University POLITEHNICA of Bucharest, Romania

PhD. Thesis

Contributions to the Investigation on the Operating of a Diesel Engine Fuelled by Gasoline-Diesel, Gasoline-Biodiesel B20 Fuels under the Reactivity Controlled Compression Ignition Strategy

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CHAPTER ONE

1 INTRODUCTION

1.1 Introduction

Energy is like blood for the world economy and starting from this comparison; the whole world depends on energy resources. Fossil fuels and burning materials are reaching almost 80% of the world's energy demand Han et al. [1]. Internal combustion engines have been dominant in automotive applications for more than 100 years due to their high power output, efficiency and stability. Compression ignition (CI) engines provided with direct injection technology have high efficiency, being operated in large numbers in different sectors, such as transportation, construction and power plants, according to Heywood [2]. Thus, it leads to increasing demand for diesel fuel consumption, with multiple economic, technical and environmental consequences. Therefore, reducing the emissions levels, especially those of CO_2, $NO_{x,}$ and PM remains a key concern referring to diesel engine operation [3,4].

In spite of the aforementioned notable advantages of biofuels over diesel, several studies reported their dissimilar combustion characteristics. This difference between the biofuel and diesel performance can be ascribed to issues related to the viscosity, volatility, and compression capacity of the biofuels that affect the ignition delay (ID) and combustion behaviour. Thus, it is important to overcome the problems linked to biofuels for improved performance of the engines [17].

The RCCI is a dual fuel combustion technique that begins with gasoline and diesel as the corresponding low and high reactive fuel (LRF and HRF). The RCCI combustion can operate over a wide-ranging load with almost zero levels of NOx and soot emission, acceptable pressure rise rate and high indicated efficiency [24]. .

1.2 Project Motivation

1.3 Objectives of This Study

The objectives of the study presented here are as follows:

- Review of using higher gasoline fuel than spark ignition engine design.
- Review of previous studies of using the different rates of gasoline fuel mixing with diesel or biodiesel fuels associated with CDC, GCI and RCCI engines.
- Review of using different simulation tools on the operation in RCCI technology. Then Wiebe-2-Zones-AVL-BOOST Software 2020 under RCCI strategy.
- Create two Wiebe-2-Zones-AVL-BOOST models, a multi-point fuel injection (MPI) model and single point injection (SPI) model.
- Build of the experimental test CDC.
- Experiment on the RCCI engine performance, combustion, and emissions by using (8 and 5% gasoline fuels) in gasoline diesel blends with engine speed at 1400 rpm (speed of maximum brake torque) and (12 and 21% gasoline fuels) in gasoline –diesel blends with engine speed at 2400 rpm (speed of maximum brake power) under (60 and 100) % engine loads conditions respectively, under RCCI technology.

1.4 Thesis Layout

This study is divided into seven chapters to cover all the work details and every chapter consists of different sections as described below:

- **Chapter one:** provides an introduction
- **Chapter two:** provides a literature review
- **Chapter three:** Include collects and analyses of using different simulation tools on the operation in RCCI technology.
- **Chapter four:** includes created two Wiebe-2-Zones-AVL-BOOST models, a multi-point fuel injection (MPI) model and single point injection (SPI) model.
- **Chapter five:** Includes experimentation the effect of diesel fuel on the CDC engine.
- **Chapter six:** includes the experimental test on a 4-cylinder, 4-stroke, naturally aspirated water-cooled DI Tractor diesel engine under RCCI technology after making all the necessary modifications at different gasoline-diesel blends and 60 and 100 % engine loads.
- **Chapter seven**: includes the summaries.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Introduction

2.2 Review Fuel Properties

2.2.1 Review of Gasoline Fuel Properties

Gasoline is produced by crude oil..

2.2.1.1 Octane Number

2.2.1.2 Density

2.2.1.3 Kinematic Viscosity

2.2.1.4 Stoichiometric Air Fuel Ratio

2.2.1.5 Auto-Ignition Temperature

2.2.1.6 Flash Point

2.2.1.7 Ignition Delay

2.2.1.8 Heat Vaporization

2.2.1.9 Flammability

2.2.2 Review of Diesel Fuel Properties

Diesel is considered more efficient compared to gasoline as it releases a smaller amount of greenhouse gases.

2.2.2.1 Cetane number

2.2.2.2 Viscosity

2.2.2.3 Density heating

2.2.2.4 Lubricity

2.2.2.5 Ignition quality

2.2.2.6 Flashpoint

2.2.2.7 Oxidation stability

2.2.2.8 Cloud point

2.2.2.9 Pour point

2.2.2.10 Ash water sediment

2.2.3 Review of biofuel properties

This is a vegetable oil that has glycerol removed from it.

2.2.3.1 Lubricity

2.2.3.2 Cetane number

2.2.3.3 Availability

2.2.3.4 Cloud point, Pour point

2.3 Review of using gasoline with higher research octane number than engine design in SI engine

The latest study examined the probability of enhancement in engine performance by decreasing hazardous gases and was experimentally investigated in this study using three types of gasoline fuel RON95, 97 and 102. The Mitsubishi Campro CPS 1.6 L4 cylinder with cr 11: 1 engine is used in this study. The engine was operated with an engine speed interval of 500 rpm within the range of 1000 rpm to 3500 rpm. The throttle body was kept constant at 11%. The original ECU includes CPS (Cam Profile Switching system), an eddy current dynamometer and control, and an exhaust gas analyzer. Under the various load conditions and within speed range the findings of the study indicated that fuel RON97 shows enhancement in BSFC reduced by 13% and 24% of the fuel of RON 102 and RON95. In addition, RON97 shows higher torque and engine power in contrast to RON102 and RON95. Unlike RON102 and RON95 brake thermal efficiency of RO97 was found higher at 14% and 30% correspondingly. The lower NOx emission was found using high octane of RON102 by an average of 25%, and 102% compared to RON95 and RON97. The lower octane fuel of RON95 was determined of higher emission of CO compared to the high octane of RON97 and RON102 fuel.

2.4 Review of using the different rates of gasoline in diesel or biodiesel fuels in CDC, GCI and RCCI engines.

This subchapter reviewed in details the effects of gasoline in diesel or biodiesel fuels towards the improvement of the main three important aspects which are the engine's combustion characteristics, performance and exhaust emissions when combined with the CDC, GCI and RCCI technologies (CDC as a reference).

2.4.1 Combustion parameters analysis

2.4.1.1 Ignition delay analyses

2.4.1.1.1 Ignition delay for classical diesel combustion technology

2.4.1.1.2 Ignition delay for gasoline compression ignition technology

2.4.1.1.3 Ignition delay for reactivity control compression ignition technology

2.4.1.2 Analysis of the heat release rate (HRR)

2.4.1.2.1 The heat release rate for classical diesel combustion technology

2.4.1.2.2 The heat release rate for gasoline compression ignition technology

2.4.1.2.3 The heat release rate for reactivity control compression ignition technology

2.4.1.3 Engine efficiency

2.4.1.3.1 Efficiency for classical diesel combustion technology

2.4.1.3.2 Efficiency for gasoline compression ignition technology

2.4.1.3.3 Efficiency for reactivity control compression ignition technology

2.4.1.4 Engine Exhaust Emissions

2.4.1.4.1 Exhaust emissions for classical diesel combustion technology

2.4.1.4.2 Exhaust emissions for gasoline compression ignition technology

2.4.1.4.3 Exhaust emissions for reactivity control compression ignition technology

2.4.2 Conclusion

From all previous pages, we can conduct that to get the best engine performance and emissions; we need to make a tradeoff between three factors, which are below:

- **Engine Operating Conditions:** this factor starts from changing Cr, EGR, CA, SI etc. until how we can add the fuel to the engine, like DI, PFI and normal aspirator.
- **Engine Design:** this factor start from the kind of engine CDC, GCI, or RCCI, the number and shape of a cylinder and other auxiliary devices and systems connected with the engine.
- **Fuels:** this factor includes the type, quality and quantity of fuel usage with the engine.

Furthermore, the engine performance, fuel economy, and exhaust emissions of RON95, RON97 and RON102 gasoline grades fuels are experimentally evaluated on a representative Malaysian engine model. With fuel RON97 it has been found higher torque, brake power, brake thermal efficiency, and lower BSFC in all conditions compared to RON102 and RON95. The study found that (NOx) emission was reduced in the case of RON102 compared to the use of RON95 and RON97 and the carbon monoxide (CO) emission decreased when fueling with RON102 and RON97 compared to RON95. It is asserted that RON97 has a good perspective than the most common RON95 fuel for widely used Malaysian engine models having the latest technology consisting of VVT, VTEC, MIVEC, and CPS systems, producing more engine power with fuel economy, and improving the emissions concentration.

The ongoing issues related to the strict pollution regulation and energy crisis encountered by the present internal combustion engines are revisited. It is recommended to use novel biodiesel combined with advanced technologies to resolve these issues. Biodiesel is preferred as fuel in the new GCI and RCCI engines due to its high oxygen content and CN. Repeated research revealed that the novel DBG blends can productively be used in the CDC system following the double injection fuel strategy which ensures an early SOI, low exhaust emissions and improved performance of the engine. In addition, the high NOx emission and low efficiency of the GCI can be overcome by mixing biofuel with gasoline via multiple injection strategies. The HC and CO emissions can be lowered and engine performance can be improved using the RCCI technology wherein either through the selection of LRF or advanced technologies-assisted engine design and operation parameters optimization. It is established that the RCCI technology with optimal engine design and regulated operation may be beneficial for the reduction of the engine's exhaust emissions and enhancement of efficiency. In short, this all-inclusive overview may provide taxonomy for navigating the cited topic with multifaceted future benefits.

CHAPTER THREE

3 SIMULATION STUDY BY DIFFERENT SOFTWARE TOOLS ON THE OPERATION IN RCCI MODE OF A COMPRESSION IGNITION ENGINE, CORRELATION BETWEEN FUEL PROPERTIES AND ENGINE OPERATING PARAMETERS

3.1 Introduction

3.2 RCCI Strategy Concept

3.3 Different Simulation Tools With RCCI Strategy

3.3.1 Zero-Dimensional Tools

3.3.2 One-Dimensional Tools

Figure 3.1.Schematic layout of the test bench [133]

3.3.3 Multi-Dimensional Tools

3.4 Simulation test

3.4.1 Engine test bench setup

Tractor diesel engine 4-cylinders, 4-strokes, naturally aspirated DI, water-cooled was used with this study, Politehnica of Bucharest University, internal combustion engine lab was the place for this engine, integrated into the measurement assembly as schematized in figure 3.12 and general engine specification test was shown in Table 3.3.

