

INFLUENCE OF BIODIESEL AND BIODIESEL BLENDED WITH ETHANOL FUELS ON  
COMBUSTION AND EMISSION CHARACTERISTICS OF DIESEL ENGINE AND VEHICLE



PHOBKRIT KANOKKHANARAT

A THESIS REPORT SUBMITTED IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR THE DEGREE OF  
MASTER OF ENGINEERING IN AUTOMOTIVE ENGINEERING  
SCHOOL OF ENGINEERING  
KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG  
YEAR 2023  
KMITL-2023-EN-M-037-012

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

INFLUENCE OF BIODIESEL AND BIODIESEL BLENDED WITH ETHANOL FUELS ON  
COMBUSTION AND EMISSION CHARACTERISTICS OF DIESEL ENGINE AND VEHICLE



PHOBKRIT KANOKKHANARAT

A THESIS REPORT SUBMITTED IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR THE DEGREE OF  
MASTER OF ENGINEERING IN AUTOMOTIVE ENGINEERING  
SCHOOL OF ENGINEERING  
KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG  
YEAR 2023  
KMITL-2023-EN-M-037-012

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้



COPYRIGHT 2023

SCHOOL OF ENGINEERING

KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

**THESIS TITLE** Influence of biodiesel and biodiesel blended with ethanol fuels on combustion and emission characteristics of diesel engine and vehicle

**STUDENT NAME** Mr. Phobkrit Kanokkhanarat

**STUDENT ID** 62601156

**DEGREE** Master of Engineering

**PROGRAM** Automotive Engineering

**ADVISOR** Assoc.Prof. Dr. Nattawoot Depaiwa

**CO-ADVISOR** Dr. Chadchai Srisurangkul

**CO-ADVISOR** Assoc.Prof. Dr. Masaki Yamakita

### ABSTRACT

Emissions from diesel engines and vehicles are dangerous to human health and the environment. Biodiesel and ethanol, obtained from agricultural products, are one of the alternative solutions to reduce the emissions. The purpose of this research is to investigate the influence of diesel fuels (B10 and B20), biodiesel fuel (B100), and biodiesel blended with ethanol fuels (B100E5 and B100E10) on the combustion and emission characteristics of diesel engine and vehicle. Ethanol blends into biodiesel fuel by weight ratio as known B100E5 (95%biodiesel with 5%ethanol) and B100E10 (90% biodiesel with 10%ethanol). Diesel engine test was performed on constant engine speed of 1000, 1500, and 2000 rpm and variable engine loads of 56, 84, 112, and 140 Nm. The combustion pressure and cumulative heat release of biodiesel fuel are not significantly different from diesel fuel. While the heat release rate is lower. After blending ethanol into biodiesel fuel, the combustion pressure, heat release rate, and cumulative heat release are higher than both diesel and biodiesel fuel. The indicated thermal efficiency of blended ethanol fuels is higher by around 5% to 8% compare to diesel and biodiesel fuel. The smoke intensity decreased by around 70% for biodiesel fuel and 90% for blended ethanol fuel compared to diesel fuel. The diesel vehicle test was tested based on the New European Driving Cycle. The emissions such as particulate number and particulate mass are decreased by around 30% to 40% when using biodiesel and blended ethanol fuel in both cases with and without the DOC system.

**Keywords:** Biodiesel, Ethanol, Combustion characteristic, Emissions, Diesel Engine and Vehicle

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

## ACKNOWLEDGEMENT

First and foremost, I would like to express my great appreciation for the scholarship from Thailand Advance Institute of Science and Technology, and Tokyo Institute of Technology (TAIST-Tokyo Tech).

I would like to express my grateful thank you for the help provided and for recommendations from my advisor Assoc.Prof. Dr. Nattawoot Depaiwa of King Mongkut's Institute of Technology Ladkrabang, co-advisor Dr. Chadchai Srisurangkul of National Science and Technology Development Agency, and co-advisor Assoc.Prof. Dr. Masaki Yamakita of Tokyo institute of technology. The important person to constructive and valuable suggestions for this research, Assoc.Prof. Dr. Preechar Karin of the Department of Mechanical Engineering at King Mongkut's Institute of Technology Ladkrabang for his kind guidance and supervision through all obstacles and challenges during this work.

My special thanks are extended to KMITL Automotive Laboratory friends for support and advice during the experiment, including the KMITL Automotive laboratory for the facilities and experimental devices.

Finally, I have to express my very greatest gratitude to my parents and my special person who always support encouraged and understand me throughout my years of study. This thesis would not have been possible without the contribution and inspiration of many people.

Phobkrit Kanokkhanarat

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

# TABLE OF CONTENTS

ABSTRACT.....	I
ACKNOWLEDGEMENT .....	II
TABLE OF CONTENTS.....	III
LIST OF TABLES.....	VI
LIST OF FIGURES .....	VII
CHAPTER 1 INTRODUCTION .....	1
1.1 Research background .....	1
1.2 Objective.....	2
1.3 Scope of work.....	2
CHAPTER 2 LITERATURE REVIEW.....	4
2.1 Diesel engine.....	4
2.1.1 Stage cycles of diesel engine.....	4
2.1.2 Phases of the diesel combustion process.....	5
2.2 Emissions of diesel engine .....	6
2.3 Biodiesel production in Thailand.....	8
2.3.1 Biodiesel production process.....	9
2.4 Biodiesel in compression ignition engine.....	10
2.5 Biodiesel blends with ethanol fuel.....	11
CHAPTER 3 EXPERIMENTAL METHODOLOGY .....	15
3.1 Experimental samples.....	15
3.1.1 Biodiesel group.....	15

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

3.1.2 Biodiesel blended with ethanol group.....	16
3.2 Diesel engine test.....	17
3.2.1 Engine specification.....	17
3.2.2 Eddy current dynamometer’s specification.....	18
3.3 Diesel vehicle test.....	19
3.4 Data collection system.....	23
3.4.1 Pressure and Crank angle.....	23
3.4.2 Emissions collecting of diesel engine test.....	24
3.4.3 Emission collecting of diesel vehicle test.....	25
3.4.4 Data acquisition system.....	25
3.5 Schematic diagram.....	27
3.6 Calculation method.....	28
3.6.1 Combustion characteristic.....	28
3.6.2 Engine performance.....	29
CHAPTER 4 RESULTS AND DISCUSSIONS.....	31
4.1 Diesel engine test.....	31
4.1.1 Combustion characteristic.....	31
4.1.2 Engine performance.....	57
4.1.3 Emissions.....	63
4.1.4 Morphology of particulate matters.....	71
4.2 Diesel vehicle test.....	74
CHAPTER 5 CONCLUSION.....	86
REFERENCES.....	88

APPENDIX A.....	92
APPENDIX B.....	97
APPENDIX C.....	113
AUTHOR BIOGRAPHY.....	129



เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

## LIST OF TABLES

Table 3.1 Fuel's properties .....	17
Table 3.2 Engine's specification .....	18
Table 3.3 Eddy current dynamometer's specification .....	19
Table 3.4 Vehicle's specification.....	20
Table 3.5 New European Driving Cycle.....	21
Table 4.1 SEM images of fuel trapped on filter papers for measured the PM mass.....	80



## LIST OF FIGURES

Figure 2.1 Stage cycles of diesel engine [9].....	5
Figure 2.2 Phases of the diesel combustion process on heat release rate diagram [10] .....	5
Figure 2.3 Diesel combustion flame zone [11] .....	7
Figure 2.4 Biodiesel supply chain [12].....	8
Figure 2.5 Biodiesel production diagram [13].....	9
Figure 2.6 The ignition delay of ultra-low sulfur diesel and biodiesel [14] .....	10
Figure 2.7 The smoke intensity of various mixed biodiesel fuels [15].....	11
Figure 2.8 Viscosity of butanol and ethanol blending with biodiesel and diesel fuels [16] .....	12
Figure 2.9 Atomization while injecting the fuel [17] .....	12
Figure 2.10 Ignition delay of biodiesel-ethanol blended fuel [19] .....	13
Figure 2.11 Phase behavior of (a) diesel-PME-ethanol (b) diesel-biodiesel-ethanol99.5% at room temperature [22,23].....	14
Figure 2.12 the stability of phase separation by adding palm methyl ester (PME) into diesel-ethanol blended fuel. [24].....	14
Figure 3.1 Samples of Ethanol, Diesel B10, B20 and Biodiesel B100 .....	16
Figure 3.2 Samples of Biodiesel B100, B100E5 and B100E10.....	16
Figure 3.3 Direct injection diesel engine (Isuzu 4JJ-TC).....	18
Figure 3.4 Eddy current dynamometer (Tokyo Plant ED-150-LC).....	19
Figure 3.5 Diesel Vehicle.....	20
Figure 3.6 European urban and highway driving cycle .....	21
Figure 3.7 Diesel vehicle test on chassis dynamometer .....	22
Figure 3.8 Pressure sensor .....	23
Figure 3.9 Crank encoder.....	24
Figure 3.10 (a)Smoke intensity meter and (b)filter paper .....	24
Figure 3.11 AVL gas analyzer [25].....	25
Figure 3.12 Dewesoft DAQ system.....	26

Figure 3.13 DewesoftX software monitor .....	26
Figure 3.14 Schematic diagrams of engine dyno testing.....	27
Figure 3.15 Schematic diagrams of chassis dyno testing.....	28
Figure 4.1 Pressure – Volume diagram at engine load 56Nm and engine speed 1000RPM.....	32
Figure 4.2 Pressure – Volume diagram at engine load 84Nm and engine speed 1000RPM.....	33
Figure 4.3 Pressure – Volume diagram at engine load 112Nm and engine speed 1000RPM.....	33
Figure 4.4 Pressure – Volume diagram at engine load 140Nm and engine speed 1000RPM.....	34
Figure 4.5 Pressure – Volume diagram at engine load 56Nm and engine speed 1500RPM.....	34
Figure 4.6 Pressure – Volume diagram at engine load 84Nm and engine speed 1500RPM.....	35
Figure 4.7 Pressure – Volume diagram at engine load 112Nm and engine speed 1500RPM.....	35
Figure 4.8 Pressure – Volume diagram at engine load 140Nm and engine speed 1500RPM.....	36
Figure 4.9 Pressure – Volume diagram at engine load 56Nm and engine speed 2000RPM.....	36
Figure 4.10 Pressure – Volume diagram at engine load 84Nm and engine speed 2000RPM.....	37
Figure 4.11 Pressure – Volume diagram at engine load 112Nm and engine speed 2000RPM.....	37
Figure 4.12 Pressure – Volume diagram at engine load 140Nm and engine speed 2000RPM.....	38
Figure 4.13 Pressure – Crank angle diagram at engine load 56Nm and engine speed 1000RPM..	38
Figure 4.14 Pressure – Crank angle diagram at engine load 84Nm and engine speed 1000RPM..	39
Figure 4.15 Pressure – Crank angle diagram at engine load 112Nm and engine speed 1000RPM	39
Figure 4.16 Pressure – Crank angle diagram at engine load 140Nm and engine speed 1000RPM	40
Figure 4.17 Pressure – Crank angle diagram at engine load 56Nm and engine speed 1500RPM..	40
Figure 4.18 Pressure – Crank angle diagram at engine load 84Nm and engine speed 1500RPM..	41
Figure 4.19 Pressure – Crank angle diagram at engine load 112Nm and engine speed 1500RPM	41
Figure 4.20 Pressure – Crank angle diagram at engine load 140Nm and engine speed 1500RPM	42
Figure 4.21 Pressure – Crank angle diagram at engine load 56Nm and engine speed 2000RPM..	42
Figure 4.22 Pressure – Crank angle diagram at engine load 84Nm and engine speed 2000RPM..	43
Figure 4.23 Pressure – Crank angle diagram at engine load 112Nm and engine speed 2000RPM	43
Figure 4.24 Pressure – Crank angle diagram at engine load 140Nm and engine speed 2000RPM	44
Figure 4.25 Combustion duration.....	44

Figure 4.26 Cumulative heat release diagram at engine load 56Nm and engine speed 1000RPM	45
Figure 4.27 Cumulative heat release diagram at engine load 84Nm and engine speed 1000RPM	45
Figure 4.28 Cumulative heat release diagram at engine load 112Nm and engine speed 1000RPM	46
Figure 4.29 Cumulative heat release diagram at engine load 140Nm and engine speed 1000RPM	46
Figure 4.30 Cumulative heat release diagram at engine load 56Nm and engine speed 1500RPM	47
Figure 4.31 Cumulative heat release diagram at engine load 84Nm and engine speed 1500RPM	47
Figure 4.32 Cumulative heat release diagram at engine load 112Nm and engine speed 1500RPM	48
Figure 4.33 Cumulative heat release diagram at engine load 140Nm and engine speed 1500RPM	48
Figure 4.34 Cumulative heat release diagram at engine load 56Nm and engine speed 2000RPM	49
Figure 4.35 Cumulative heat release diagram at engine load 84Nm and engine speed 2000RPM	49
Figure 4.36 Cumulative heat release diagram at engine load 112Nm and engine speed 2000RPM	50
Figure 4.37 Cumulative heat release diagram at engine load 140Nm and engine speed 2000RPM	50
Figure 4.38 Heat release rate diagram at engine load 56Nm and engine speed 1000RPM	51
Figure 4.39 Heat release rate diagram at engine load 84Nm and engine speed 1000RPM	52
Figure 4.40 Heat release rate diagram at engine load 112Nm and engine speed 1000RPM	52
Figure 4.41 Heat release rate diagram at engine load 140Nm and engine speed 1000RPM	53
Figure 4.42 Heat release rate diagram at engine load 56Nm and engine speed 1500RPM	53
Figure 4.43 Heat release rate diagram at engine load 84Nm and engine speed 1500RPM	54
Figure 4.44 Heat release rate diagram at engine load 112Nm and engine speed 1500RPM	54
Figure 4.45 Heat release rate diagram at engine load 140Nm and engine speed 1500RPM	55
Figure 4.46 Heat release rate at engine load 56Nm and engine speed 2000RPM	55
Figure 4.47 Heat release rate at engine load 84Nm and engine speed 2000RPM	56

Figure 4.48 Heat release rate diagram at engine load 112Nm and engine speed 2000RPM.....	56
Figure 4.49 Heat release rate diagram at engine load 140Nm and engine speed 2000RPM.....	57
Figure 4.50 Calorific values of the samples .....	58
Figure 4.51 Heat energy input rate .....	58
Figure 4.52 Fuel consumption rate.....	59
Figure 4.53 Indicated specific fuel consumption .....	60
Figure 4.54 Brake specific fuel consumption .....	60
Figure 4.55 Indicated specific energy consumption .....	61
Figure 4.56 Brake specific energy consumption .....	61
Figure 4.57 Indicated thermal efficiency .....	62
Figure 4.58 Brake thermal efficiency .....	62
Figure 4.59 Fuel-Air equivalent ratio .....	65
Figure 4.60 Normalized Fuel-Air equivalent ratio .....	65
Figure 4.61 Exceed oxygen emission.....	66
Figure 4.62 Normalized exceed oxygen emission.....	66
Figure 4.63 Smoke intensity .....	67
Figure 4.64 Normalized smoke intensity .....	67
Figure 4.65 Exhaust temperature .....	68
Figure 4.66 Carbon monoxide emission .....	68
Figure 4.67 Normalized carbon monoxide emission.....	69
Figure 4.68 Carbon dioxide emission.....	69
Figure 4.69 Normalized carbon dioxide emission.....	70
Figure 4.70 NOx emission.....	70
Figure 4.71 Normalized NOx emission .....	71
Figure 4.72 Optical microscope images of B10, B20, B100, B100E5, and B100E10.....	72
Figure 4.73 Scanning electrical microscope images of B10, B20, B100, B100E5, and B100E10.....	73
Figure 4.74 Agglomerate particle size distribution of B10, B20, B100, B100E5 and B100E10 .....	74
Figure 4.75 Average particle size of B10, B20, B100, B100E5 and B100E10 .....	74

Figure 4.76 Realtime measurement of particulate number of diesel vehicle.....	75
Figure 4.77 Realtime measurement of hydrocarbon emission of diesel vehicle .....	76
Figure 4.78 Realtime measurement of NOx emission of diesel vehicle .....	76
Figure 4.79 Realtime measurement of carbon monoxide emission of diesel vehicle .....	77
Figure 4.80 Realtime measurement of carbon dioxide emissison of diesel vehicle.....	77
Figure 4.81 Particulate matter number of diesel vehicle .....	78
Figure 4.82 Particulate matter mass of diesel vehicle.....	79
Figure 4.83 Hydrocarbon emission of diesel vehicle .....	81
Figure 4.84 Carbon monoxide emission of diesel vehicle.....	82
Figure 4.85 Carbon dioxide emission of diesel vehicle.....	83
Figure 4.86 NOx emission of diesel vehicle.....	84



# CHAPTER 1

## INTRODUCTION

### 1.1 Research background

The world's energy consumption is increasing every year around the world. Petroleum Oil is the main energy source for transportation. The world energy statistics report in 2018, around 50% of oil consumption came from the road and it increased to around 18% within 45 years from 1973 to 2018 [1]. In 2019, gas and diesel fuels consumed almost 40% of oil consumption products in Thailand [2]. According to the report of the Department of Alternative Energy Development and Efficiency in 2020, the demand of diesel product increased from 22626 million liters to 23920 million liters in 2016 to 2020 or 5.7% within 4 years [3]. C. ChooChuay et al. [4] have investigated the causes of PM<sub>2.5</sub> in Bangkok. The five main causes are vehicle exhaust, biomass combustion, sea salt mist, power plants, and pollutants from industry which accounted for 43.7%, 24.0%, 10.5%, 6.48%, and 4.46%, respectively. Furthermore, PM<sub>2.5</sub> emitted from diesel vehicles is more than from gasoline vehicles by around ten times [5,6].

The significantly disadvantaged of diesel combustion engines is the emissions. The emissions from the incomplete combustion of diesel engines are hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), and nitrogen oxides (NO<sub>x</sub>), and particulate matter (PMs) [7]. Many researchers have investigated and developed clean energy or alternative source from renewable sources. Plants can absorb carbon dioxide (CO<sub>2</sub>) caused by greenhouse gases in photosynthesis. Photosynthesis provides a complete cycle of carbon cycling, not increasing or decreasing carbon (Carbon Neutral). Biofuel is the product from plants such as biodiesel and ethanol. Oxygen atoms in the biofuels can reduce the amount of soot particulate emissions in proportion to the content of diesel fuel [8].

Solving the problem of soot particulate pollution in large cities. It also helps reduce global warming problems, energy security and crop price problems from farmers who make up the majority of the country's population. The goal of this research is to investigate the impact of diesel

(B10 and B20), biodiesel (B100), and biodiesel blended with ethanol (B100E5 and B100E10) on thermal efficiency and soot emissions on compression ignition engines. The comparing process of combustion characteristics such as cumulative heat release and heat release rate, and engine performance such as thermal efficiency, specific fuel consumption, specific energy consumption by using an unmodified engine. As well as an analysis of the soot emission at various engine loads (56, 84, 112, and 140 Nm) and constant engine speeds (1000, 1500, and 2000 rpm). Including evaluate the actual driving of a diesel vehicle on urban driving and highway driving by simulated on chassis dynamometer. Furthermore, the experiment investigates a diesel vehicle in urban and highway driving conditions to observe the impact of diesel and biofuels on soot reduction and vehicle performance as fuel consumption. Furthermore, the experiment investigates a diesel vehicle in urban and highway driving conditions to observe the impact of diesel and biofuels on soot reduction and vehicle performance as fuel consumption.

## 1.2 Objective

- 1) To investigate the influence of diesel, biodiesel, and biodiesel blended with ethanol fuels on combustion characteristics and engine performance of a diesel engine.
- 2) To observe the effects of diesel, biodiesel, and biodiesel blended with ethanol fuels on a diesel vehicle.
- 3) To investigate the emissions reduction of diesel, biodiesel, and biodiesel blended with ethanol on a diesel engine and diesel vehicle.

## 1.3 Scope of work

- 1) Use diesel fuel (diesel B10 and diesel B20) and biodiesel fuel as a commercial form.
- 2) Use the ethanol with a purity of 99.5% to blend into biodiesel B100 by percent weight 5% and 10% and string until it is a homogeneous mixture.
- 3) To study and analyze the combustion characteristics, engine performance, and the reduction of emissions of diesel, biodiesel, and biodiesel blended with ethanol on a compression ignition diesel engine under various engine loads with constant engine speed conditions.

- 4) To study and simulate the actual driving of diesel vehicles by using a chassis dynamometer to investigate the influence of diesel, biodiesel, and biodiesel blended with ethanol fuel on the emissions reduction.



เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

# CHAPTER 2

## LITERATURE REVIEW

### 2.1 Diesel engine

A diesel engine is a type of internal combustion engine which was discovered in 1897 by “Rudolph Diesel”. Conventional diesel engines are generally known as compression ignition engines. In the principle of compression ignition engines, fuel is injected directly into the combustion chamber at the top dead center (TDC) while compression by moving up the piston to increase the pressure inside the combustion chamber to self-ignite the fuel under high pressure and temperature.

#### 2.1.1 Stage cycles of diesel engine

The 4 strokes consist of, intake, compression, power, and exhaust as show in **Figure 2.1**.

1. Intake stroke: the piston starts moving from top dead center (TDC) to bottom dead center (BDC) while the intake valve is opened, and the exhaust valve is closed. During the piston moving down, fresh air is sucked into the combustion chamber.
2. Compression stroke: Both the intake valve and exhaust valve are closed at this stroke. During the piston moves up from BDC to TDC, the pressure cylinder and temperature are increased corresponding to compression.
3. Power stroke: During the end of the compression stroke, the fuel is injected into the combustion chamber and starts the combustion. The energy from the chemical combustion reaction is converted into mechanical energy through the piston to the crankshaft.
4. Exhaust stroke: After finishing the power stroke at BDC, the exhaust valve is opened while the intake valve is still closed. The piston moves up to push exhaust air out of the combustion chamber.

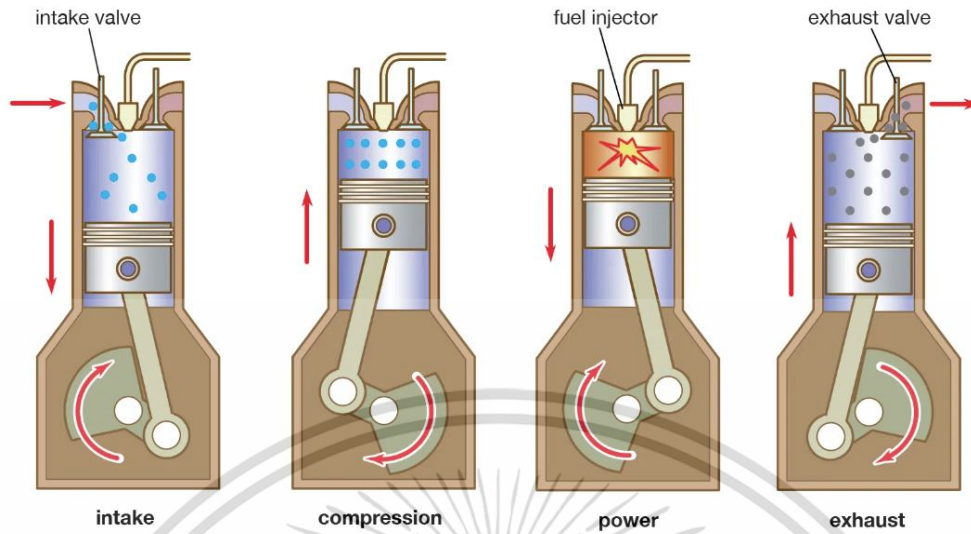


Figure 2.1 Stage cycles of diesel engine [9]

### 2.1.2 Phases of the diesel combustion process

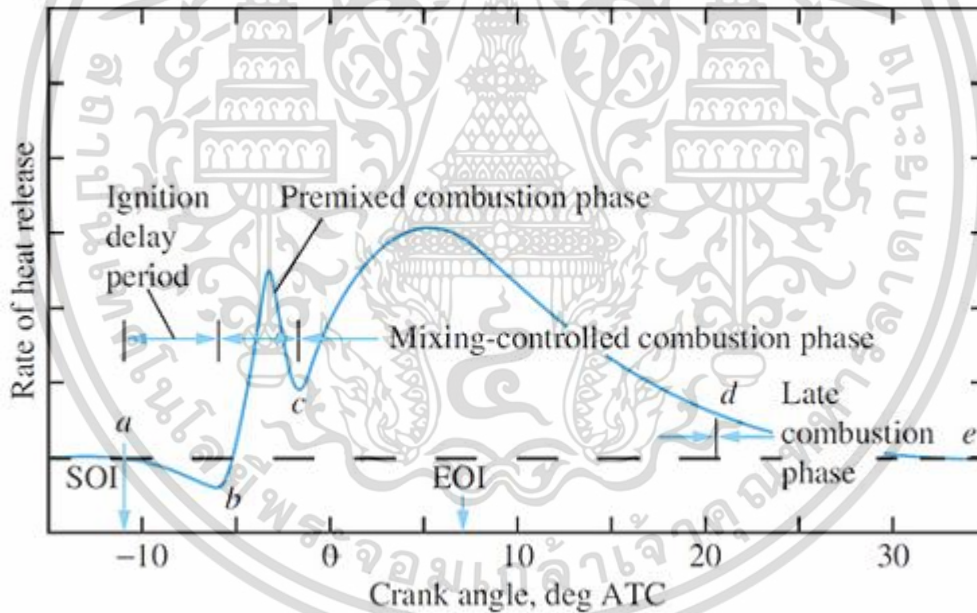


Figure 2.2 Phases of the diesel combustion process on heat release rate diagram [10]

Figure 2.2 shows the phases of the diesel combustion process on the heat release rate diagram from the start of injection to the end of combustion. An ignition delay (a to b) is the period between the start of fuel injection (SOI) into the combustion chamber and start of combustion (SOC).

A premixed combustion phase (b to c). the heat release rate curve recovers from the negative zone due to the evaporation of the fuel which has mixed with air under combustible limits during the ignition delay period occurs rapidly in a short time. When the fuels which ready for burning are added to this burning mixture and burn in this phase, the high heat release rate characteristics of this phase result.

A mixing controlled combustion (c to d). When the fuel and air that are premixed during the ignition delay have been consumed and released some of the energy, the heat release rate is controlled by the rate at which mixture becomes available for burning. While several processes are involved fuel atomization, vaporization, mixture formation, and chemical reaction in the spray. In this phase, the burning rate of diffusion flame is primarily controlled by the fuel and air mixing process.

A late combustion phase (d to e). The heat release continues at a lower release rate. Because a small fraction of the fuel may have unburned, and a fraction of the fuel energy in soot and the combustion product can be still released. During this period, the cylinder charge mixing promotes more complete combustion and less dissociated gases. The kinetics of the final burnout processes become slower as the temperature of the cylinder gases fall during expansion.

## 2.2 Emissions of diesel engine

The exhaust gases emitted from the diesel engine contain several constituents that are hazardous to the environment and human health. By the emissions from diesel engine consist of carbon monoxide (CO), hydrocarbon (HC), nitrogen Oxides (NO<sub>x</sub>), and particulate matters (PMs) as shown in Equation 2.1. Figure 2.3 shows the combustion phenomena in combustion chamber.



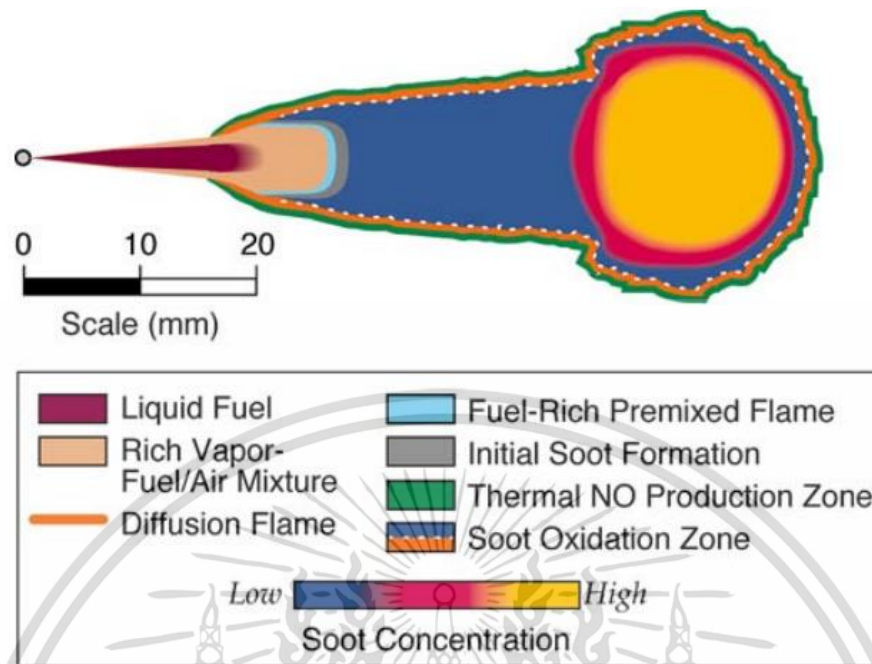


Figure 2.3 Diesel combustion flame zone [11]

Carbon monoxide (CO), hydrocarbon (HC), and aldehyde are emitted in the exhaust as the result of incomplete combustion. When engines operate in enclosed areas, such as underground mines, buildings under construction, tunnels, or warehouses, the emitted gasses can accumulate in the ambient atmosphere and cause headaches, dizziness, lethargy, eye irritation, and choking sensations. Hydrocarbons also have a negative environmental effect, being an important component of smog.

Nitrogen oxides (NO<sub>x</sub>) are generated from nitrogen and oxygen under the high pressure and temperature condition in the cylinder. NO<sub>x</sub> consists mostly of nitric oxide (NO) and a small fraction of nitrogen dioxide (NO<sub>2</sub>). Nitrogen dioxide is quite hazardous to human health. NO<sub>x</sub> emissions are also a main environmental concern because of their role in the smog formation.

Particulate matter (PM) is a complex aggregate of solid and liquid material. Its origin is carbonaceous particles generated during combustion. The primary carbon particles form larger agglomerates and combine with several other, both organic and inorganic, components of diesel exhaust.

## 2.3 Biodiesel production in Thailand

Biodiesel, also known as B100, is a fuel produced from vegetable oils, animal fats, or waste cooking oil. By using alcohol-based chemical processing to convert into a substance ethyl ester (Ethyl ester) or methyl ester (Methyl ester) that has properties similar to diesel fuel. Biodiesel can be mixed with diesel to save on the import of crude oil or oil products. Hence, biodiesel production provides the country with a means of achieving a greater degree of security over its energy supplies.

In Thailand, biodiesel is mostly produced from crude palm oil (CPO), although Thai manufacturers also use refined bleached and deodorized palm oil (RBDPO), palm stearin, and other vegetable oils (Figure 2.4). In 2020, Thailand has oil palm plantations are 5.9 million rai, yielding 16.2 million tons, which in turn produced 2.9 million tons of CPO, 1.4 million tons can be used as raw materials in the biodiesel industry, or 48% of all national production of CPO. The rest is used for household consumption.

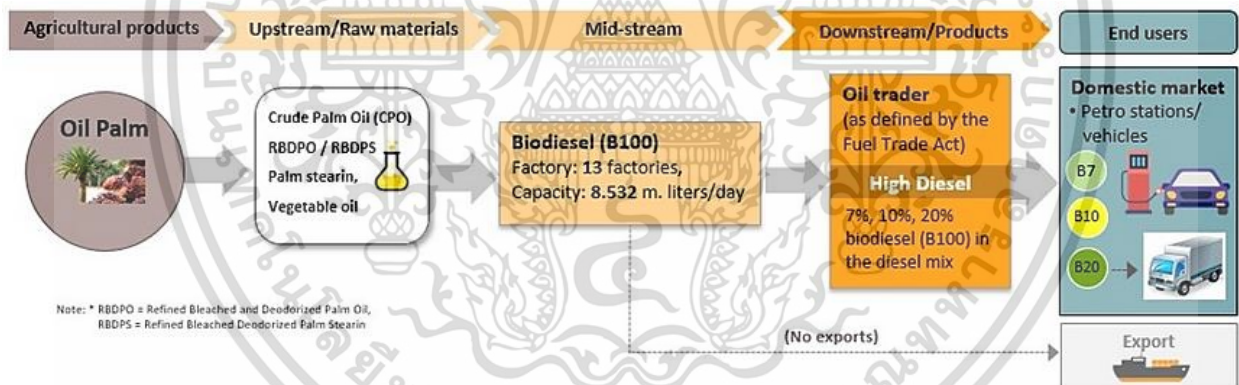


Figure 2.4 Biodiesel supply chain [12]

### 2.3.1 Biodiesel production process

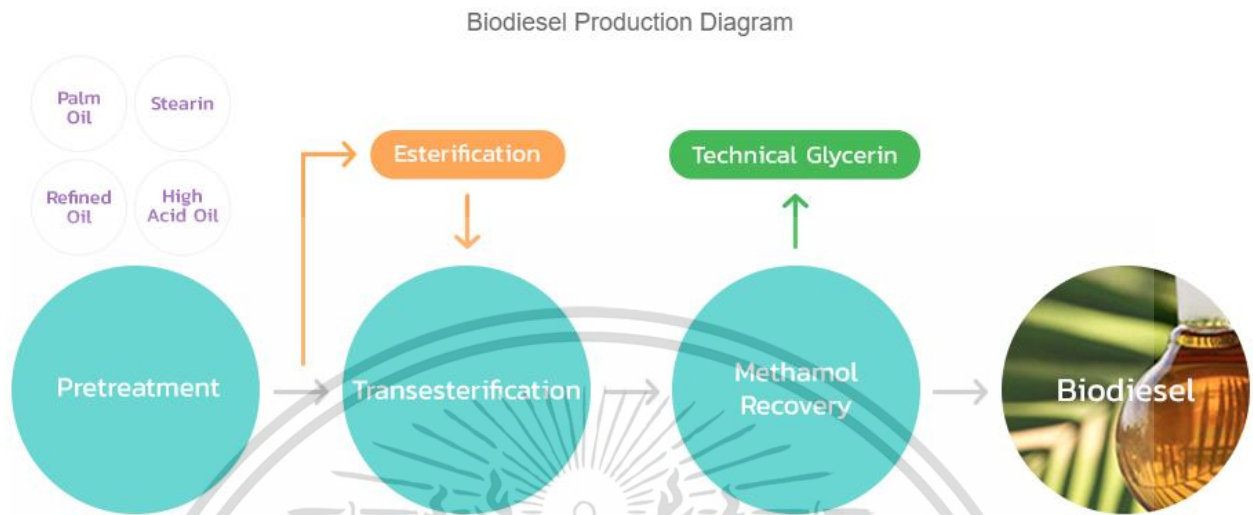


Figure 2.5 Biodiesel production diagram [13]

Figure 2.5 shows the biodiesel production process diagram in Thailand. The palm oil purification process, or pretreatment unit, is the preparation process of the palm oil quality to be ready for the production. By adding phosphoric acid to degumming sticky rubber, then add bleaching powder to absorb impurities mixed in crude palm oil. And bleaching starch also serves to filter the sticky rubber from crude palm oil to separate fatty acid before it is refined. This process has got refined palm oil (RPO) and fatty acids from crude palm oil refining.

The transesterification reaction is the use of refined palm oil (RPO), or refined palm stearin (RPS) for transesterification reaction with methanol. By filled excess methanol in order for the reaction to produce the most Methyl Ester, alkali was used as a catalyst to produce biodiesel and glycerin. The esterification reaction converts palm fatty acid distillate to biodiesel by reacting with methanol and using acid as a catalyst. Since the biodiesel products which obtained from this reaction cannot meet the specification of B100, hence, it has been fed into the transesterification unit once more.

Methanol recovery is to increase the purity of the product. By washing the contaminants in crude biodiesel with water. The rinse water is evaporated before being fed into the excess Methanol tank and distilled to achieve a purity of methanol more than 99.5%.

## 2.4 Biodiesel in compression ignition engine

S. H. Yoon et al. [14] investigated ultra-low sulfur diesel (ULSD) and biodiesel on combustion and emission characteristics of a compression ignition engine. They observed the ignition delay of biodiesel was slightly shorter than ULSD because of the higher cetane number and oxygen content. However, the combustion characteristics of ULSD and biodiesel have similar behaviors of pressure and heat release rate at various engine loads. The brake thermal efficiency and emissions of biodiesel was lower than ULSD. A. Tripatara et al. [15] investigate diesel and biodiesel fuels in Thailand on a single-cylinder diesel engine. They have observed the combustion characteristics of diesel and biodiesel have similar behaviors. The reduction of smoke intensity increased when the proportion of biodiesel increased in mixed fuels.

