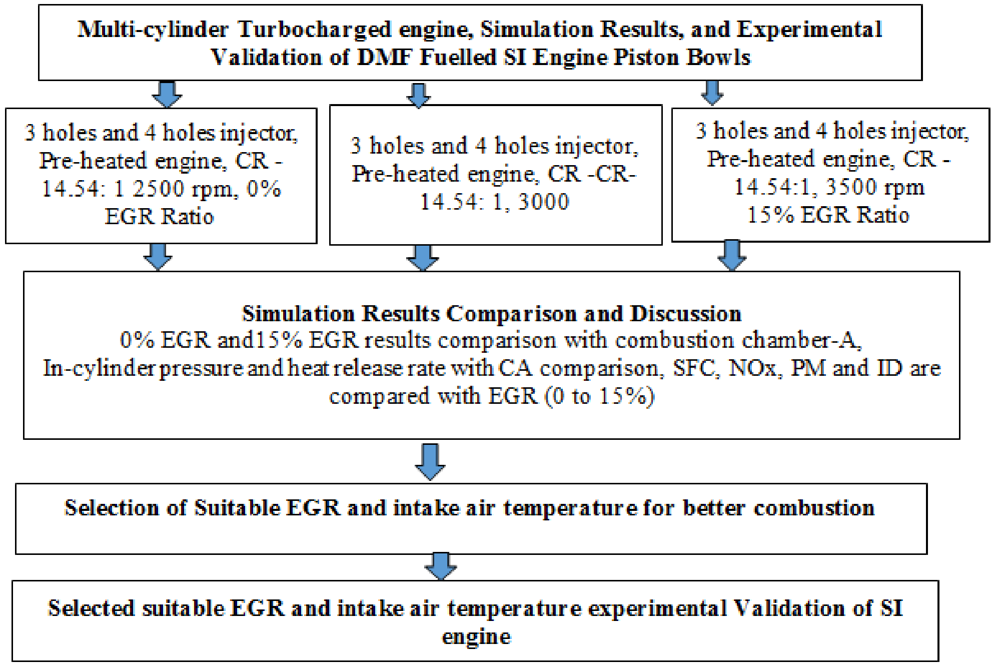

Figure 2.2 Multi-cylinder precooled turbocharged engine simulation methodology

Hence, this is a great challenge to create and select a better combustion chamber and select a suitable EGR ratio for low NOx emission and high efficiency[18]. The simulation split into two phases, the first phase was focused on performing and predicting suitable injector holes due to increasing the volume of fuel injection and EGR for better combustion for DMF engine and the second phase was concentrated to select suitable combustion chamber bowl for DMF HCI engine as shown in Figure 2.1, 2.2., and 2.3.[19][20] Diesel RK combustion simulation is well supported to find the significance of piston bowl parameters, namely compression ratio (CR) swirl ratio (SR), Exhaust Gas recirculation (EGR), and injection timing (IT), injection pressure (INJP). Cycle fuel mass (CFM) and find optimum combustion and fabrication piston bowl points to achieve better combustion and experiment results and discussed[11]. Injector selection methods are a significant step for DMF engines due to 1.6 times lower calorific value than diesel fuel. Hence required to select suitable injectors for injecting required injection duration.

Diesel RK software is well supported to design the Injector, like the number of holes, angle of injection, and the results of visualisation of fuel spray in different zones. It can also save as windows graphics files, namely AVI or animated GIF files[21]. Visualisation data was supported to find a spray pattern and plot a picture, as in 3D and shown in Figure 3.2[21]. The evolution of fuel sprays and their Near Wall Flow (NWF) in a combustion chamber and the