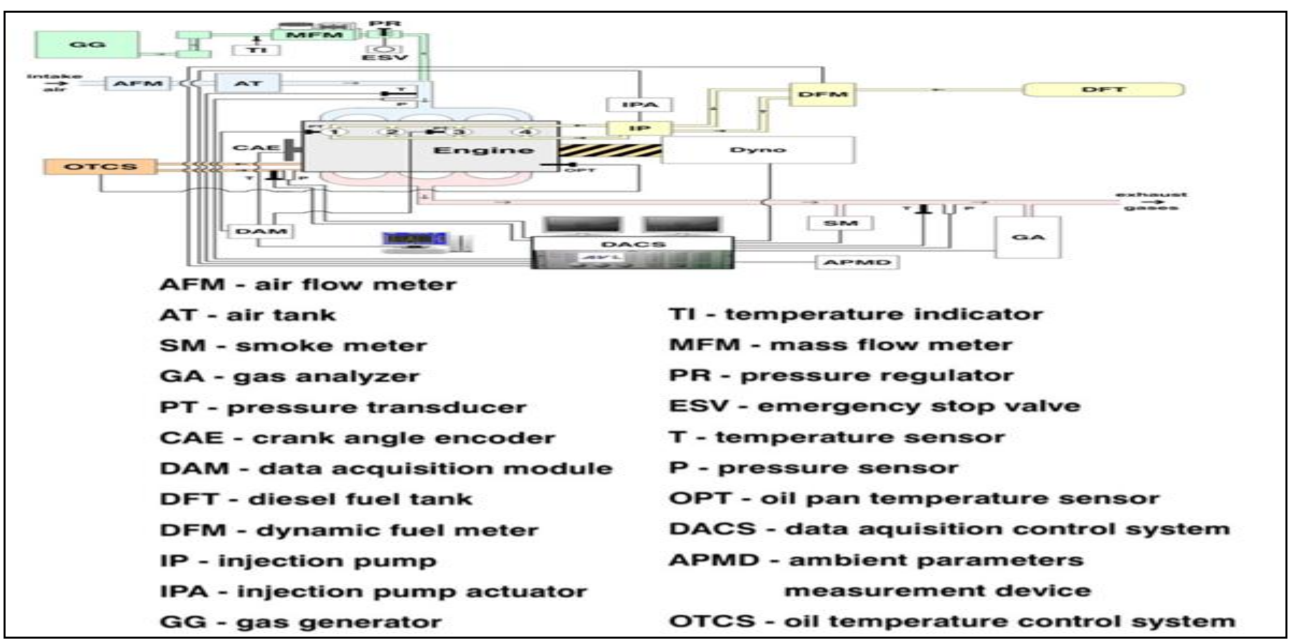

Figure 3.2.Schematic of the engine testbed [151]

The test engine is loaded using an AVL eddy-current dynamometer, as shown in Figure 3.7. The AVL digital display meter is controlling the engine speed and the engine output is connected to the AVL 620 INDISET data acquisition system.

3.4.2 Engine Simulation Model

In this study, the simulation related to the combustion process involved a particular Wiebe-2-Zone model, created and operating under AVL-BOOST software 2020, fully capable to project combustion features, output, performance, and exhaust emissions for the tested engine. Figures 3.13 and 3.14 are shown the schematic of the engine and Wiebe-2-Zone parameters screen.

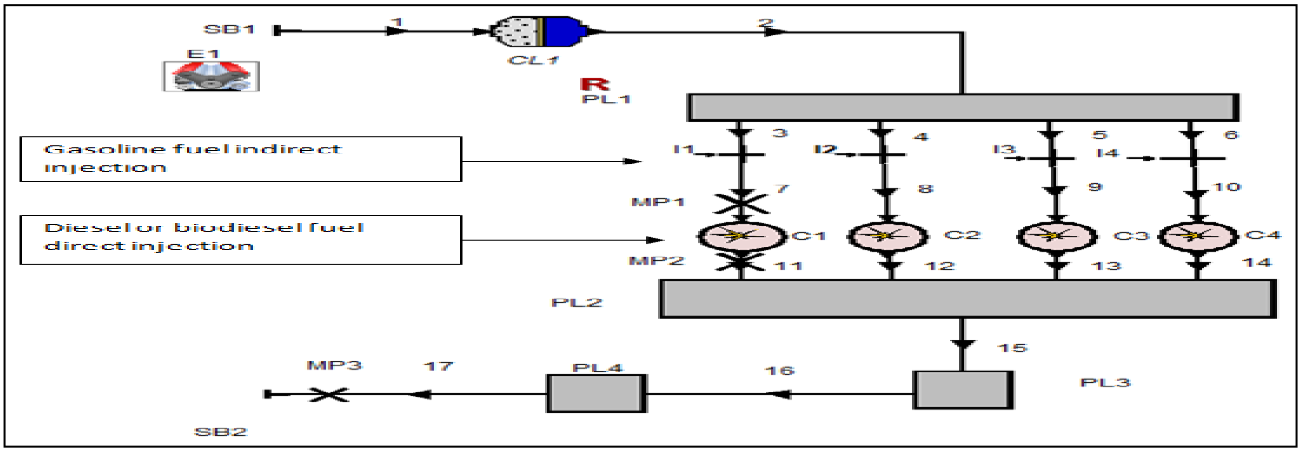

Figure 3.3. The schematic model of the engine configuration for RCCI operation

3.4.3 Calibration and Validation Model

3.5 Results and Discussions

Following the calibration of the model with these fuels, the same list of engine combustion and emissions parameters came into the described numerical analysis when simulating the engine fueling with different gasoline rates (5, 10, 20, 50 and 80%) port-fuel injected (PFI), and diesel after that B20 as primary fuels, in-cylinder direct injected fuels when operating at full load and a maximum speed of 2400 rpm.

Figures 3.16-3.20 highlight the results concerning this enumeration of parameters when using different gasoline percentages in addition to pure diesel or biodiesel (B20) fuels.

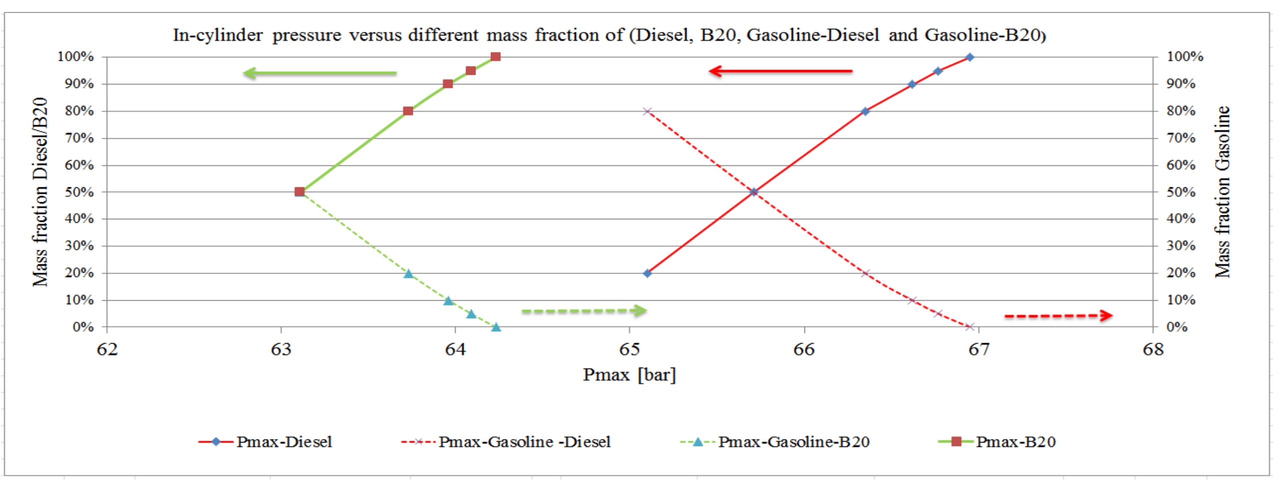

Figure 3.4. Peak fire pressure for different mass fractions (diesel, B20, gasoline-diesel and gasoline-B20 blends)

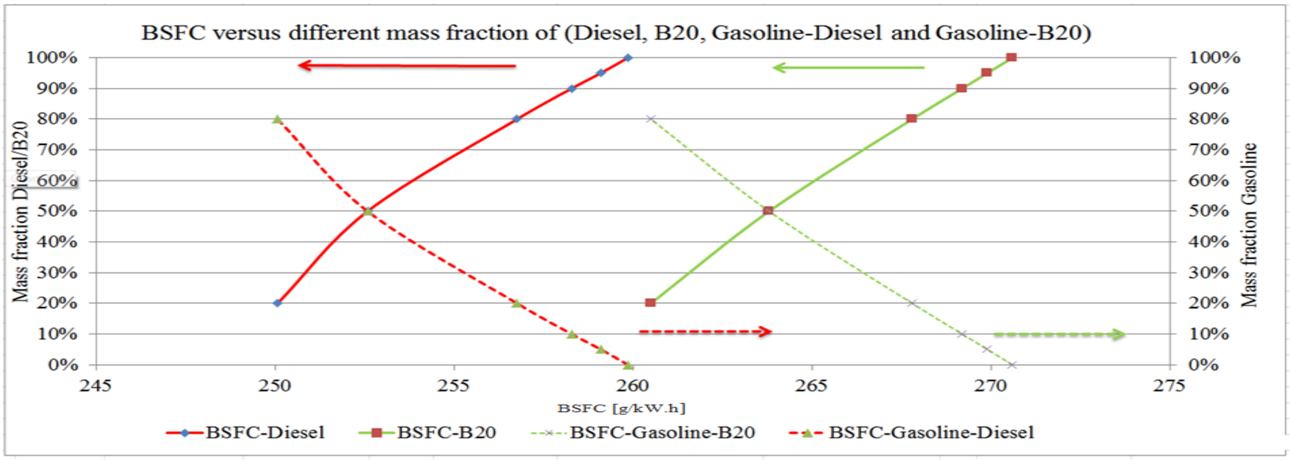

Figure 3.5. BSFC for different mass fractions (diesel, B20, gasoline-diesel and gasoline-B20 blends)