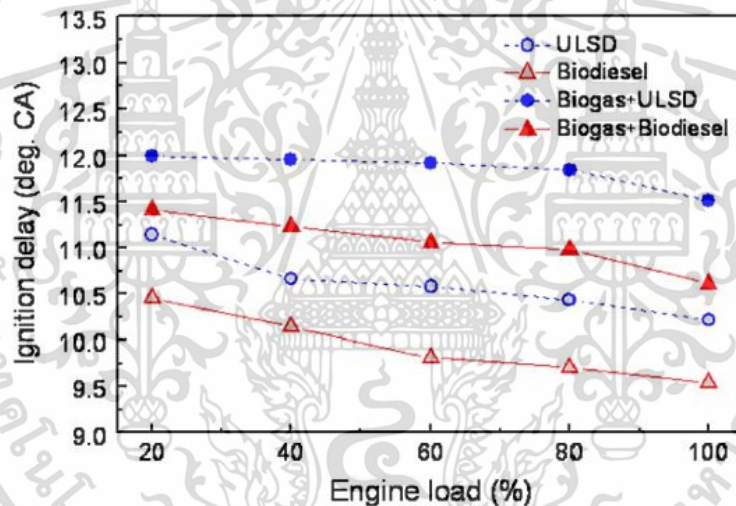


Figure 2.6 The ignition delay of ultra-low sulfur diesel and biodiesel [14]

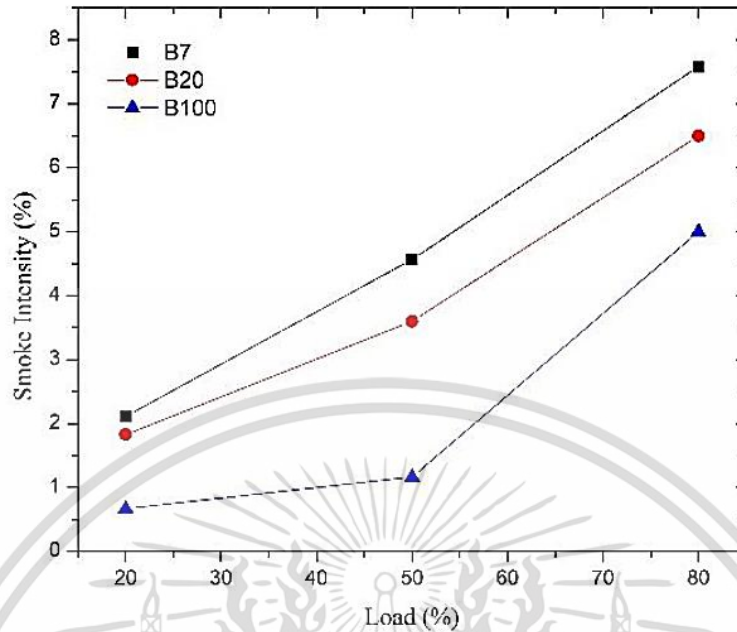


Figure 2.7 The smoke intensity of various mixed biodiesel fuels [15]

## 2.5 Biodiesel blends with ethanol fuel

Another alternative resource which is manufactured from agricultural products such as sugarcane juice, cassava, and molasses is ethanol. Lapuerta M et al. [16] investigated the modeling viscosity of butanol and ethanol blending with biodiesel and diesel fuels. They have observed viscosity values of diesel and biodiesel blends decrease when alcohol content increases as shown in Figure 2.6. A low viscosity and density of blended fuel, Zhan C et al. [17] and Geng L et al. [18] was occurred by adding ethanol into biodiesel fuel. It leads to better atomization while injecting the fuel as shown in Figure 2.7

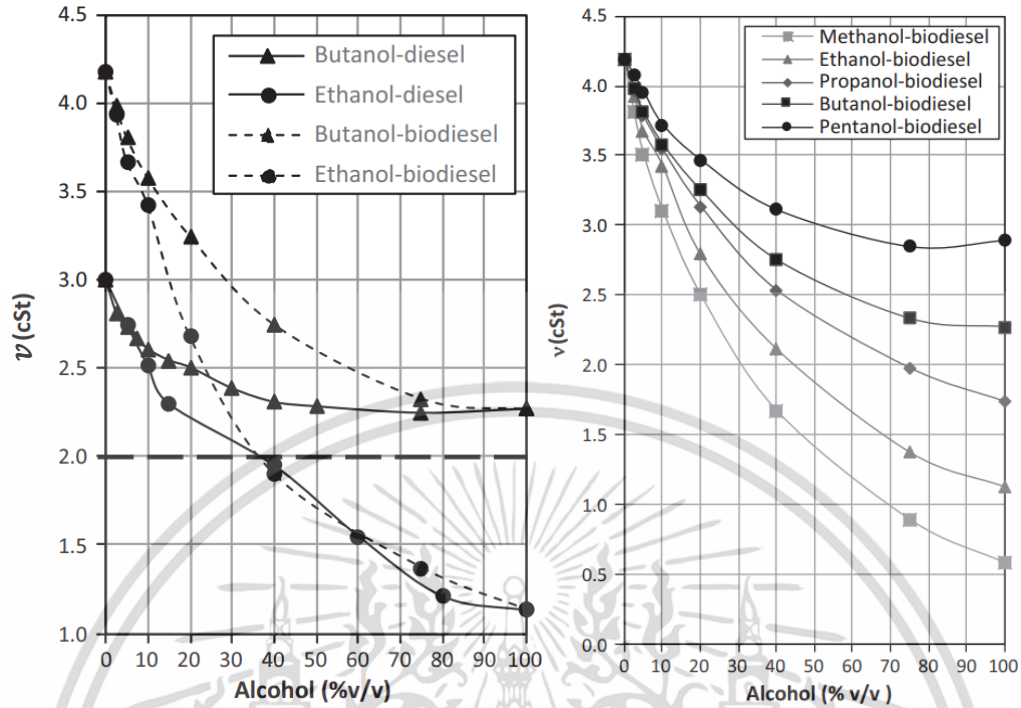


Figure 2.8 Viscosity of butanol and ethanol blending with biodiesel and diesel fuels [16]

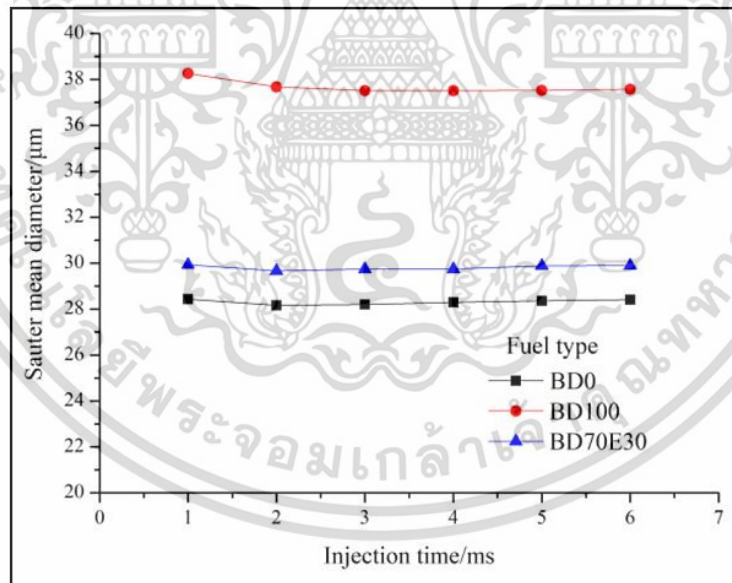


Figure 2.9 Atomization while injecting the fuel [17]

Fang Q et al. [19] and Sayin C et al. [20] have discovered the high oxygen content and the low cetane number of ethanol. There is an increase in the duration of the ignition delay of biodiesel-ethanol blended fuel as shown in Figure 2.8. The longer premixed duration and higher

oxygen content in the blended fuel result in more complete combustion and the start of the combustion process retarded nearly the optimum ignition setup point of the unmodified engine.

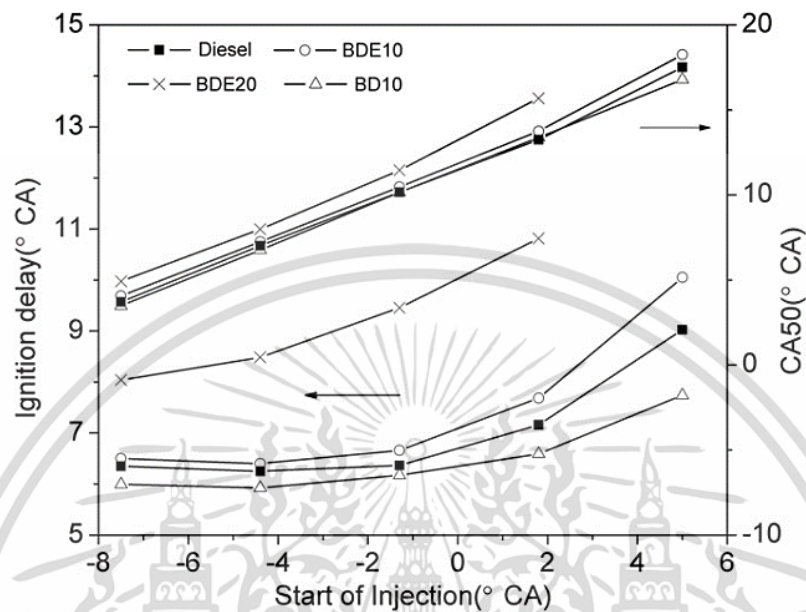


Figure 2.10 Ignition delay of biodiesel-ethanol blended fuel [19]

The most trouble of blending diesel fuels with ethanol is poor miscibility and stability of layer separation depending on blending temperature, duration, and ethanol percentage Jackson MM et al. [21]. Kwanchareon P. et al [22] and Chotwichien A et al. [23] investigated the stability of phase separation by adding palm methyl ester (PME) into diesel-ethanol blended fuel. The stability and miscibility of blended fuel could be better with increasing PME proportion as shown in **Figure 2.9**. Tongroon M et al. [24] have been studied the stability of ethanol in diesel- biodiesel-ethanol blends in various ethanol percent at room temperature at (27-30 °C) and at the lowest winter temperature of Thailand (5 °C). The results showed that Thailand's commercial B20 fuel can mix up to 20% of ethanol without phase separation at both temperatures within three months as shown in **Figure 2.10** by green zone is no phase separation and red zone is observed phase separation.

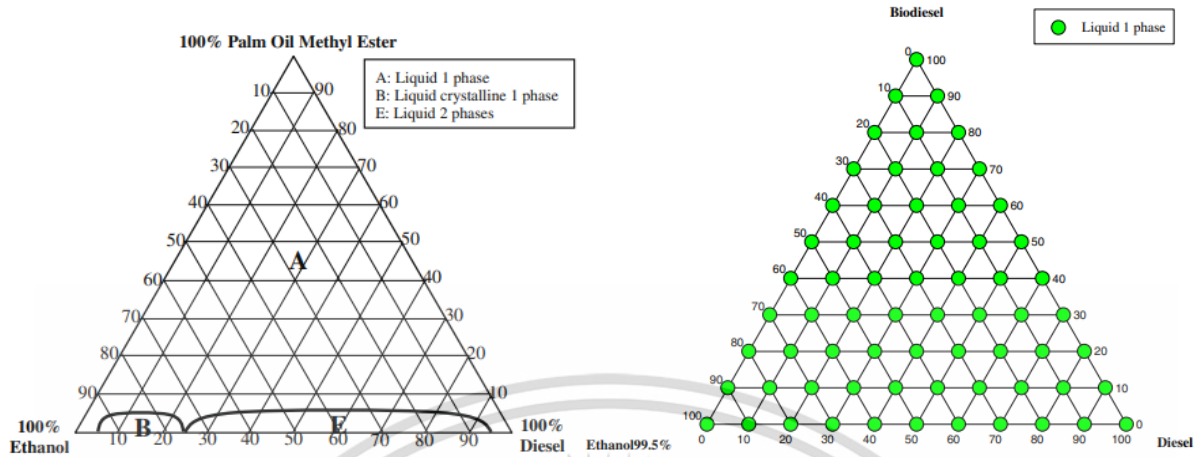


Figure 2.11 Phase behavior of (a) diesel-PME-ethanol (b) diesel-biodiesel-ethanol99.5% at room temperature [22,23]

	Room temperature (27 – 30 °C within 3 months)					Low temperature (5 °C within 3 months)						
	B3	B5	B7	B10	B15	B20	B3E5	B5	B7E5	B10	B15	B20
E5												
E7												
E10												
E15												
E20												

Figure 2.12 the stability of phase separation by adding palm methyl ester (PME) into diesel-ethanol blended fuel. [24]

# CHAPTER 3

## EXPERIMENTAL METHODOLOGY

To investigate and observe the influence of fuels on a diesel engine and diesel vehicle. The fuels which used to investigate in this research consists of diesel (B10 and B20), pure biodiesel (B100), and biodiesel blended with ethanol (B100E5 and B100E10) fuel. The investigateion on a diesel engine based on the combustion characteristics, engine performances, and emissions. The operating conditions for engine test are performed on variable engine loads of 56, 84, 112, and 140Nm at constant engine speed of 1000, 1500, and 2000rpm. For a diesel vehicle, it tests on the chassis dynamometer with a new European driving cycle to investigate the emitted emission in the urban and highway.

### 3.1 Experimental samples

This research divided the samples into 2 groups, such as biodiesel group and biodiesel blended with ethanol group, for a more efficient observation and investigation.

#### 3.1.1 Biodiesel group

Biodiesel group consists of 3 samples.

1. Diesel B10 (Diesel 90% and Biodiesel 10%)
2. Diesel B20 (Diesel 80% and Biodiesel 20%)
3. Biodiesel B100 (Biodiesel 100%)

Diesel and biodiesel obtained from the commercial form. Diesel B10 and B20 contain 10% and 20% pure biodiesel or B100 mixed in diesel fuels respectively. Biodiesel B100 is conducted from based palm oil via the acid-esterification and transesterification with methanol process also known as palm methyl ester (PME).



Figure 3.1 Samples of Ethanol, Diesel B10, B20 and Biodiesel B100

### 3.1.2 Biodiesel blended with ethanol group

Biodiesel blended with ethanol group consist of 3 samples.

1. Biodiesel B100 (Biodiesel 100%)
2. Biodiesel-ethanol B100E5 (Biodiesel 95% and Ethanol 5%)
3. Biodiesel-ethanol B100E10 (Biodiesel 90% and Ethanol 10%)

All biodiesels are pure biodiesel B100. Ethanol was conducted from sugarcane juice, cassava, and molasses with a purity of 99.5%. Biodiesel blended with ethanol (B100E5 and B100E10) contain approximately 5% and 10% ethanol by weight mixed in pure biodiesel. Blending between biodiesel and ethanol by stirring under surrounding temperature to be the homogeneous mixture [22].



Figure 3.2 Samples of Biodiesel B100, B100E5 and B100E10

**Table 3.1** Fuel's properties

Fuel Properties	Standard	B10	B20	B100	Ethanol
Carbon (% mass)	ASTM D 5291	84.66	82.61	76.73	52.2
Hydrogen (% mass)	ASTM D 5291	13.56	13.45	12.45	13.0
Oxygen (% mass)	ASTM D 5291	1.79	3.94	10.82	34.8
Calorific value (MJ/kg)	ASTM D 240	45.63	44.95	39.94	28.05
Viscosity @ 40°C (mm <sup>2</sup> /s)	ASTM D 445	3.0	3.1	4.5	1.2
Density @ 15°C (kg/m <sup>3</sup> )	ASTM D 1298	835	827	875.3	792.0
Distillation (°C)	ASTM D 86-11b				
T10		180	177.4	336.2	77.8
T90		344.2	348.4	352.3	80

### 3.2 Diesel engine test

Diesel engine test is the process of comparing engine performance such as thermal efficiency, specific fuel consumption, specific energy consumption, and combustion characteristics such as heat release rate by using an unmodified direct injection diesel engine. As well as an analysis of the emission at variable engine loads of 56, 84, 112, and 140 Nm and at constant engine speed of 1000, 1500, and 2000 rpm.

#### 3.2.1 Engine specification

An engine specification of direct injection diesel engine which used in this research is shown in **Table 3.2** and **Figure 3.3**.

Table 3.2 Engine's specification

Items	Details
Engine Model	Isuzu 4JJ1-TC
Engine Type	Diesel
Injection Type	Direct Injection
Displacement Volume	2,999 cc
Compression Ratio	18.3: 1
Bore x Stroke	95.4 mm x 104.9 mm
Related Power	52 kW @2000rpm

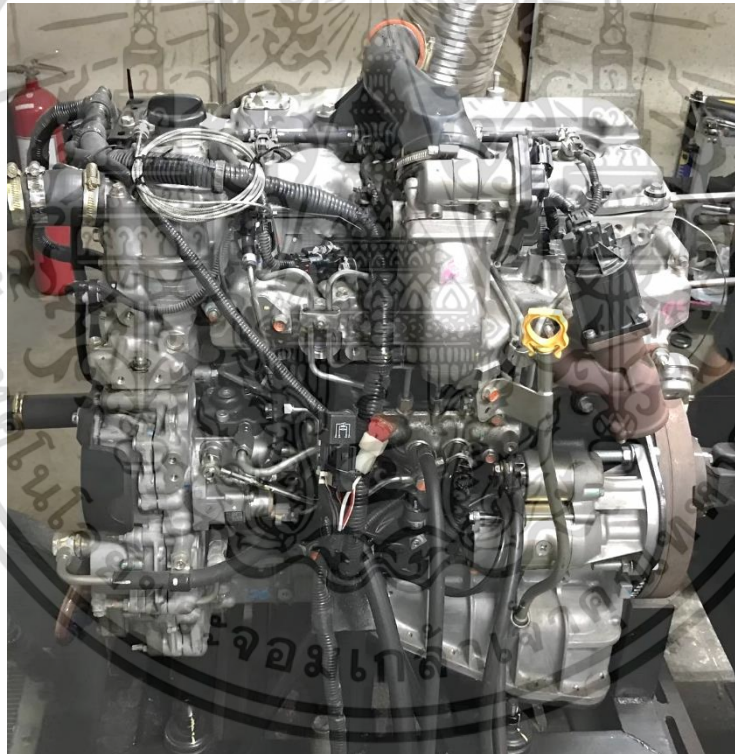


Figure 3.3 Direct injection diesel engine (Isuzu 4JJ-TC)

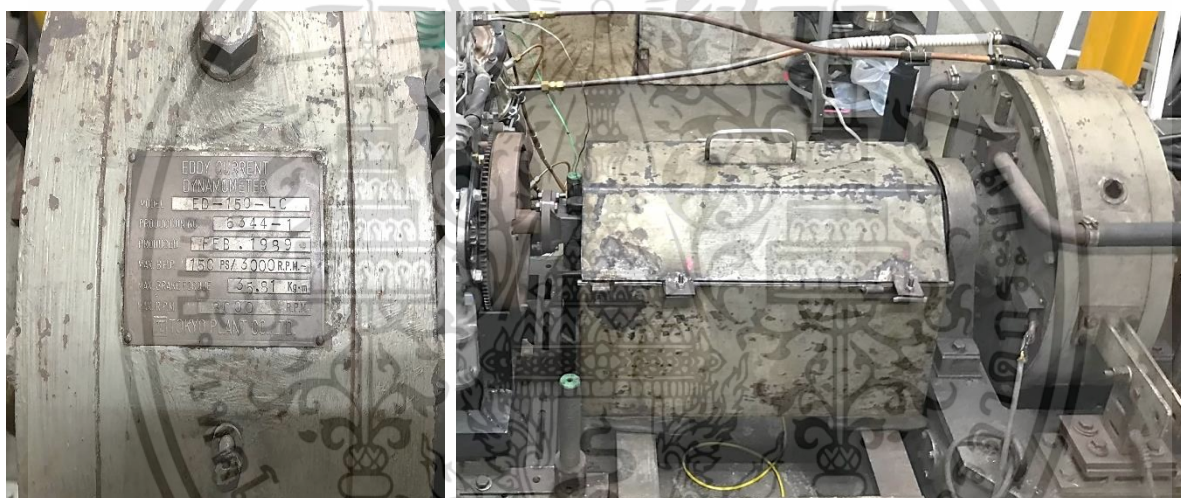
### 3.2.2 Eddy current dynamometer's specification

Eddy current dynamometer, Tokyo Plant ED-150-LC, was coupled with the engine and applied the loads through the flywheel of the engine while also measuring torque and power. A

cooling system of the eddy current dynamometer used the external water cooling. The specification of the eddy current dynamometer is shown in **Table 3.3** and **Figure 3.4**.

**Table 3.3** Eddy current dynamometer's specification

Items	Details
Model	Tokyo Plant ED-150-LC
Maximum Brake Horsepower	150 PS / 3000rpm
Maximum Brake Torque	35.81 kgm
Maximum Speed	3000rpm



**Figure 3.4** Eddy current dynamometer (Tokyo Plant ED-150-LC)

### 3.3 Diesel vehicle test

To evaluate the emitted emissions of the sample fuels on a commercial diesel vehicle during driving in urban and highways. The diesel vehicle test is tested on the chassis dynamometer at the Pollution control department. The specification of a diesel vehicle is shown in **Table 3.4** and **Figure 3.5**. The driving cycle is based on the New European Driving Cycle. It covers urban driving (Phase 1) with a maximum speed of 50 km/h and highway driving (Phase 2) with a maximum speed of 120 km/h, as shown in **Figure 3.6**.

Table 3.4 Vehicle's specification

Items	Details
Vehicle	Toyota Hilux Tiger
Engine type	Diesel, 4 Cylinder, In-line 2KD-FTV
Injection type	Direct Injection
Displacement volume	2,500 cc
Compression ratio	18.5: 1
Bore x Stroke	92.0 mm x 93.8 mm
Maximum Power	75 kW @3600 rpm
Maximum Torque	260 N.m. @1600-2400 rpm
Vehicle Mass	1590 kg



Figure 3.5 Diesel Vehicle

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ตัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

Table 3.5 New European Driving Cycle

Characteristics	Urban Driving (UD)	Highway Driving (HD)
Distance (km)	4	7
Duration (s)	780	400
Maximum Speed (km/h)	50	120

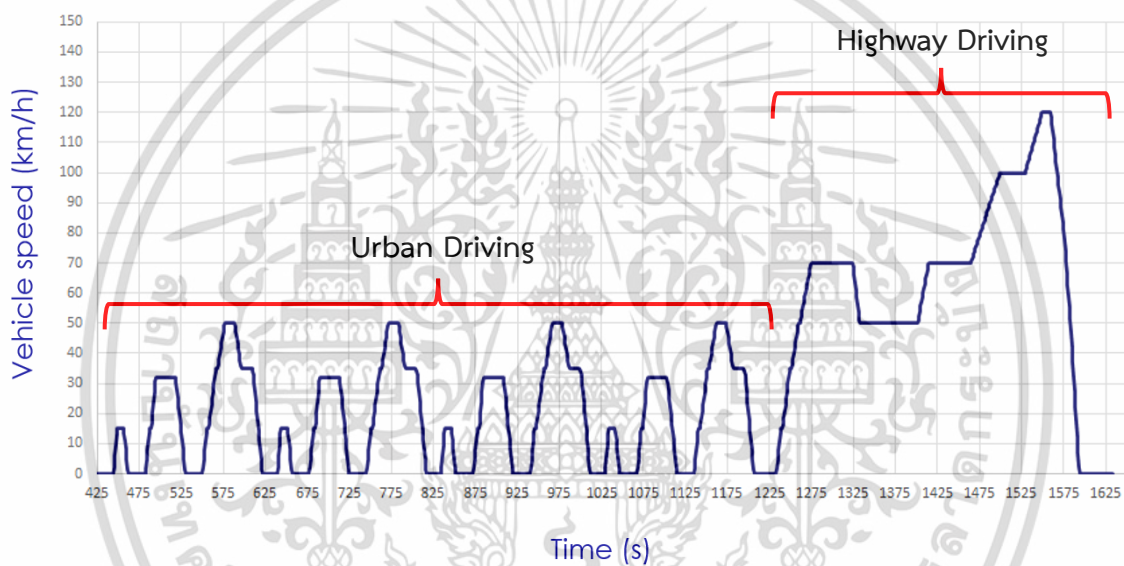


Figure 3.6 European urban and highway driving cycle

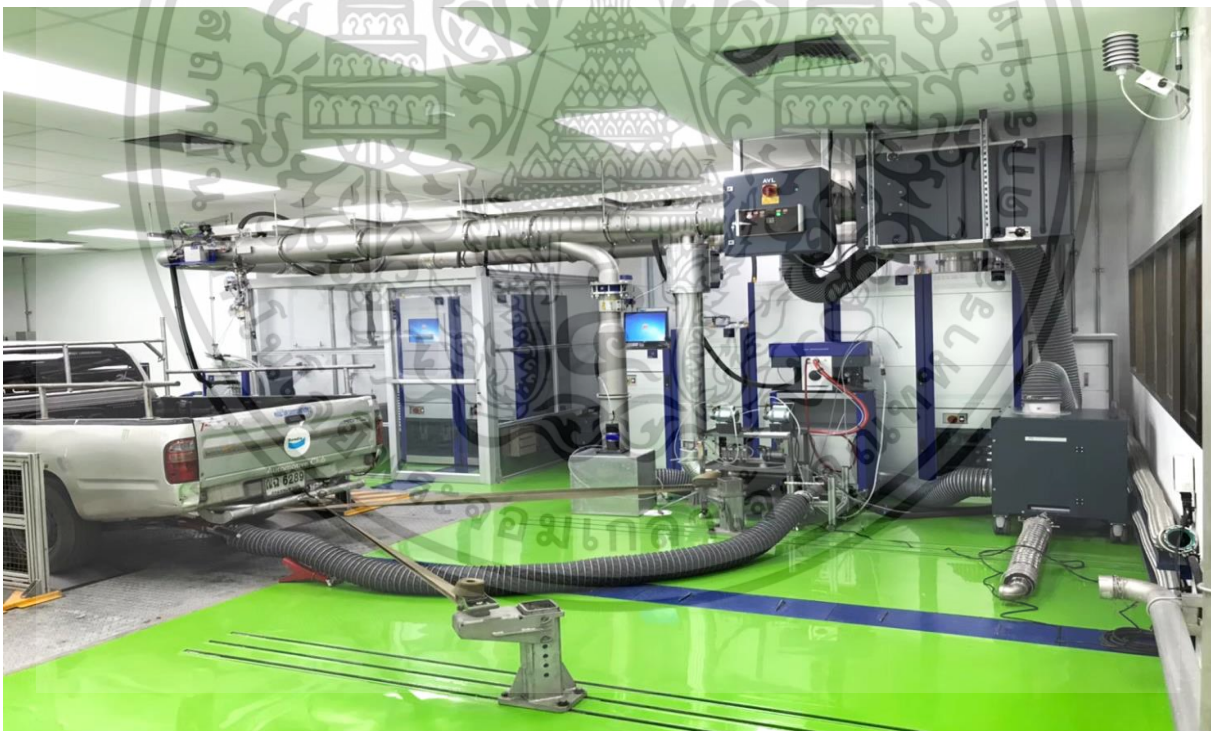
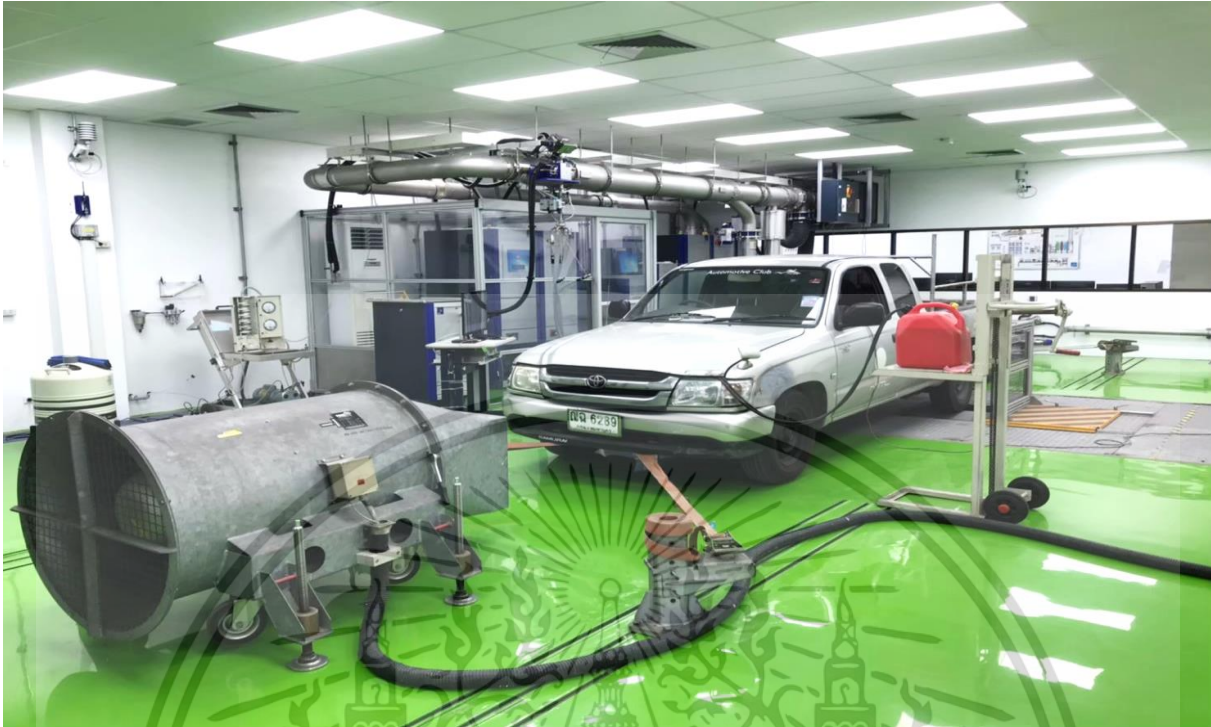


Figure 3.7 Diesel vehicle test on chassis dynamometer

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

### 3.4 Data collection system

#### 3.4.1 Pressure and Crank angle

To observe the phenomenon occurring in the tested engine, the pressure in the combustion chamber is measured by a piezoelectric crystal sensor “Kistler 6052C31” which can measure up to 250 bar with high sensitivity  $\pm 0.7\%$  mounted at the cylinder head as shown in **Figure 3.8**. To trace the actual time of crank angle position and calculate the combustion chamber volume, the optical crankshaft encoder “CA-RIE-360”, a customized disc with 720 slits, is mounted between the sensors gate at the end of dynamometer shaft. The resolution of the encoder sensor is 0.5 degrees. The function is based on the transmission light principle. The infrared beam is emitted and received at the sensor as shown in **Figure 3.9**.

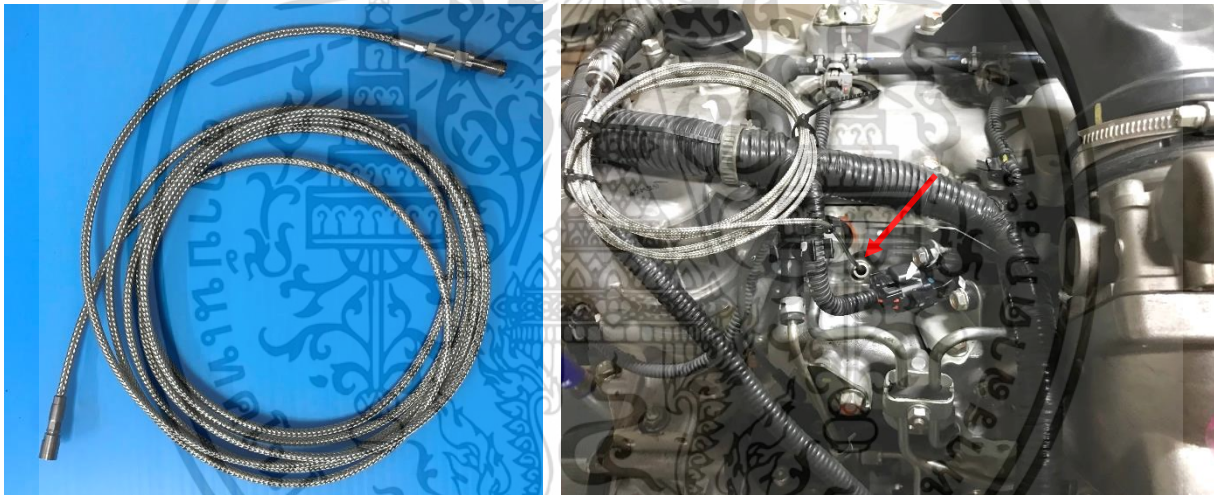


Figure 3.8 Pressure sensor



Figure 3.9 Crank encoder

### 3.4.2 Emissions collecting of diesel engine test

The exhaust emission quantity was measured by a smoke intensity meter, which optically evaluates soot collected on smoke paper filters by the light reflection method. The smoke meter is applied to measure the concentration of particulate matter in exhaust gas before and after trapping on the particulate filter. The 0% intensity means no particulate on the filter, while 100% intensity means the particulate covered all of the areas. **Figure 3.10** shows the smoke intensity meter “Okuda DSM – 240” and filter paper. Moreover, the other gases emitted from the engine such as carbon dioxide (CO<sub>2</sub>), and nitrogen oxide (NO) were measured by AVL exhaust gas analyzer “DITEST GAS 1000” as shown in **Figure 3.11**.



Figure 3.10 (a)Smoke intensity meter and (b)filter paper



Figure 3.11 AVL gas analyzer [25]

### 3.4.3 Emission collecting of diesel vehicle test

Emitted emissions are measured by the dilute exhaust gas analyzer by “AVL CVS i60” in the AVL bag cabinet. All exhaust is diluted via dilution tunnel and feed into the CVS system. To prevent the physical and chemical changes in PMs, the dilution ratio, temperature, and moisture content of the CVS system are kept constant. Particulate matters mass is measured by weighing the filter paper be and after collected the soot. Particulate matter number is measured by AVL particle counting machine.

### 3.4.4 Data acquisition system

To monitor and collect the combustion characteristics in the combustion chamber, the data from the pressure sensor and crank angle sensor are stored by a DEWESOFT DAQ system as shown in **Figure 3.12**. DewesoftX software, shown in **Figure 3.13**, is used to calculate various parameters in real-time data such as pressure-crank angle diagrams and pressure-volume diagrams. The collecting data from the DAQ system is collected with a total of 1000 cycles when the engine running condition was stable at every set engine condition.

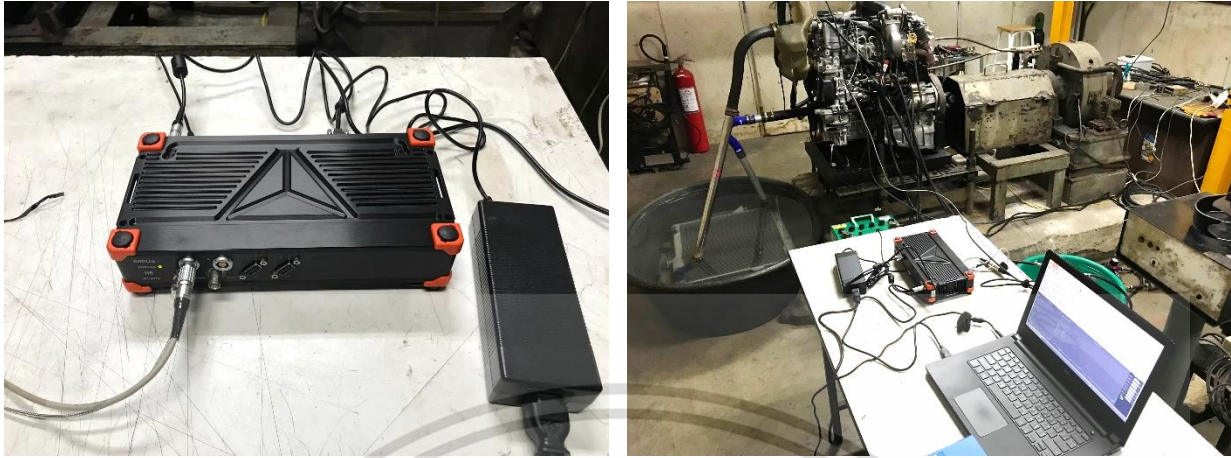


Figure 3.12 Dewesoft DAQ system

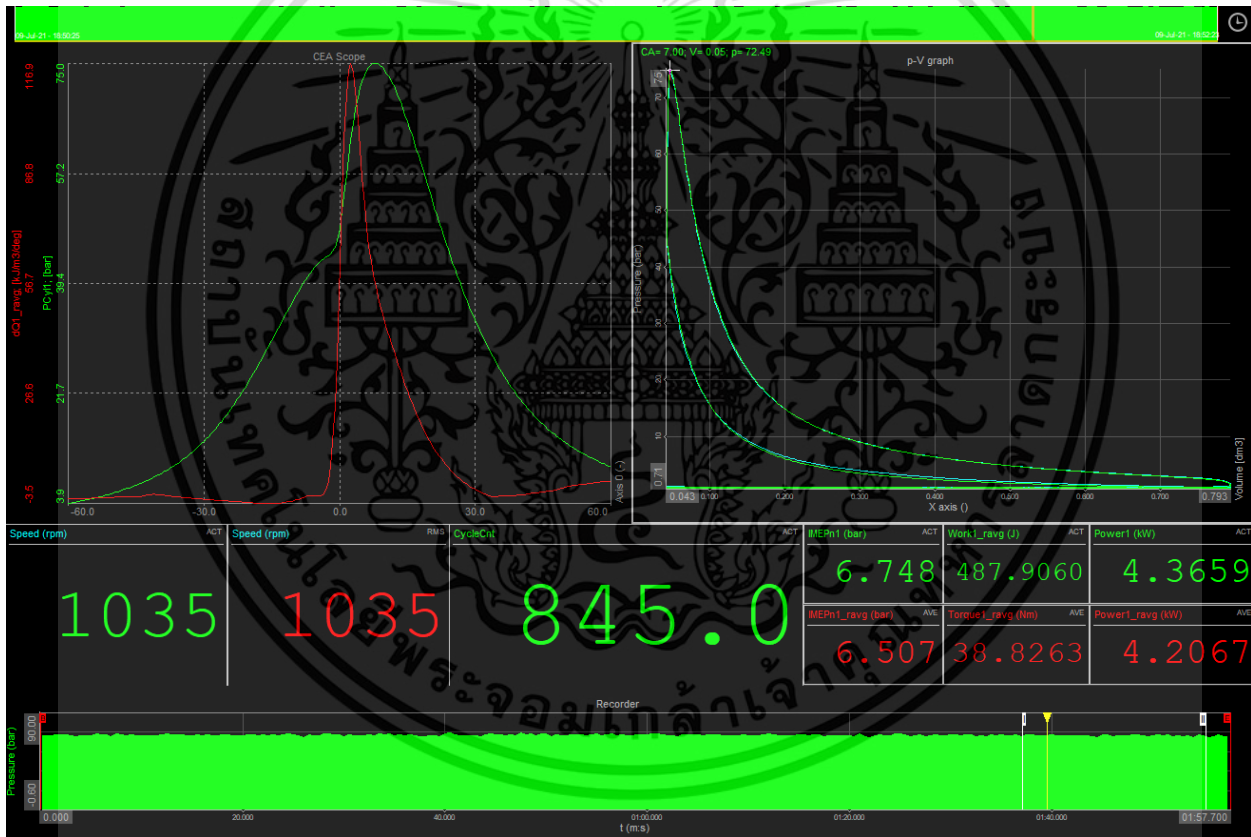


Figure 3.13 DewesoftX software monitor

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

### 3.5 Schematic diagram

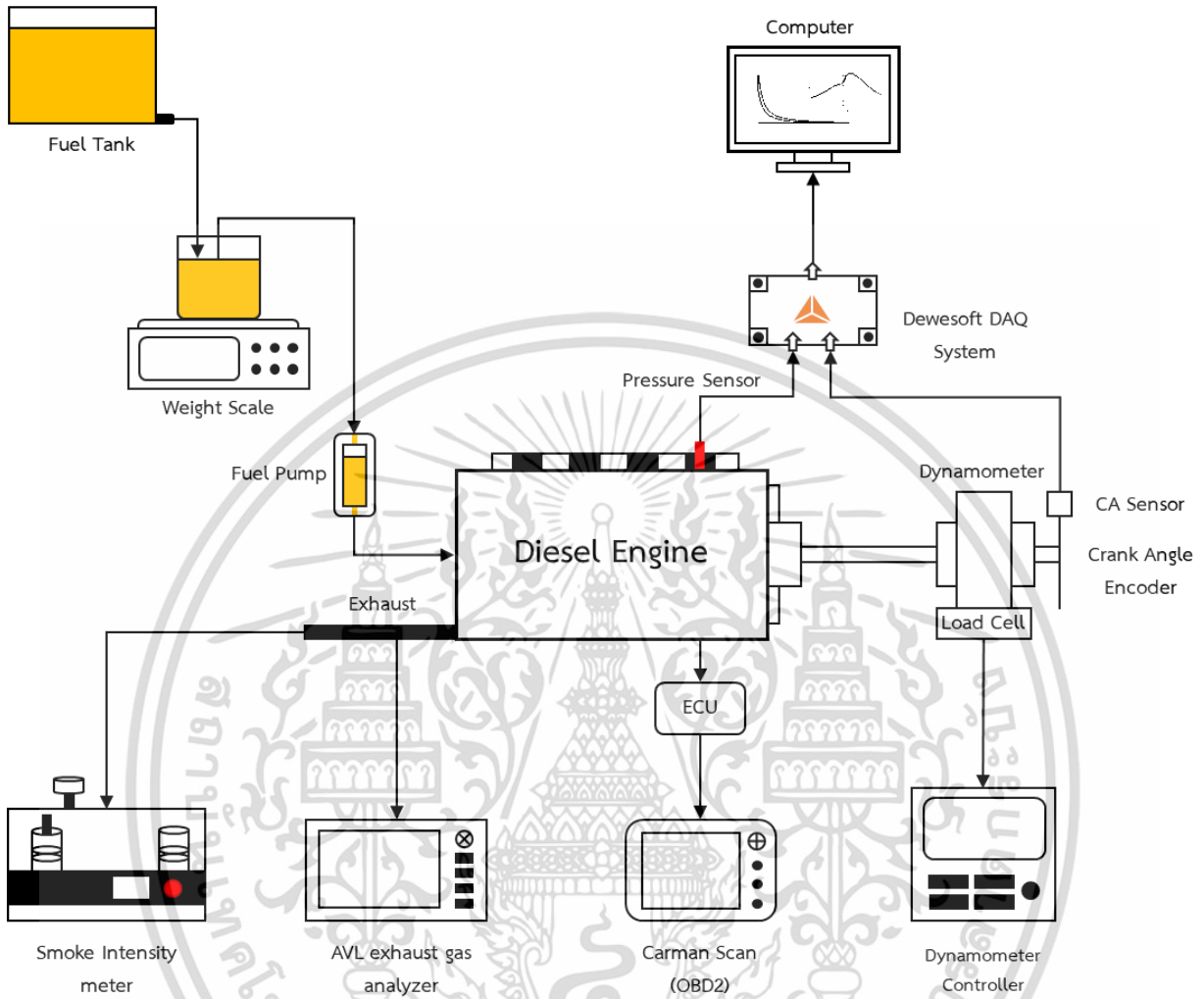


Figure 3.14 Schematic diagrams of engine dyno testing

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

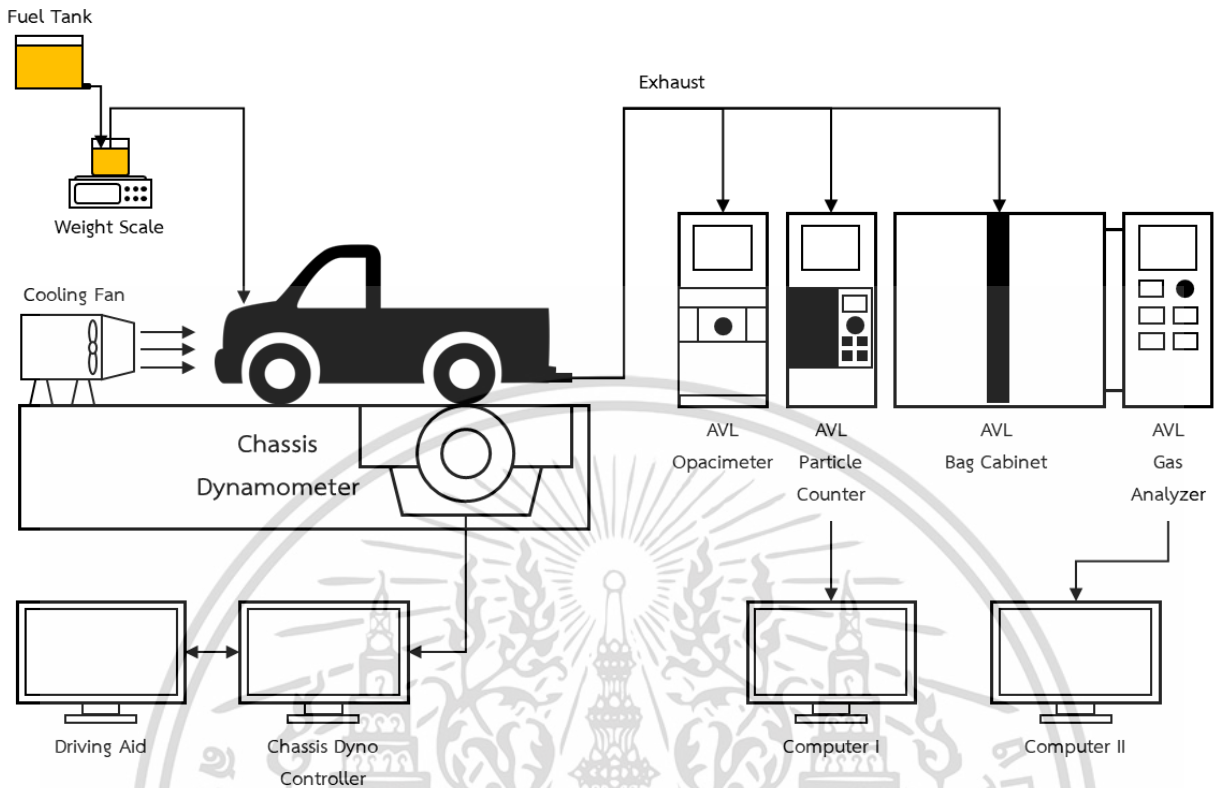


Figure 3.15 Schematic diagrams of chassis dyno testing

### 3.6 Calculation method

The parameters from the combustion data were used to calculate and investigated the quantitative combustion information according to J.B Heywood [10]. The calculations are divided into 2 types of the combustion characteristics which are used to explain the compression and expansion pressure versus crank angle in the combustion chamber such as cumulative heat release and heat release rate, and the engine performance which is used to explain the performance of the fuels as fuel consumption, energy consumption, and thermal efficiency.