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Mode of Performance (#1 = Full Load)	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Engine Speed, [rpm]	2000	2500	2700	2900	3000	3500	3200	3300	3400	3500
Cycle Fuel Mass, [g] CFM Calc	0.222	0.23	0.24	0.25	0.26	0.27	0.28	0.29	0.3	0.31
Injection / Ignition Timing, [deg B.TDC]	21	21	21	21	21	21	21	21	21	21
Atmosphere Pressure at sea level, [bar]	1	1	1	1	1	1	1	1	1	1
Atmosphere Temperature at sea level, [K]	300	300	300	300	300	300	300	300	300	300
Altitude Above Sea Level, [km]	0.411	0.411	0	0	0.411	0	0	0	0	0
Velocity of flight (for aircraft engines only), [km/h]	0	0	0	0	0	0	0	0	0	0
Inlet Pressure Losses (before compressor), [bar]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Differential Pressure in exhaust (tail) system, [bar]	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Compressor Pressure Ratio (HP Stage)	2	2	2	2	2	2	2	2	2	2
Compressor Adiabatic Efficiency (HP Stage)	0.732	0.732	0.732	0.732	0.732	0.732	0.732	0.732	0.732	0.732
Fraction of the Exhaust Gasflow By-passed before Turbine	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Fraction of the Airflow By-passed after Compressor into atmosphere	0	0	0	0	0	0	0	0	0	0
Average Total Turbine Inlet Pressure (HP St.) (or first appr.), [bar]	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
Turbocharger Efficiency (HP Stage)	0.534	0.534	0.534	0.534	0.534	0.534	0.534	0.534	0.534	0.534
EGR Ratio	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Gasoline Injection Timing, [deg B.TDC]	100	100	100	100	100	100	100	100	100	100

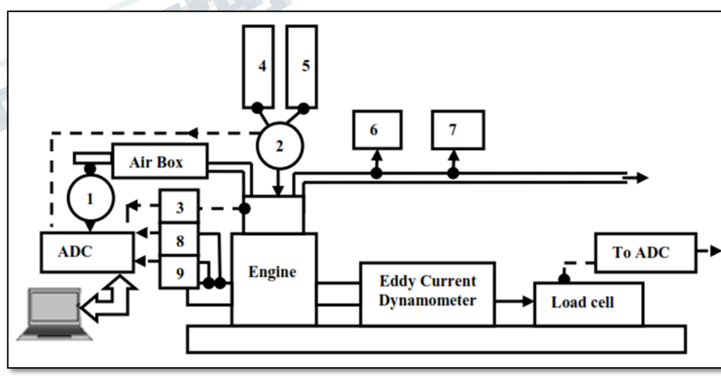
Figure 2.3 Operating Parameters for thermodynamic simulations

Swirl's effects are predicted and presented hereunder. The deformation of sprays by swirl can predict NWF depending on the angle of sprays and wall impingement[22]. Evolution of NWF under the swirl and NWF interaction among themselves and Fuel allocation study for the distinct zones. The injection rate and heat release curves can also be studied for spray visualisation in Diesel RK simulation[19][21][22][23].

3.0 EXPERIEMNTAL SETUP

Table: 2 Experimental Setup

Make & Model	6 ERDI cylinder SI engine
Research Engine Type	Four strokes / Water-cooled / CI engine.
Number of cylinder/ Bore/Stroke	One / 150mm /180 mm.
Compression Ratio Diesel/ DMF fuel	Diesel 17.5:1/ DMF 28.54:1
In-cylinder pressure limit	0 to 240 bar
Engine Direction of rotation/ Speed	Clockwise/ 1500rpm to 1600rpm
Ignition timing DMF fuel engine	31^0BTDC (Adjustable)
Inlet / Exhaust Valve clearance	0.18 mm /0.20mm
Type /Engine oil Lubricating system	Gear type/ Force feed system
Oil Sump capacity /Lubricating oil pump delivery	5.70 liters/6.50 lit/min



Airflow sensor, 2. Fuel flow sensor, 3. A pressure sensor, 4. Diesel tank, 5.DMF tank, 6. Five gas analysers, 7. Smoke Meter, 8. RPM Indicator, 9. Crank Angle encoder.
Figure 2.4 Experimental Layout