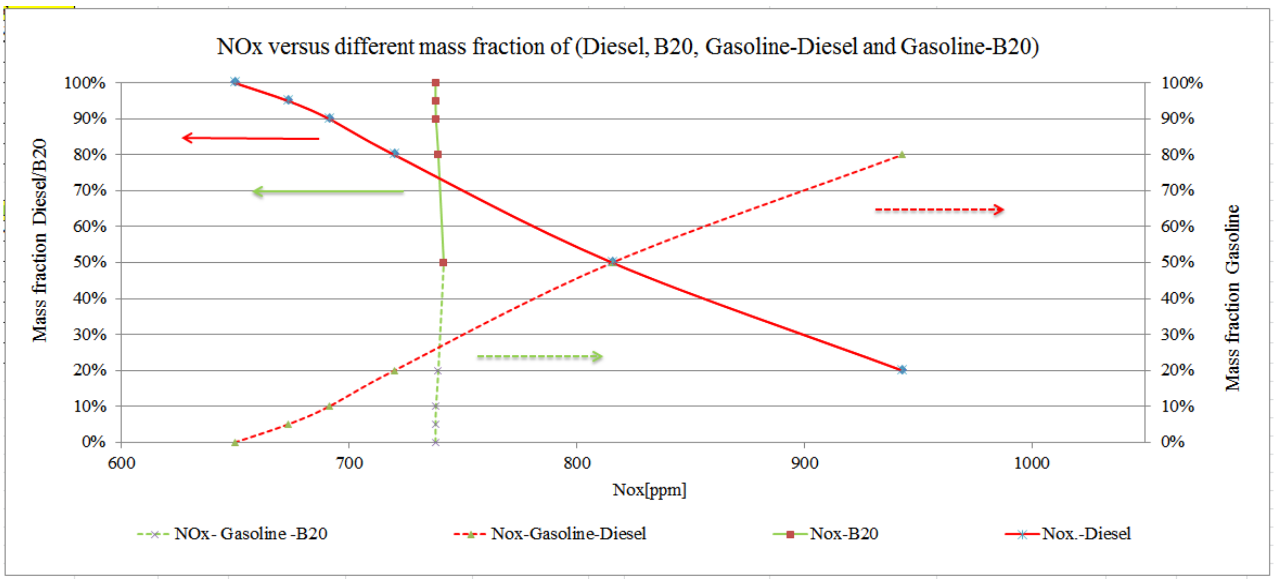

Figure 3.6. NOx emissions for different mass fractions (diesel, B20, gasoline-diesel and gasoline-B20 blends).

3.6 Conclusion

Performance, efficiency and emissions values were theoretically investigated for a normally aspirated diesel tractor engine, as a response to the fueling strategy with different percentages of mass fractions of gasoline mixed with diesel or biodiesel (B20), when operating the engine at full load and a maximum speed of 2400 rpm. Simulation performed with the AVL-Boost-Wiebe-2-Zone combustion model allowed the evaluation of the peak fire pressure, peak fire temperature, BSFC, NOx and Soot emissions. The performed analysis suggested the existence of a potential to improve diesel engine operation, noticing that:

3.6.1 By increasing mass fractions of gasoline fuel when mixing with diesel fuel in RCCI strategy, compared to classic diesel configuration:

- Peak fire pressure decreased from 67 bar to 65.1 bar and gasoline-diesel blends were higher than gasoline-B20 blends.
- There is no significant change in peak fire temperature which found it increased from 1979.7 K to 1981 K but they were higher than gasoline-B2O blends.

- BSFC decreased from 259.86 [g/kW.h] to 250.07 [g/kW.h] and they were lower than gasoline-B20 blends.
- NOx emissions increased from 649.7 [ppm] to 943.1 [ppm] and the NOx after 50% mass fractions of gasoline-diesel blends were higher than with gasoline-B20blends.
- Soot emissions decreased from 1.55 [g/kW.h] to 0.1 [g/kW.h] and they were a little higher than gasoline-B20 blends.

3.6.2 By increasing mass fractions of gasoline fuel when mixing with biodiesel B20 in RCCI strategy, compared to B20 fuel:

- There is a little decrease in the level of peak fire pressure from 64.23 bar to 63.11 bar and they were lower than gasoline-diesel blends.
- There is no significant change in peak fire temperature which found decreased from 1952.7 K to 1944.4 K but they were lower than gasoline-diesel blends.
- BSFC decreased from 270.6 [g/kW.h] to 260.5 [g/kW.h] and they were higher than gasoline-diesel blends.
- There is no significant effect on the NOx emissions levels only a little from 738[ppm] to 741.6 [ppm], taking into consideration, that there was an illogical result with 20% and 80% mass fractions of B20 and gasoline fuels respectively, so it was cancelled.
- Soot emissions decreased from 1.44 [g/kW.h] to 0.1 [g/kW.h] and they were a little lower than gasoline-diesel blends.

Table 3.1. The effectiveness of increasing gasoline fuel in gasoline/diesel (G/D) and Gasoline/B20 (G/B20) blends

Fuel	P.F.P	P.F.T	BSFC	NOx	Soot
By increasing gasoline in G/D	⇩	⇔	⇩	⇧	⇩
Comparison between G/D and G/B20 blends	Higher	Higher	Lower	Higher	Higher
By increasing gasoline in G/B20	⇩	⇔	⇩	⇧	⇩

CHAPTER FOUR

4 ANALYSIS OF THE EFFECT OF MPI AND SPI WITH DIFFERENT RATIOS OF GASOLINE-DIESEL AND GASOLINE-B20 FUELS ON ENGINE PERFORMANCE, COMBUSTION CHARACTERISTICS AND EMISSIONS

4.1 Introduction

4.1.1 Types of Fuel Injection System:

4.1.1.1 Depending on the Location of the Fuel Injector

4.1.1.2 Depending on the Duration and Timing of Fuel Injection

4.1.1.3 Depending on the Number of Fuel Injectors

4.1.1.4 Depending on the Control Fuel Method

4.2 Multipoint Injection Fuel (MPI)

Each cylinder in the MPI approach had a single fuel injector.

4.3 Single Point Injection Fuel (SPI)

SPI indicates that only a single fuel injector is present.

4.4 Direct Injection Fuel In-cylinder

4.5 Simulation Tests

4.5.1 Engine Test Bench Setup

4.5.2 Engine Simulation Model

This chapter created two AVL-BOOST models called the multi-point fuel injection (MPI) model and single point injection (SPI) model as shown in figures. 2 and 3respectively, and every model run with different GD and GB20 fuels with two engine speeds of 1400 rpm and 2400 rpm. The models consist of all pipes, plenums, injection points and other engine parts. Simulation related to the combustion process involved a particular Wiebe-2-Zone model, created and operating under AVL-BOOST software 2020, fully capable to project combustion features, output, performance, and exhaust emissions for the tested engine.

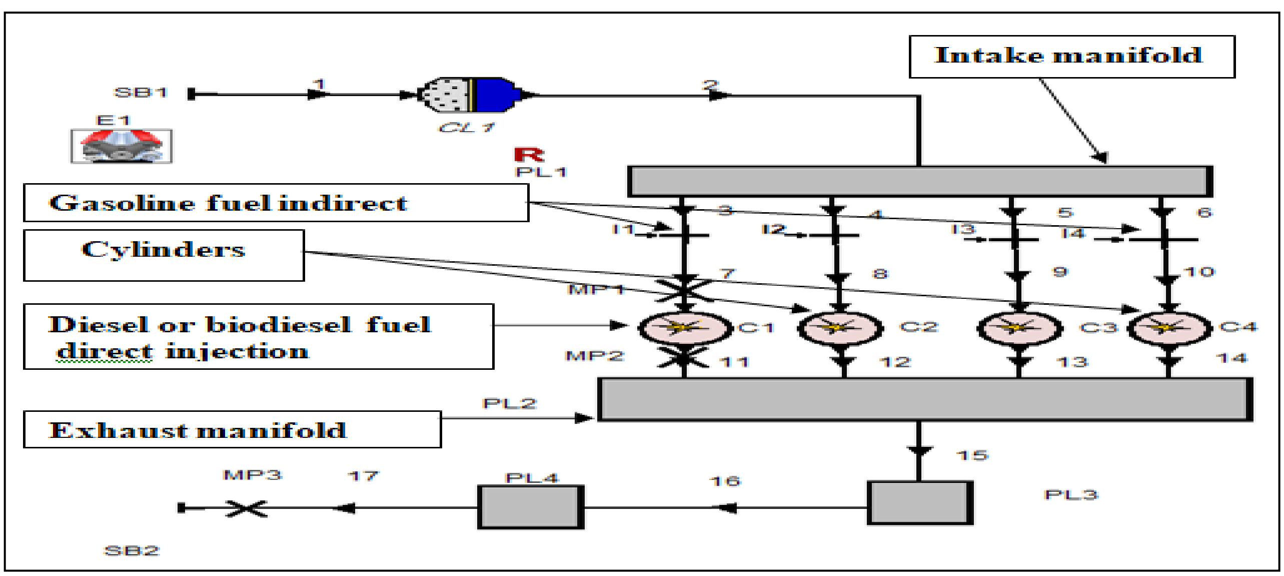

Figure 4.1. The schematic model of the engine configuration for RCCI operation (MPI model)

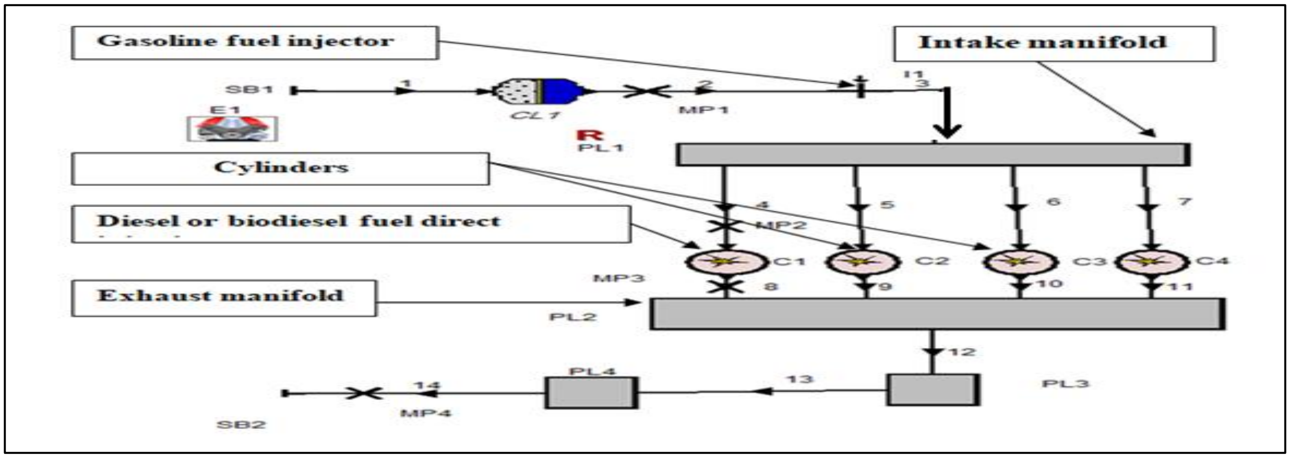

Figure 4.2.The schematic model of the engine configuration for RCCI operation (SPI model)