#### 3.6.1 Combustion characteristic

##### Cumulative Heat Release

Cumulative heat release (CHR) is an important parameter to characterize the efficiency of the combustion process. The cumulative heat release in combustion cylinder is determined by the following equation.

$$\text{Cumulative Heat Release (CHR)} = \left[ \frac{k}{k-1} \right] \cdot PdV + \left[ \frac{1}{k-1} \right] \cdot VdP \quad (3.1)$$

### Heat Release Rate

Heat release rate (HRR) represents the effects of the fuel injection system, premixed mode, and late combustion. The heat release rate is obtained from the first law of thermodynamics. It is calculated by the following equation.

$$\text{Heat Release Rate (HRR)} = \left[ \frac{k}{k-1} \right] \cdot \frac{PdV}{d\theta} + \left[ \frac{1}{k-1} \right] \cdot \frac{VdP}{d\theta} \quad (3.2)$$

### 3.6.2 Engine performance

The engine performance is described by specific fuel consumption, specific energy consumption, and thermal efficiency in indicated values and brake values which are determined by the following equations.

#### Specific Fuel Consumption

The rate of fuel consumption to the power produced by an engine, measured in kg/kWh, is referred to as ISFC and BSFC.

$$\text{Indicated Specific Fuel Consumption (BSFC)} = \frac{\text{Fuel Consumption Rate}}{\text{Indicated Power}} = \frac{\dot{m}_f}{PdV} \quad (3.3)$$

$$\text{Brake Specific Fuel Consumption (BSFC)} = \frac{\text{Fuel Consumption Rate}}{\text{Brake Power}} = \frac{\dot{m}_f}{4\pi \cdot \frac{N}{60} \cdot \frac{1}{2}} \quad (3.4)$$

#### Specific Energy Consumption

The rate of energy consumption to the power produced by an engine, measured in kJ/kWh, is referred to as ISEC and BSEC.

$$\text{Indicated Specific Energy Consumption (ISEC)} = \text{ISFC} \cdot \text{LHV} \quad (3.5)$$

$$\text{Brake Specific Energy Consumption (BSEC)} = \text{BSFC} \cdot \text{LHV} \quad (3.6)$$

## Thermal Efficiency

Thermal efficiency is amount of power output from heat energy given to a system.

$$\text{Indicated Thermal Efficiency (ITE)} = \frac{\text{Indicated Power}}{\text{Energy Input}} = \frac{PdV \cdot \frac{N}{60} \cdot \frac{1}{2}}{\dot{m}_f \cdot Q_{LHV}} \quad (3.7)$$

$$\text{Brake Thermal Efficiency (BTE)} = \frac{\text{Brake Power}}{\text{Energy Input}} = \frac{4\pi\tau \cdot \frac{N}{60} \cdot \frac{1}{2}}{\dot{m}_f \cdot Q_{LHV}} \quad (3.8)$$

**Where** P is pressure in a cylinder (bar), V is volumetric ( $\text{m}^3$ ), N is engine speed (rev/min),  $\dot{m}_f$  is mass fuel consumption rate (g/s), LHV is low heating value (kJ),  $Q_{LHV}$  is Energy input (kJ/kg), k is specific heat ratio, and  $\theta$  is angular displacement in a cylinder or Crank angle (deg).

# CHAPTER 4

## RESULTS AND DISCUSSIONS

### 4.1 Diesel engine test

#### 4.1.1 Combustion characteristic

The combustion characteristics investigate the combustion profile of the samples such as the combustion pressure data plot with respect to the volumetric and crank angle, cumulative heat release, and heat release rate.

##### Combustion pressure

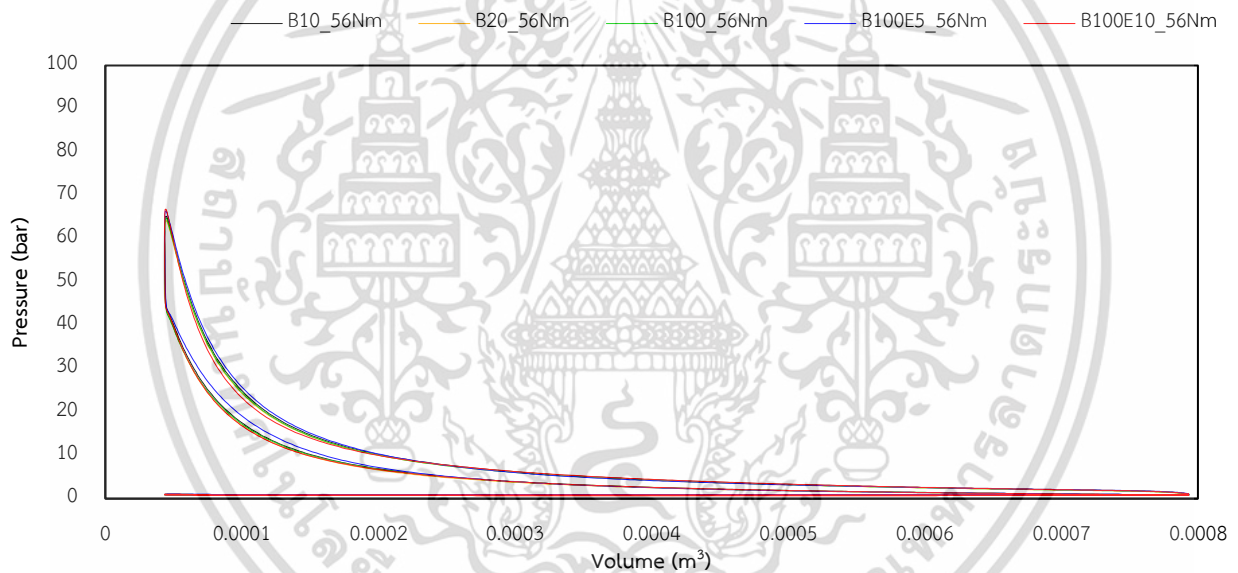
The combustion pressure plot with respect to the volumetric diagrams in **Figures 4.1 to 4.12** and combustion pressure versus crank angle diagrams in **Figures 4.13 to 4.24**. When comparing the different fuels in the same condition, the combustion pressure is not significantly different when increasing the biodiesel proportion. While it is obviously increased with increasing the ethanol ratio in the fuels. For increasing the ethanol ratio from around 5% to 10% is not significantly different from the blended ethanol fuel. Because ethanol has better atomization, shorter evaporation duration, and higher compressibility. They indicate a higher rate of vaporization and better combustion mixture formation resulting in higher combustion pressure.

When comparing the increasing engine loads with the constant engine speed, the combustion pressure increases because a higher engine load will be higher injected fuel to burn and achieve more power. Concerning increasing engine speed, the fuels will have higher evaporation. As a result, the combustion pressure during the compression stroke slightly increases. The constant engine load requires almost the same amount of the load output, which results in the maximum combustion pressure is not significantly different.

The ignition delay period is more prolonged with the percent of ethanol increase because of higher auto ignition temperature, higher heat of vaporization and lower cetane number of ethanol [26]. The experiment results, B100 has a slightly shorter ignition delay than diesel B10

and B20. The ignition delay of B100E5 and B100E10 is longer than B100. For the ignition delay period is longer, there is increased the accumulate premixed fuel and the mixing time of air and fuel, resulting in more fuel combusted in the premixed combustion phase. As a result, ethanol blended fuels provide higher combustion pressure.

Combustion duration is the period between start to the end of combustion as shown in **Figure 4.25**. The combustion duration is longer with the engine load and engine speed increases. While, it is shorter with increasing the biodiesel and ethanol blend into the fuel. Because higher oxidation rate from higher oxygen concentration in the fuels [27]. As a result, biodiesel blended with ethanol fuel is a shorter combustion duration than biodiesel and diesel fuel [28].



**Figure 4.1** Pressure – Volume diagram at engine load 56Nm and engine speed 1000RPM

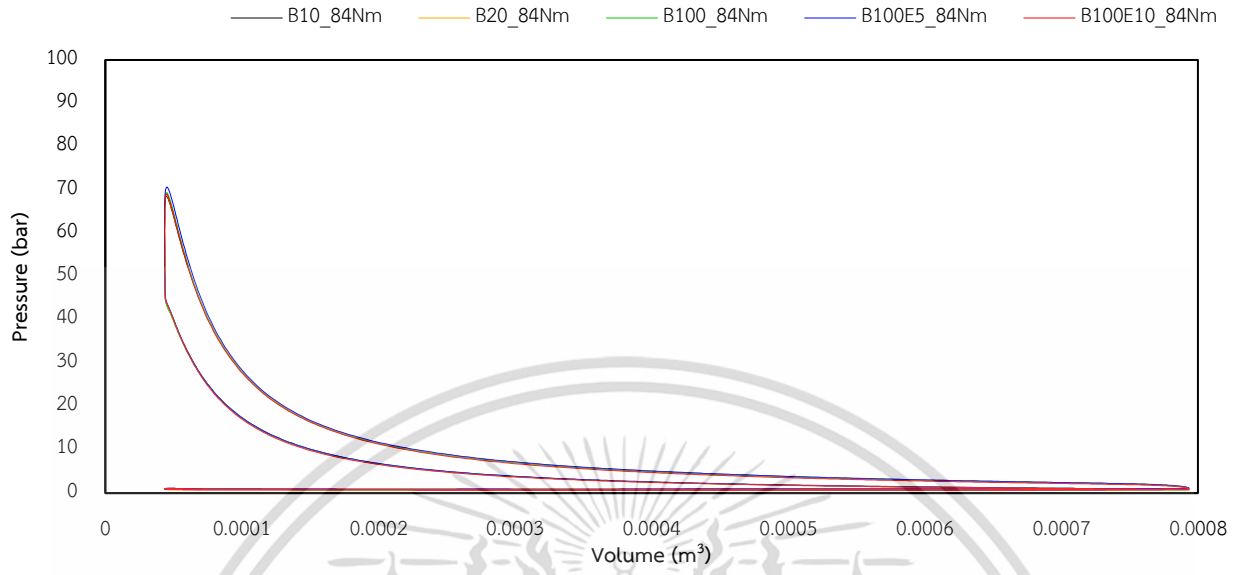


Figure 4.2 Pressure – Volume diagram at engine load 84Nm and engine speed 1000RPM

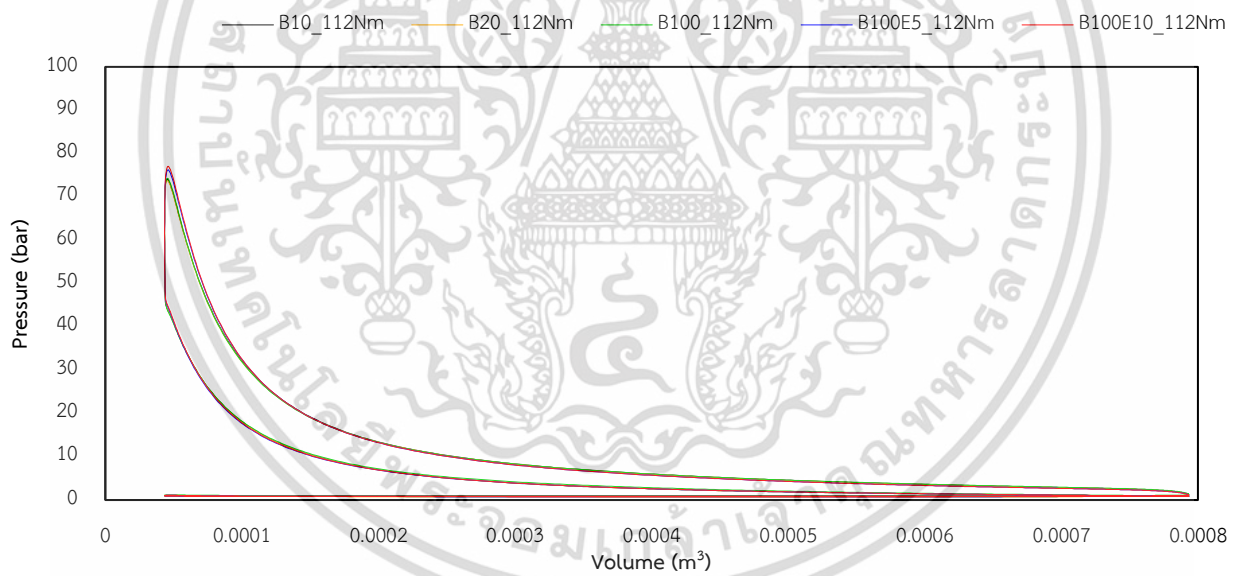


Figure 4.3 Pressure – Volume diagram at engine load 112Nm and engine speed 1000RPM

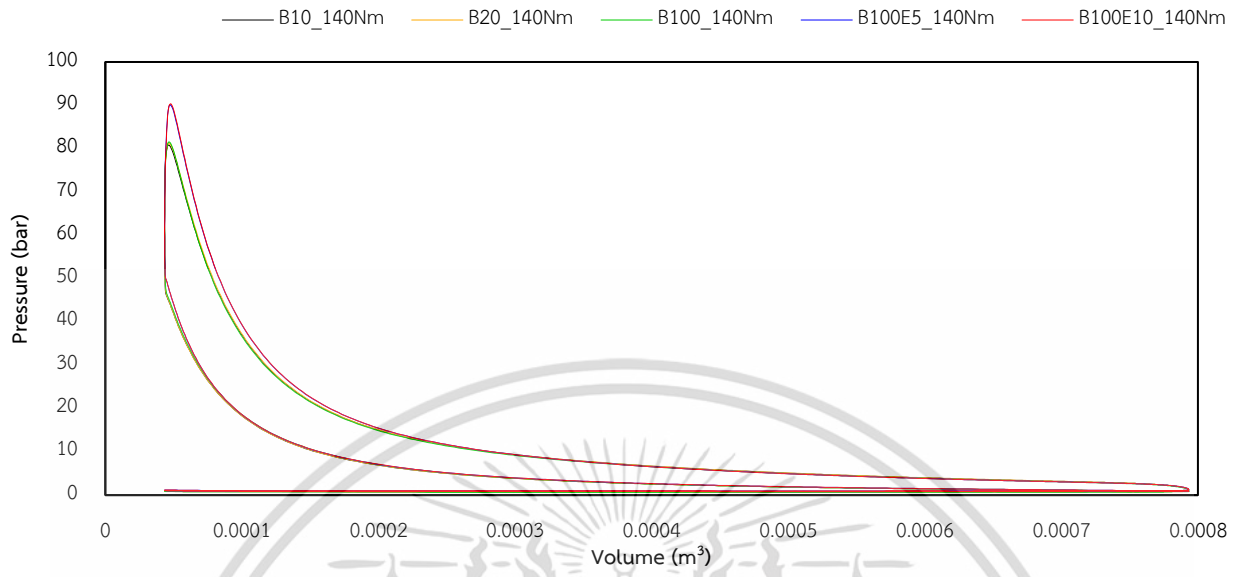


Figure 4.4 Pressure - Volume diagram at engine load 140Nm and engine speed 1000RPM

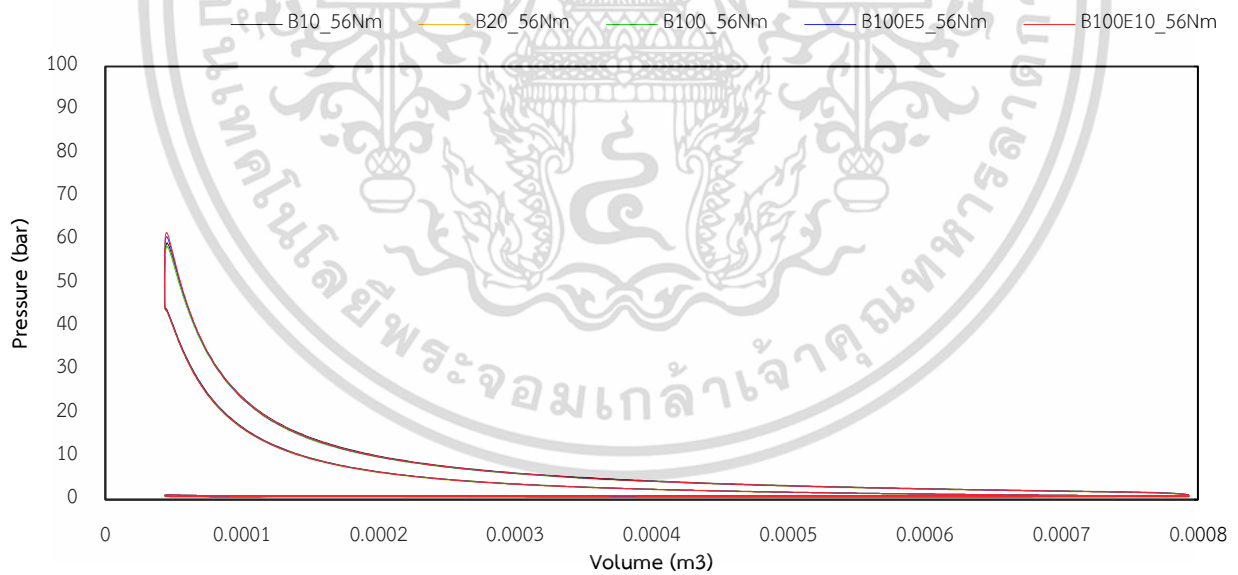


Figure 4.5 Pressure - Volume diagram at engine load 56Nm and engine speed 1500RPM

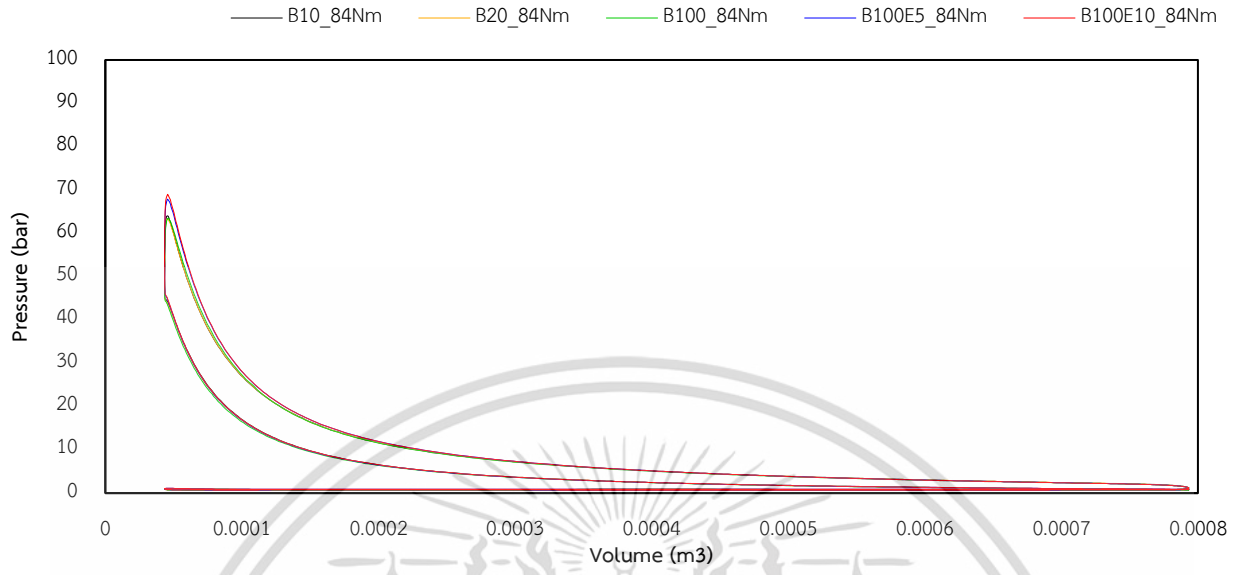


Figure 4.6 Pressure – Volume diagram at engine load 84Nm and engine speed 1500RPM

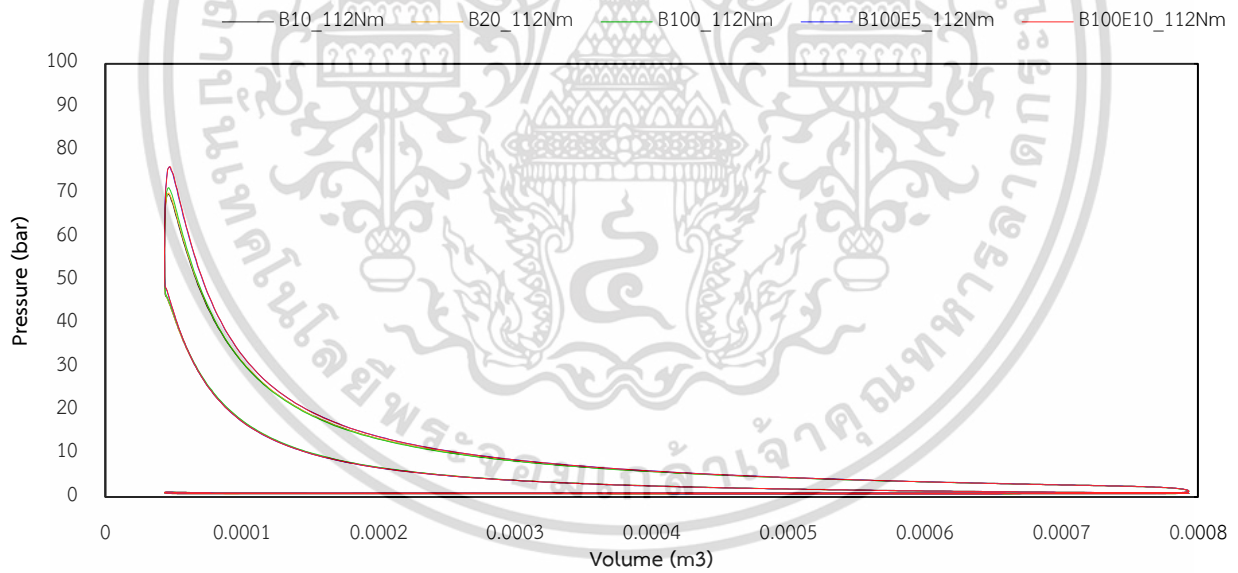


Figure 4.7 Pressure – Volume diagram at engine load 112Nm and engine speed 1500RPM

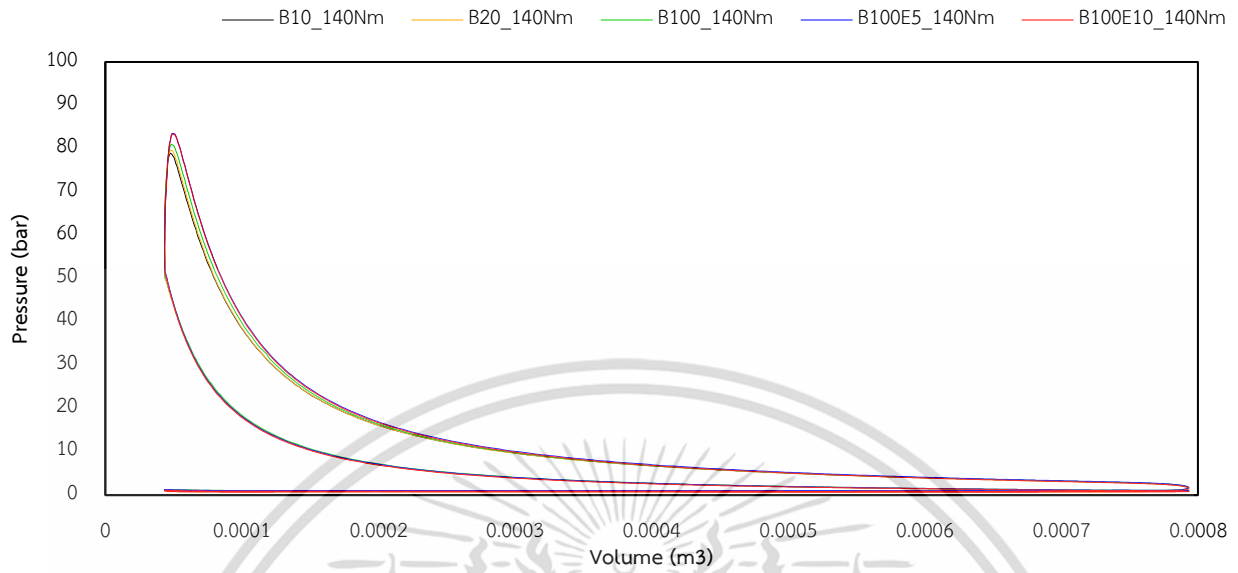


Figure 4.8 Pressure - Volume diagram at engine load 140Nm and engine speed 1500RPM

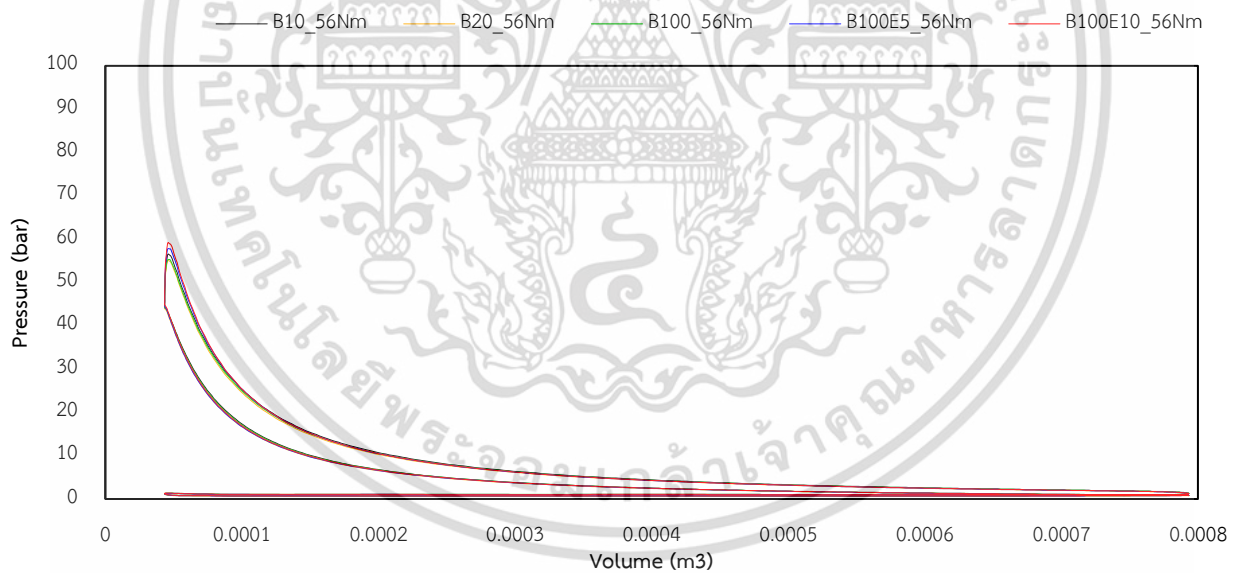


Figure 4.9 Pressure - Volume diagram at engine load 56Nm and engine speed 2000RPM

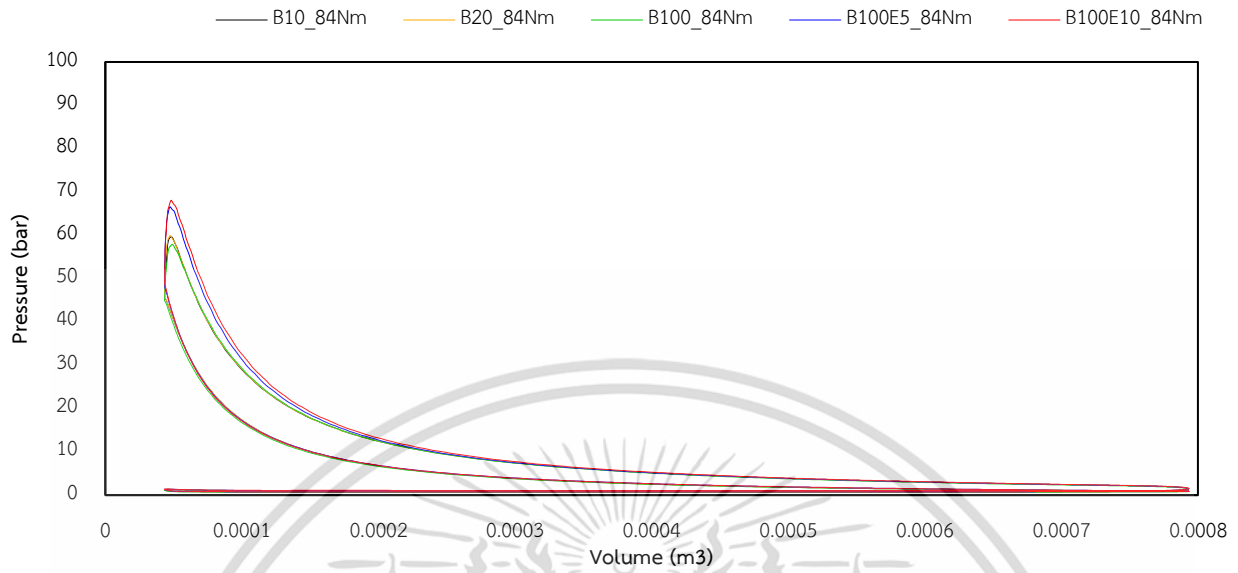


Figure 4.10 Pressure - Volume diagram at engine load 84Nm and engine speed 2000RPM

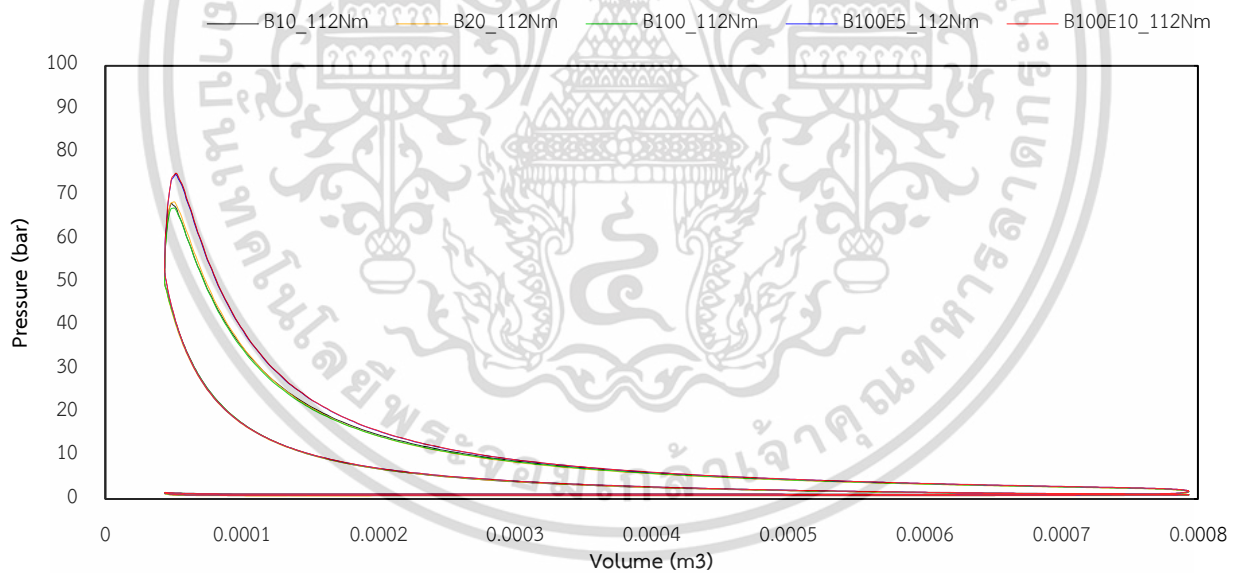


Figure 4.11 Pressure - Volume diagram at engine load 112Nm and engine speed 2000RPM

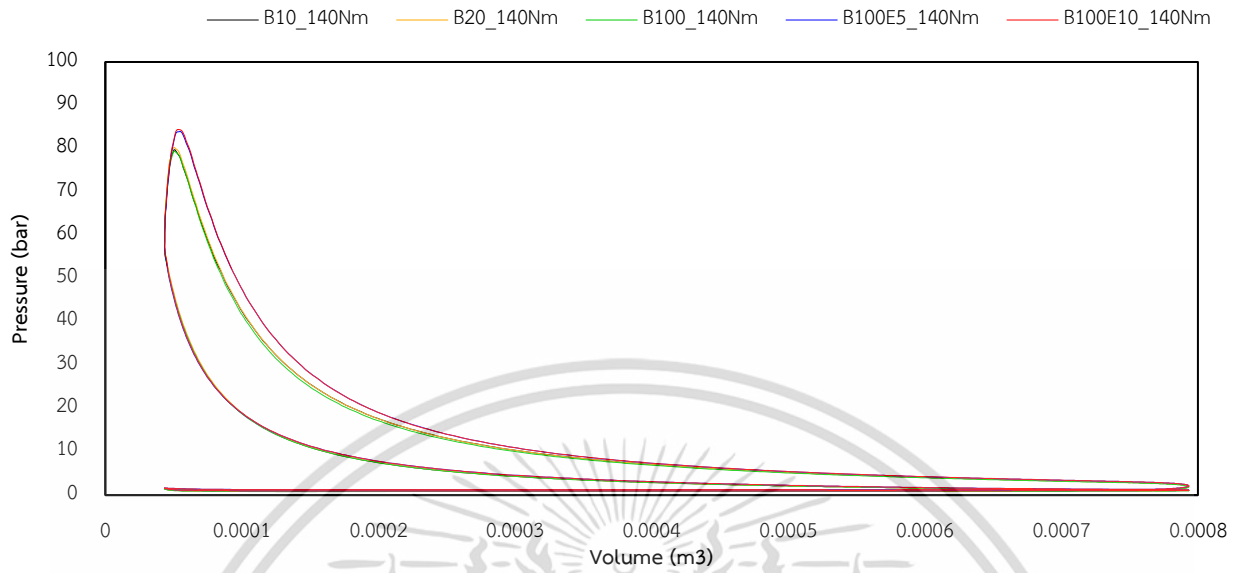


Figure 4.12 Pressure – Volume diagram at engine load 140Nm and engine speed 2000RPM