Table: 3 Experimental Results

RPM	P_eng	BMEP	Torque	m_f	SFC	SFC_ISO	Eta_f	IMEP	Eta_i	Sp	FMEP	Eta_m
2000	186.74	5.8707	891.67	0.222	0.42798	0.2464	0.31387	8.6894	0.46456	12	2.0841	0.73801
2500	219.91	5.5308	840.05	0.23	0.47065	0.26967	0.28541	8.8661	0.45753	15	2.4864	0.68987
2700	247.44	5.7622	875.2	0.24	0.47139	0.28291	0.28496	9.3063	0.46023	16.2	2.6357	0.68615
2900	282.93	6.1344	931.73	0.25	0.46124	0.27702	0.29123	9.7351	0.46218	17.4	2.7225	0.69261
3000	304.67	6.3854	969.85	0.26	0.46083	0.26462	0.29149	9.9293	0.45327	18	2.7017	0.70269
3200	345.67	6.792	1031.6	0.28	0.46657	0.28055	0.2879	10.563	0.44775	19.2	2.828	0.70603
3300	367.31	6.9985	1063	0.29	0.46897	0.28207	0.28643	10.849	0.44401	19.8	2.8834	0.70822

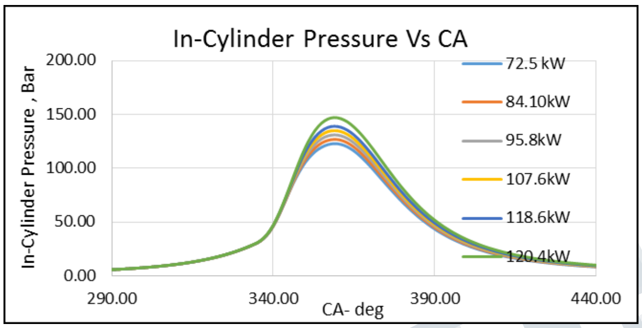
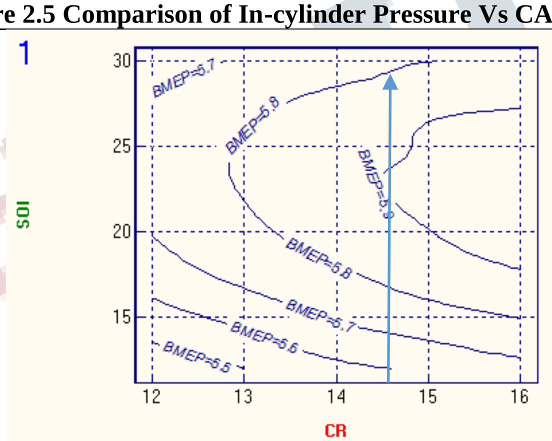
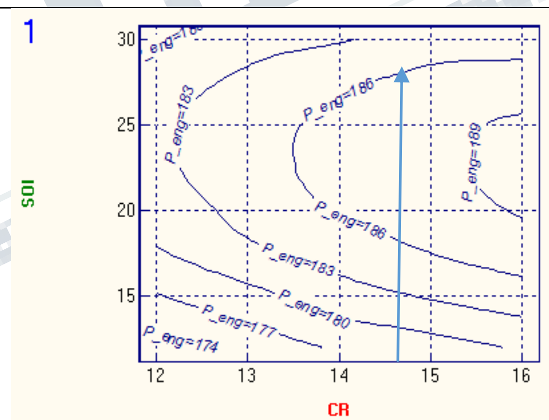