4.5.3 Calibration and Validation Model

For much understanding, the simulation tests in this chapter are divided into four categories as below:

4.5.4 Pure Diesel (D100) -1400RPM-MPI-SPI

4.5.5 Pure diesel (D100) -2400RPM-MPI-SPI

4.5.6 Biodiesel (B20) -1400RPM-MPI-SPI

4.5.7 Biodiesel (B20) -2400RPM-MPI-SPI

4.6 Results and discussions

Collect these results also classified into four categories as follows:

4.6.1 Different Gasoline- Diesel Blends (GD) - 1400RPM-MPI-SPI

GD_1400RPM										
MPI										
%GD	PBT[K]	PFT[K]	P[bar]	T[K]	NOx[ppm]	Lambda[-]	LHV[J/Kg]	FCC[g]	AE	RE [kJ]
0.00G	2689.5	1991.6	46.9	983.8	1065.9	1.307	4.28E+07	0.0463	1.98E+06	1.973
0.05G	2687.9	1990.6	46.6	976.6	1092.2	1.310	4.28E+07	0.0462	1.98E+06	1.973
0.10G	2694.0	1989.8	46.3	969.6	1118.6	1.312	4.29E+07	0.0462	1.98E+06	1.973
0.20G	2687.3	1988.1	45.7	956.7	1175.9	1.318	4.29E+07	0.0461	1.98E+06	1.973
0.50G	2719.0	1982.0	44.3	923.2	1305.9	1.341	4.31E+07	0.0456	1.97E+06	1.954
0.80G	2681.3	1977.0	43.2	895.6	1446.0	1.366	4.34E+07	0.0452	1.96E+06	1.953
SPI										
%GD	PBT[K]	PFT[K]	P[bar]	T[K]	NOx[ppm]	Lambda[-]	LHV[J/Kg]	FCC[g]	AE	RE [kJ]
0.00G	2734.0	1990.0	46.89	982.6	1096.0	1.309	4.28E+07	0.04625	1.98E+06	1.972
0.05G	2734.5	1989.8	46.63	976.5	1118.8	1.312	4.28E+07	0.04624	1.98E+06	1.974
0.10G	2732.9	1988.8	46.37	970.7	1142.3	1.315	4.29E+07	0.04624	1.98E+06	1.975
0.20G	2726.4	1987.4	45.87	959.3	1191.7	1.321	4.29E+07	0.04625	1.99E+06	1.979
0.50G	2710.1	1981.8	44.49	927.4	1338.9	1.340	4.31E+07	0.04621	1.99E+06	1.983
0.80G	2669.5	1979.4	43.28	899.0	1502.2	1.357	4.34E+07	0.04626	2.01E+06	1.986

Depending on the above Table 4.8 the study highlights the following results.

4.6.1.1 Maximum Engine Pressure (Pmax)

4.6.1.2 Peak Fire Temperature (PFT)

4.6.1.3 Peak Maximum Temperature (PBT)

4.6.1.4 Brake Specific Fuel Consumption (BSFC)

4.6.1.5 Carbon Monoxide Emissions (CO)

4.6.1.6 Soot Emissions

4.6.1.7 Nitrogen Oxides Emissions (NOx)

4.6.2 Different Gasoline-Diesel Blends (GD) 2400RPM-MPI-SPI

GD_2400RPM										
MPI										
%GD	PBT[K]	PFT[K]	P[bar]	T[K]	NOx[ppm]	Lambda[-]	LHV[J/Kg]	FCC[g]	AE	RE [kJ]
0.00G	2724.5	1930.8	47.4	990.4	646.1	1.4575	4.28E+07	0.04191	1.79E+06	1.788
0.05G	2721.8	1937.3	47.1	983.8	642.2	1.4498	4.28E+07	0.04220	1.81E+06	1.803
0.10G	2728.9	1939.7	46.8	977.2	714.1	1.4527	4.29E+07	0.04221	1.81E+06	1.805
0.20G	2711.0	1935.9	46.3	965.0	758.5	1.4586	4.29E+07	0.04222	1.81E+06	1.810
0.50G	2689.3	1932.7	44.9	933.5	889.0	1.4785	4.31E+07	0.04223	1.82E+06	1.817
0.80G	2704.5	1934.1	43.7	907.1	1032.7	1.4918	4.34E+07	0.04245	1.84E+06	1.830
SPI										
%GD	PBT[K]	PFT[K]	P[bar]	T[K]	NOx[ppm]	Lambda[-]	LHV[J/Kg]	FCC[g]	AE	RE [kJ]
0.00G	2743.0	1934.5	47.2	991.3	637.2	1.458	4.28E+07	0.04190	1.79E+06	1.787
0.05G	2736.4	1933.6	47.0	985.5	651.4	1.461	4.28E+07	0.04189	1.79E+06	1.789
0.10G	2750.2	1933.2	46.8	979.6	668.0	1.464	4.29E+07	0.04190	1.80E+06	1.791
0.20G	2745.9	1932.2	46.3	968.8	699.9	1.470	4.29E+07	0.04190	1.80E+06	1.797
0.50G	2718.4	1929.7	45.0	938.5	862.2	1.488	4.31E+07	0.04191	1.81E+06	1.802
0.80G	2666.3	1928.5	43.8	911.3	918.3	1.507	4.34E+07	0.04192	1.82E+06	1.806

Depending on the above Table 4.10 the study highlights the following results.

4.6.2.1 Maximum engine pressure (Pmax)
4.6.2.2 Peak Fire Temperature (PFT)
4.6.2.3 Peak Maximum Temperature (PBT)
4.6.2.4 Brake-specific fuel consumption (BSFC)
4.6.2.5 Carbon Monoxide (CO) Emissions
4.6.2.6 Soot emissions
4.6.2.7 Nitrogen Oxides (NOx) Emissions
4.6.3 Different Gasoline- Biodiesel Blends (GB20) -1400RPM-MPI-SPI

Table 4.1. Performance, emissions and combustion parameters with different gasoline-B20 blends for MPI and SPI strategies at 1400rpm

GB20-1400RPM										
MPI										
%GB20	PBT[K]	PFT[K]	P[bar]	T[K]	NOx[ppm]	Lambda[-]	LHV[J/Kg]	FCC[g]	AE	RE [kJ]
0.00G	2749.7	2012.8	47.1	984.7	1049.4	1.437	4.15E+07	0.04816	2.00E+06	1.988
0.05G	2734.0	2010.0	46.8	978.3	1045.0	1.431	4.16E+07	0.04810	2.00E+06	1.990
0.10G	2735.5	2007.8	46.6	972.2	1044.2	1.425	4.17E+07	0.04806	2.00E+06	2.002
0.20G	2728.8	2003.0	46.1	960.3	1039.8	1.401	4.19E+07	0.04805	2.01E+06	2.012
0.50G	2716.3	1991.3	44.7	927.4	1025.8	1.375	4.25E+07	0.04807	2.04E+06	2.057
0.80G	2735.7	1974.1	43.4	897.9	990.0	1.338	4.31E+07	0.04811	2.07E+06	2.059
SPI										
%GB20	PBT[K]	PFT[K]	P[bar]	T[K]	NOx[ppm]	Lambda[-]	LHV[J/Kg]	FCC[g]	AE	RE [kJ]
0.00G	2799.2	2020.3	46.6	982.5	1009.0	1.425	4.15E+07	0.04815	2.00E+06	1.991
0.05G	2756.8	2019.7	46.3	976.6	1007.0	1.419	4.16E+07	0.04814	2.00E+06	1.999
0.10G	2718.0	2019.7	46.1	970.1	1006.0	1.413	4.17E+07	0.04815	2.01E+06	2.007
0.20G	2786.1	2019.5	45.6	958.1	1004.6	1.400	4.19E+07	0.04815	2.02E+06	2.021
0.50G	2779.6	2018.6	44.1	924.9	989.6	1.365	4.21E+07	0.04814	2.02E+06	2.051
0.80G	2708.0	2018.4	42.9	895.5	962.5	1.329	4.31E+07	0.04816	2.08E+06	2.065

Depending on the above Table 4.11 the study highlights the following results.

4.6.3.1 Maximum Engine Pressure (Pmax)
4.6.3.2 Peak Fire Temperature (PFT)

4.6.3.3 Peak Maximum Temperature (PBT)
4.6.3.4 Brake specific fuel consumption (BSFC)
4.6.3.5 Carbon Monoxide (CO) Emissions
4.6.3.6 Soot emissions
4.6.3.7 Nitrogen Oxides (NOx) Emissions

4.6.4 Different Gasoline – Biodiesel Blends (GB20)-2400RPM-MPI-SPI

Table 4.2. Performance, emissions and combustion parameters with different gasoline-B20 blends for MPI and SPI strategies at 2400 rpm

GB20-2400RPM										
MPI										
%GB20	PBT[K]	PFT[K]	P[bar]	T[K]	NOx[ppm]	Lambda[-]	LHV[J/Kg]	FCC[g]	AE	RE [kJ]
0.00G	2791.9	1960.0	45.8	979.3	732.7	1.607	4.17E+07	0.04218	1.760E+06	1.758
0.05G	2786.1	1958.0	45.6	968.3	731.7	1.600	4.17E+07	0.04220	1.760E+06	1.752
0.10G	2785.0	1956.3	45.4	979.6	731.5	1.593	4.17E+07	0.04218	1.760E+06	1.758
0.20G	2780.0	1953.6	44.8	978.1	734.5	1.578	4.19E+07	0.04200	1.760E+06	1.768
0.50G	2777.2	1944.9	43.5	937.1	732.3	1.537	4.25E+07	0.04200	1.785E+06	1.800
0.80G	2776.1	1932.5	42.4	909.2	718.0	1.498	4.31E+07	0.04252	1.833E+06	1.824
SPI										
%GB20	PBT[K]	PFT[K]	P[bar]	T[K]	NOx[ppm]	Lambda[-]	LHV[J/Kg]	FCC[g]	AE	RE [kJ]
0.00G	2812.4	1954.2	45.9	991.3	732.3	1.608	4.15E+07	0.04220	1.75E+06	1.746
0.05G	2759.9	1959.1	45.8	985.4	735.6	1.601	4.16E+07	0.04220	1.76E+06	1.753
0.10G	2763.4	1959.5	45.4	979.5	742.9	1.601	4.17E+07	0.04220	1.76E+06	1.760
0.20G	2780.0	1959.7	45.0	968.2	747.4	1.594	4.19E+07	0.04221	1.77E+06	1.774
0.50G	2800.3	1961.0	43.5	937.0	751.3	1.579	4.25E+07	0.04221	1.79E+06	1.803
0.80G	2771.1	1962.7	42.4	908.9	740.0	1.495	4.31E+07	0.04222	1.82E+06	1.804

Depending to Table 4.12 the study highlights the following results.