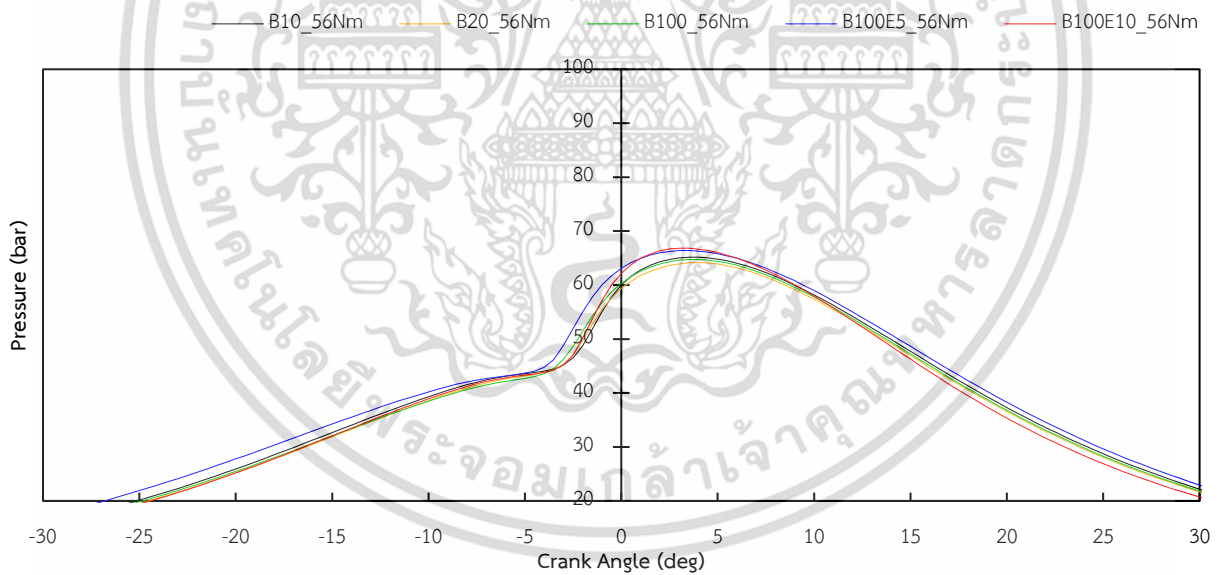


Figure 4.13 Pressure – Crank angle diagram at engine load 56Nm and engine speed 1000RPM

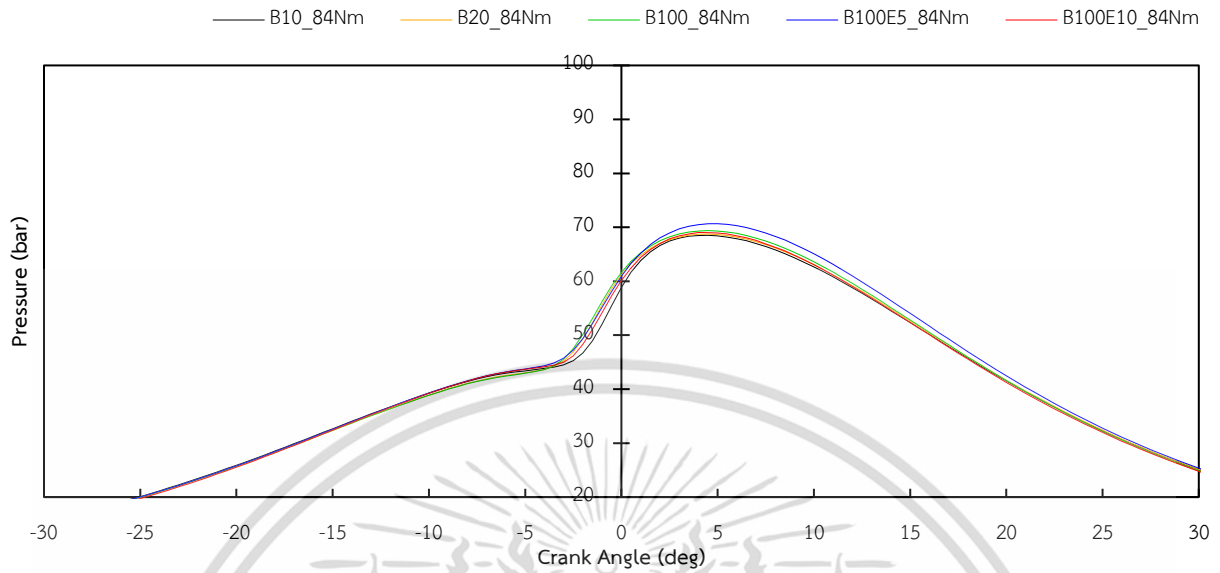


Figure 4.14 Pressure – Crank angle diagram at engine load 84Nm and engine speed 1000RPM

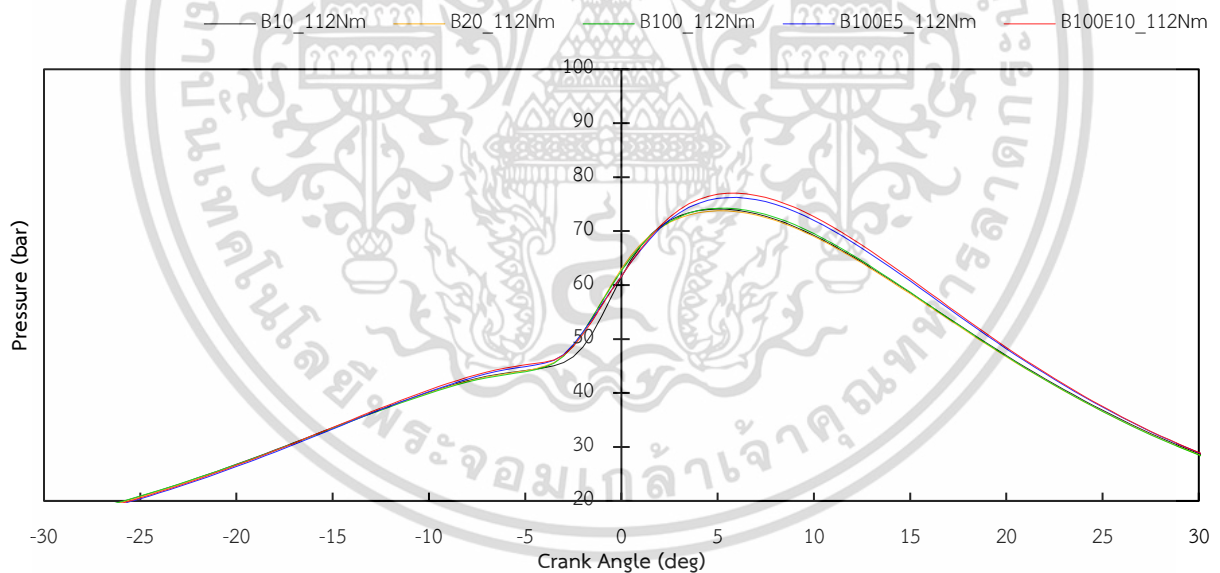


Figure 4.15 Pressure – Crank angle diagram at engine load 112Nm and engine speed 1000RPM

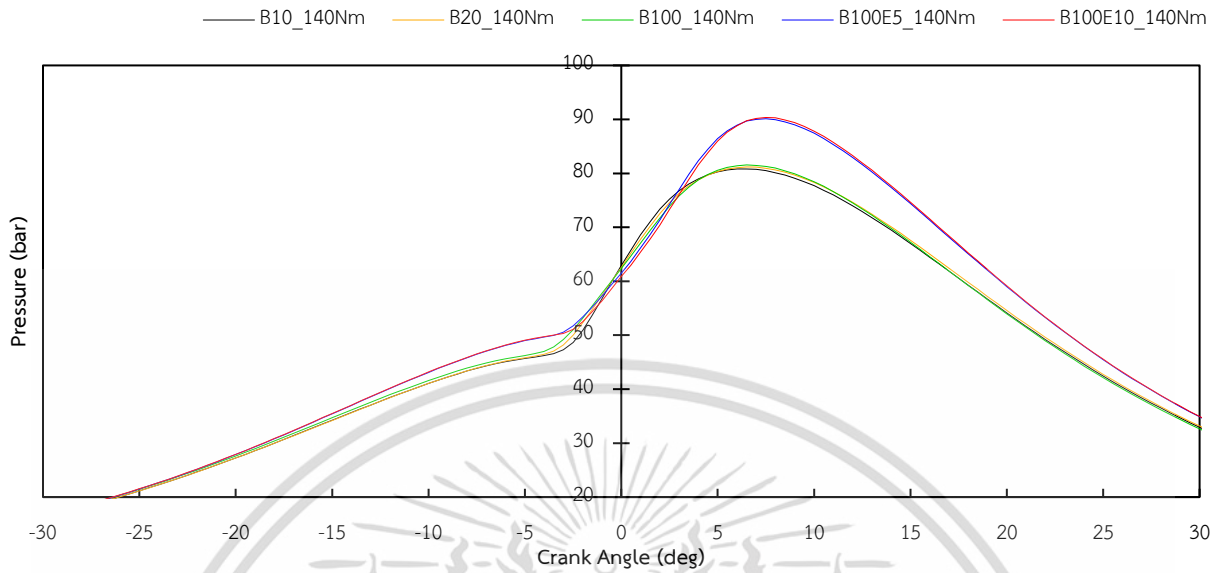


Figure 4.16 Pressure – Crank angle diagram at engine load 140Nm and engine speed 1000RPM

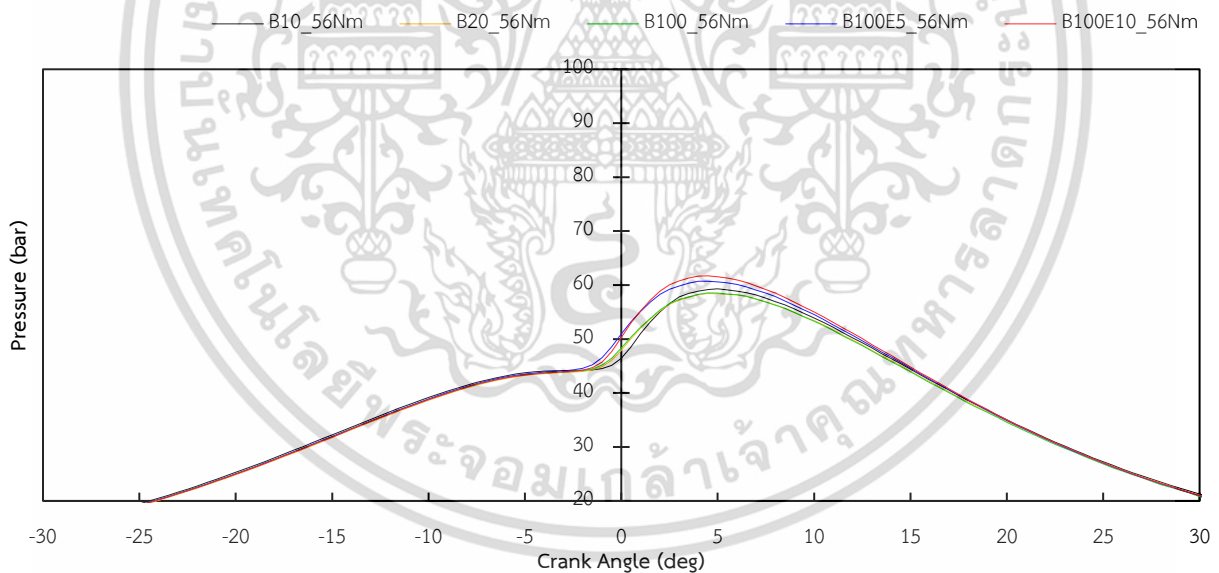


Figure 4.17 Pressure – Crank angle diagram at engine load 56Nm and engine speed 1500RPM

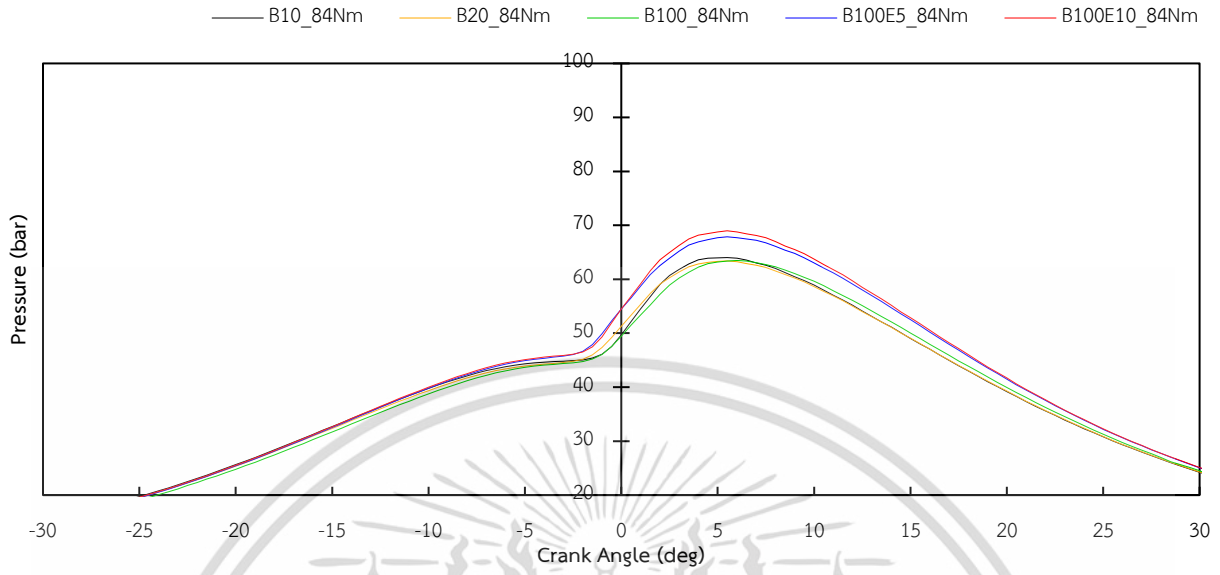


Figure 4.18 Pressure – Crank angle diagram at engine load 84Nm and engine speed 1500RPM

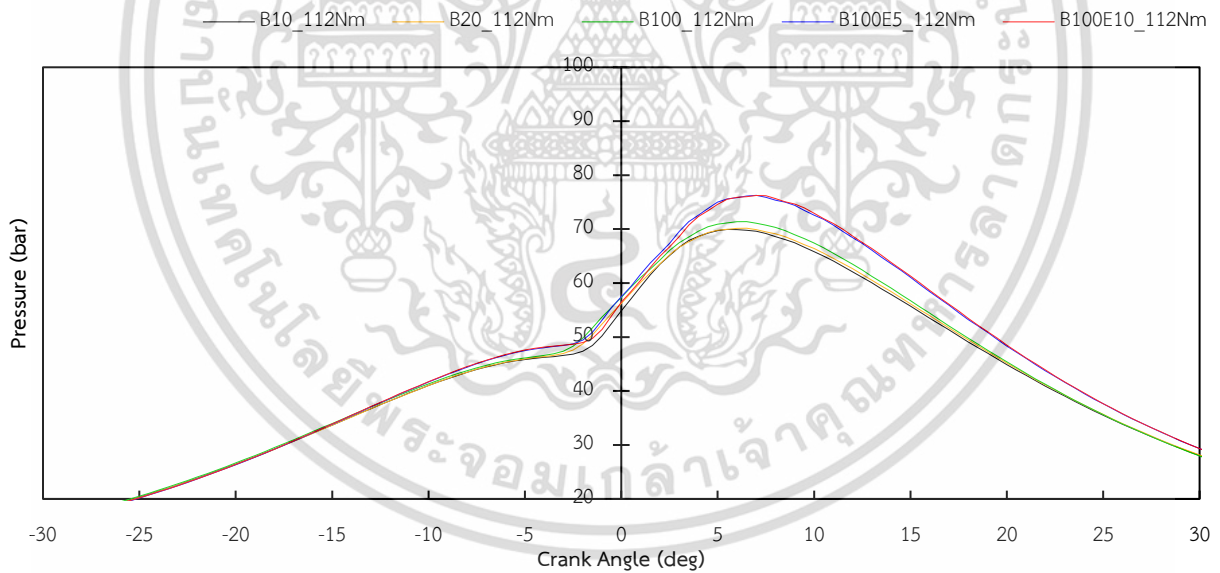


Figure 4.19 Pressure – Crank angle diagram at engine load 112Nm and engine speed 1500RPM

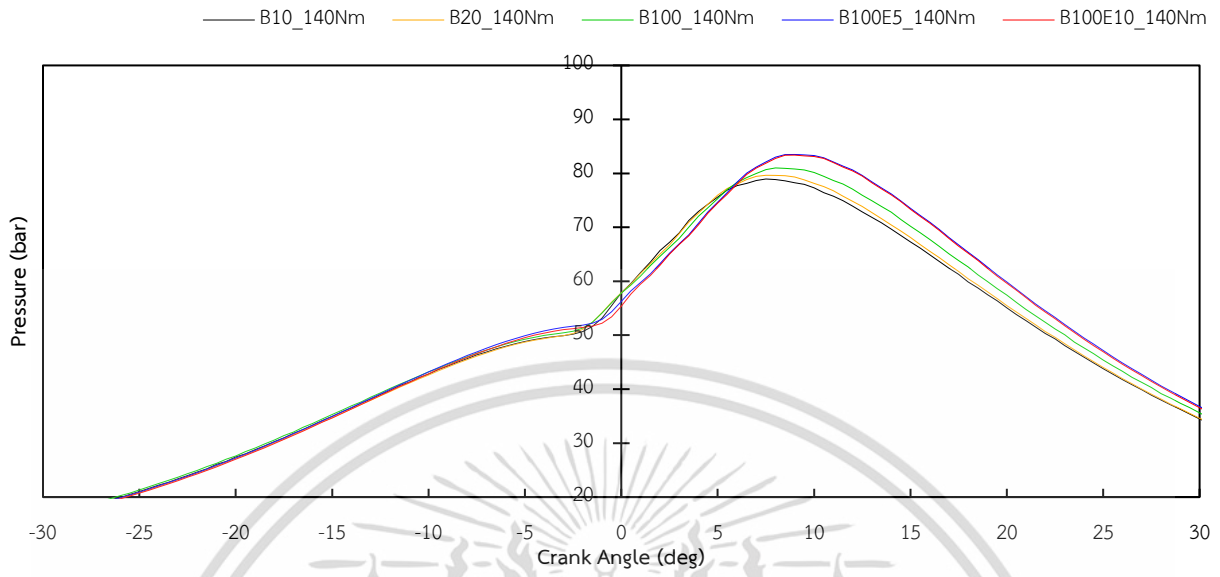


Figure 4.20 Pressure – Crank angle diagram at engine load 140Nm and engine speed 1500RPM

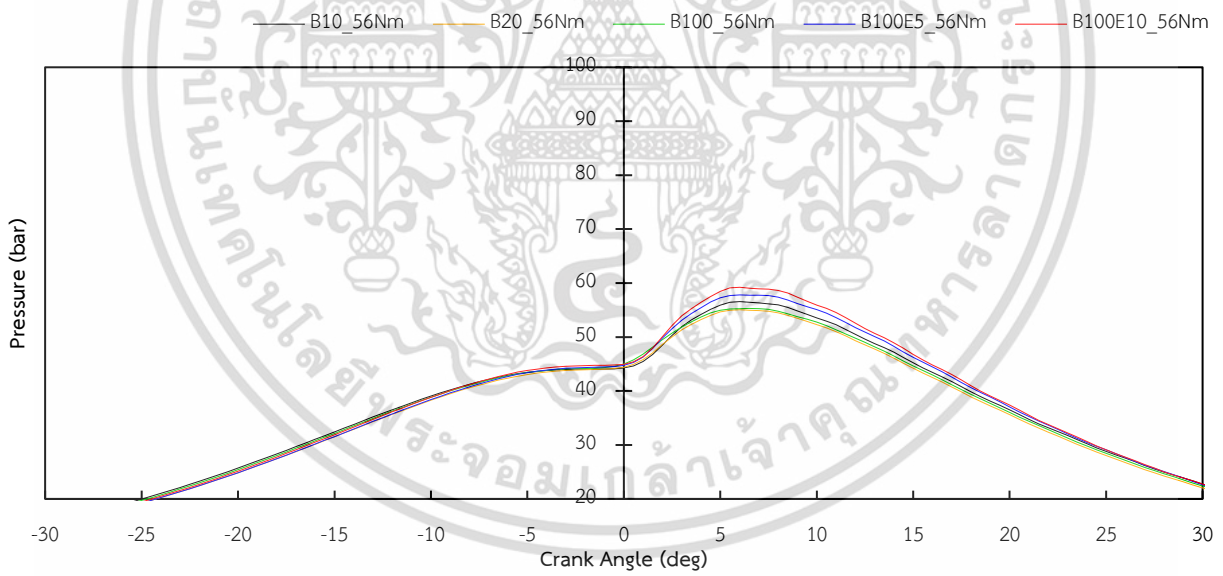


Figure 4.21 Pressure – Crank angle diagram at engine load 56Nm and engine speed 2000RPM

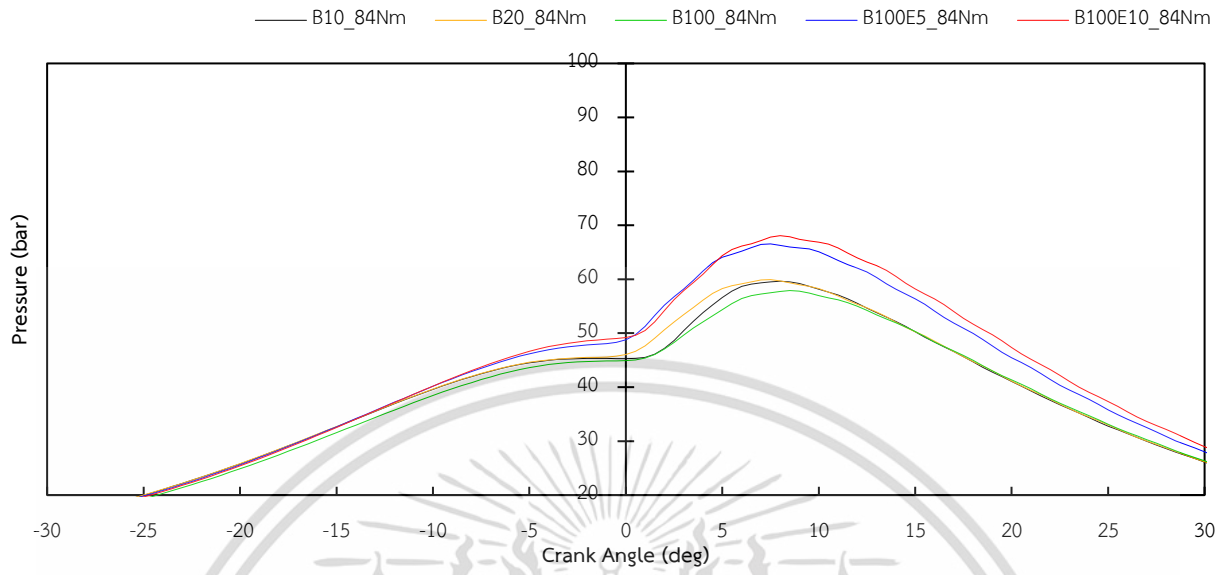


Figure 4.22 Pressure – Crank angle diagram at engine load 84Nm and engine speed 2000RPM

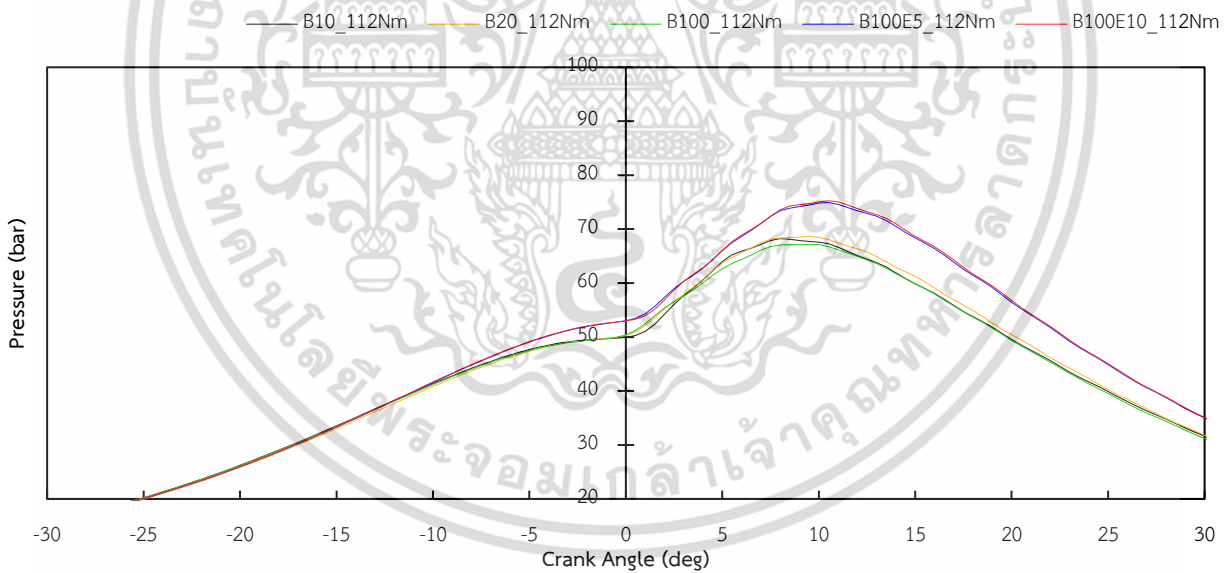


Figure 4.23 Pressure – Crank angle diagram at engine load 112Nm and engine speed 2000RPM

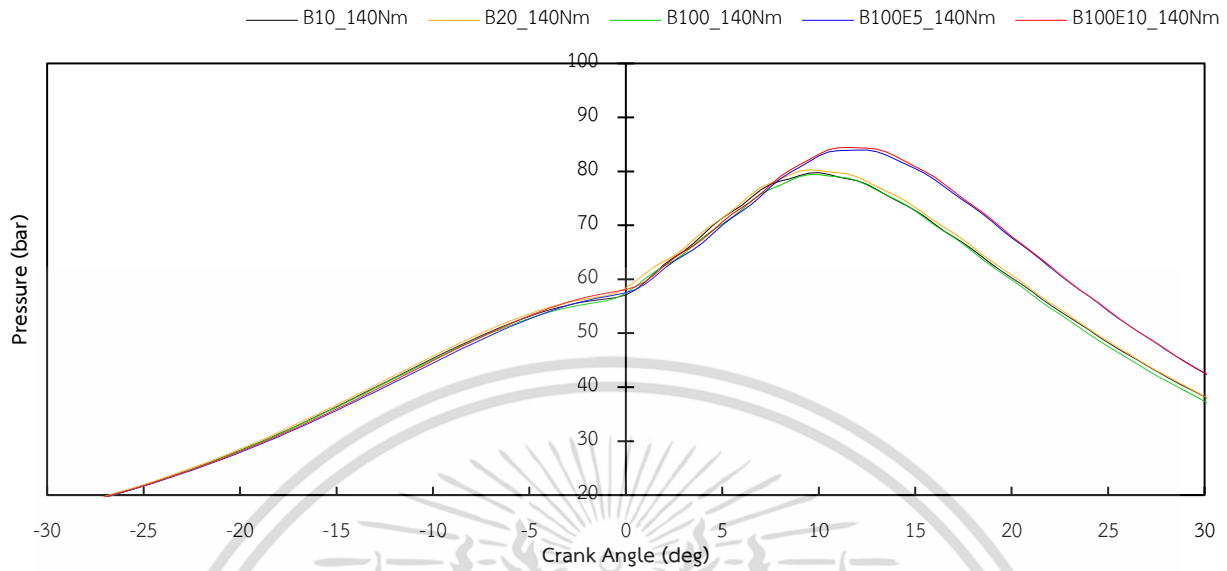


Figure 4.24 Pressure – Crank angle diagram at engine load 140Nm and engine speed 2000RPM

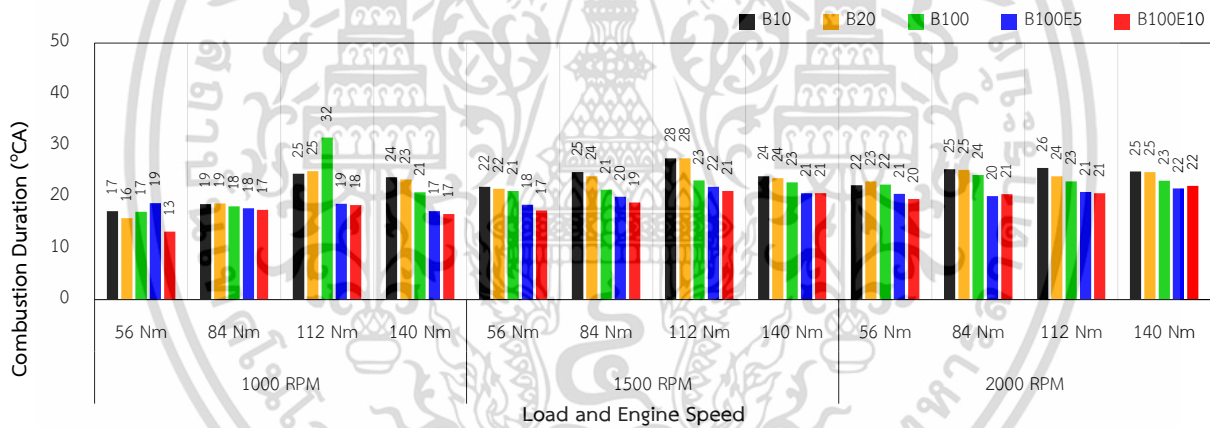


Figure 4.25 Combustion duration

### Cumulative of heat release

The cumulative heat release (CHR) of all tested fuels is shown in **Figures 4.26 to 4.37**. The cumulative heat release of diesel B10, B20, and biodiesel B100 is not significantly different. The biodiesel blended with ethanol fuels is higher in cumulative heat release than diesel and biodiesel fuels. Because a higher oxygen concentration of ethanol-blended fuels advanced the combustion quality in both premixed and diffusion combustion phases. When compared with the engine load increases and a constant engine speed, the cumulative heat release is also increased with more

fuel injected. With regard to the higher engine speeds and a constant engine load, the total heat loss is lower than at a lower engine speed. So, the cumulative heat release is increased with increasing the engine speed.

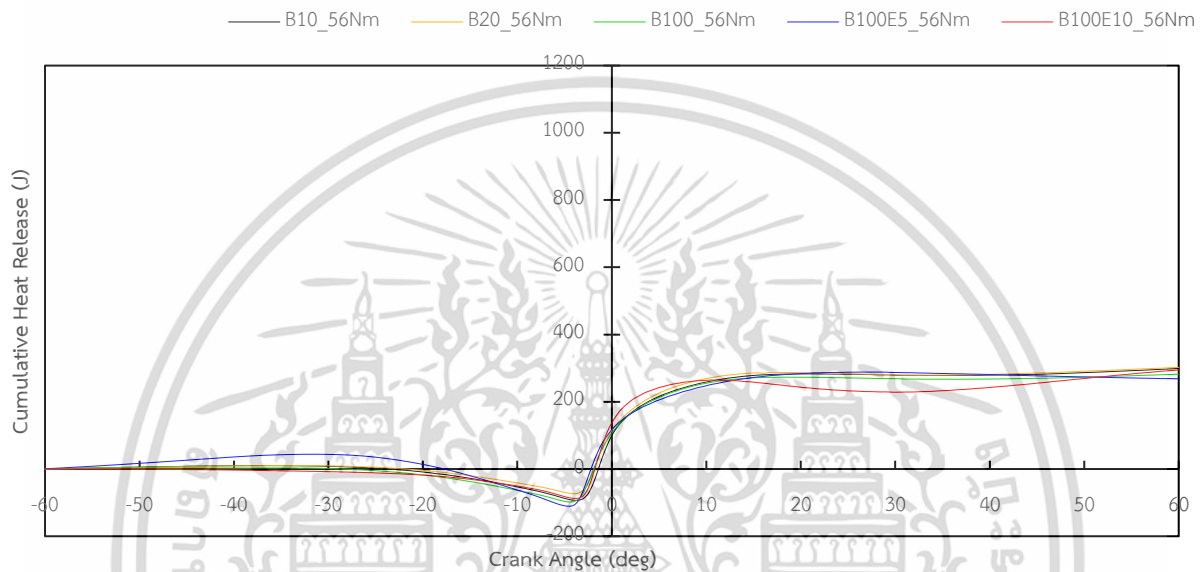


Figure 4.26 Cumulative heat release diagram at engine load 56Nm and engine speed 1000RPM

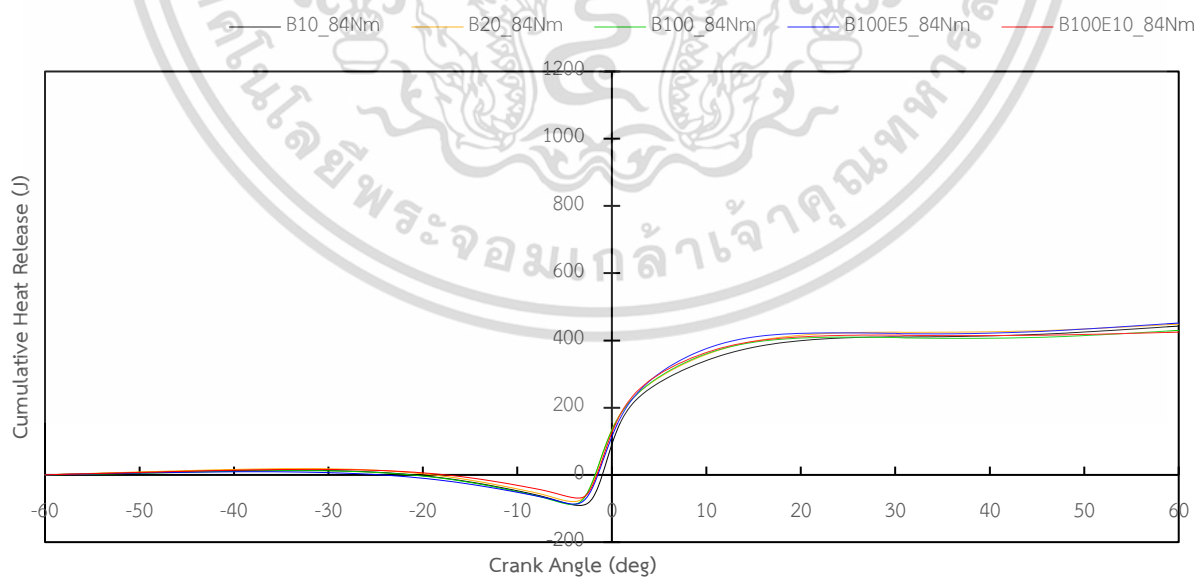


Figure 4.27 Cumulative heat release diagram at engine load 84Nm and engine speed 1000RPM

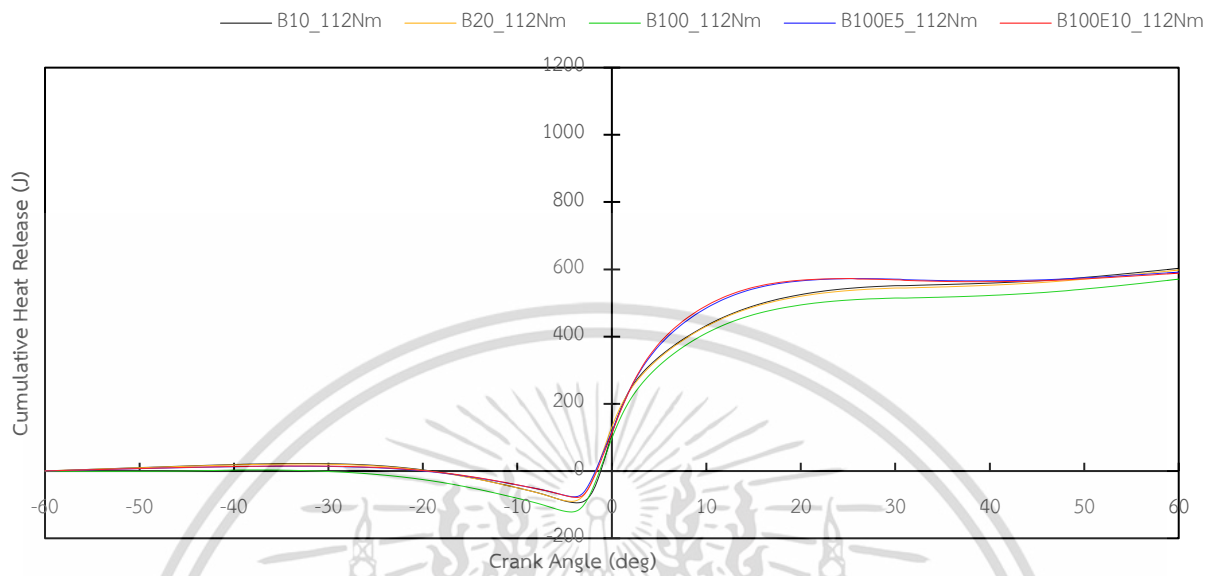


Figure 4.28 Cumulative heat release diagram at engine load 112Nm and engine speed 1000RPM