Figure 2.5 Comparison of In-cylinder Pressure Vs CA



A- start of ignition(SOI) vs compression ratio(CR) BMEP variation



B start of ignition(SOI) vs compression ratio(CR) engine power(IP) variation

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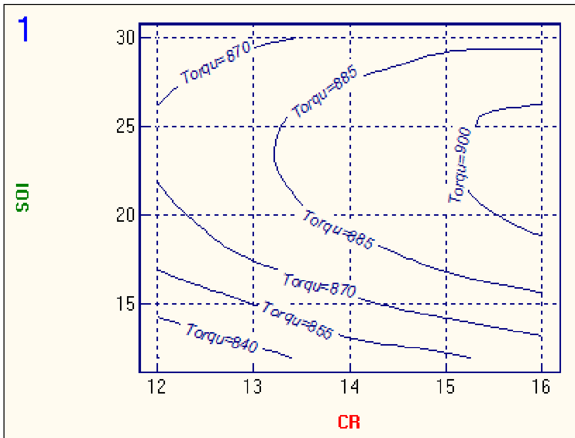
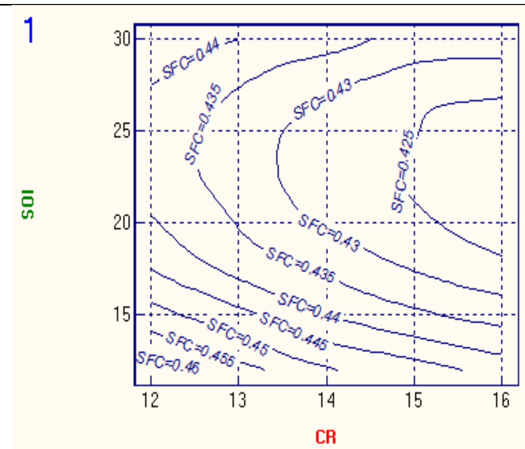
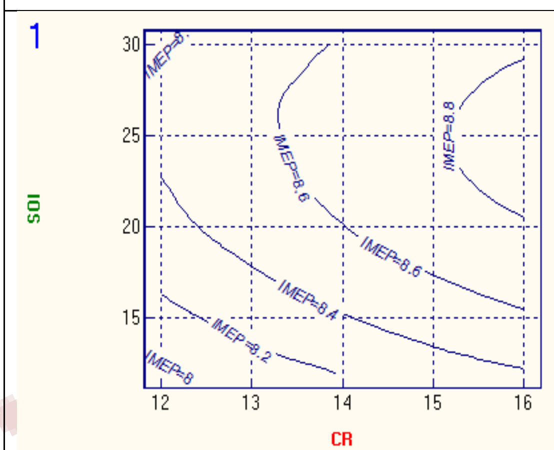


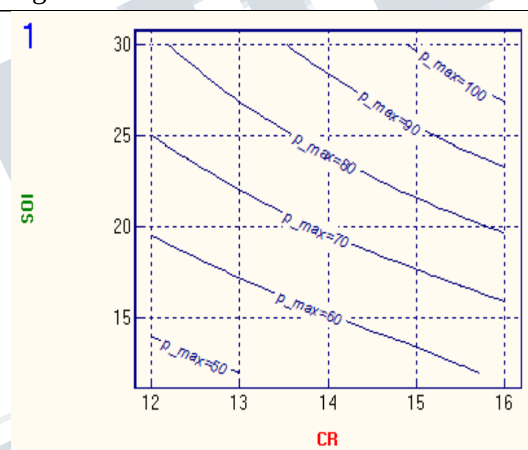
C start of ignition(SOI) vs compression ratio(cr) Engine Torque variation