4.6.4.1 Maximum engine pressure (Pmax)
4.6.4.2 Peak Fire Temperature (PFT)
4.6.4.3 Peak Maximum Temperature (PBT)
4.6.4.4 Brake Specific Fuel Consumption (BSFC)
4.6.4.5 Carbon Monoxide (CO) emissions
4.6.4.6 Soot Emissions
4.6.4.7 Nitrogen Oxides (NOx) Emissions

4.7 Function parameter

Function= 25%NOx+10%CO+25%Soot+40%BSFC …………………… (1)

Furthermore, by comparing these Functions for each case in this research, we can get the best possible result by choosing the type of fuel, engine operating conditions and appropriate engine design to achieve the objectives of the study when reducing the Function value means less emissions, less consumption of fuel and high engine performance. This comparison was divided into two parts according to the engine speeds of 1400 and 2400 as follows.

4.7.1 Different Gasoline-Diesel and Gasoline-Biodiesel Blends (GD-GB20-1400RPM-MPI-SPI)

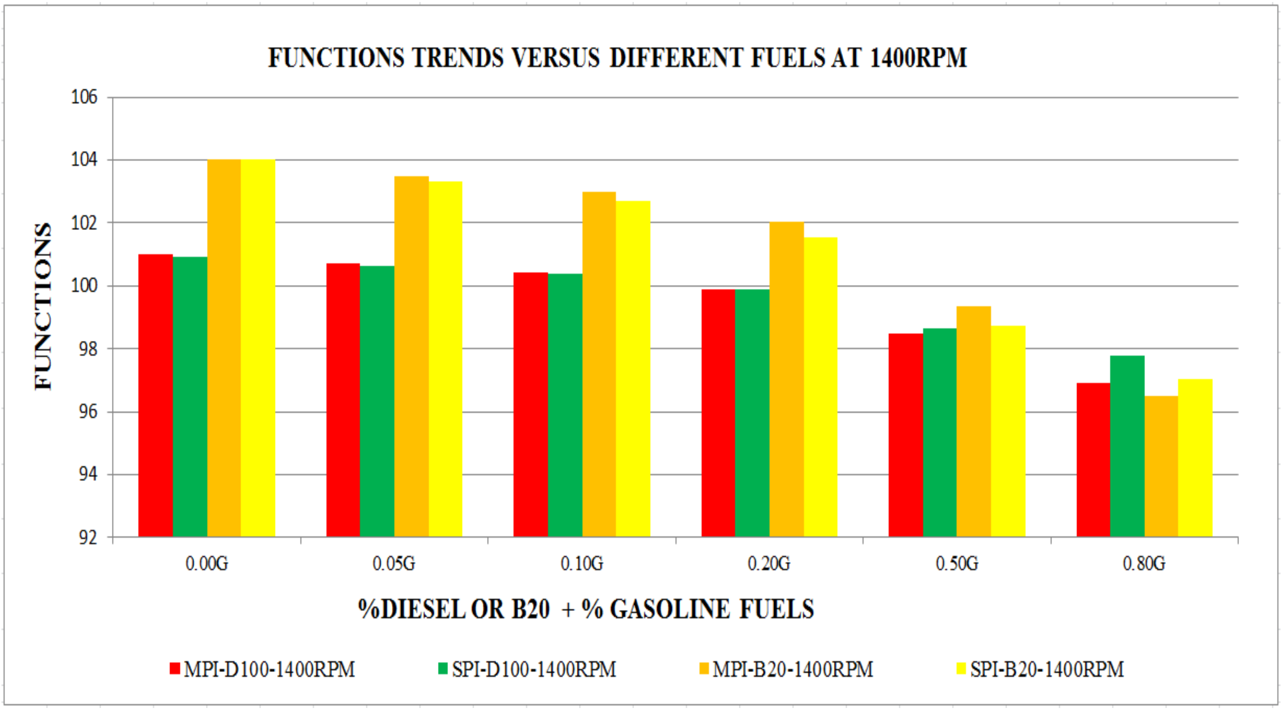

Figure 4.3. Function values versus different mass fractions of GD and GB20 blends with MPI and SPI strategies at1400 rpm

4.7.2 Different Gasoline-Diesel and Gasoline-Biodiesel Blends (GD-GB20-2400RPM -MPI-SPI)

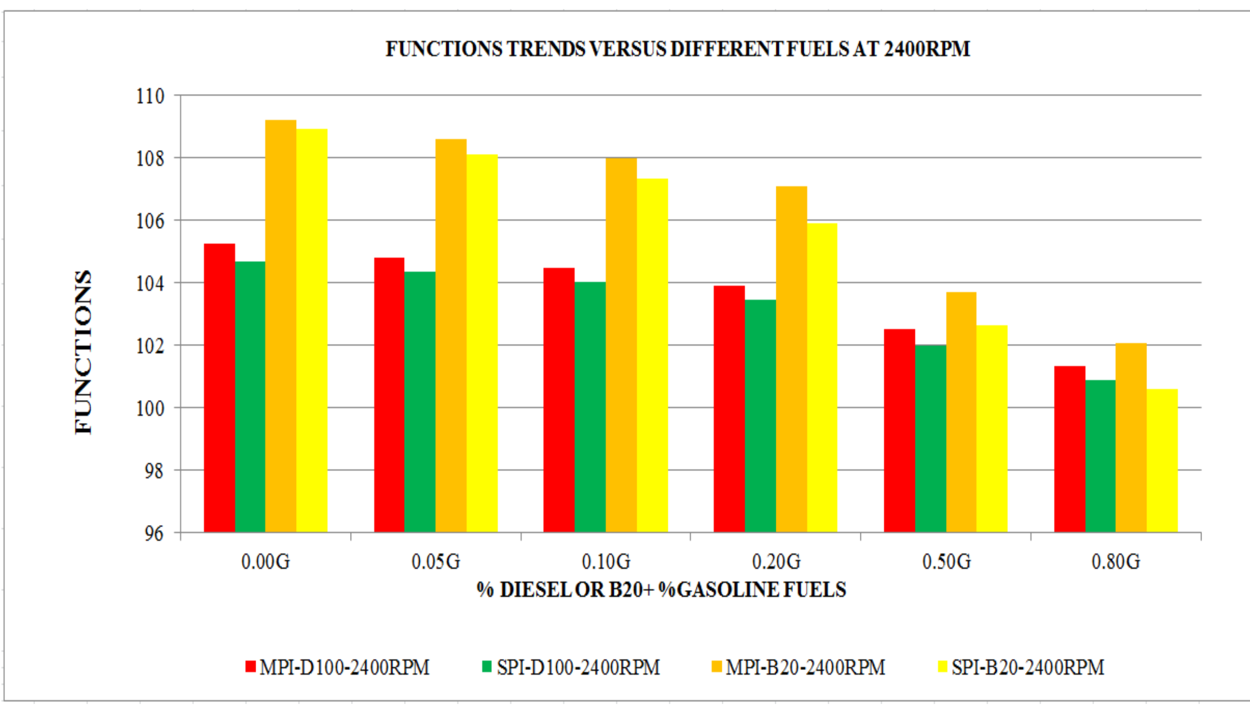

Figure 4.4. Function values versus different mass fractions of GD and GB20 blends with MPI and SPI strategies at 2400 rpm

4.8 Conclusion

This chapter simulated the Wiebe-2-Zones-AVL-BOOST software 2020, with a four-cylinder, four strokes and DI Tractor diesel engine with different GD and GB20 blends, engine speeds at 1400 rpm and 2400 rpm and two injection fuel strategies MPI and SPI. The key findings of this chapter were as follows:

- The change of PBT and PFT was so little from 1-3% so there was no effect of this temperature on the NOx concentration.
- BSFC was observed to decrease when increasing gasoline percentages from 0 to 80% in the GD and GB20 blends due to the increase of the potential to form a more homogenous mixture for combustion, to ensure more oxygen content and better atomization with the RCCI strategy compared to CDC combustion [157]. The difference between BSFC with these two strategies was so little less than 1%. [116] RCCI provided more efficient control over the combustion process and can reduce BSFC and exhaust emissions. RCCI provides a low fuel consumption offered due to its short combustion duration [117]. With GB20 blend and high and low-speed engines found SPI strategy produced less BSFC than the MPI strategy; this recommended using SPI strategy when the fuels are GB2O blends with low and high-speed engines rather than with GD blends.
- With different GD and GB20 found that soot emissions are observed to decrease when increasing gasoline percentages from 0 to 80% in the mixture for two strategies due to higher oxygen content, volatility and the lower distillation point of gasoline [6]. As well as the increasing of lambda had an important facture to increase oxygen content for the combustion process then reducing soot emissions. On another hand found that the difference between soot emissions with MPI and SPI strategies were approximately zero these clarify there was no effect of the fuel injection strategy on concentration for the soot emissions.
- Different GD and GB20 blends with MPI and SPI strategies at 1400 rpm and 2400 rpm found that NOx emissions increased by increasing lambda due to the stoichiometric to lean mixtures fuels with high oxygen content at high temperatures led to a high level of NOx formation.
- Different GD at 1400 rpm and different GB20 blends at 2400 rpm found that NOx emissions were higher with SPI compared to MPI strategies due to MPI strategy had lower in-cylinder pressure and temperature, many injectors fuels and near from intake valve fuel compared to SPI strategy as well as the residence time combustion (α 50%) was shorter with MPI compared to SPI strategies as shown in Table 4.9 which caused by less time to produce lower NOx emissions.
- Different GD at 2400 rpm and different GB20 blends at 1400 rpm found that NOx emissions were higher with MPI compared to SPI strategies due to a longer time of residence period combustion (α50%) with MPI strategy compared to SPI strategy.
- By increasing gasoline percentages from 0 to 80% in GD and GB20 blends with MPI and SPI strategies at 1400 rpm and 2400 rpm engine speeds found that Function values decreased, furthermore they were lower with different GD blends compared to different GB20 blends expecting that the lowest Function value was with 80G20B20 with SPI strategy at 2400rpm engine speed and with 80G20B20 with MPI strategy at 1400 rpm engine speed.
- Recommend to run this Tractor diesel engine under RCCI technology with 50-80% G in GD blends under SPI injection fuel strategy and it was under MPI injection fuel strategy with GB20 at low engine speed.
- Recommend to run this Tractor diesel engine under RCCI technology with 50-80% G in GD and GB20 blends under SPI injection fuel strategy at high engine speed.