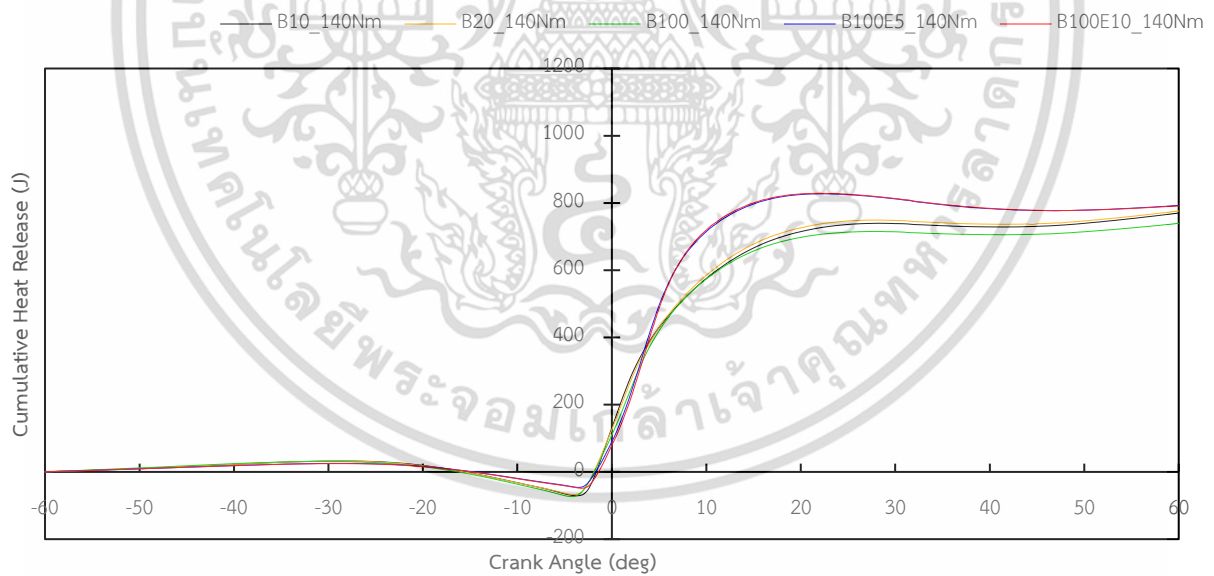


Figure 4.29 Cumulative heat release diagram at engine load 140Nm and engine speed 1000RPM

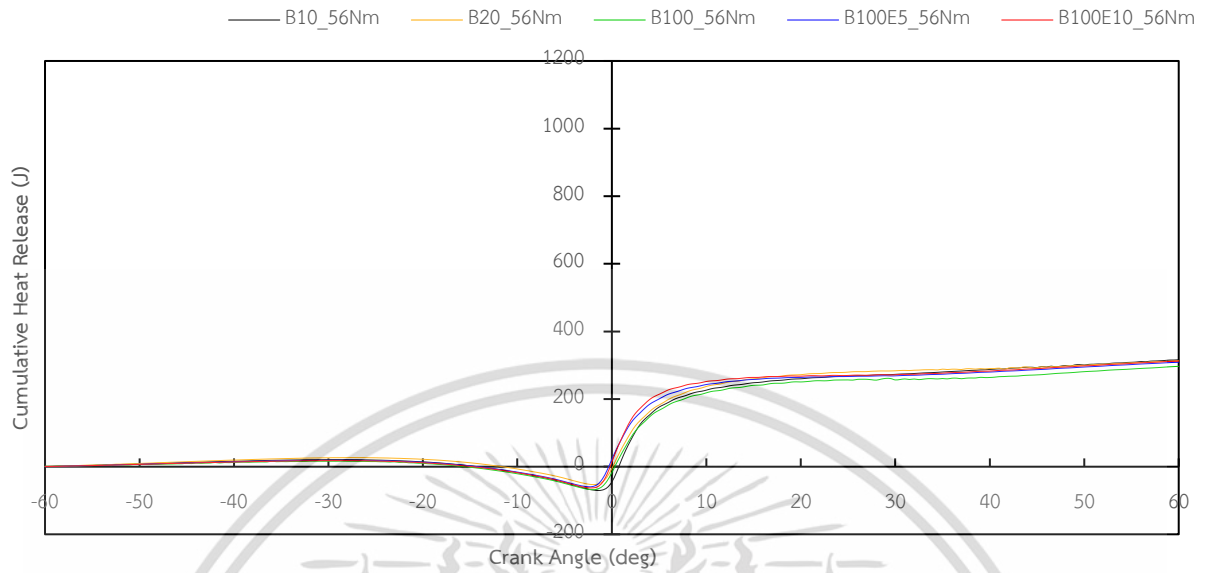


Figure 4.30 Cumulative heat release diagram at engine load 56Nm and engine speed 1500RPM

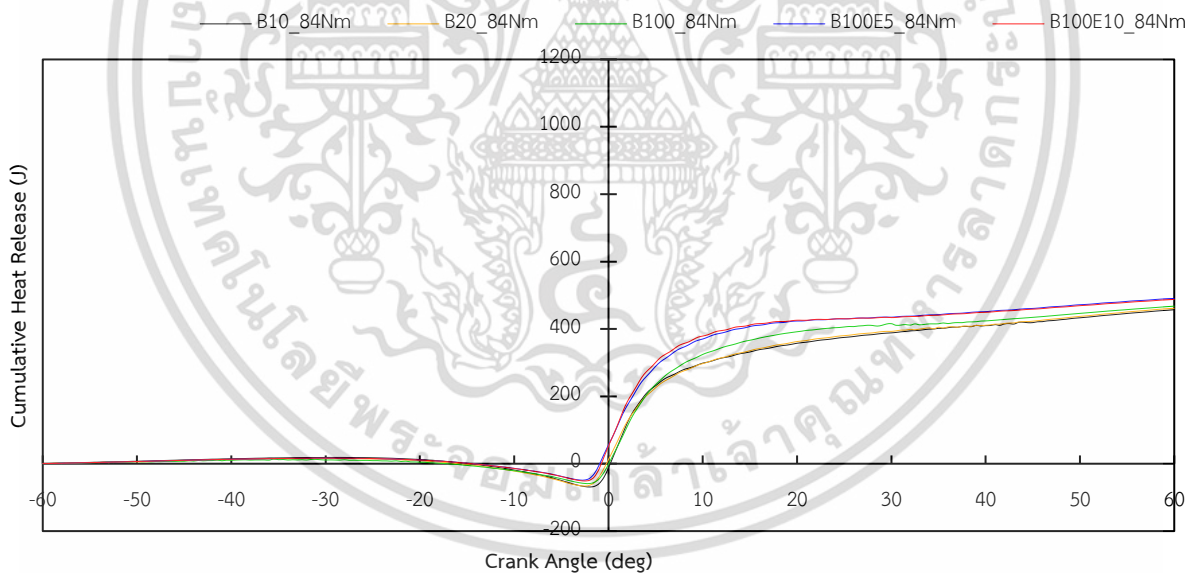


Figure 4.31 Cumulative heat release diagram at engine load 84Nm and engine speed 1500RPM

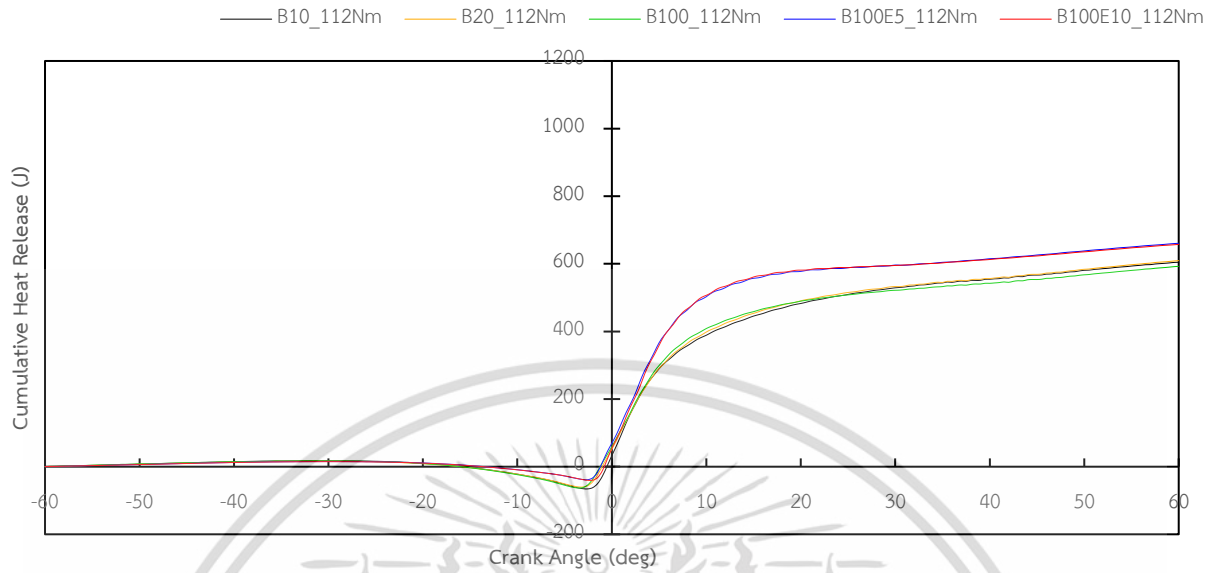


Figure 4.32 Cumulative heat release diagram at engine load 112Nm and engine speed 1500RPM

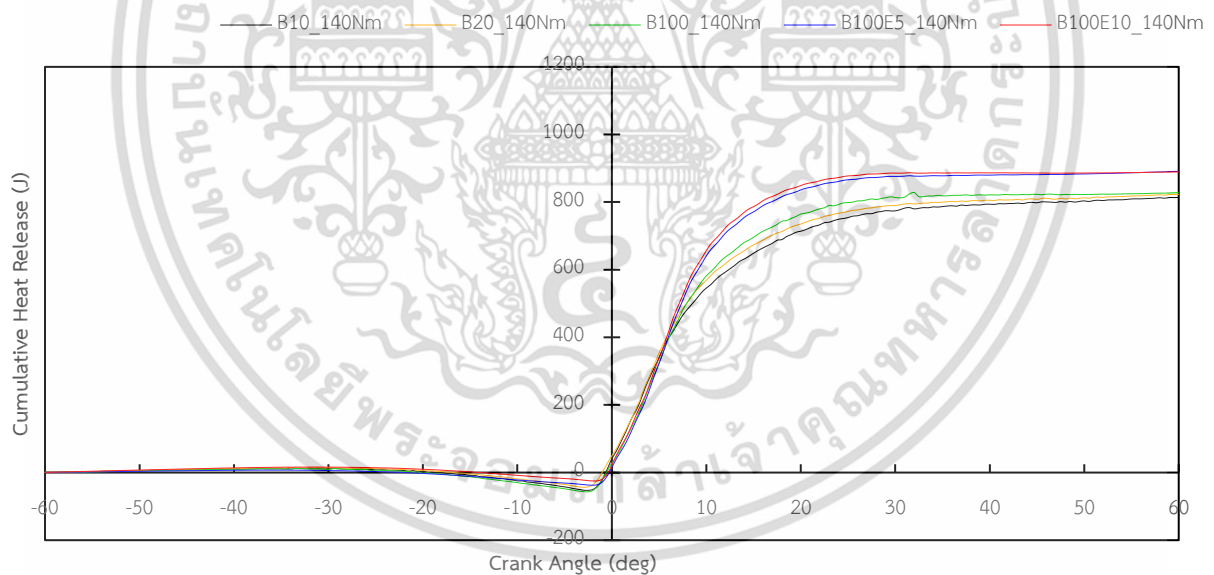


Figure 4.33 Cumulative heat release diagram at engine load 140Nm and engine speed 1500RPM

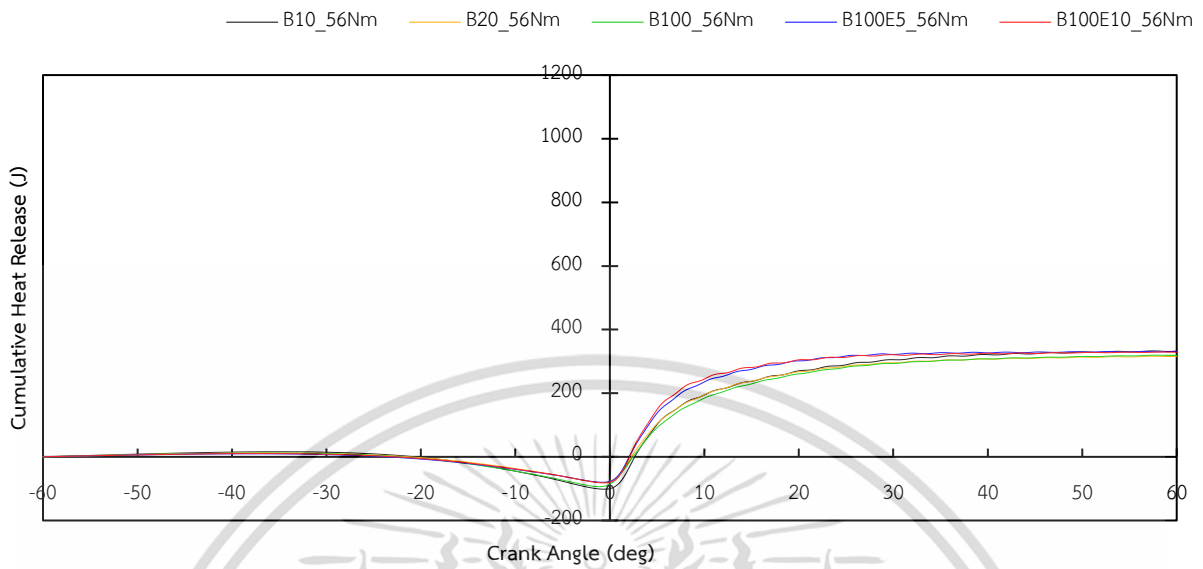


Figure 4.34 Cumulative heat release diagram at engine load 56Nm and engine speed 2000RPM

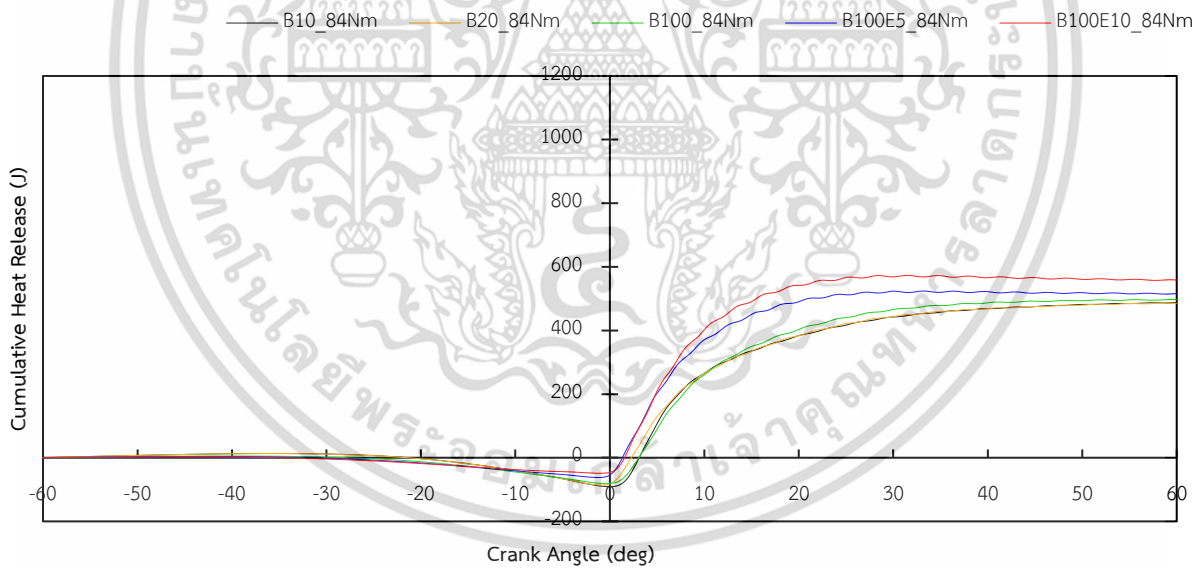


Figure 4.35 Cumulative heat release diagram at engine load 84Nm and engine speed 2000RPM

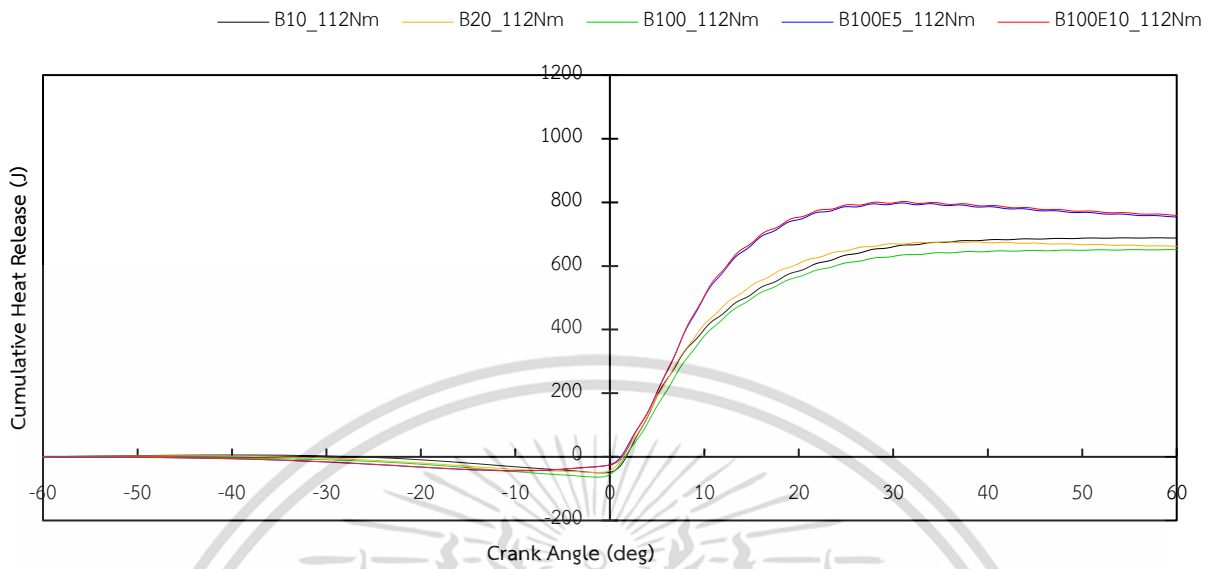


Figure 4.36 Cumulative heat release diagram at engine load 112Nm and engine speed 2000RPM

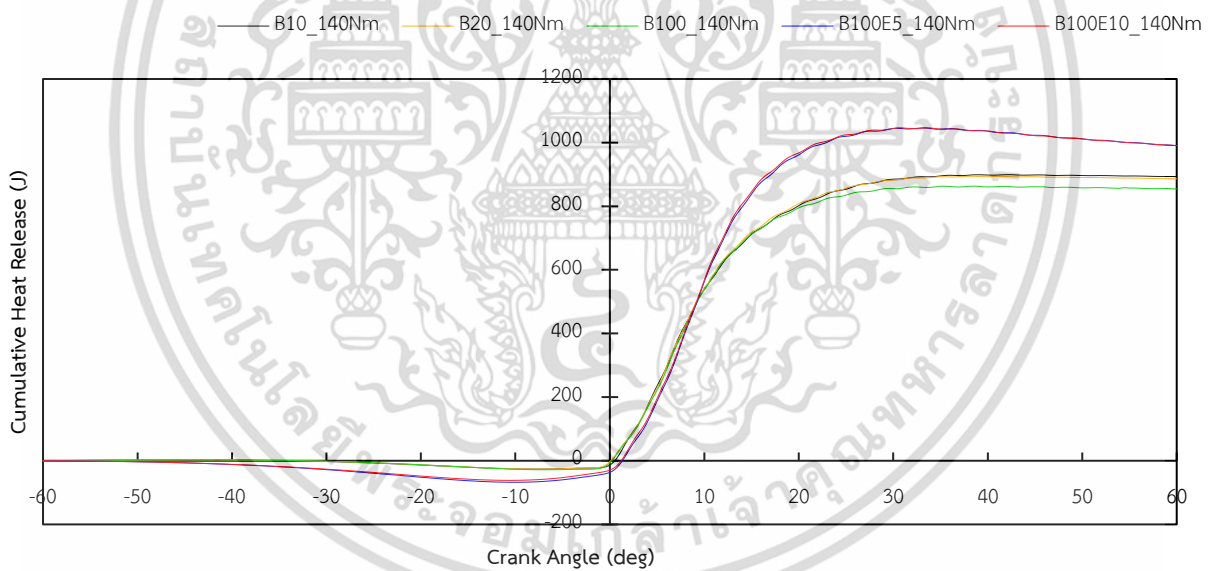


Figure 4.37 Cumulative heat release diagram at engine load 140Nm and engine speed 2000RPM

### Heat release rate

The heat release rate (HRR) graphs are shown in **Figures 4.38 to 4.49**. When increasing biodiesel concentration, the ignition delay period is shorter, and a lower heat release rate. Because the shorter ignition delay period has less time for mixing fuels and air and less time to

accumulate premixed fuel. So, When the combustion starts, the heat release rate is lower. While a higher ethanol concentration, the ignition delay period is longer. It means a higher accumulation of premixed fuel. The better homogeneous mixture and higher accumulation of premixed fuel, resulting in a higher heat release rate. And also, higher under the mixing-controlled combustion phase [29]. This is because the excess oxygen content left over during the premixed combustion phase burns in the diffusion combustion phase [30]. When compared with the engine load increases and a constant engine speed, the heat release rate is also increased with more fuel injected. With regard to the higher engine speeds and a constant engine load, It affect to the longer ignition delay period as shown in the heat release diagram.

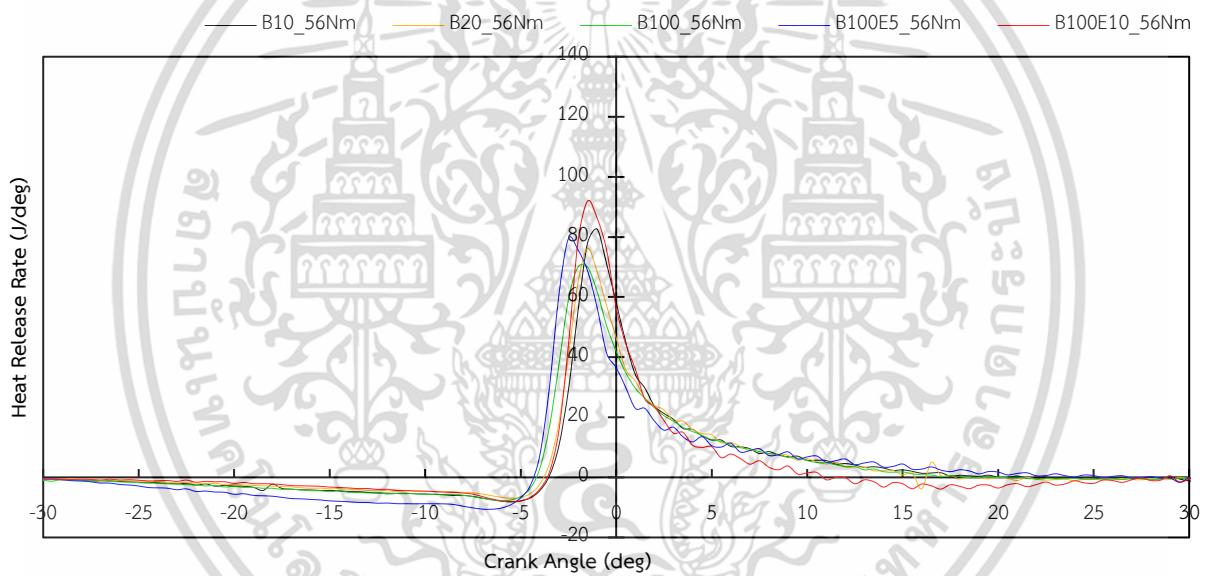


Figure 4.38 Heat release rate diagram at engine load 56Nm and engine speed 1000RPM

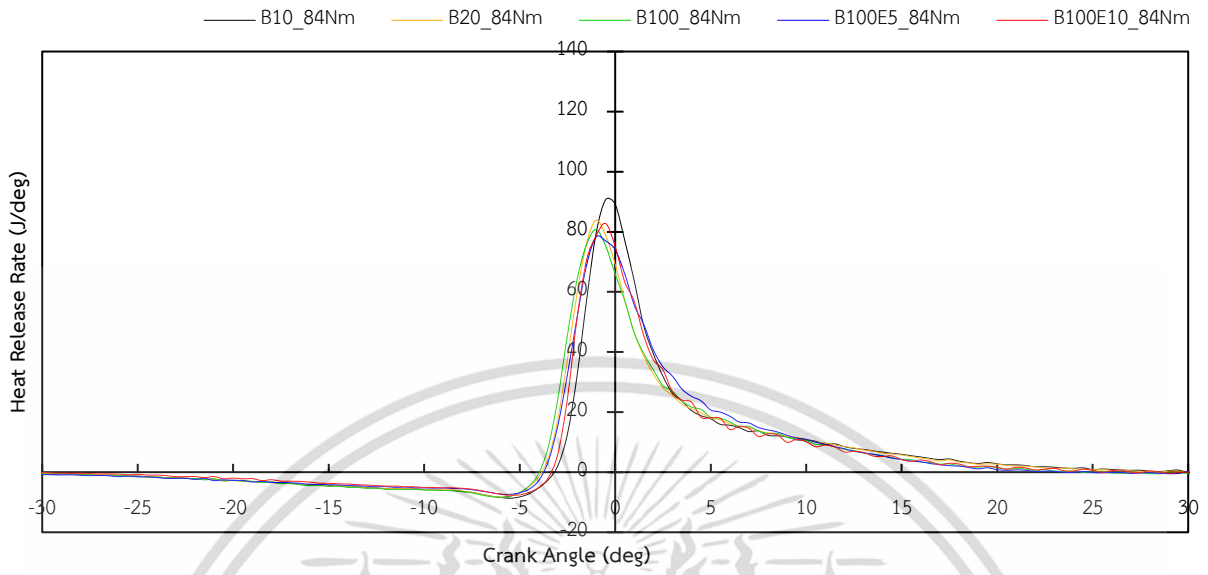


Figure 4.39 Heat release rate diagram at engine load 84Nm and engine speed 1000RPM

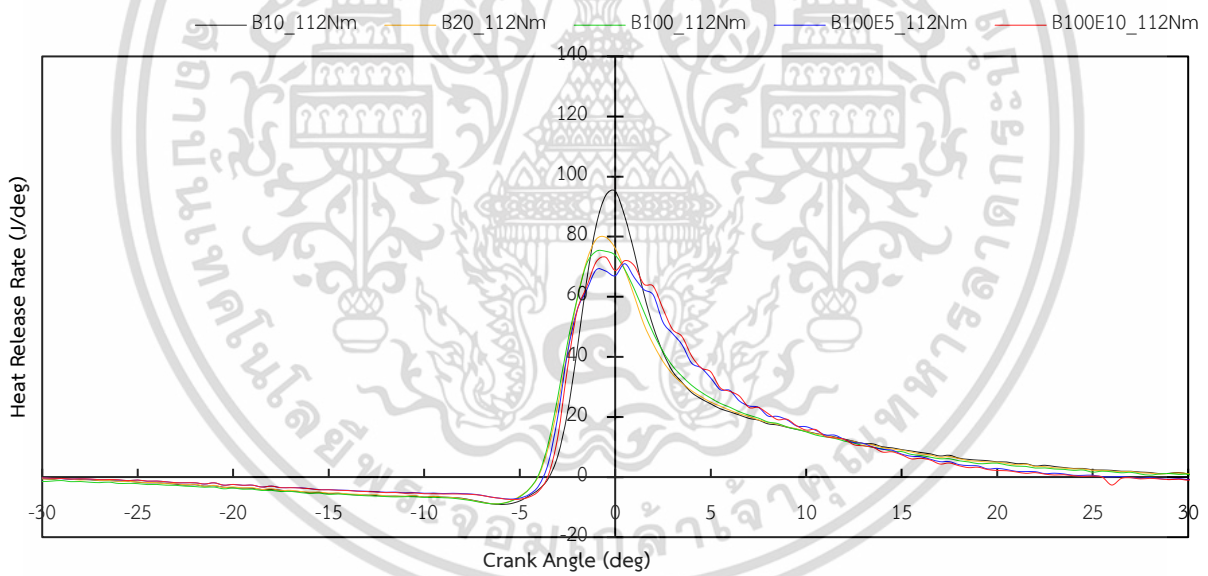


Figure 4.40 Heat release rate diagram at engine load 112Nm and engine speed 1000RPM

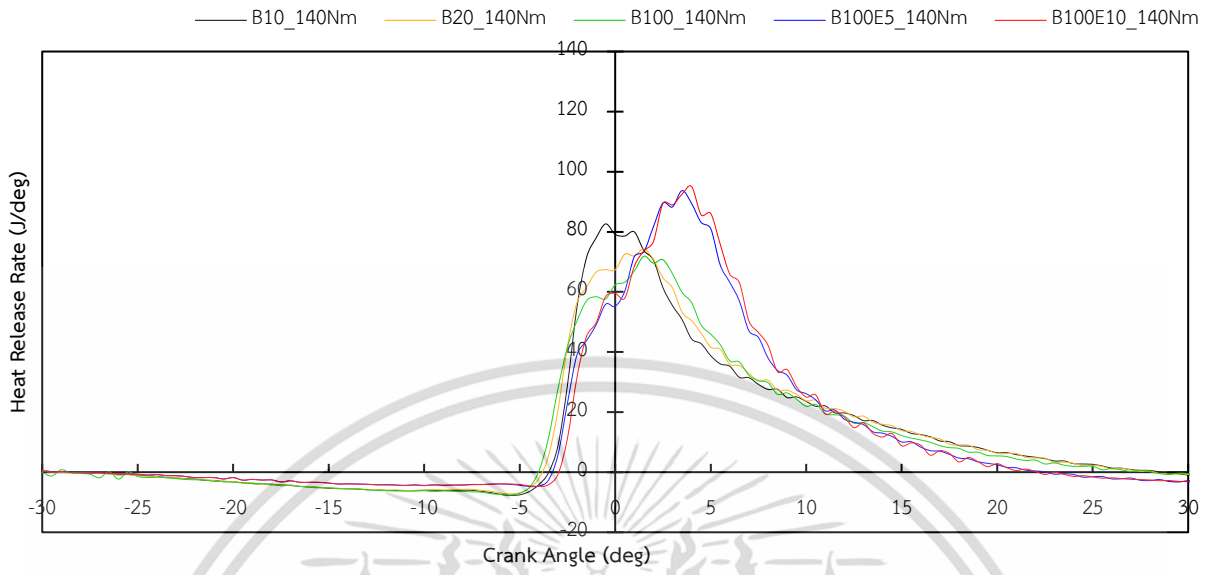


Figure 4.41 Heat release rate diagram at engine load 140Nm and engine speed 1000RPM

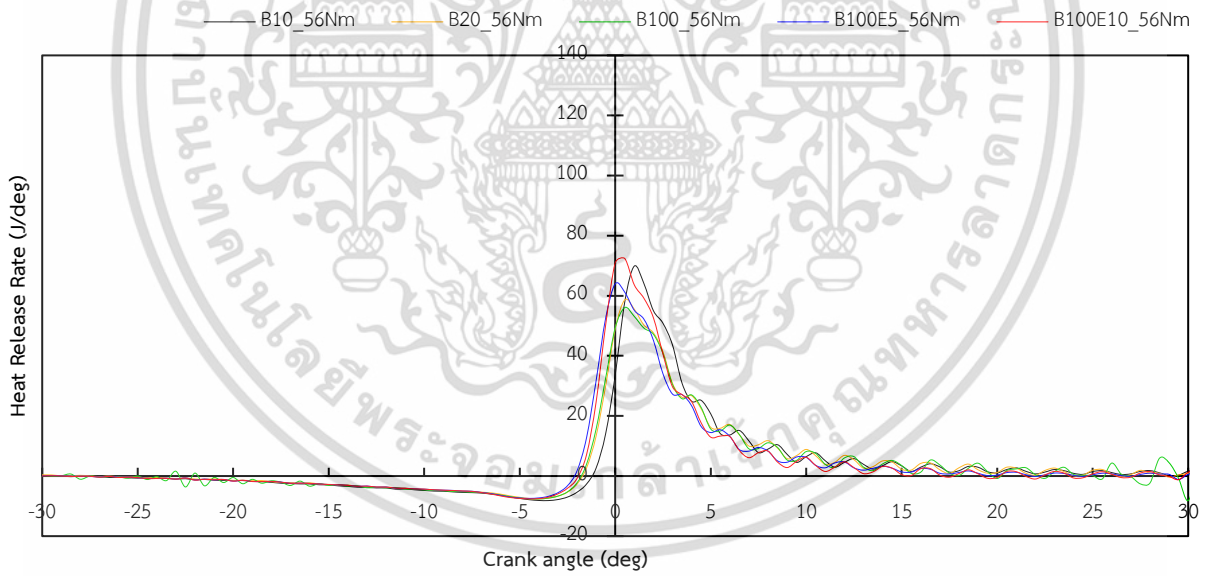


Figure 4.42 Heat release rate diagram at engine load 56Nm and engine speed 1500RPM

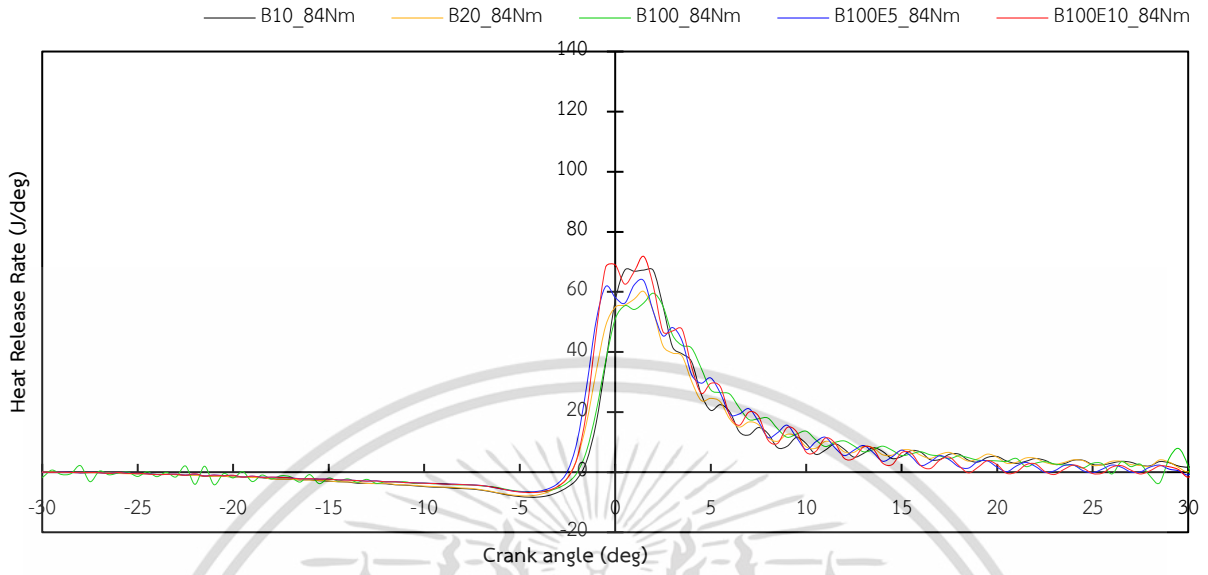


Figure 4.43 Heat release rate diagram at engine load 84Nm and engine speed 1500RPM

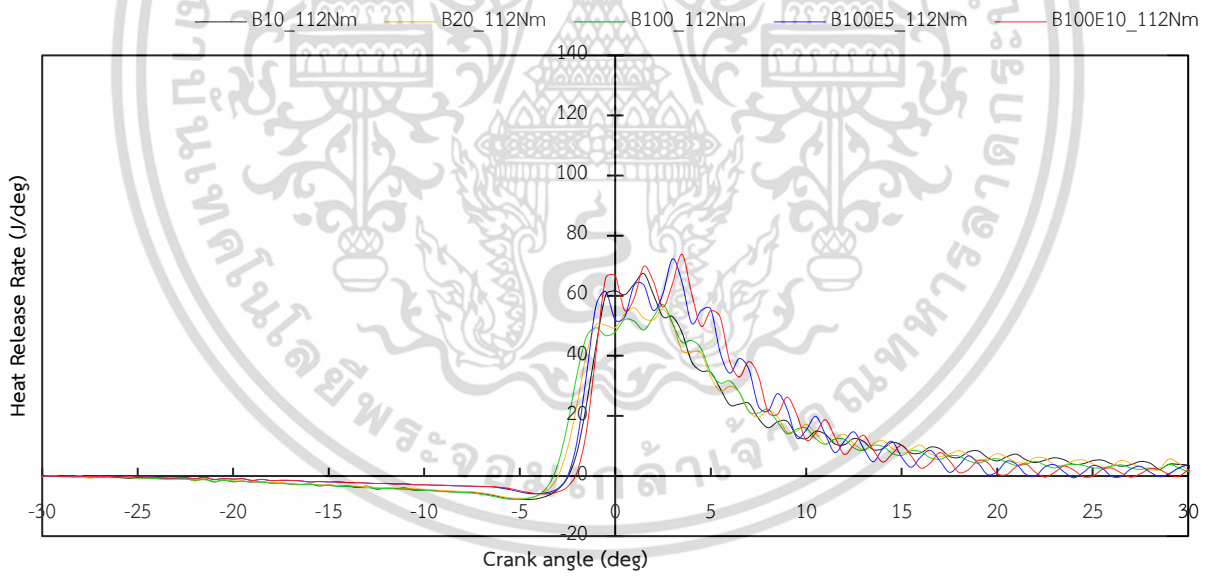


Figure 4.44 Heat release rate diagram at engine load 112Nm and engine speed 1500RPM

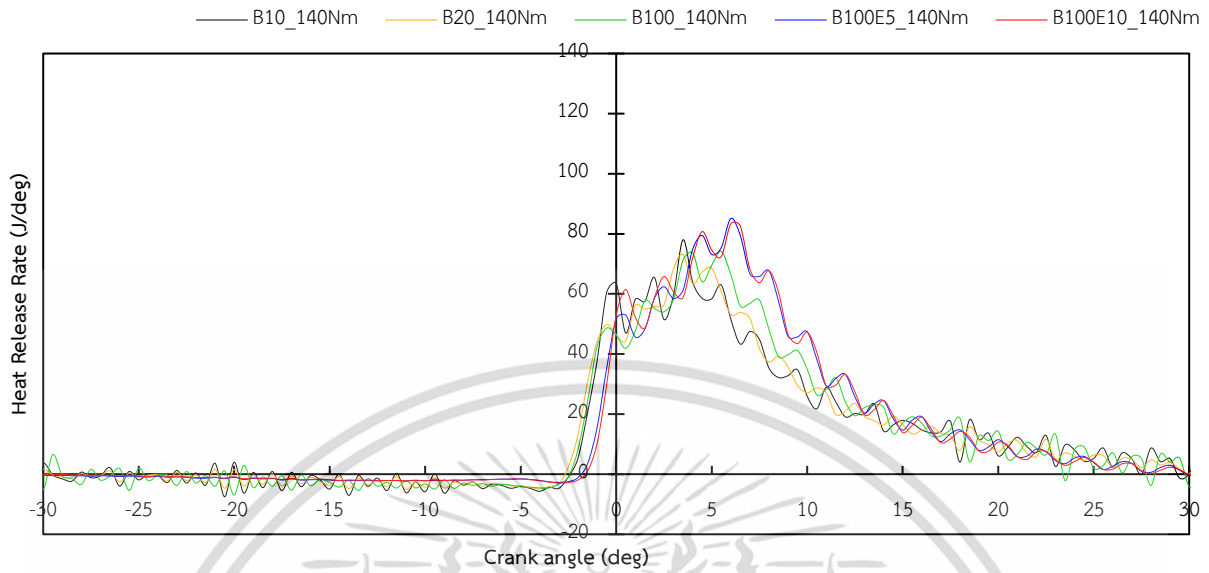


Figure 4.45 Heat release rate diagram at engine load 140Nm and engine speed 1500RPM