D- start of ignition(SOI) vs compression ratio(cr) Engine SFC variation



E- start of ignition(SOI) vs compression ratio(cr) Engine IMEP variation



F- start of ignition(SOI) vs compression ratio(cr) Engine P_MAX variation

Figure 2.6 Comparison of performance parameters concerning CR

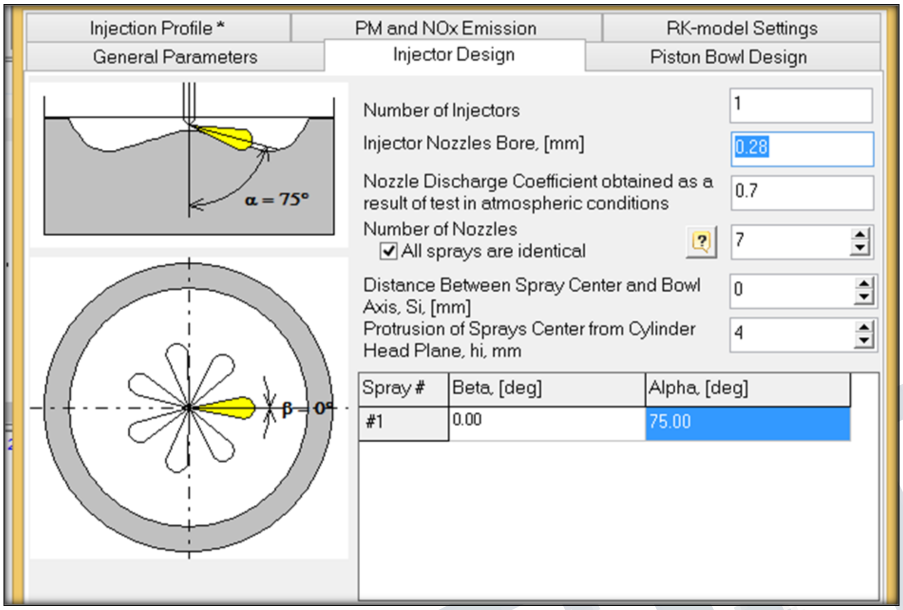


Figure 2.7 Fuel Injection and injector design

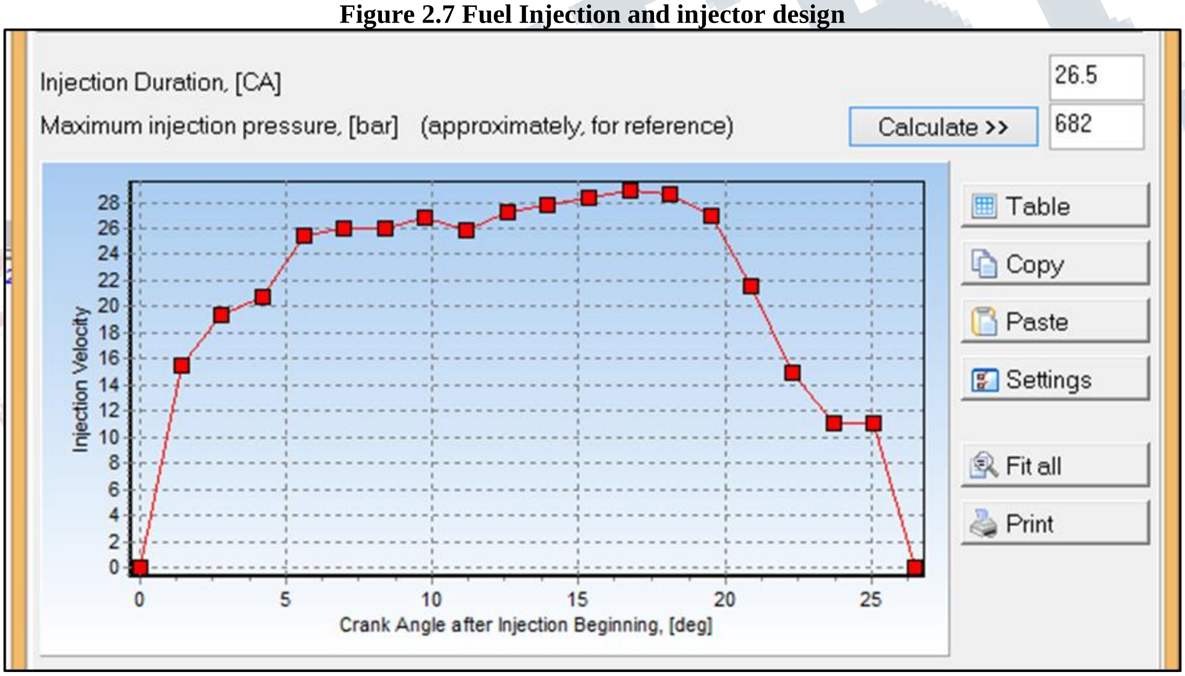


Figure 2.7 Fuel Injection and injector design

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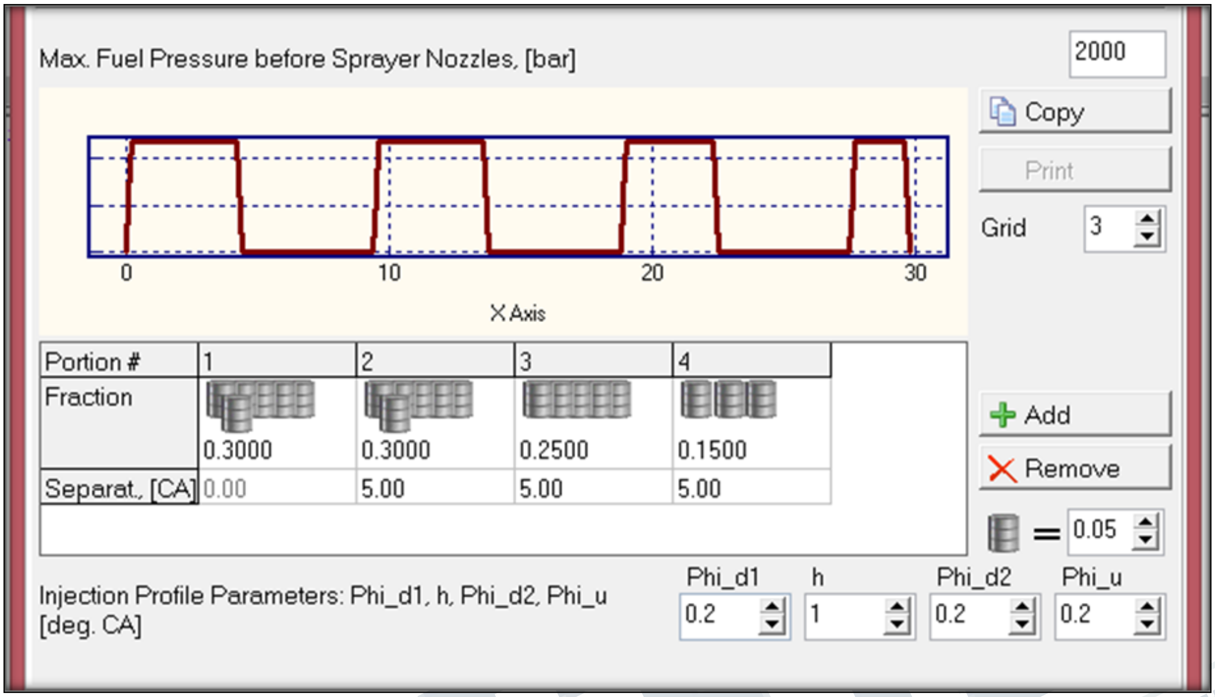

Figure 2.8 Fuel Injection and profile parameters

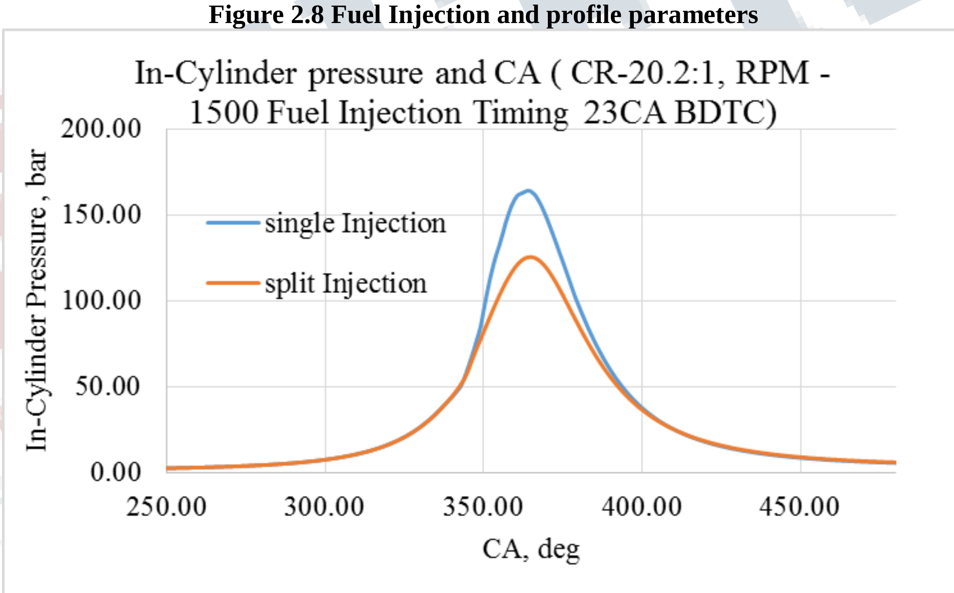

Figure 2.9 In-Cylinder Pressure Vs CA of single and split injection

4.0 Results and Discussion

Currently, the supply of diminishing fossil fuel reserves and the rise in environmental, political and economic consequences have caused significant concerns in the development of modern society; these have forced policy-makers and researchers to look for renewable and green energy sources. Deemed as a promising renewable alternative to traditional fossil fuels, 2,5-dimethylfuran (DMF, chemical formula C6H8O)—a derivative of furan—has the potential to relieve the growing shortage of fossil fuels while satisfying the increase in global energy demand and minimizing the adverse effects of climate change. DMF can be used as a clean source of liquid transportation biofuel, given that it is directly obtained from biomass-derived carbohydrates. In reviewing current DMF production methods, this review paper analyzes and presents the comparison of catalytic