CHAPTER FIVE

5 EXPERIMENTAL INVESTIGATION OF CONVENTIONAL DIESEL ENGINE OPERATING WITH DIESEL FUEL AT ENGINE SPEEDS, 1400 RPM (MAXIMUM ENGINE TORQUE) AND 2400 RPM(MAXIMUM ENGINE POWER)

5.1 Introduction

5.2 Diesel Engine Instrumentation

The same Tractor diesel engine 4-cylinders, 4-strokes, naturally aspirated DI, water-cooled were used with this study.

5.2.1 Eddy-Current Dynamometer

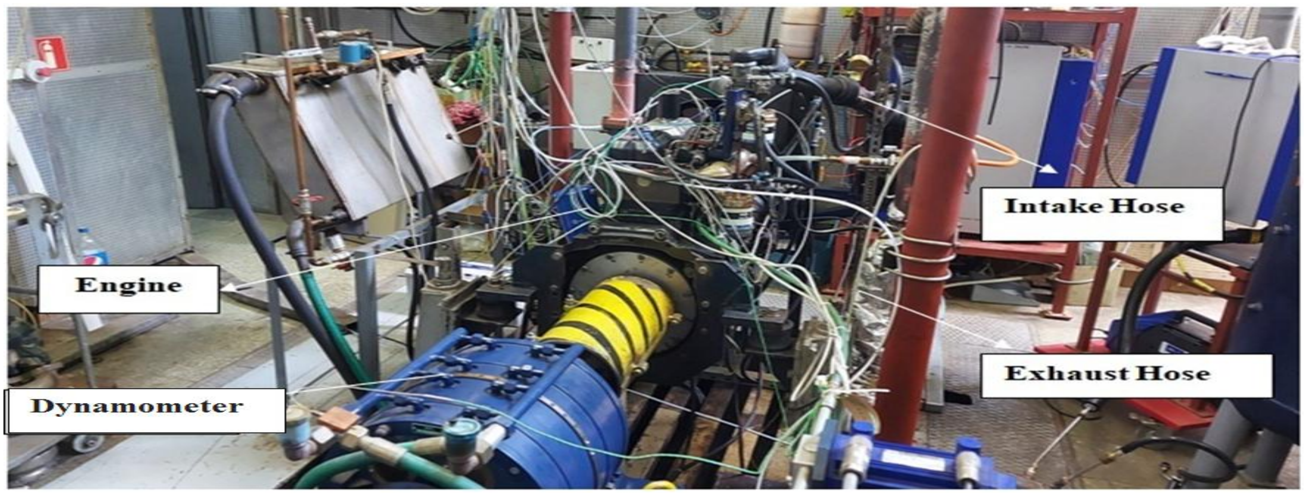

Figure 5.1. Engine test bench

5.2.2 In-cylinder Pressure Measurement

5.2.3 Temperatures Measurement

5.2.4 Fuel line Pressure Measurement

5.2.5 Gas Emissions Analyzer

5.3 Experimental Methods.

5.3.1 Instrument Calibration Procedures

5.3.2 Experimental Error Analysis

5.3.3 Test Fuels Properties

5.4 Results and discussions

In this chapter, in-cylinder pressure, rate of heat release, integral heat release, effective power, effective torque, brake specific fuel consumption, carbon monoxide, soot and nitrogen oxide emissions were investigated at engine speed 1400 (maximum brake torque) and engine speed at 2400 rpm (maximum brake power) Tractor diesel engine (CDC combustion) fueled with diesel fuel under different engine loads (20, 40, 60, and 100) % as reference fuel test as following:

5.4.1 In-cylinder Pressure

5.4.2 Rate of Heat Release (RHR)

5.4.3 Integral Heat Release

5.4.4 Effective Power

Table 5.1. Experimental engine performance and emissions

_INDEP_T	Eng. Speed	ALPHA	TORQUE	E.P.	FB_RATE	BSFC	LAMBDA	Nox	S415_FSN	CO2	COH	COL
Eng. Load	rpm	%	Nm	kW	kg/h	g/kWh	-	ppm	FSN	ppm	ppm	ppm
20%	1400	38.2	46.8	6.85	2.51	366.42	3.95	452	0.11	35097	1750.2	357.5
40%		39	76.9	11.28	3.42	303.19	3.13	686	0.14	45004	1614.2	250.2
60%		40.1	153.7	22.53	4.85	215.27	1.94	1318	0.68	74755.8	1474.2	135.7
100%		99.9	211.6	31.02	7.01	225.98	1.36	958	4.6	108073	2062.9	604
20%	2400	87.6	41	10.31	5.24	508.24	3.24	239	0.36	44675	1776.4	381
40%		88.3	82	20.6	7.2	349.51	2.57	290	0.96	55868.7	1723.4	341.3
60%		89.1	106	26.65	8.57	321.58	2.13	321	1.28	67985.6	1710.4	332.6
100%		99.8	157.6	39.59	11.86	299.57	1.56	423	3	94706.6	1743.5	360.7

5.4.5 Brake Specific Fuel Consumption (BSFC)

5.4.6 Carbon Monoxide (CO) Emissions

5.4.7 Smoke Emissions (FSN)

5.4.8 Nitrogen Oxides Emissions (NOx)

5.5 Conclusions

This chapter experienced the effect of using diesel fuel with a Tractor diesel engine at different engine loads from 20% to100%with low engine speed at 1400 rpm (high engine torque) and high engine speed at 2400 rpm (high engine power) on engine performance, combustion and engine exhaust emissions. The main conclusions are listed in the following:

- By increasing engine load and speed, the difference between in-cylinder pressures started to decrease and the pressure curve shifted from TDC to the right and started to improve brake thermal efficiency (BTE).
- RHR occurred retarded by increasing engine loads for these two engine speeds due to increased amount of fuel, on another hand, RHR was retarded with a high engine speed of 2400 rpm compared to a low engine speed of 1400 rpm and this improved engine performance and emissions due to the ignition delay prolonged, and the total combustion duration prolonged for the retarded the curve of rate heat release.
- Effective power increased by increasing engine speeds and loads due to high turbulence and high amount of fuel consumption which produced high engine power.
- Increasing engine loads caused decreasing in BSFC it was found that BSFC increased by increasing engine speed for the same engine load due to increased fuel consumption with high engine speed compared to low engine speed.
- CO emissions were highest with 1400 rpm at 100% engine load compared to all tests due to low combustion efficiency and low lambda with low engine speed.
- Smoke emissions increased by increasing engine loads due to increasing consumption of fuel with increasing engine load.
- NOx emissions increased by increasing engine loads due to increased combustion temperature which helped to generate much NOx emissions, On another hand low engine speed found that NOx emissions increased compared to high engine speed due to the increase of engine torque and improve combustion efficiency.

CHAPTER SIX

6 EXPERIMENTAL INVESTIGATION OF REACTIVITY CONTROL COMPRESSION IGNITION ENGINE OPERATION WITH DIFFERENT GASOLINE-DIESEL FUELS

6.1 Introduction

6.2 RCCI Engine Instrumentation

6.2.1 Gasoline Fuel Injection System

This gasoline injection electric device runs by 12 V-DC to supply the injector fuel with a pulse at different sequences and periodical times. A suitable amount of gasoline fuel determine by changing the frequency and the periodical time through this gasoline injection electric device which can change the injection frequency from 0 to 100 Hz and also periodical time can change from 0 to 100% depending on how much gasoline fuel need for every test to mix with air to make the mixture needed to run the RCCI combustion engine test. As well as the engine test was supported with pressure gauges, thermocouples, pressure regulators, a gasoline flow meter, and an emergency rapid stop valve for cut air delivery to ensure the safe operation of the test engines shown in figure 6.3.

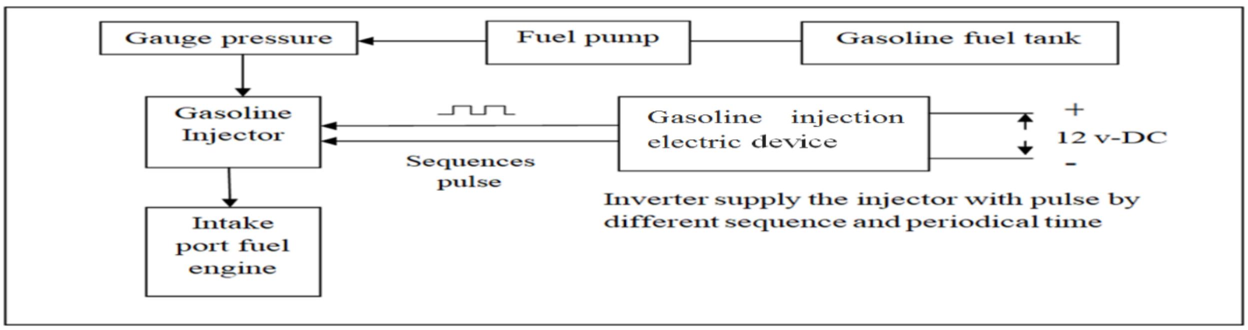

Figure 6.1 Gasoline fuel injection system

During the flow of the gasoline fuel from the tank to the gasoline fuel injection system, it passes through a mechanical weight to calculate the weight of the gasoline consumed during a certain time as in figure 6.4. To increase the accuracy of measuring the consumed gasoline fuel, an electronic weight was used for this purpose to measure the amount of consumed gasoline within a time of one minute for each required frequency and periodical time. Note that this measurement was done outside the engine and before starting the engine tests. When testing the engine started, the same frequency and time are used for the injected gasoline as shown in Table 6.1 and figure 6.5. The tests were repeated for each test three times and the rate was found to reduce the percentage of errors.