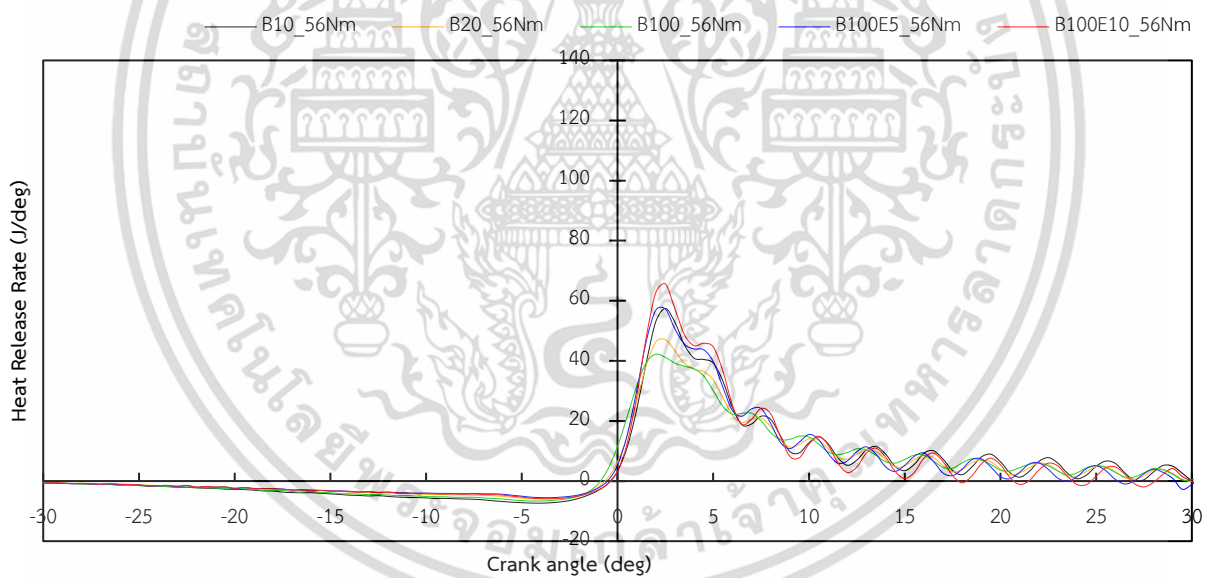


Figure 4.46 Heat release rate at engine load 56Nm and engine speed 2000RPM

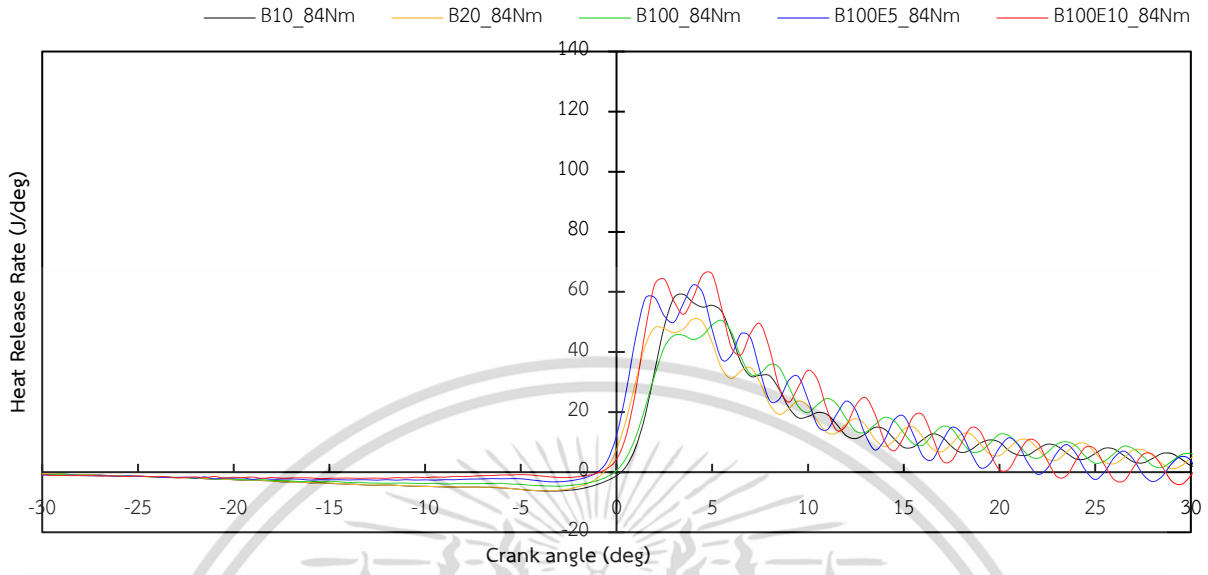


Figure 4.47 Heat release rate at engine load 84Nm and engine speed 2000RPM

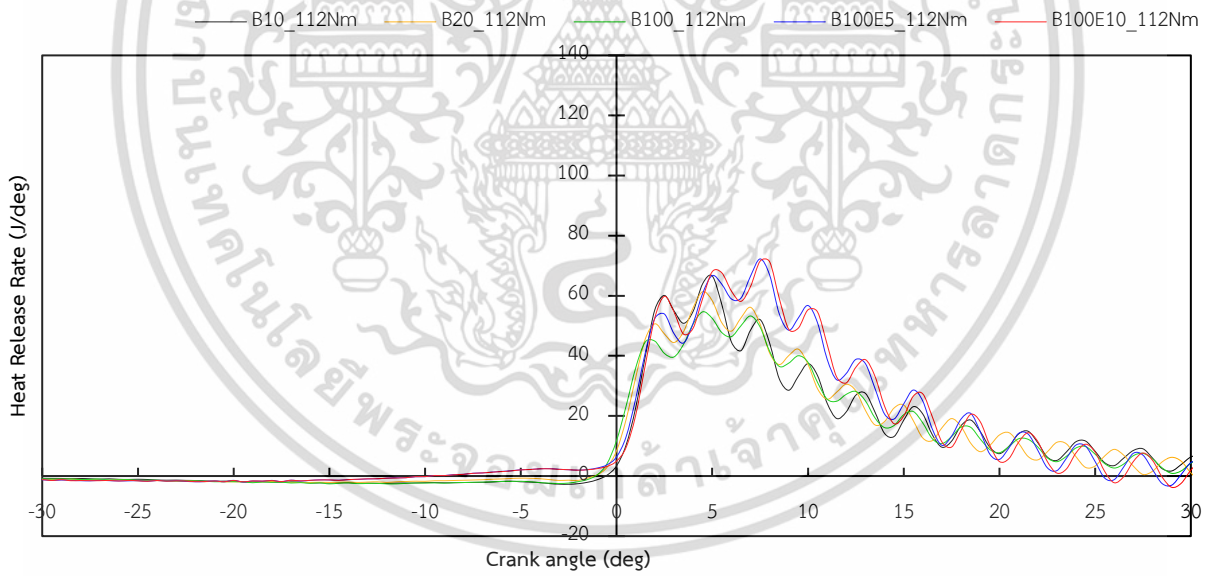


Figure 4.48 Heat release rate diagram at engine load 112Nm and engine speed 2000RPM

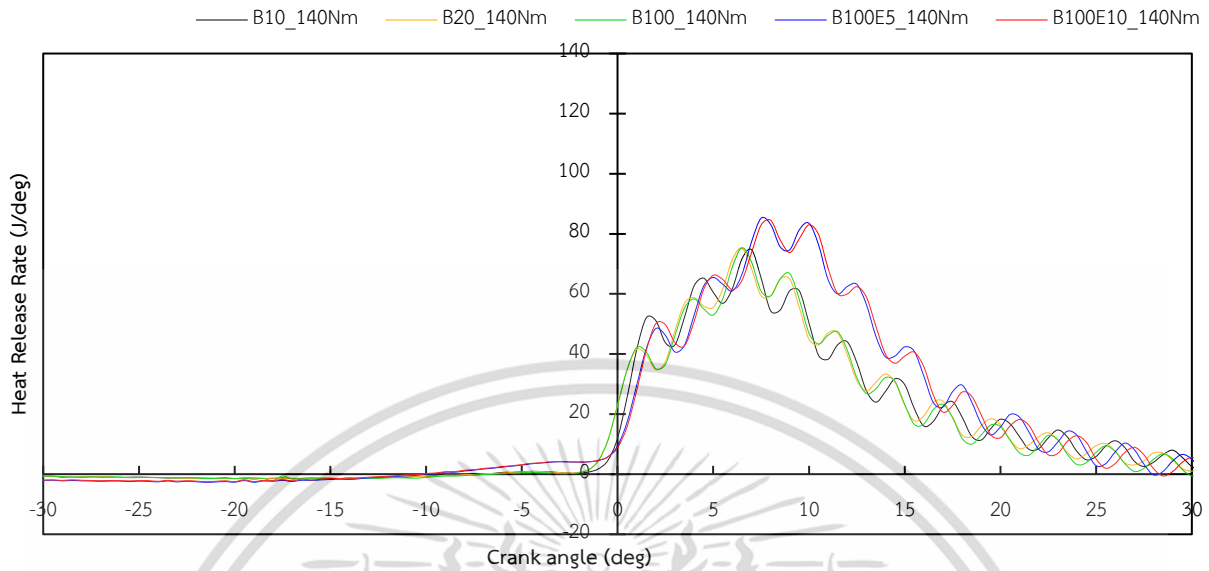


Figure 4.49 Heat release rate diagram at engine load 140Nm and engine speed 2000RPM

#### 4.1.2 Engine performance

The calorific value is reduced when the proportion of biodiesel and ethanol increases as shown in Figure 4.50. The heat energy input rate of each sample in each test condition is almost the same quality input, as shown in Figure 4.51. Consequently, the fuel consumption rate is increased with the higher engine speed and engine load due to producing more power output. Also, with a lower calorific value when increasing the biodiesel and ethanol blend into the fuel. The fuel consumption rate increases around 15% for B100 and 18% for blended ethanol fuel compared to diesel fuel, as shown in Figure 4.52.

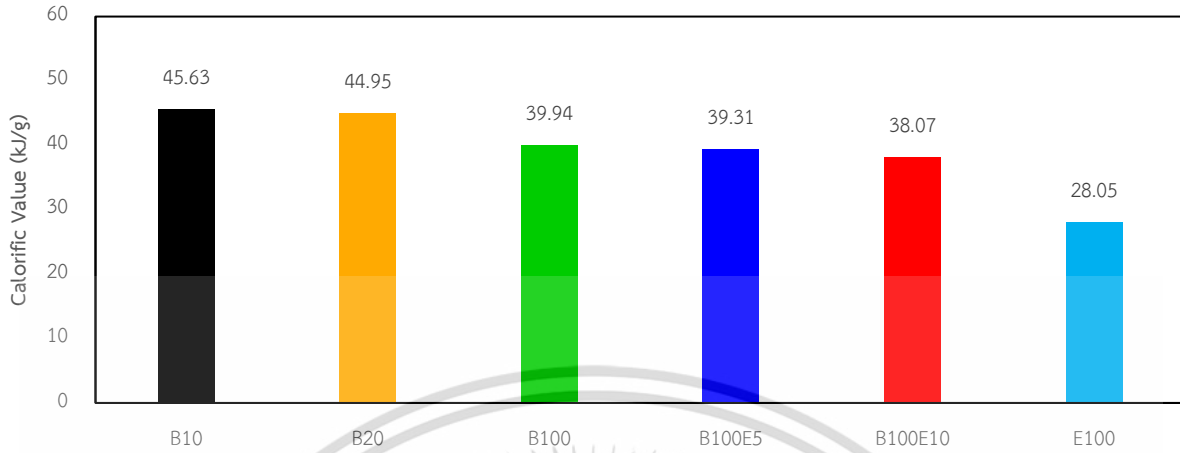


Figure 4.50 Calorific values of the samples

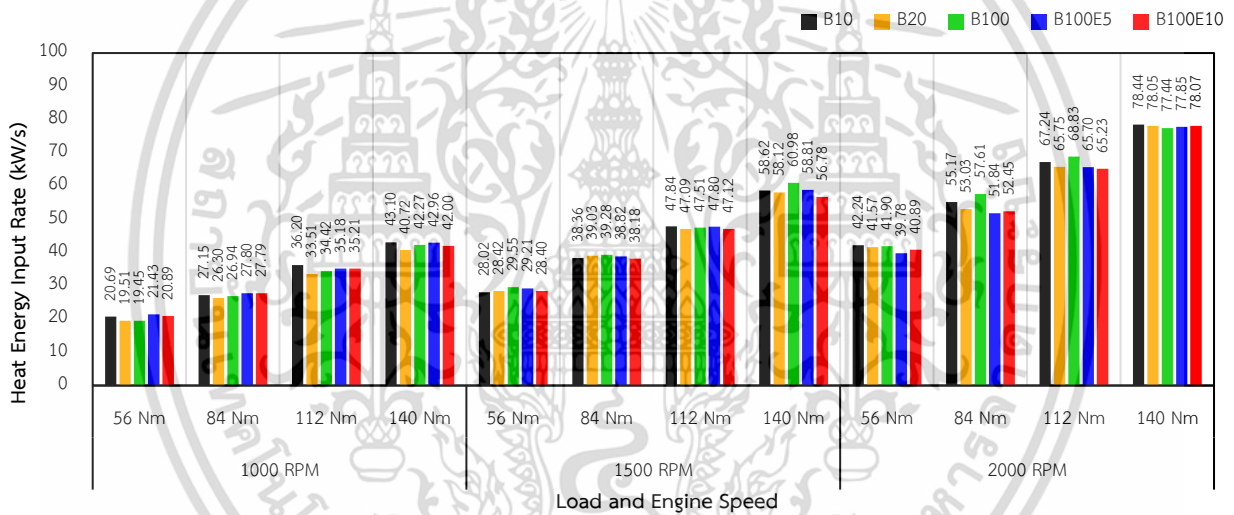


Figure 4.51 Heat energy input rate

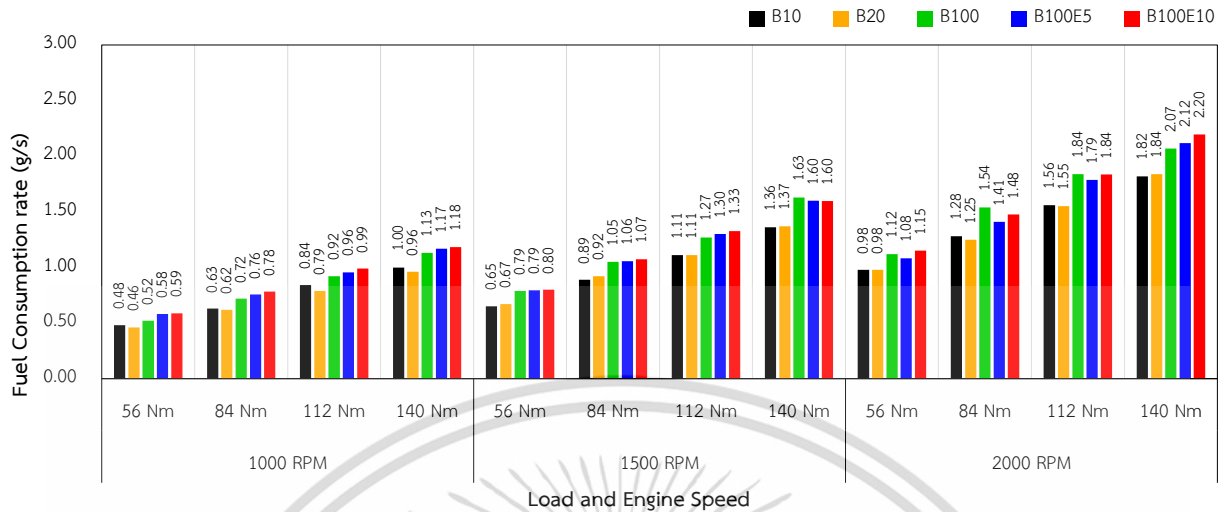


Figure 4.52 Fuel consumption rate

The indicated values, such as the indicated specific fuel consumption (ISFC), indicate specific energy consumption (ISEC) and indicated thermal efficiency (ITE), are estimated from the in-cylinder pressure and fuel consumption rate. In addition, the brake values, such as the brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC), and brake thermal efficiency (BTE), are calculated from the measured data such as engine speed, torque, and fuel consumption rate.

The indicated specific fuel consumption (ISFC) and brake specific fuel consumption (BSFC) are the value of fuel consumption with indicated power and brake power respectively, as shown in Figures 4.53 and 4.54. Both of these show the same trends as decreasing with increasing the engine load. Because while testing, the engine is set up at the target engine speed and increases the loads gradually. Thus, if the engine load increases, the engine will increase the engine revolution automatically to go to the setup condition. As a consequence, at the higher engine revs is a higher speed combustion cycle. that means there is less time of heat energy loss from heat radiation to the chamber cylinder wall and cooling system than at a lower engine speed. Considering the fuels, similar patterns are observed in the fuel consumption rate results with low energy content fuels achieving a higher BSFC. While ISFC, the impact of calorific values could only obviously be at a low engine speed of 1000 rpm and engine load of 56 Nm. The biodiesel blended with ethanol fuels show a lower ISFC than the diesel fuels because the better combustion quality

of ethanol-blended fuel generates higher indicated power. This characteristic could be clearly seen in the higher engine speed and engine load conditions. So, ISFC is increased by around 18% for B100 and 12% for blended ethanol fuel compared to diesel fuel. BSFC of blending ethanol is increased by around 18% for diesel fuel and 2% for B100.

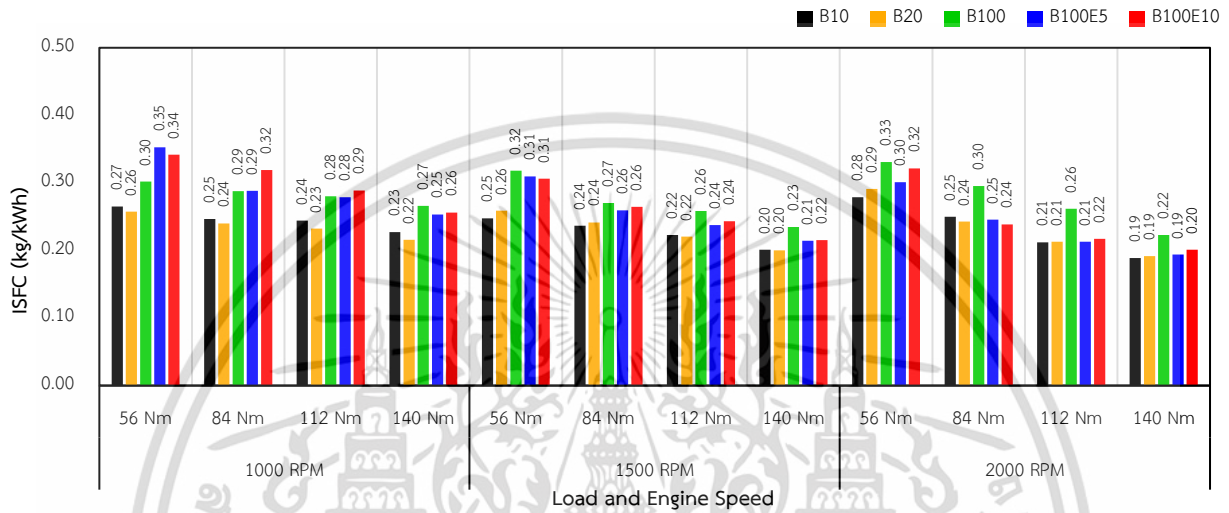


Figure 4.53 Indicated specific fuel consumption

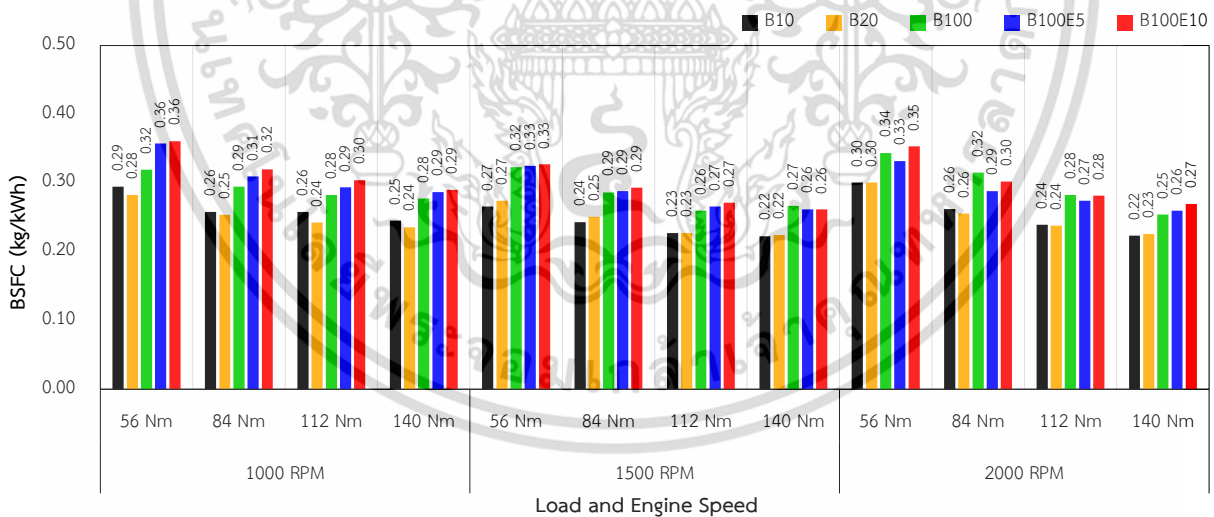


Figure 4.54 Brake specific fuel consumption

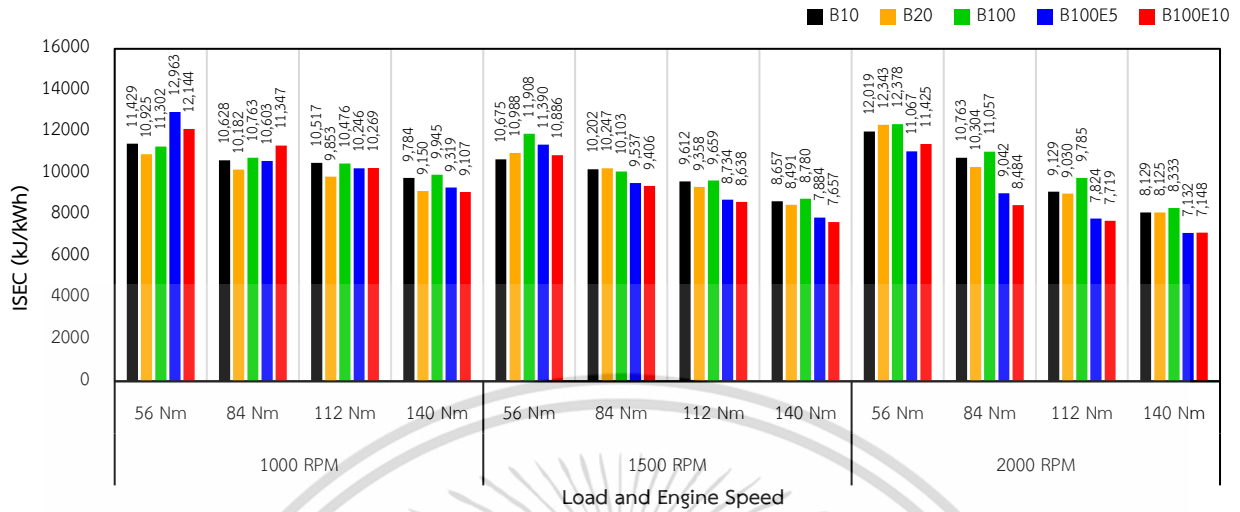


Figure 4.55 Indicated specific energy consumption

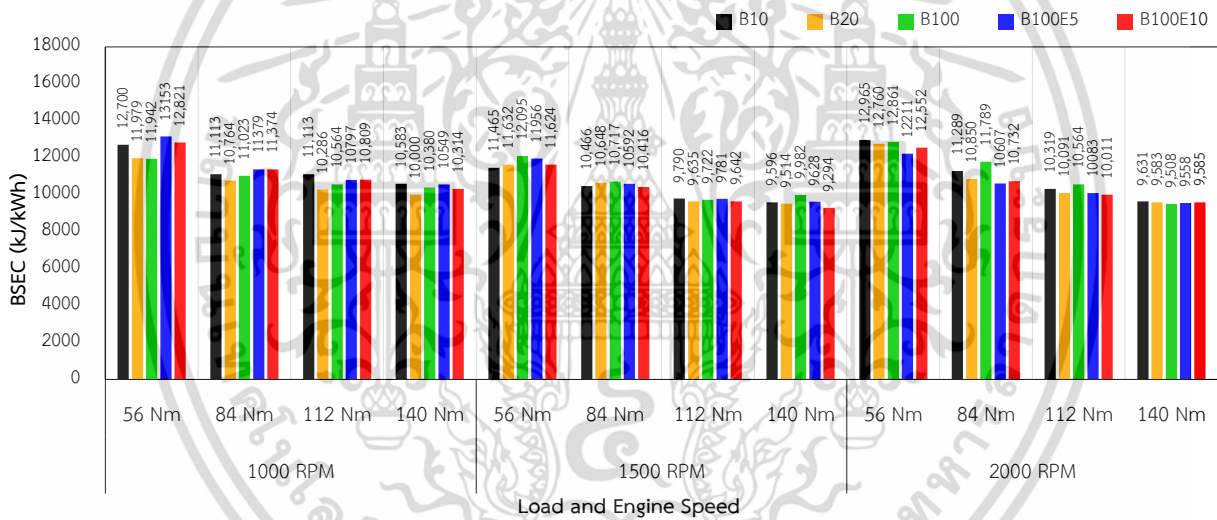


Figure 4.56 Brake specific energy consumption

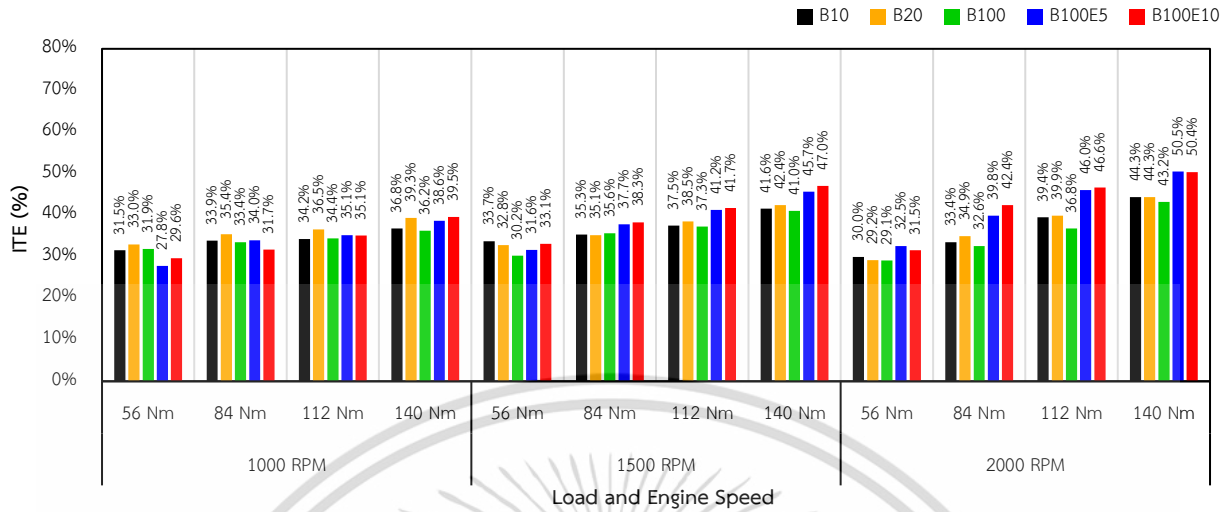


Figure 4.57 Indicated thermal efficiency

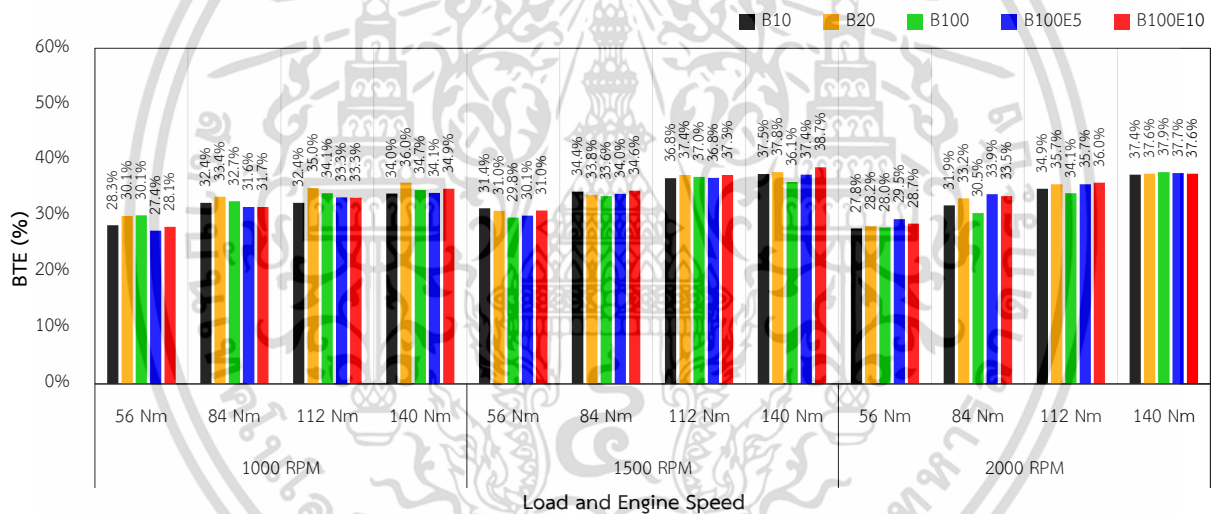


Figure 4.58 Brake thermal efficiency

For indicated specific energy consumption (ISEC) and brake specific energy consumption (BSEC) are shown in Figures 4.55 and 4.56. The results show that biodiesel blended with ethanol fuels are lower than diesel and biodiesel fuels. Because Ethanol-containing fuels can convert thermal energy into mechanical energy better than biodiesel and diesel. Due to the combustion of ethanol fuel has a higher burning rate. This causes more heat energy to be converted into mechanical energy. Figures 4.57 and 4.58 show the indicated thermal efficiency (ITE) and brake thermal efficiency (BTE). Both thermal efficiency increases with a higher engine load. Blending

ethanol can improve the better combustion from a higher oxygen concentration, better atomization, longer ignition delay, and more homogeneous mixture to be promoted in more complete combustion. As results in lower specific energy consumption and higher indicated thermal efficiency of ethanol-blended fuel. The ITE is higher than BTE by around 5% to 7% in diesel and biodiesel fuels. Especially, in the case of blended ethanol fuel because the ethanol has a lower lubricity resulting in higher friction loss. Also, higher with the engine speed increase, the friction loss will be higher resulting in a higher difference between ITE and BTE [31,32]. So, ITE is increased with blending ethanol by around 5% to 8% compared to diesel and biodiesel fuel. While BTE is not significantly different in each test condition.

#### 4.1.3 Emissions

The fuel-air equivalent ratio is estimated back from the exhaust emissions as shown in **Figure 4.59**. The equivalent ratio decreases with increasing the ethanol proportion in biodiesel blended with ethanol fuels because of higher oxygen concentration of the blended fuel. It also decrease with the higher power because the exhaust pressure is higher from higher engine revolutions as higher boost pressure of the turbocharger, resulting in the volume of air intake being more sucked during the intake stroke. Hence, the equivalent ratio at engine speed of 1000 rpm is higher than equivalent ratio at 1500 and 2000 rpm, as shown in **Figure 4.60**.

**Figure 4.61** shows the exceed oxygen. The exceed oxygen emission is related with the oxygen concentration in the fuels and the combustion chamber. The lower exceed oxygen emission occurred at engine speed of 1000 rpm with engine load 112 and 140 Nm of diesel fuel. Because higher fuel was injected to reach higher torque of 112 and 140 Nm, resulting in higher consumption of oxygen for the combustion as show the lower exceed oxygen emission on these conditions.

**Figure 4.63** describes the smoke intensity. The highest smoke intensity occurred at engine speed of 1000 rpm and engine load of 112 and 140 Nm for diesel fuels (B10 and B20). At engine speed 1000 rpm has a higher fuel-air equivalent ratio, which means this engine speed has rich combustion than the others. The rich combustion leads to incomplete combustion, resulting in higher smoke intensity. However, Biodiesel and Biodiesel blended with ethanol fuels have a lower

smoke intensity because ethanol properties promoted to more complete combustion [33,34,35]. The smoke intensity is reduced by increasing biodiesel concentration to around 20% for B20 and 70% for B100 compared to B10. After blending ethanol could more reduce the smoke intensity by around 90% for diesel fuels and 70% for B100.

The exhaust temperature, measured by a thermocouple at the exhaust pipe, is higher with engine speeds and loads increase, as shown in **Figure 4.65**. Because a higher combustion pressure from more fuels at higher load leads to higher combustion temperature. Moreover, the higher engine load and speed have faster operating combustion, it is less time for heat loss to the cooling system and heat radiation. The exhaust temperature of biodiesel blended with ethanol fuels is lower than diesel and biodiesel fuels because of higher exceed oxygen emission. The higher temperatures of diesel and biodiesel fuels are the result of the heat from the chemical reaction between carbon and oxygen emitted during the carbon monoxide (CO) and carbon dioxide (CO<sub>2</sub>) formation processes. So, the amount of CO and CO<sub>2</sub> emissions represent in **Figures 4.66** and **4.68** in percent volume units.

The carbon monoxide (CO) emission is generated from the incomplete combustion. CO emission is higher at engine speed of 1000 rpm and engine load of 112 and 140 Nm. Because at these conditions have a higher injected fuel and lower oxygen resulted in the incomplete combustion. CO emission is decreased by blending ethanol fuel around 50% for diesel fuel and 25% for pure biodiesel.

The carbon dioxide (CO<sub>2</sub>) emission decreases with the lower carbon content and higher oxygen content in the fuel. With same amount of power, Carbon dioxide (CO<sub>2</sub>) also decreased with increasing the power, as shown in **Figure 4.69**. So, Carbon dioxide (CO<sub>2</sub>) emission is decreased by blending ethanol fuel by around 10% to 12% for diesel and biodiesel fuel, respectively.

The most concerning of diesel engine emission is NO<sub>x</sub> emissions. The impact on NO<sub>x</sub> emission comes from oxygen concentration, fuel-air equivalent ratio, and combustion temperature [36]. NO<sub>x</sub> emissions are increased with increasing the engine load. It is also higher when blended ethanol into the fuels because oxygen enrichment in the combustion chamber is favorable to nitrogen oxide formation, as shown in **Figure 4.70**. At condition of engine speed of

1000 rpm and 140 Nm is a quite high NO<sub>x</sub> emission. Because the lower energy content of biodiesel blended with ethanol fuels makes the recirculation emission or EGR system not open fully for increasing the required power. So, NO<sub>x</sub> emission increases with a higher ethanol concentration by around 60% for diesel fuel and 70% for pure biodiesel fuel.