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performance in biomass conversion into DMF. In addition, the applicability of DMF in spark-ignition (SI) engines is thoroughly analyzed based on the spray and flame, combustion, performance, and emission characteristics of SI engines running on DMF compared with ethanol and gasoline. More interestingly, the knocking, lubrication, and wear characteristics in SI engines fueled with DMF are also evaluated and discussed. Nonetheless, further investigation on optimization strategies on the DMF production process should be conducted before the initiation of large-scale commercialization and the application of DMF to real-world SI engines.

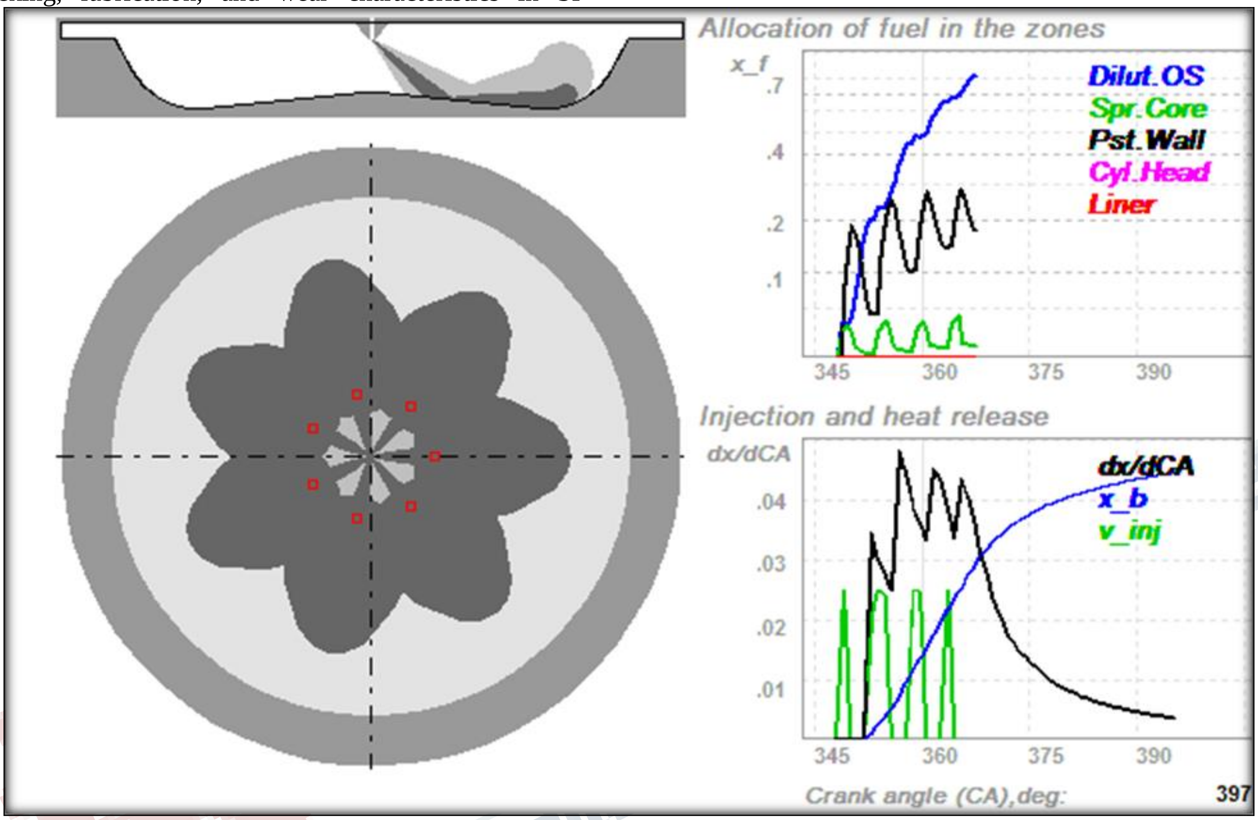

Figure 2.10 Allocation of fuel in the zones and injection profile and heat release rate Vs CA of split injection

When multi-injection is carried out in the SI motor through the common rails injection system with a high pressure, a changing interval of injection pulses can induce a sequential injection pulse profile change, although other control parameters are identical. For the development of injection strategy, variations in an injection rate that affect the air-fuel mixing and combustion process will be necessary. This study examined the effects of injection rate form on DMF combustion and emissions using the numeric simulation simulations using the thermodynamic simulation Tool and shown in Figure 2.10.