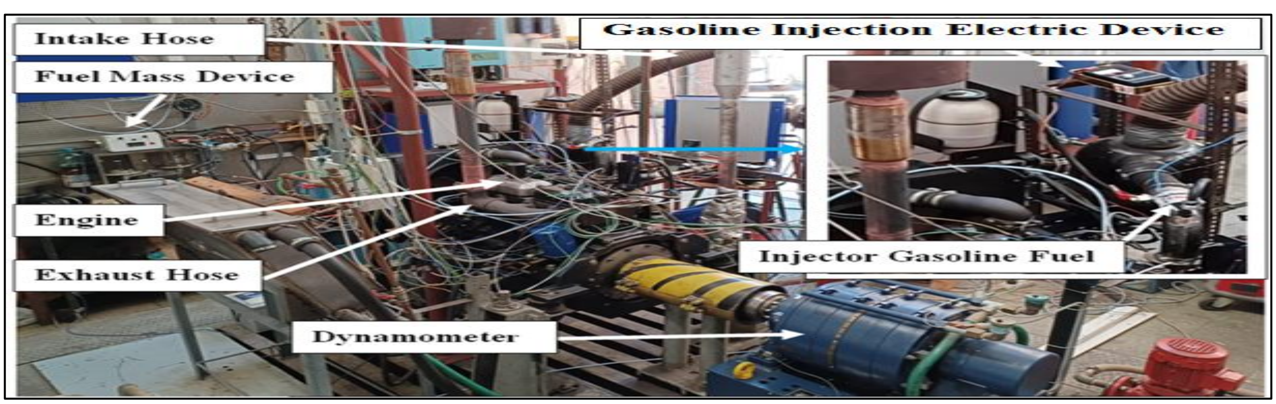

Figure 6.2.RCCI engine test bench

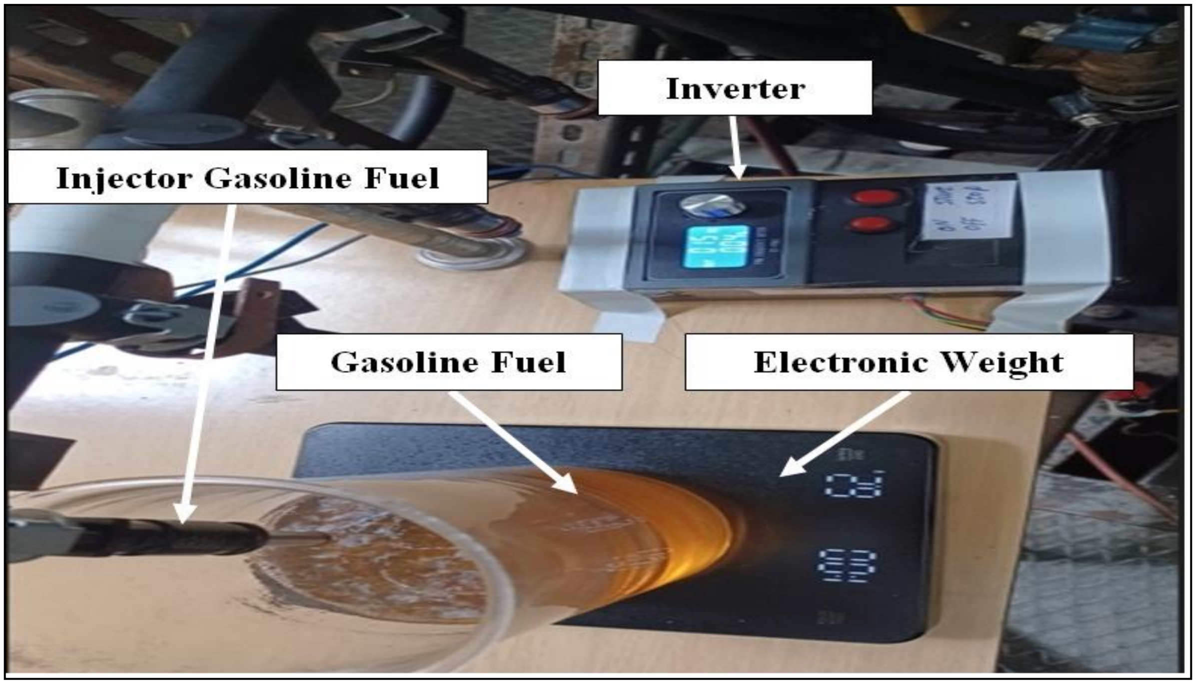

Figure 6.3. Electronic weight to measure gasoline fuel consumed

6.3 Experimental Methods

The study experimental the RCCI engine performance, combustion, and emissions the effect of using (8 and 5% gasoline fuels) in gasoline diesel blends with engine speed at 1400 rpm (speed of maximum brake torque) and (12 and 21% gasoline fuels) in gasoline –diesel blends with engine speed at 2400 rpm (speed of maximum brake power) under (60 and 100)%engine loads conditions respectively.

Before starting any test it must check some important items, oil, fuel and water engine levels, then warm up the gas emissions analyzer for ten minutes, adjust the dynamometer controller to zero loads and check that all data acquisition system and gas emissions analyzer are connected to the computer with on mode.

Then, the engine must warm up until reaches 85 ºC. Then the engine speed increases slowly until reaches the specific engine speed of 1400 rpm (maximum engine torque) and leaves it for 2 minutes before applying an engine load of 60% finally it starts to inject gasoline fuel into the intake port fuel with an 8% gasoline fuel percentage. After that collect the results from the AVL- system computers and exhaust gas analyzer system after being ready and repeat these steps three times and take the average results to reduce the errors. Then repeat all previous steps with 5% gasoline fuel percentage and 100 % engine load.

After that, it must repeat all the previous steps with 2400 rpm engine speeds (maximum engine power), 12 and 21% gasoline fuel percentages and 60 and 100 % engine loads respectively. Finally, collect all the experimental results for this study.

6.3.1 Instrument Calibration Procedures and Experimental Error Analysis

6.3.2 Test Fuels Properties

6.4 Results and Discussions

RCCI engine results were collected related to engine performance, combustion, and emissions for two speeds engine: firstly at 1400 rpm (speed of max brake torque) with two gasoline fuel rates (8 and 5% gasoline fuels) in gasoline diesel blends secondly at 2400 rpm (speed of max brake power) with two gasoline fuel rates (12 and 21% gasoline fuels) in gasoline –diesel blends under two engine loads (60% and 100 %). Results of the experimental divided into two groups as follows:

6.4.1 Comparison of Engine Performance and Exhaust Emissions between RCCI Technology and CDC Engine at 1400 rpm

Table 6.1. Experimental results of RCCI engine tests with different GD and (60 and 100%) engine loads at 1400 rpm and 2400 rpm.

Engine speed	**RPM**	**1400 RPM**				**2400 RPM**			
Engine load	**[%]**	CDC-60%	RCCI-60%	CDC-100%	RCC-100%	CDC-60%	RCCI-60%	CDC-100%	RCCI-100%
GD	**[%]**	0.00	0.08	0.00	0.05	0.00	0.21	0.00	0.12
Gasoline	**g/min**	0.00	6.50	0.00	6.50	0.00	28.00	0.00	28.00
	Kg/h	0.00	0.39	0.00	0.39	0.00	1,68	0.00	1.68
Diesel	**Kg/h**	5.23	4.64	7.45	7.38	9.81	6.46	11.97	11.92
Total fuel	**Kg/h**	5.23	5.03	7.45	7.77	9.81	8.14	11.97	13.60
Power	**kW**	20.2	19.8	29.8	31.4	26.7	26.6	40.0	46.9
BSFC	**g/kW.h**	258.5	253.5	249.7	247.1	367.7	305.6	299.6	290.3
Torque	**Nm**	135.1	134.3	203.3	213.0	106.0	106.7	158.9	185.6
THC	**ppm**	55	17	63	31	374	482	50	40
COL	**ppm**	147	451	205	649	849	1215	512	1441
Soot	**FSN**	0.68	0.91	4.6	3.3	1.28	1.37	3	4.5
NOx	**ppm**	664	685	1013	1059	299	360	436	491
Lambda	**[-]**	2.107	2.238	1.477	1.390	1.847	2.073	1.502	1.501

6.4.1.1 Engine Performance

6.4.1.1.1 Effective Power and Torque

6.4.1.1.2 Brake Specific Fuel Combustion (BSFC)

6.4.1.2 Exhaust Gas Emissions

6.4.1.2.1 Carbon Monoxide (COL) Emissions

6.4.1.2.2 Total Unburned Hydrocarbons (THC) Emissions

6.4.1.2.3 Soot Emission

6.4.1.2.4 Nitrogen Oxides (NOx) emissions

6.4.2 Comparison of Engine performance and exhaust emissions between RCCI technology and CDC engine at 2400 rpm

6.4.2.1 Engine Performance

6.4.2.1.1 Effective Power and Torque

6.4.2.1.2 Brake specific fuel consumption (BSFC)

6.4.2.2 Exhaust Gas Emissions

6.4.2.2.1 Carbon Monoxide (COL) emissions
6.4.2.2.2 Total Unburned Hydrocarbons (THC) Emissions
6.4.2.2.3 Soot Emission
6.4.2.2.4 Nitrogen Oxides emissions (NOx)

6.5 Conclusions

The Tractor diesel engine was operated under RCCI combustion technology conditions after making some modifications to add a gasoline fuel injection system which was created in this study inject8% and 5% [by mass] gasoline fuel ratios into port fuel followed by injection of diesel with 92% and 95% [by mass] as HRF inside combustion chamber by direct injection under engine speed at 1400 rpm and engine loads at 60 % and 100% respectively. Then it repeated the same tests under engine speed at 2400 rpm and engine loads at 60% and 100 % with 12 and 21% gasoline fuel ratios respectively. The results found that:

- By using 8% and 21% gasoline rate in GD blend, 60 % engine load and engine speed at 1400 rpm and 2400 rpm respectively, found that both the power and torque were approximately the same with RCCI and CDC engines. While it found that by using a 5% gasoline rate and 12% gasoline rate at 100 % engine load and engine speeds at 1400 rpm and 2400 rpm respectively, found that both the power and torque were higher with RCCI technology compared to CDC due to the combustion chamber with this Tractor diesel engine and this gasoline fuel injector used in this study was compatible with this RCCI combustion.
- By using 8% and 5% gasoline rates in GD blends with engine speed at 1400 rpm under 60 % and 100% engine loads respectively and by using 21% and 12% gasoline rates in GD blends at 2400 rpm under 60 % and 100% engine loads respectively, found that the BSFC were lower with RCCI technology compared to CDC due to lower fuel consumption and lower combustion temperature.
- By using 8% and 5% gasoline rates in GD blends at 1400 rpm under 60 % and 100% engine loads respectively and by using 21% and 12% gasoline rates in GD blends at 2400 rpm under 60 % and 100% engine loads respectively, found that carbon monoxides (COL) were higher with RCCI technology compared to CDC engine due to LTC with RCCI technology effect to reduce combustion temperature which produces much COL emissions.
- At low engine speed found that THC emissions were lower with RCCI technology compared to the CDC engine at different engine loads due to the active oxidation process which enables complete combustion by increasing oxygen content which comes from increasing lambda value. Furthermore, with high engine speed, the study found that THC was higher with RCCI technology under 60% engine loads due to incomplete combustion while at 100 % engine load THC was lower with RCCI compared to CDC engine due to high turbulence combustion.
- At low engine speed and high engine load the study found that soot emission was lower with RCCI technology compared to CDC engine, while at low engine load, the difference was so little between these two technologies due to a decrease in diesel fuel consumption with RCCI technology compared to CDC technology. While at high engine speed the study found that soot emission was higher with RCCI technology compared to CDC technology at different engine loads due to the low combustion temperature strategy with RCCI. Furthermore, soot emission increased by increasing engine loads due to increasing of consuming of fuel by increasing engine load
- By using 8% and 5% gasoline rates in GD blends with engine speed at 1400 rpm under 60 % and 100% engine loads respectively and 21% and 12% gasoline rates in GD blends with engine speed at 2400 rpm under 60 % and 100% engine loads respectively, found that NOx emissions were higher with RCCI technology compared to CDC engine due to increasing of lambda value with low engine load and due to high turbulence combustion with high engine load.