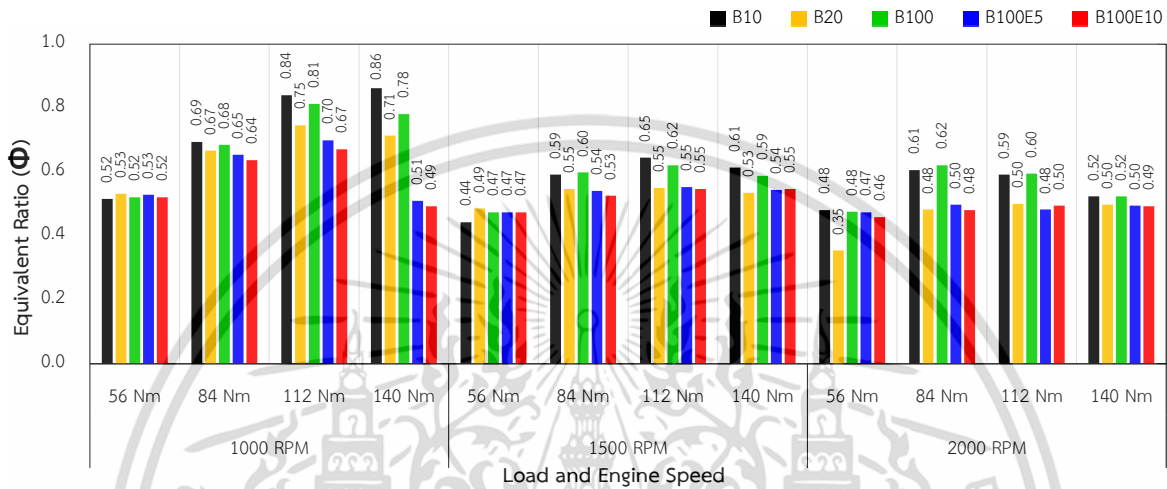


Figure 4.59 Fuel-Air equivalent ratio

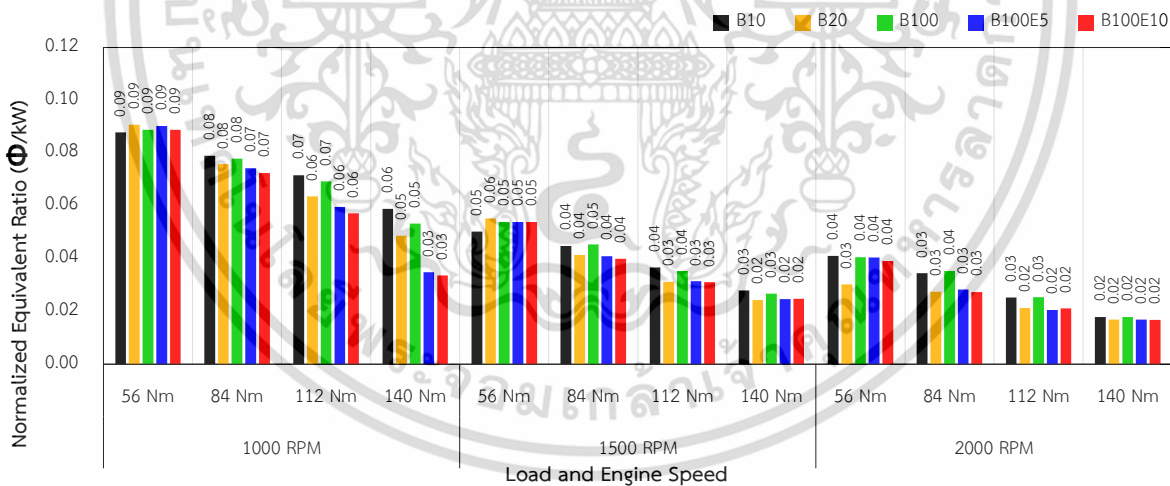


Figure 4.60 Normalized Fuel-Air equivalent ratio

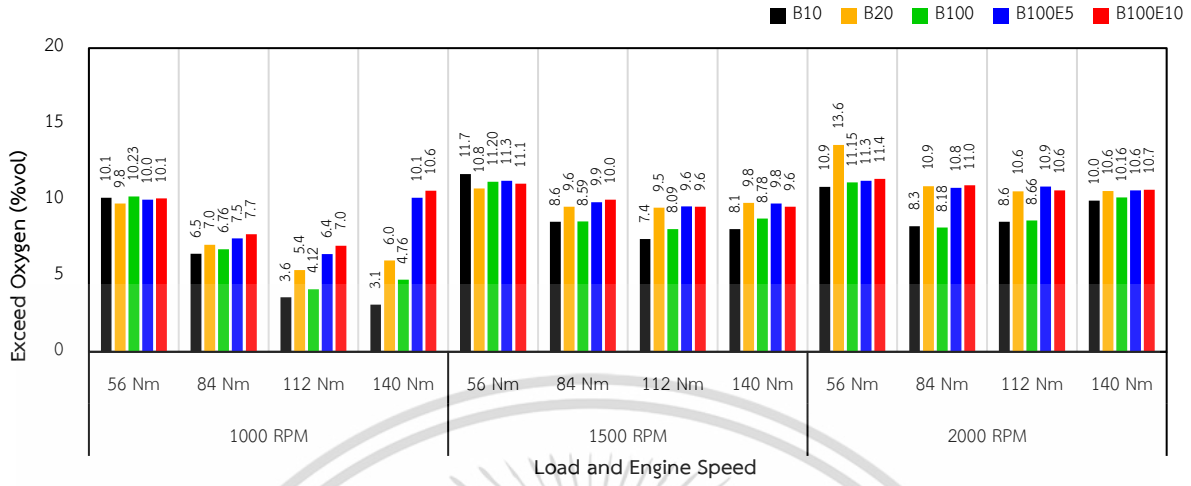


Figure 4.61 Exceed oxygen emission

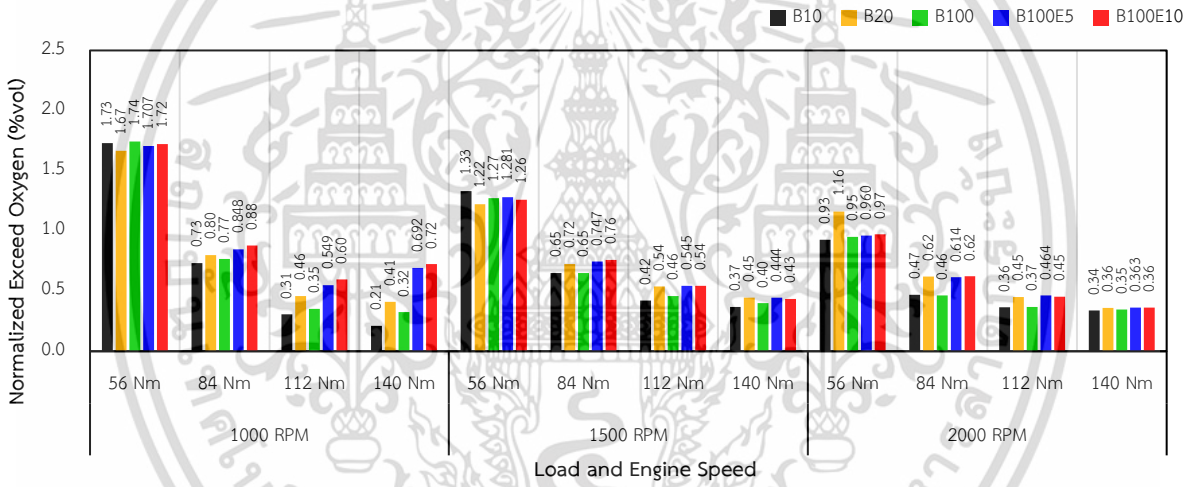


Figure 4.62 Normalized exceed oxygen emission

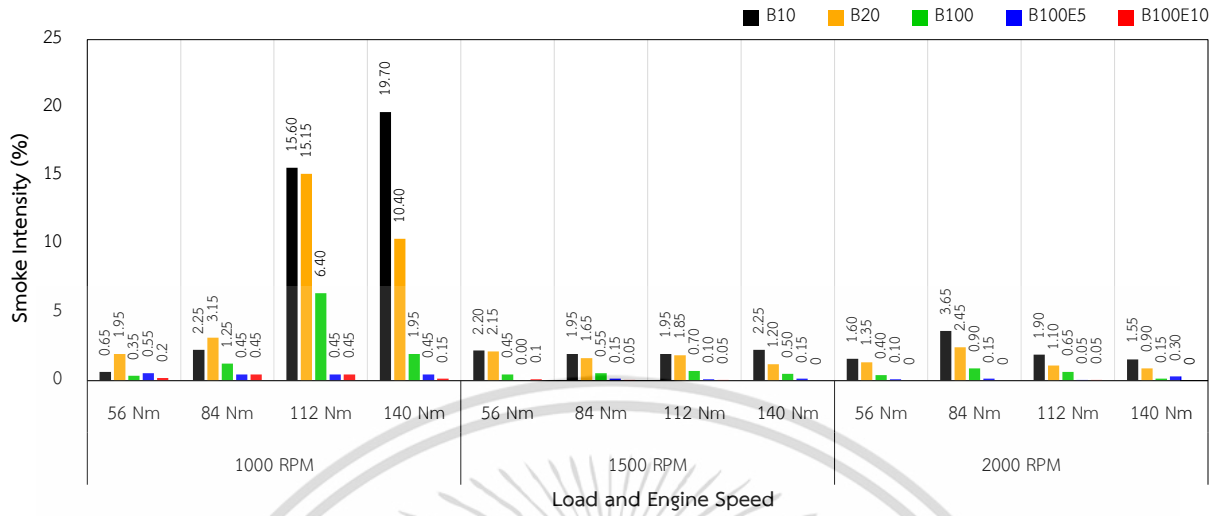


Figure 4.63 Smoke intensity

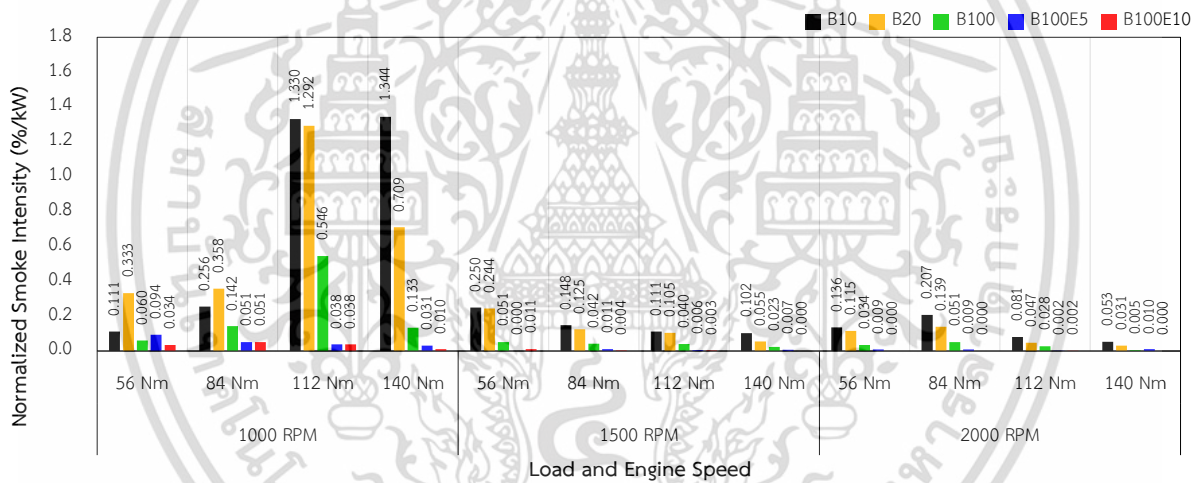


Figure 4.64 Normalized smoke intensity

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
 ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

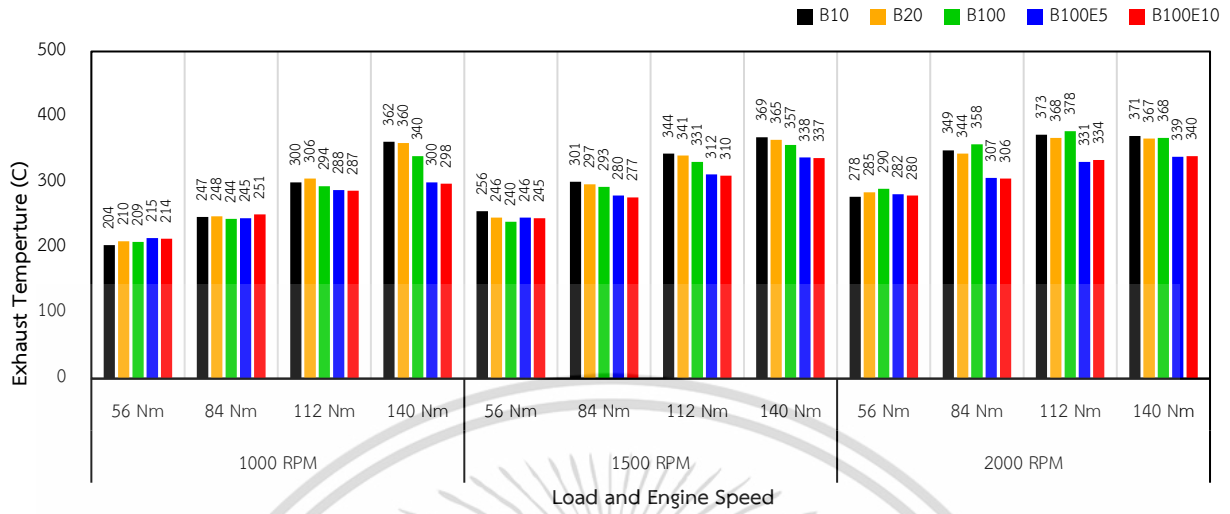


Figure 4.65 Exhaust temperature

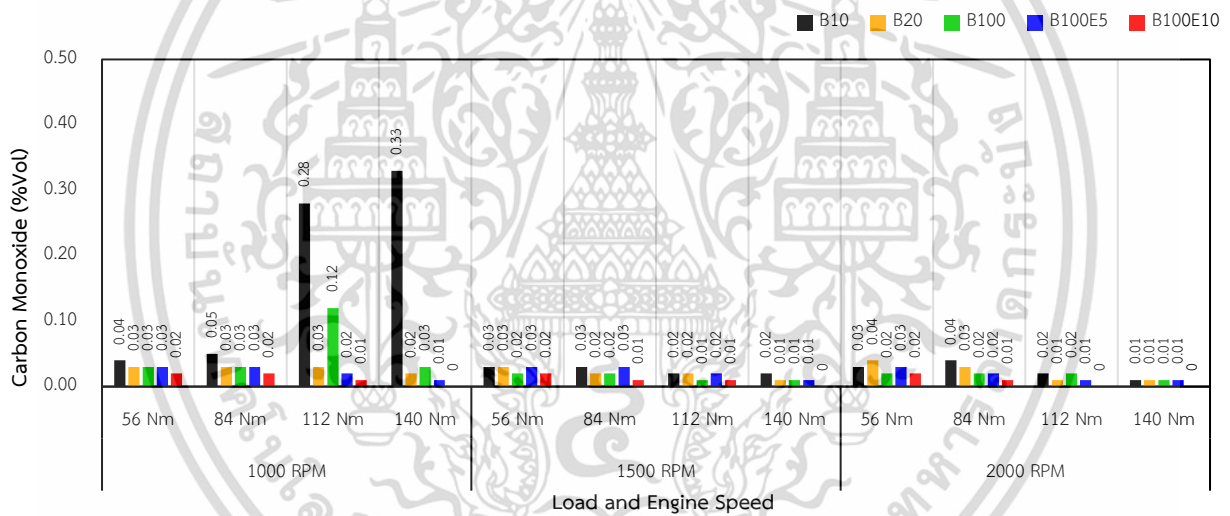


Figure 4.66 Carbon monoxide emission

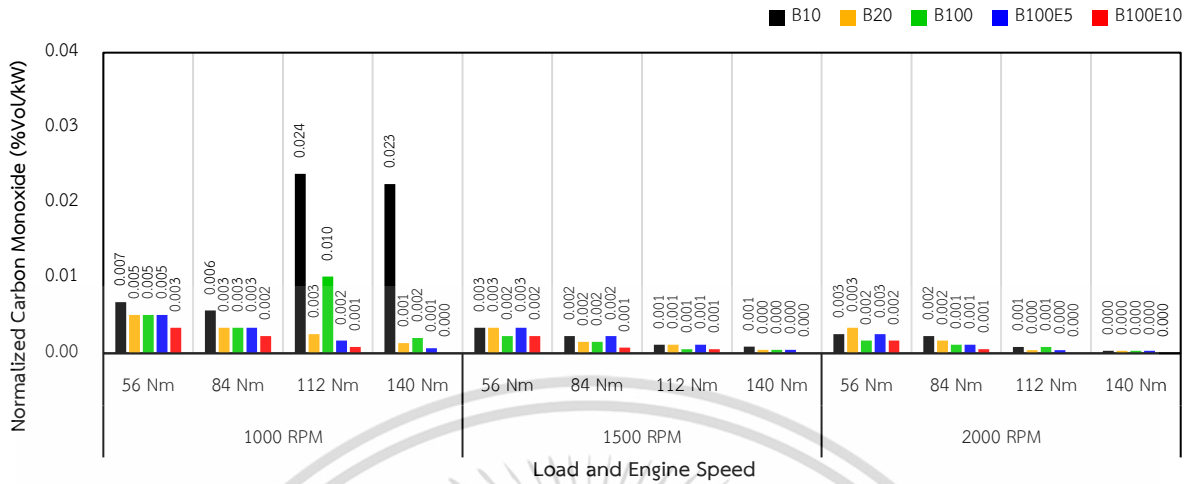


Figure 4.67 Normalized carbon monoxide emission

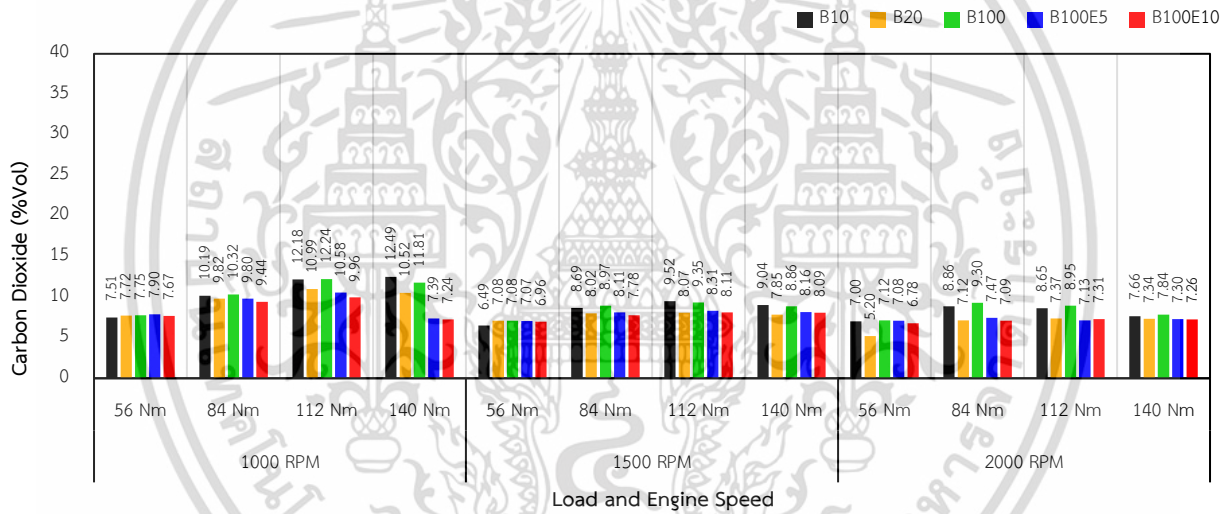


Figure 4.68 Carbon dioxide emission

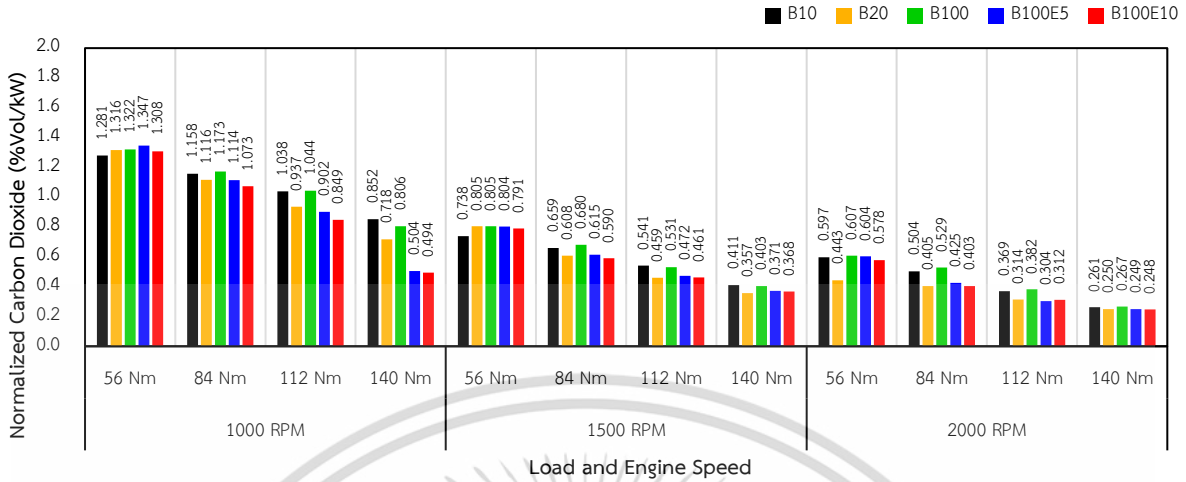


Figure 4.69 Normalized carbon dioxide emission

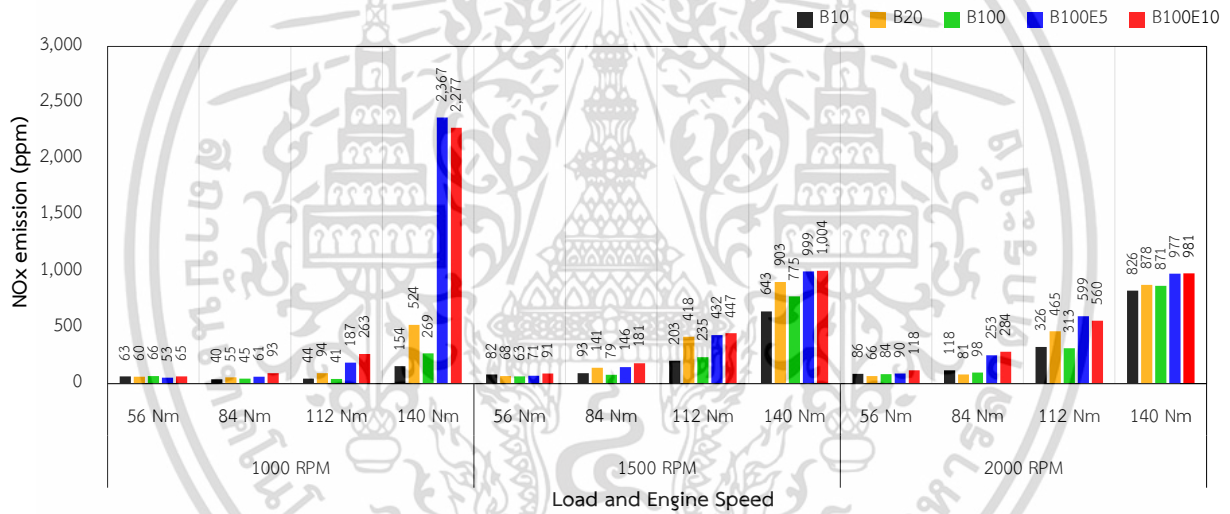


Figure 4.70 NOx emission

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

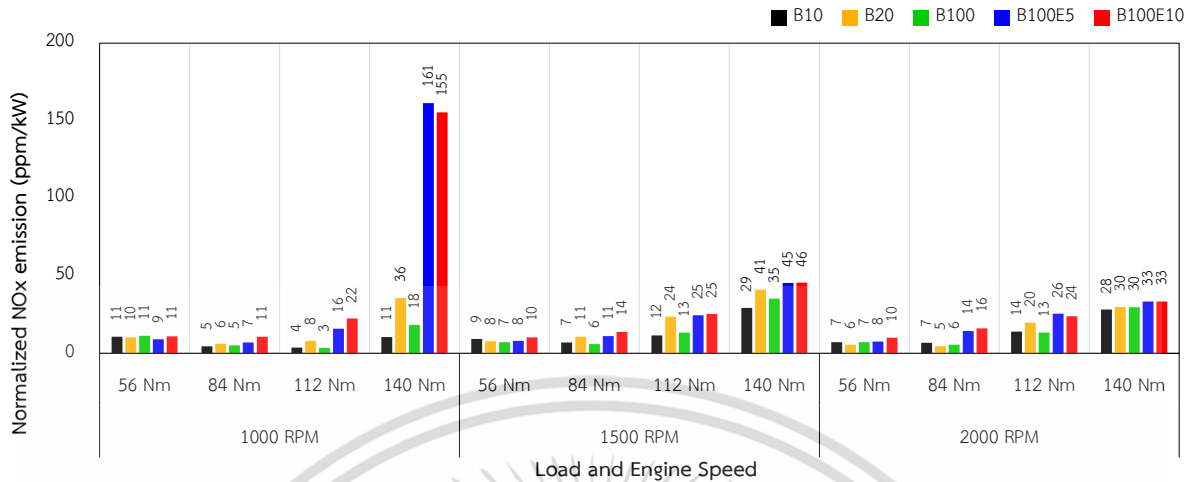


Figure 4.71 Normalized NOx emission

#### 4.1.4 Morphology of particulate matters

The soot filter papers are collected at the highest smoke intensity condition. The soot filter papers are captured by an optical microscope (OM) as shown in Figure 4.72. The analyses of agglomerate particle size are performed based on the 10k magnification scanning electron microscope (SEM) images of soot filter paper, as shown in Figure 4.73. By chosen and measured a hundred agglomerate particles by using the ImageJ tool. Most of the distribution of particle size is found around 0.05 to 0.20 $\mu\text{m}$ , as shown in Figure 4.74. Moreover, the average particle size of B10, B20, B100, B100E5, and B100E10 is 0.22  $\mu\text{m}$ , 0.21  $\mu\text{m}$ , 0.17 $\mu\text{m}$ , 0.14 $\mu\text{m}$ , and 0.13 $\mu\text{m}$  respectively, as in Figure 4.75. The morphology of particulate matters could be observed obviously from OM and SEM images. The amount of PMs reduces with the increasing biodiesel and ethanol ratio in the blended fuels. Agglomerate particle sizes could be reduced around 30% to 40% for diesel fuel and 20% for B100 by blending ethanol. Therefore, using high oxygenated biofuels, as biodiesel and biodiesel blended with ethanol fuels, in compression ignition engines substantiates that is the alternative solution to reduce particulate matter emissions.

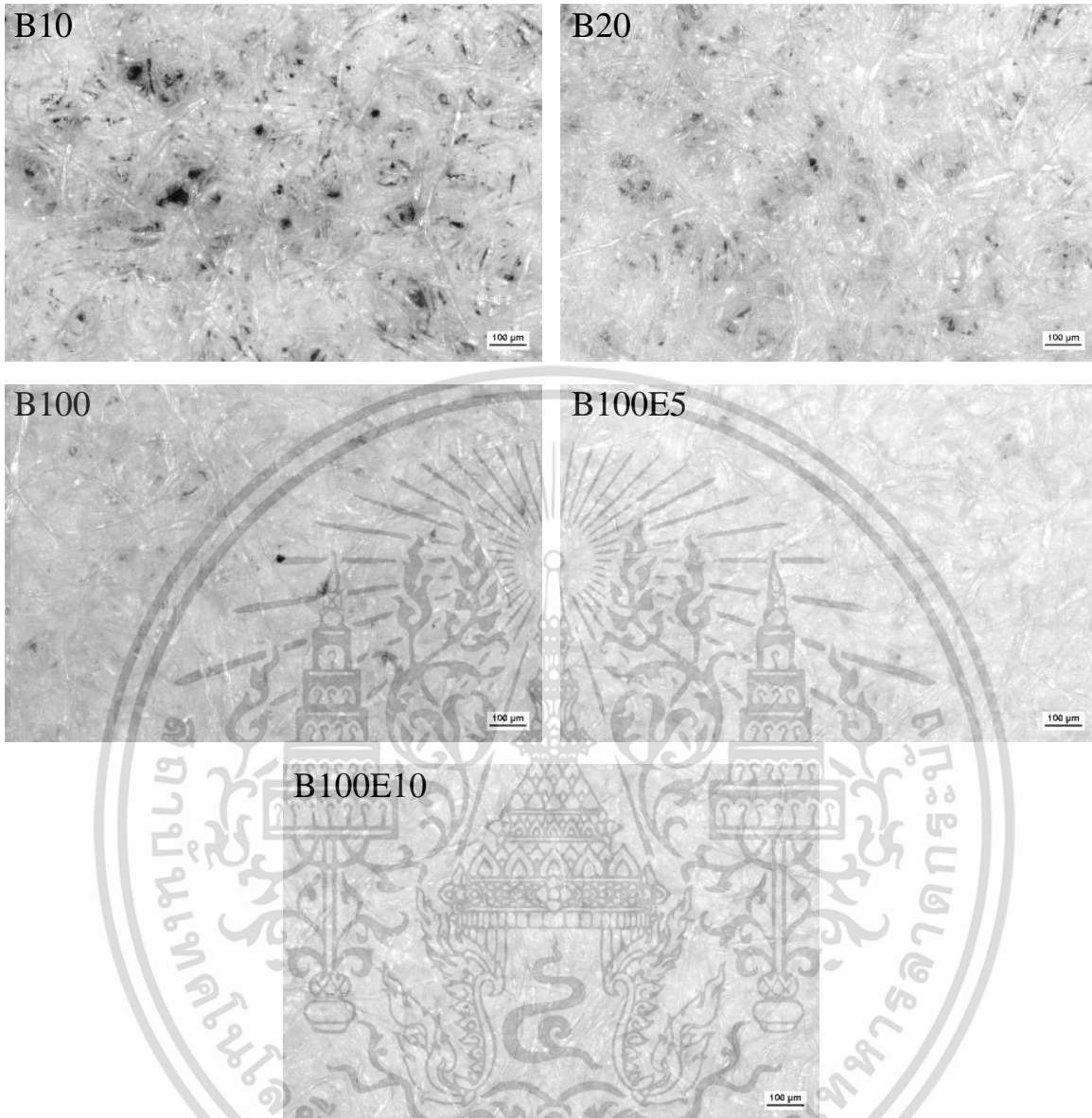


Figure 4.72 Optical microscope images of B10, B20, B100, B100E5, and B100E10

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

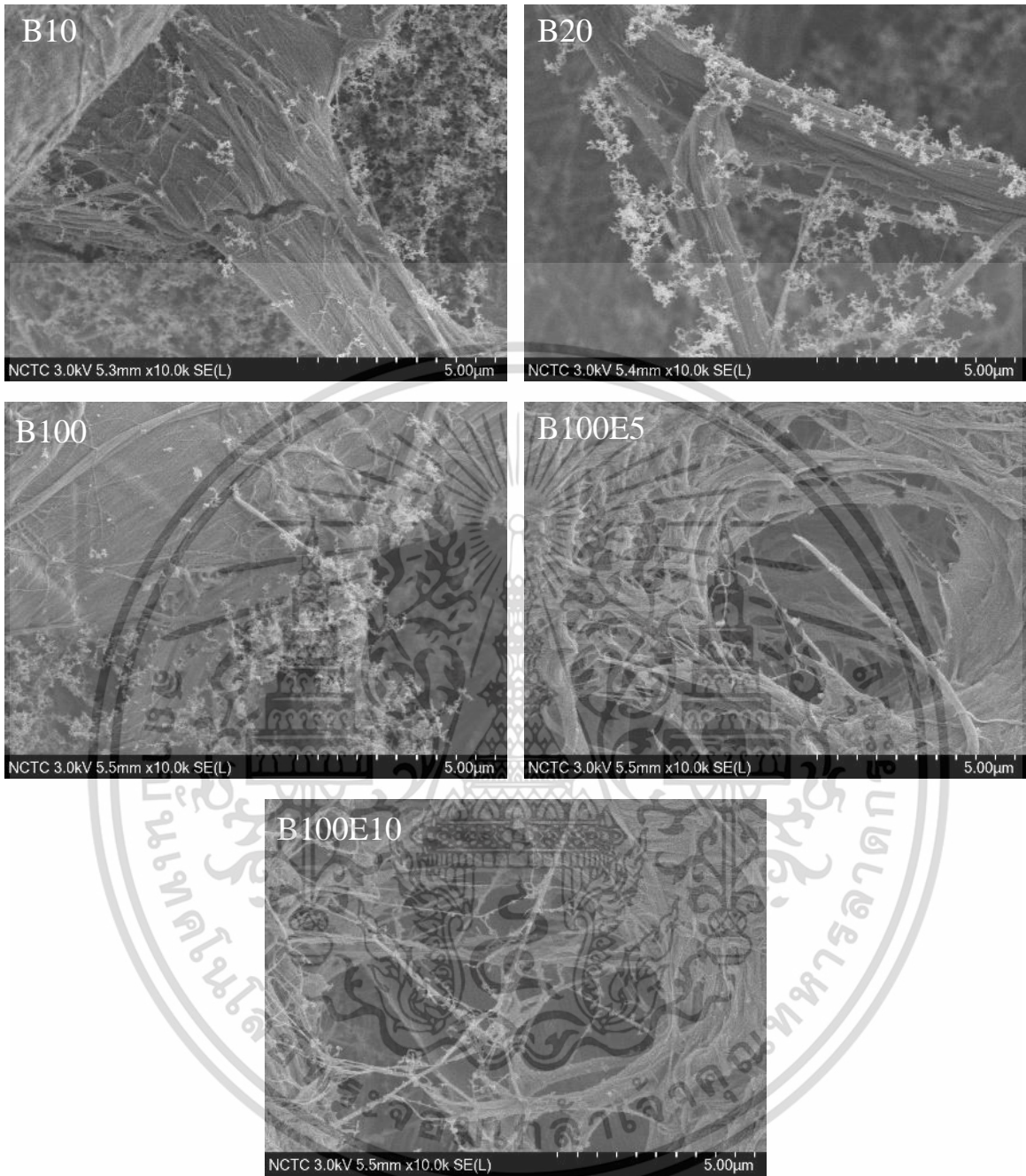


Figure 4.73 Scanning electrical microscope images of B10, B20, B100, B100E5, and B100E10

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

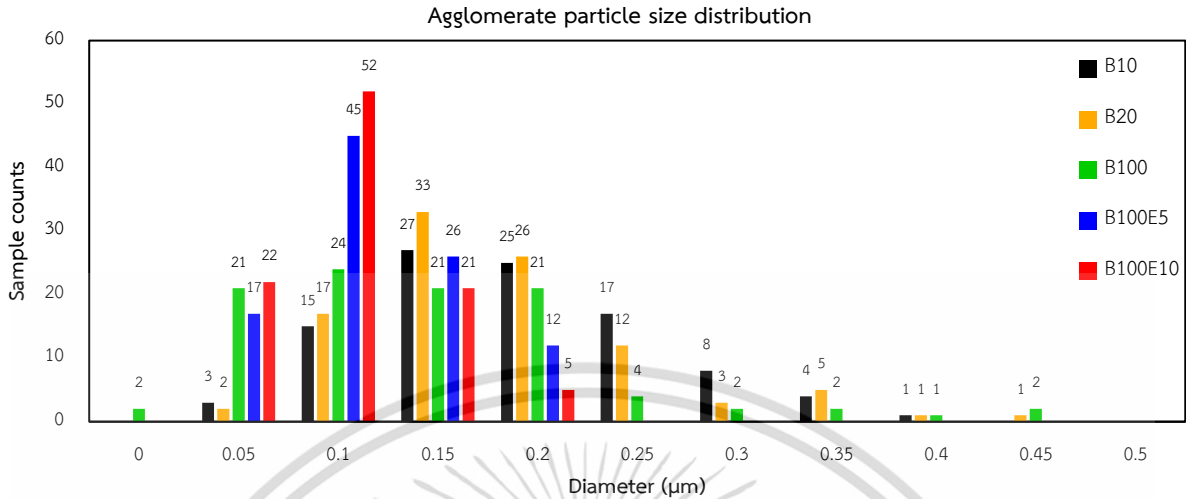


Figure 4.74 Agglomerate particle size distribution of B10, B20, B100, B100E5 and B100E10

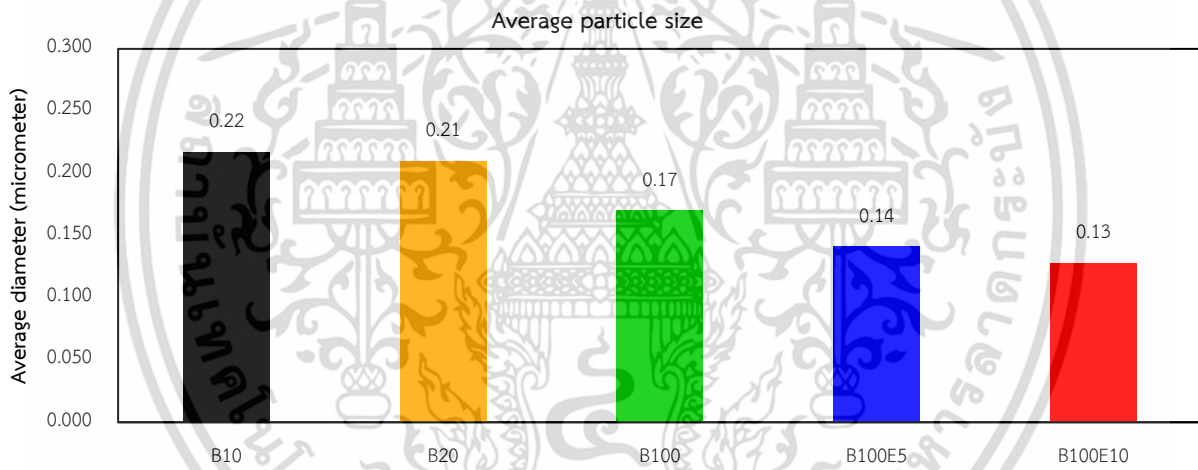


Figure 4.75 Average particle size of B10, B20, B100, B100E5 and B100E10

## 4.2 Diesel vehicle test

Realtime measurement of particulate number (PN) and emitted emission shows in **Figure 4.76 to 4.80**. PN and emitted emissions are related to acceleration and deceleration patterns. They are higher when pushing the acceleration until a steady paddle and lower when the deceleration period. The amount of particulate matter of biodiesel and biodiesel blended with ethanol fuel is lower than diesel fuels throughout the test cycle in the case of with and without the DOC system. It decreases by around 40% in urban driving and highway driving cycle.

Figures 4.81 and 4.82 show the results of particulate number and particulate mass emission as known in PN and PM. PN and PM are emitted higher during urban driving than highway driving because the vehicle runs at a lower vehicle speed. Hereby, it expects that the engine ran in the rich combustion and cold engine than the higher vehicle speed. So, PN and PM are decrease by around 30% to 40% when using biodiesel and biodiesel blended with ethanol in the case of with and without the DOC system. All PM masses are emitted under Euro 4 to Euro 5 standard around 40 to 50 mg/km. Table 4.1 shows the SEM images that resulted from PM mass measurement. The different PM masses from the different fuels could be compared with the SEM images in the magnifications of 10,000x to show how the PM agglomerates are affected in both cases of with and without DOC system.