5 Conclusion

Multi-cylinder precooled turbocharged high compression ignition engine simulation and experimental results were used to predict the following conclusion. Diesel RK Simulation and experimental results are used to obtain the following conclusion is.

- SFC, NOx, PM, and ID of three different EGR with different CFM are plotted with different EGR and investigated. SFC, NOx, PM, and ID of and rate of heat release are predicted and plotted.
- The premixed combustion zone heat release rate with EGR is higher compared to 0% EGR. The Heat release rate curve shifted to two deg BTDC due to increasing the evaporation.
- Intake Air temperature is increased from 20^0 to 45^0c by using the Precoole turbocharged system, and this technology was supported to increase the in-cylinder temperature and initiate better combustion compare to 0% EGR mode.

- In-cylinder Pressure does not drastically change for comparison of DMF and diesel fuel with and without the EGR mode test due to the high latent evaporation of DMF fuel.

1) SFC of 15 % EGR at all CFM is slightly higher with 0 % EGR for diesel and DMF fuel engines.
2) NOx of 15% EGR mode at all load conditions drastically reduced compared to with 0% EGR mode for both diesel and DMF mode operation. NOx emission was 78% lower than 0% EGR for DMF and 68% lower than diesel mode.
3) PM of DMF fuel engine is significantly lower than others shown in sections 3 and 4; hence DMF was soot-free combustion compared to a diesel engine.
Ignition Delay (ID) of DMF fuel engine is two to four degrees lower than 0% EGR mode at different CFM, as shown in section 3. Low ID was also one of the added advantages of other parameters for the selection of performance parameters. Based on the detailed analysis, the combustion was better and low emission for 15% EGR mode and selected for base fuel diesel and better combustion DMF fuel for multi-cylinder turbocharged High compression ignition engine.
, DMF has showed as a promising fuel for SI engine, even when those engines were operated under the advanced combustion modes. However, the optimization of DMF production process to target the commercialization and realization strategy should be addressed because this current cost of DMF was not still comparable with that of other commercial fuels.

Nomenclature

U_p	-	Average Piston Speed
BDC	-	Bottom Dead Center
BMEP	-	Brake Mean Effective Pressure
BP	-	Brake Power
BSFC	-	Brake Specific Fuel Consumption
BTE	-	Brake Thermal Efficiency
CO_2	-	Carbon Dioxide
CO	-	Carbon Monoxide
CN	-	Cetane Number
CR	-	Compression Ratio
CFR	-	Cooperative Fuel Research
CA	-	Crank Angle
CFM	-	Cycle Fuel Mass
DI	-	Direct Injection
EGR	-	Exhaust Gas Recirculation
FP	-	Friction Power
GHG	-	Green House Gas
HSU	-	Hartridge Smoke Unit
HC	-	Hydro Carbon
IMEP	-	Indicated Mean Effective Power
IP	-	Indicated Power
ITE	-	Indicated Thermal Efficiency
IDI	-	Indirect Injection
ICE	-	Internal Combustion Engine
ISO	-	International Standard Organisation
MTBE	-	Methyl Tetra Butyl Ether
NWR	-	Near Wall Flow
NOx	-	Nitrous Oxide
NDIR	-	Non-Dispersive Infrared Analyser
PM	-	Particulate Matter
PEG	-	Poly Ethylene Glycol
SFC	-	Specific Fuel Consumption
SOC	-	Start of Combustion
SOI	-	Start of Injection
SR	-	Swirl Ratio
U_t	-	Swirl Tangential Speed
TDC	-	Top Dead Center
TFC	-	Total Fuel Consumption
UHC	-	Unburned Hydro Carbon
VCR	-	Variable Compression Ratio

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