CHAPTER SEVEN

7 CONCLUSIONS

7.1 Summary

7.2 The Main Study Finding

This study included several parts, the first part of the literature review was related to studying the gasoline engine performance, combustion and exhaust gas emissions and it found that by using a higher RON than engine design found that less NOx and CO emissions, less fuel consumption and higher engine performance. The second part of the literature review reviewed the effect of using different gasoline ratios in diesel or biodiesel fuels in CDC, GCI and RCCI engines and it found that for best engine performance and emissions; we need to make a tradeoff between three factors, which are; engine operating conditions, engine design and kind of fuels. As well as it found that the effectiveness of increasing gasoline fuel in gasoline/diesel (G/D) and Gasoline/B20 (G/B20) blends as summarized in this Table 3.6:

Fuel	P.F.P	P.F.T	BSFC	NOx	Soot
By increasing gasoline in G/D	↓	↔	↓	↑	↓
Comparison between G/D and G/B20 blends	Higher	Higher	Lower	Higher	Higher
By increasing gasoline in G/B20	↓	↔	↓	↑	↓

Another finding of this study was related to investigating to use of Wiebe-2-Zones-AVL-BOOST software with two injection fuel strategies MPI and SPI under the RCCI strategy and it found that this model could perform RCCI strategy and it gave the following results:

- The change of PBT and PFT was so little from 1-3% so there was no effect of this temperature on the NOx concentration.
- NOx emissions increased by increasing lambda due to the stoichiometric to lean mixtures fuels with high oxygen content at high temperatures leading to a high level of NOx formation.
- By increasing gasoline percentages from 0 to 80% in GD and GB20 blends with MPI and SPI strategies at 1400 and 2400 rpm engine speeds found that Functions parameters decreased, furthermore they were lower with different GD blends compared to different GB20 blends expecting that the lowest Function value was with 20G80B20 with SPI strategy at 2400rpm engine speed and with 20G80B20 with MPI strategy at 1400 rpm engine speed.
- Functions parameters for different GD were lower with MPI compared to SPI at low engine speed while Functions parameters for different GB20 were lower with SPI compared to MPI at low engine speed.
- Recommend to use RCCI technology with this Tractor diesel engine with low engine load to improve BSFC due to RCCI technology produced uniform mixture fuel and low-temperature combustion which helps to reduce consume gasoline-diesel fuel compared to CDC engine.

The next finding was experimental Tractor diesel engine at different engine loads from 20% to 100% with low engine speed at 1400 rpm and high engine speed at 2400 rpm on engine performance; combustion and engine exhaust emissions to be as a reference for the next RCCI engine tests. And the main results were:

- By increasing engine load and speed, the difference between in-cylinder pressures started to decrease and the pressure curve shifted from TDC to the right and started to improve brake thermal efficiency (BTE).

- Effective power increased by increasing engine speeds and loads due to high turbulence and high amount of fuel consumption which produced high engine power.
- Increasing engine loads caused decreasing in BSFC while it was found that BSFC increased by increasing engine speed for the same engine load due to increased fuel consumption with high engine speed compared to low engine speed.
- CO emissions were highest with 1400 rpm at 100% engine load compared to all tests due to low combustion efficiency and low lambda with low engine speed.
- Smoke emissions increased by increasing engine loads due to increasing consumption of fuel with increasing engine load.
- NOx emissions increased by increasing engine loads due to increased combustion temperature which helped to generate much NOx emissions, On another hand low engine speed found that NOx emissions increased compared to high engine speed due to the increase of engine torque and combustion temperature which improved NOx emissions.

The finally main part of this study was to develop the existing experiment test bench (CDC) in order to provide experiments RCCI strategy. This study experimented with the engine performance, combustion, and emissions by using (8 and 5% gasoline fuels) as LRF and diesel as HRF blend with engine speed at 1400 rpm (speed of maximum brake torque) and (21 and 12% gasoline fuels) in gasoline –diesel blends with engine speed at 2400 rpm (speed of maximum brake power) under (60 and 100) % engine loads conditions respectively and it found that:

- By using 8% and 21% gasoline rate in GD blend, 60 % engine load and engine speed at 1400 rpm and 2400 rpm respectively, found that both the power and torque were approximately the same with RCCI and CDC engines and these issues must be considering to solve as mentioned in the future work. While it found that by using a 5% gasoline rate and 12% gasoline rate at 100 % engine load and engine speeds at 1400 rpm and 2400 rpm respectively, found that both the power and torque were higher with RCCI technology compared to CDC due to the combustion chamber with this Tractor diesel engine and this gasoline fuel injector used in this study was compatible with this RCCI combustion.
- By using 8% and 5% gasoline rates in GD blends with engine speed at 1400 rpm under 60 % and 100% engine loads respectively and by using 21% and 12% gasoline rates in GD blends at 2400 rpm under 60 % and 100% engine loads respectively, found that the BSFC were lower with RCCI technology compared to CDC due to lower fuel consumption and lower combustion temperature.
- By using 8% and 5% gasoline rates in GD blends at 1400 rpm under 60 % and 100% engine loads respectively and by using 21% and 12% gasoline rates in GD blends at 2400 rpm under 60 % and 100% engine loads respectively, found that carbon monoxides (COL) were higher with RCCI technology compared to CDC engine due to LTC with RCCI technology effect to reduce combustion temperature which produces much COL emissions.
- At low engine speed and high engine load the study found that soot emission was lower with RCCI technology compared to CDC engine, while at low engine load, the difference was so little between these two technologies due to a decrease in diesel fuel consumption with RCCI technology compared to CDC technology. While at high engine speed the study found that soot emission was higher with RCCI technology compared to CDC technology at different engine loads due to the low combustion temperature strategy with RCCI. Furthermore, soot emission increased by increasing engine loads due to increasing consumption of fuel by increasing engine load
- By using 8% and 5% gasoline rates in GD blends with engine speed at 1400 rpm under 60 % and 100% engine loads respectively and 21% and 12% gasoline rates in GD blends with engine speed at 2400 rpm under 60 % and 100% engine loads respectively, found that NOx emissions were higher with RCCI technology compared to CDC engine due to increasing of lambda value with low engine load and due to high turbulence combustion with high engine load and these issues suppose considering to solve as this study suggested this with the future work.

7.3 Personal Contributions

Concerning improving diesel and gasoline engines efficiency and emissions, then establishing and developing RCCI engine efficiency and emissions, this study provides severally contributions as summarized below:

1. The literature review followed two directions:
   - Review of using gasoline with higher RON than engine design in SI engine.
   - Review of using the different DBG fuels in CDC, GCI and RCCI engines.
2. An experiment was carried out on a Mitsubishi Campro, 4-cylinder, 4L, 4-strokes, and cr 11:1 in UPM University lab in Malaysia before my acceptance as a PhD, under different engine speeds and loads with three gasoline fuels RON95, RON97 and RON102. The results confirmed that using a higher RON gasoline achieved the best results in terms of efficiency, exhaust, and fuel consumption.
3. Built and simulated a 4-stroke, 4-cylinders, naturally aspirated, water-cooled and direct injection (DI) Tractor diesel engine (CDC) under RCCI technology by using Wiebe-2-Zones- AVL-BOOST Software 2020 by injected diesel than biodiesel B20 fuels as HRF in cylinders engine with DI strategy followed by injection of different ratios of gasoline fuel in PFI as LRF under RCCI strategy, at full engine load and speed. This model was calibrated with experimentally results from using pure diesel then biodiesel B20 fuels in the same Tractor diesel engine. This simulation confirmed that it can use this model to simulate the Tractor diesel engine with the RCCI combustion model.
4. Built and simulated two models MPI and SPI under the same previous software and engine test kind but with different engine loads (20, 40, 60, 80 and 100) % and engine speed at1400 rpm and 2400 rpm. These two models were calibrated with the same previous engine experiment results with pure diesel and biodiesel B20 fuels and they were in good agreement. Furthermore, RCCI simulation results encouraged this study to continue with building and experimenting with the RCCI Tractor diesel engine.
5. An experiment was conducted on the same previous Tractor diesel engine (CDC) in the lab for Polytechnic University in Bucharest, by using diesel-B07 fuel which was available in the market with different engine loads and speeds to establish these results as references to use with RCCI Tractor engine test later.
6. Developed the existing experiment test bench (CDC) in order to provide experiments RCCI strategy by making all necessary modifications including adding Gasoline Fuel Injection System and the corresponding devices for adjusting or measuring gasoline fuel, and gasoline fuel pressure.
7. Experiment tests on the test bench as RCCI strategy found that:
   - Engine power and torque were higher with the RCCI strategy at high engine loads and they were approximately the same at low engine loads compared to CDC engines at different engine speeds.
   - At different engine loads and speeds with the RCCI strategy found that BSFC were lower, COL emissions were higher and NOx emissions were higher compared to the CDC engine.
   - At high engine speed and different engine loads with RCCI strategy found that soot emissions were higher while at low engine speed and load soot emissions were higher and were lower at high engine load compared to CDC strategy.
8. I published in groups as an author and co-author of five papers in different journals: Journal Environmental Engineering and Management, Journal Energy Procedia, Journal U. P. B. and Conferences of TE-RE-RD.

7.4 Suggestions for Future Work

When it makes these following suggestions will improve engine performance, combustion and exhaust gas emissions with the Tractor diesel engine under RCCI technology.

- It suggests using a wide range of engine speeds from 1400 rpm to 2400 rpm and a wide range of engine loads from 20% to 100%.
- It suggests developing a current gasoline fuel injection system by using 4 gasoline fuel injectors (MPI) strategy, instead the single one, (SPI) strategy, as well as suggests changing the current gasoline injection electric device (inverter) which controls the number of injector pulse and periodical time injector by linking with the engine control unit (ECU) to enable electronic gasoline fuel injector.
- For improving engine performance and emission recommended to equip this Tractor engine with an electronic injection system for diesel fuel instead of this current mechanical control injection system to optimize the amount of the diesel fuel which mix with gasoline fuel inside the combustion chamber.

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