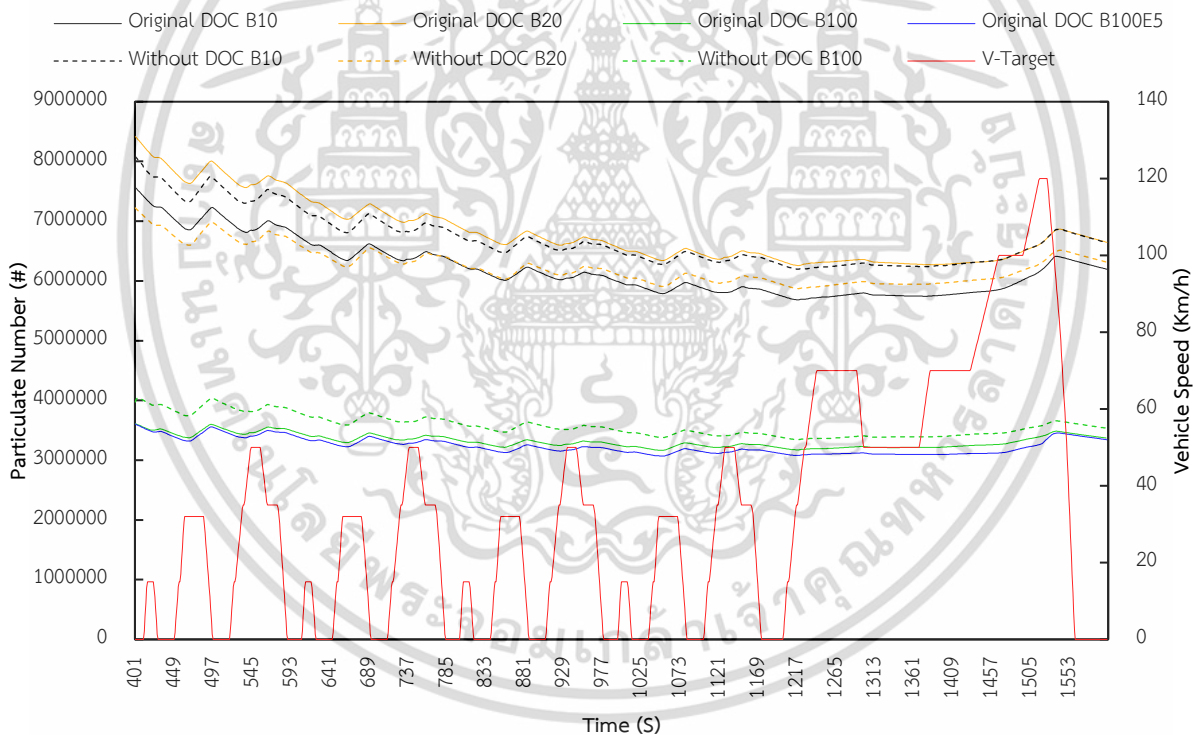


Figure 4.76 Realtime measurement of particulate number of diesel vehicle

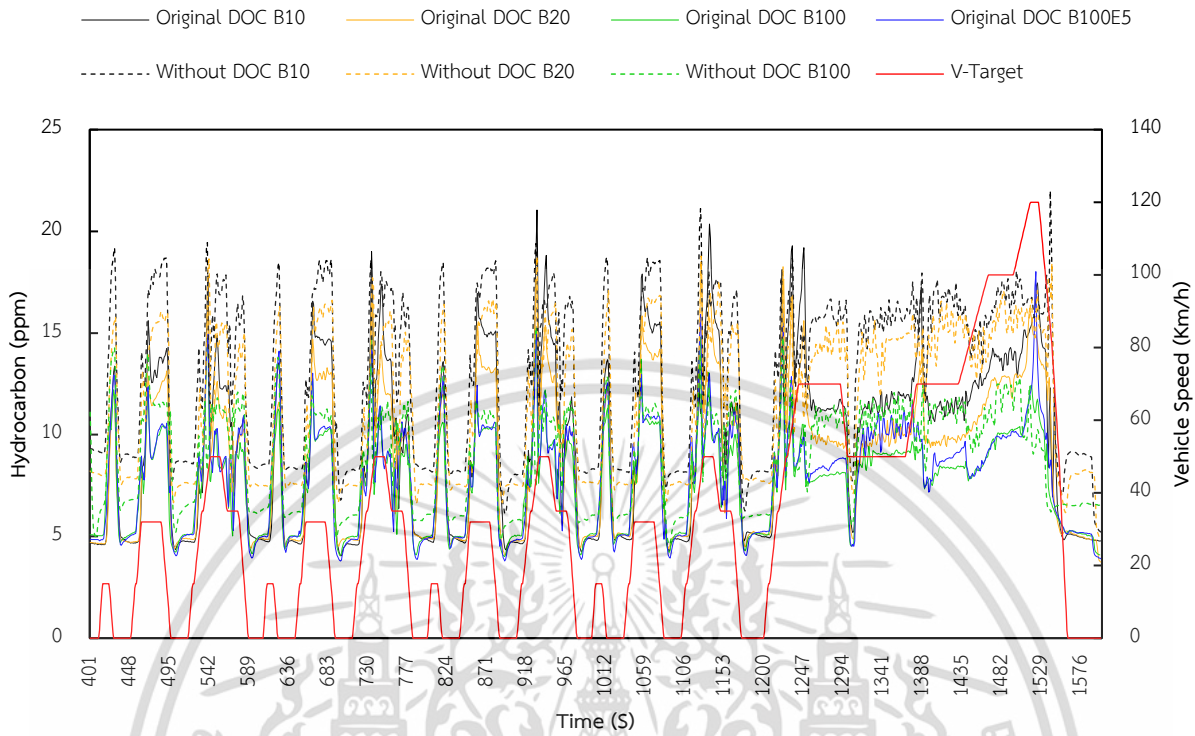


Figure 4.77 Realtime measurement of hydrocarbon emission of diesel vehicle

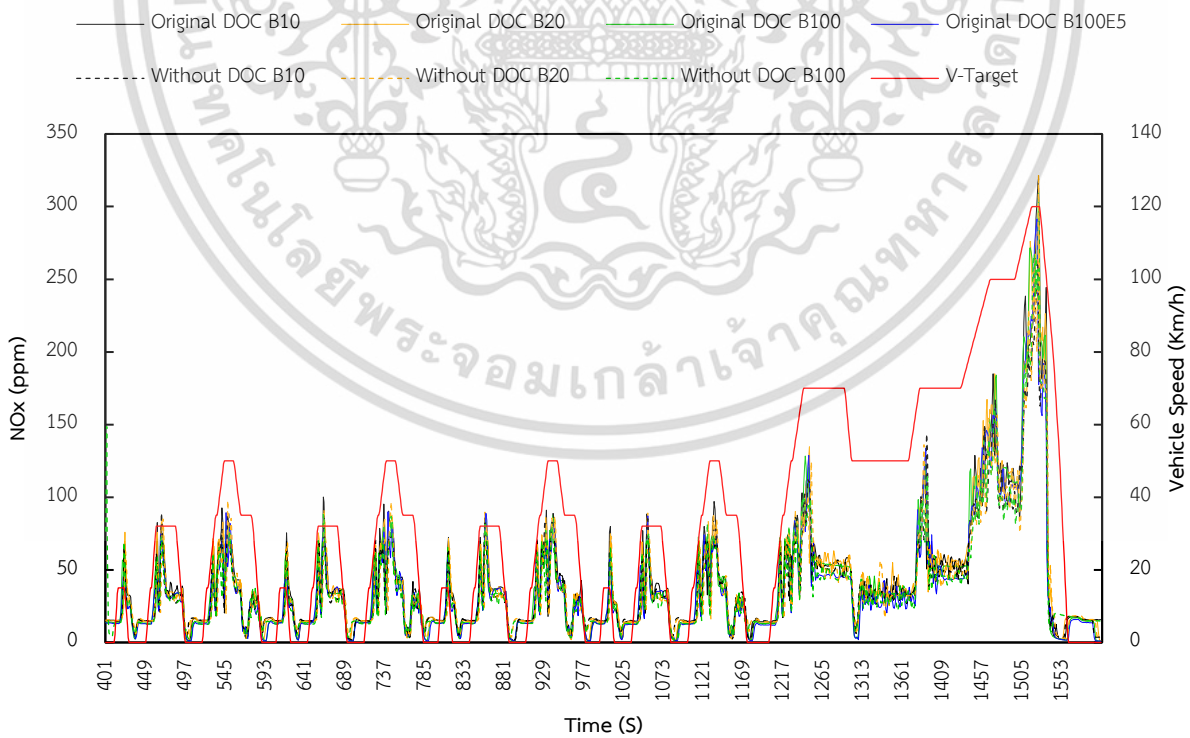


Figure 4.78 Realtime measurement of NOx emission of diesel vehicle

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

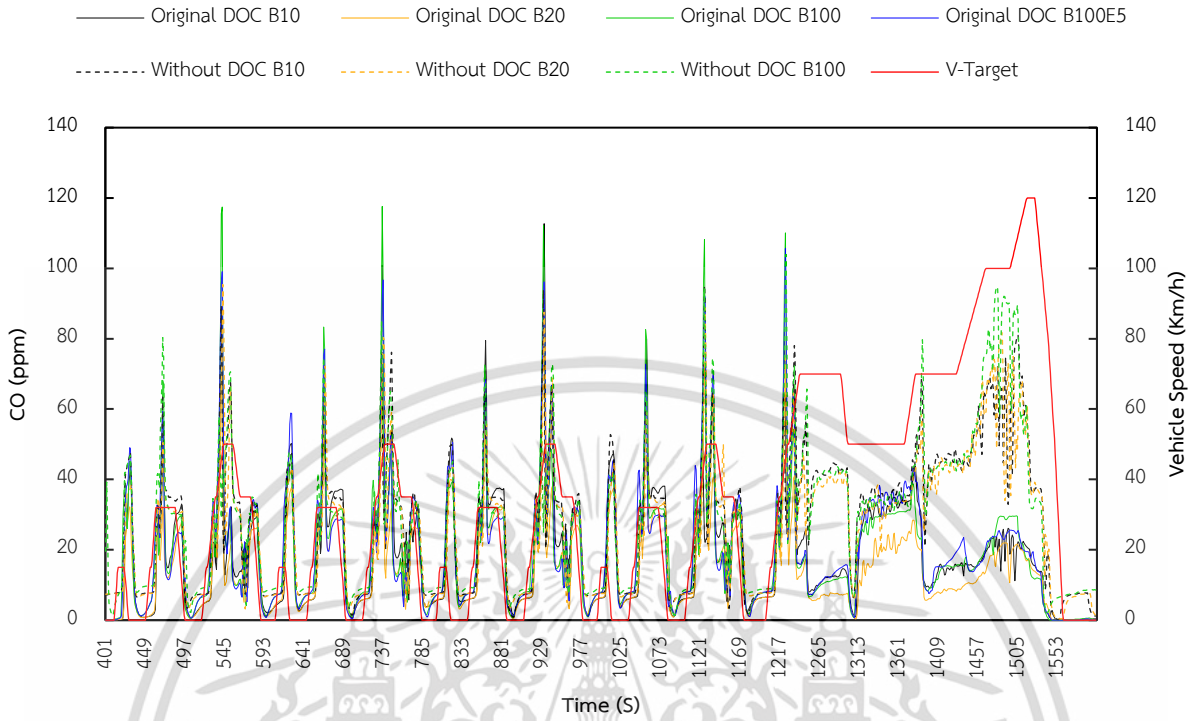


Figure 4.79 Realtime measurement of carbon monoxide emission of diesel vehicle

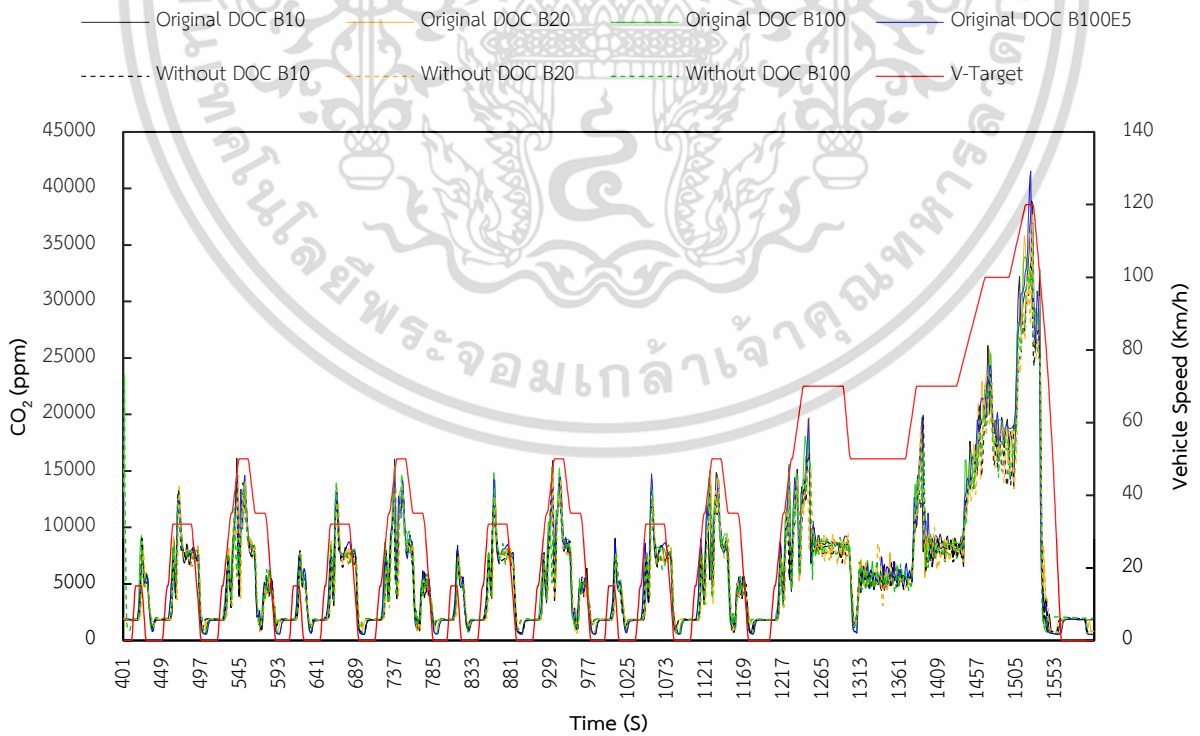


Figure 4.80 Realtime measurement of carbon dioxide emission of diesel vehicle

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

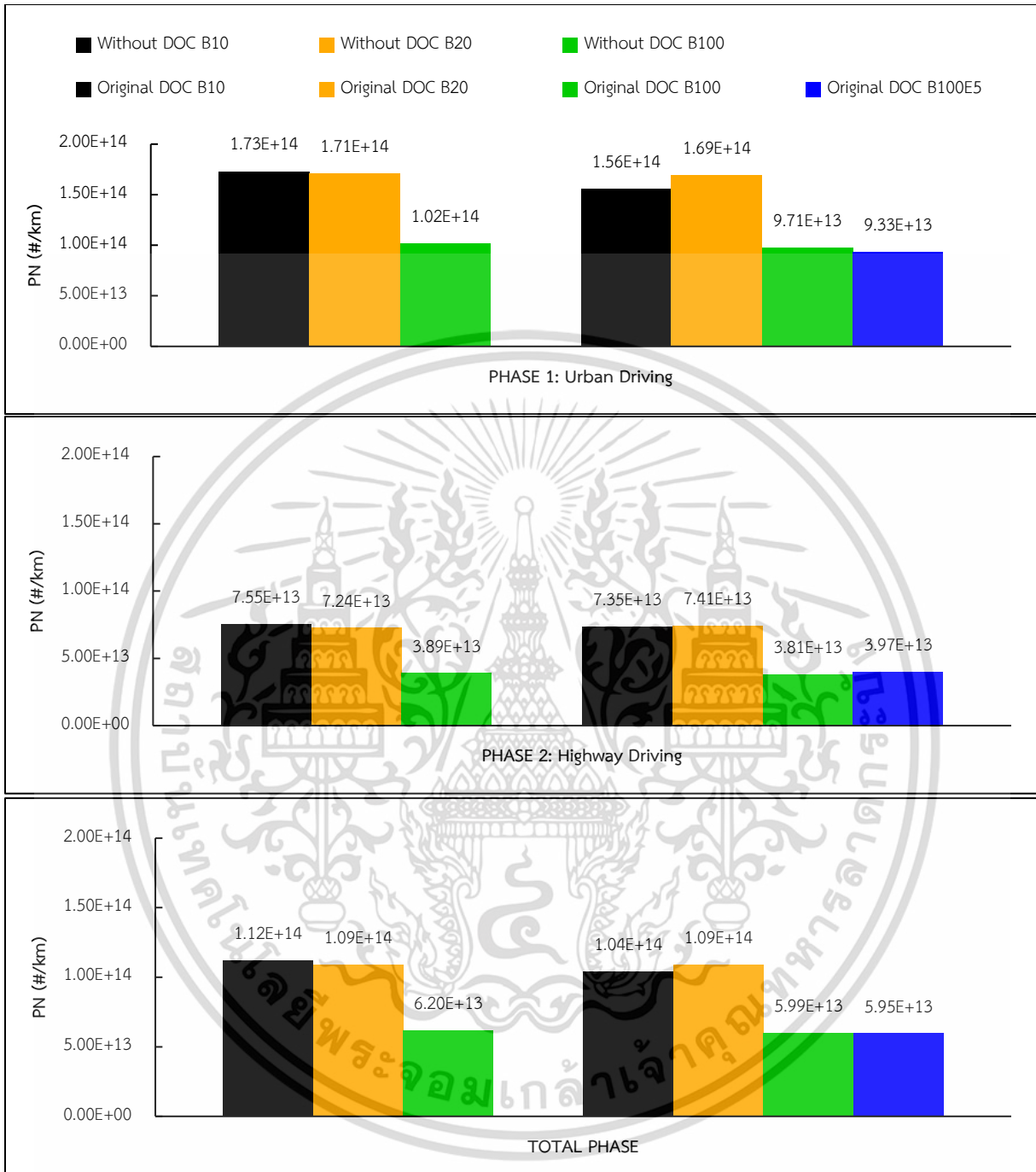


Figure 4.81 Particulate matter number of diesel vehicle

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

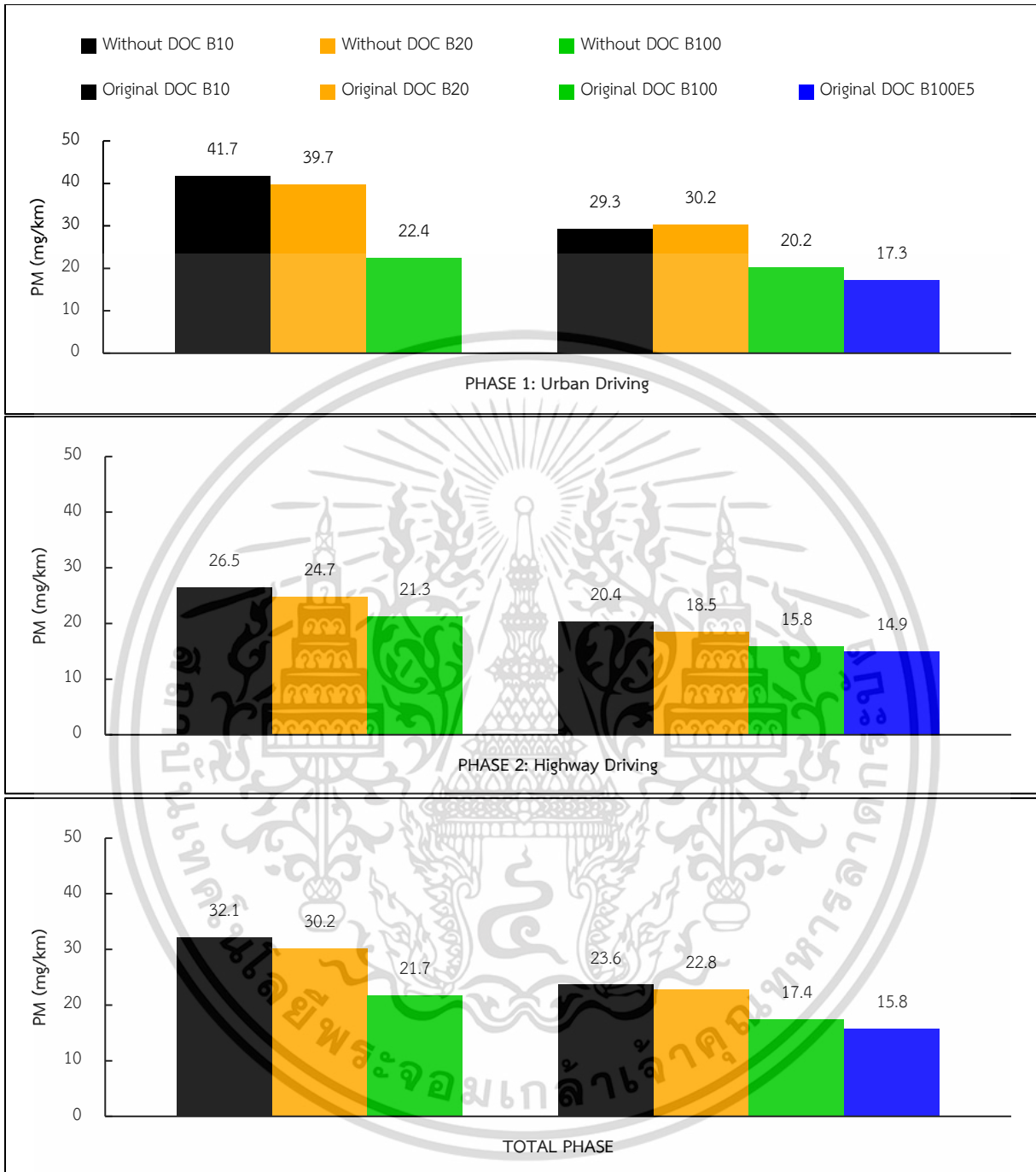

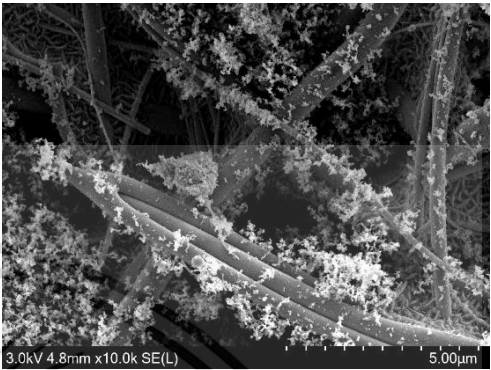
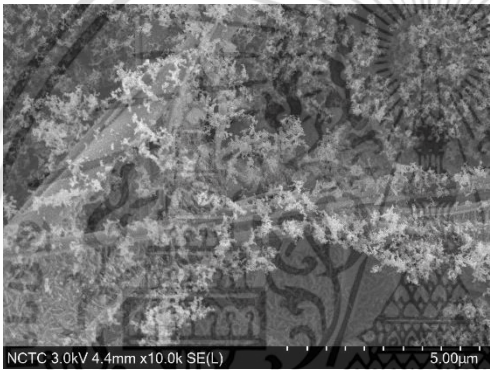
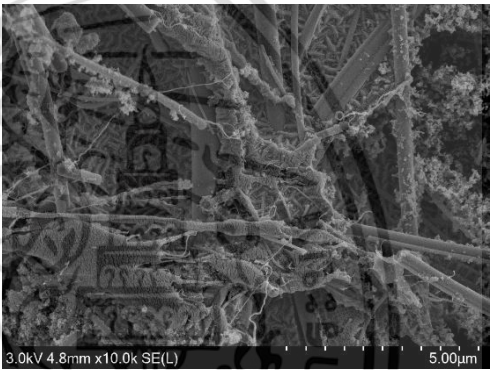

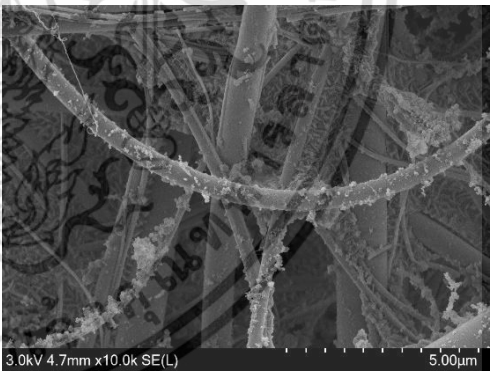
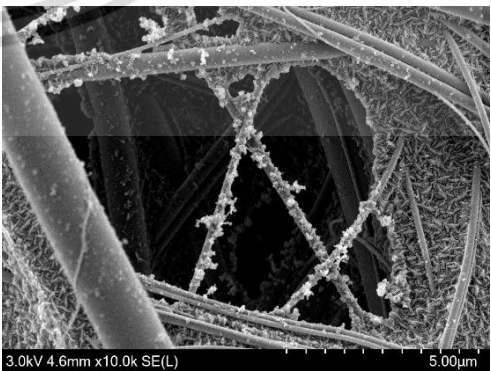


Figure 4.82 Particulate matter mass of diesel vehicle

**Table 4.1** SEM images of fuel trapped on filter papers for measured the PM mass

Fuel	Without DOC system	Original DOC system
B10		
B20		
B100		
B100E5		

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

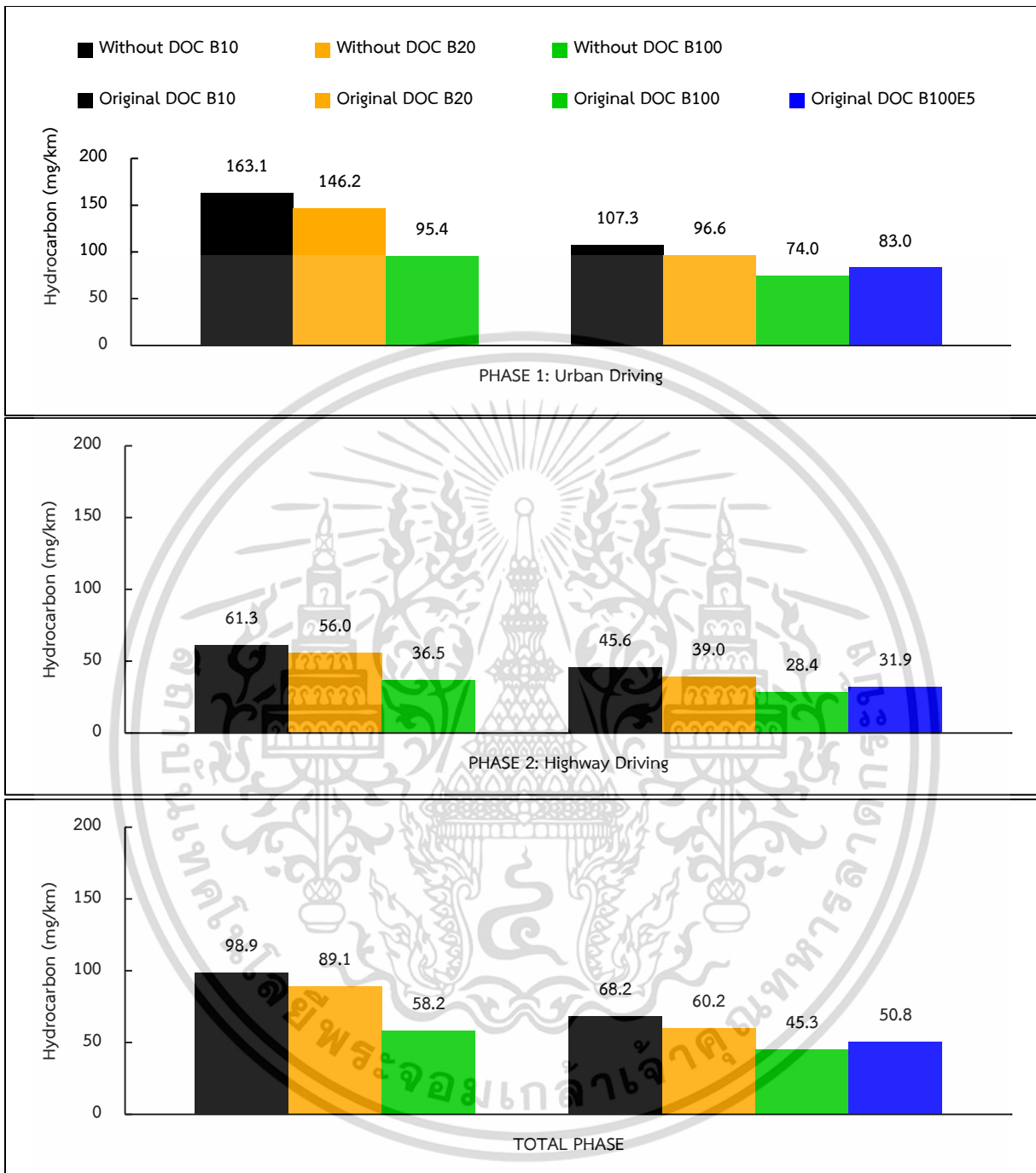


Figure 4.83 Hydrocarbon emission of diesel vehicle

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

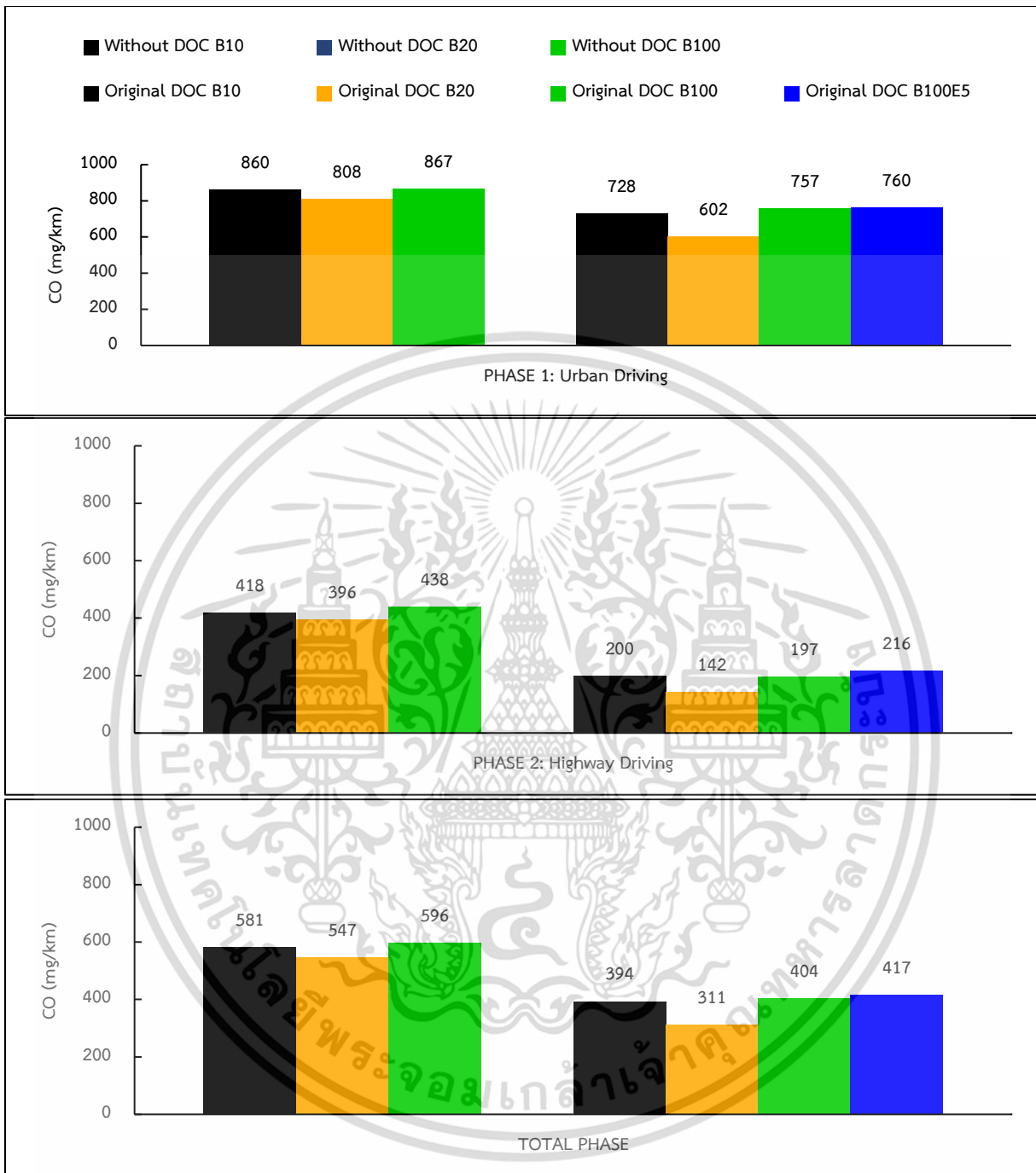


Figure 4.84 Carbon monoxide emission of diesel vehicle

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

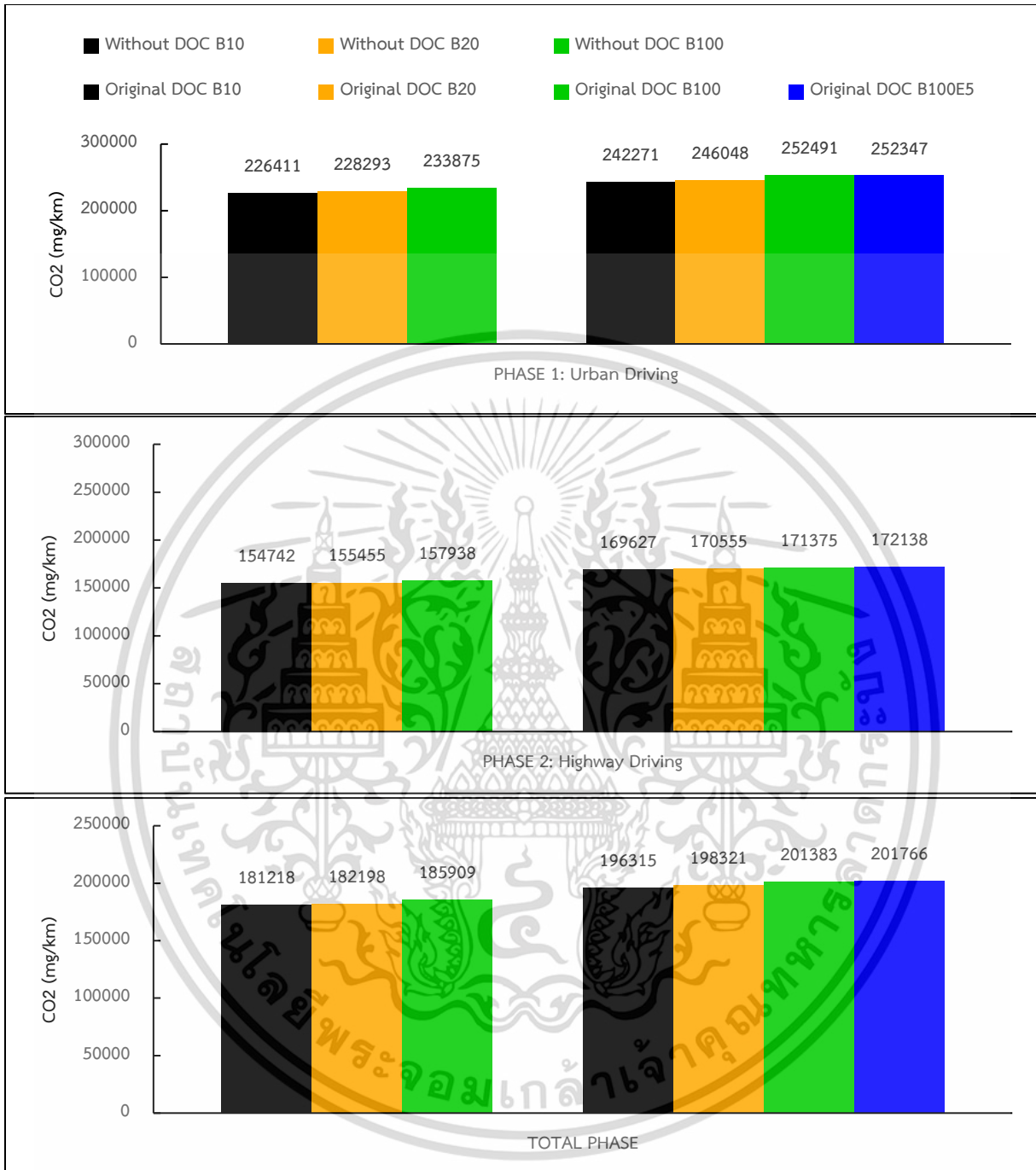


Figure 4.85 Carbon dioxide emission of diesel vehicle

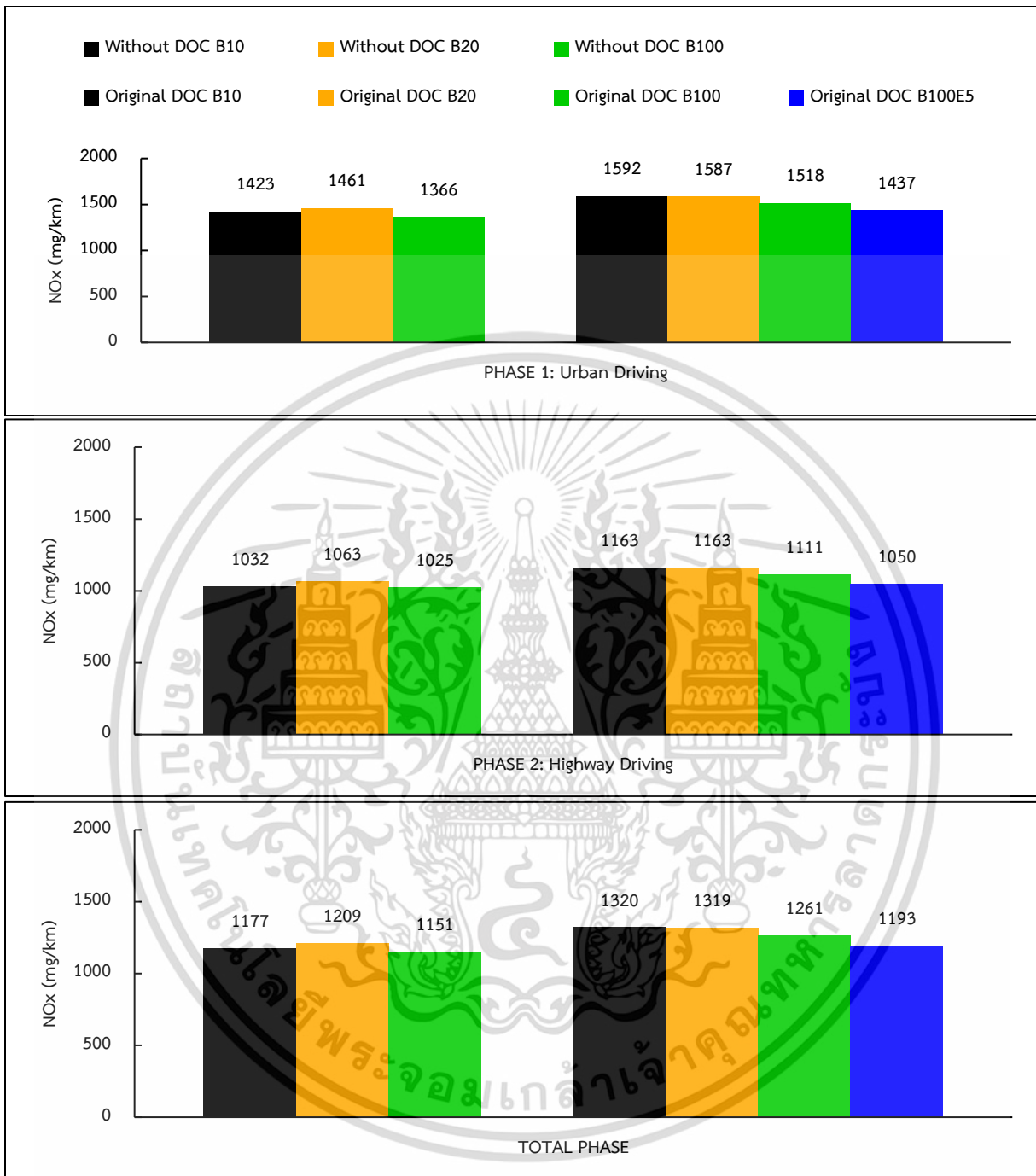


Figure 4.86 NOx emission of diesel vehicle

Hydrocarbon emission in Figure 4.83 is decreased with increasing the biodiesel and ethanol blended into the fuels by around 10% for B20, 30% for B100, and 26% for Blended ethanol fuels compared to B10. Carbon monoxide emission in Figure 4.84 is not significantly different emitted on the different fuels. The carbon monoxide emission is emitted under Euro 3

(800 mg/km) for Urban Driving and Euro 5 (630 mg/km) for Highway Driving. Carbon dioxide in **Figure 4.85** is slightly increased when using biodiesel and biodiesel blended with ethanol fuel by increasing around 3% when compared biodiesel and biodiesel blended with ethanol fuel with diesel fuel. It expects that more complete combustion and corresponds to the trend that observe in hydrocarbon emission. NOx emission in **Figure 4.86** is not significantly different on the different fuels in both case of with and without doc system. All NOx emission are emitted higher than Euro 3 standard (650 mg/km) in all driving cycle.



## CHAPTER 5

### CONCLUSION

This research investigated the influence of diesel, biodiesel, and biodiesel blended with ethanol fuels on the diesel engine and the diesel vehicle. The diesel engine test was tested on an engine dynamometer and performed at variable engine loads of 56, 84, 112, and 140 Nm at a constant engine speed of 1000, 1500, and 2000 rpm. The diesel engine test observed the combustion characteristics, engine performance, and emissions.

As the results of the diesel engine test, the combustion characteristics show that with increasing biodiesel concentration, the combustion has a shorter ignition delay period because of the higher cetane number. The heat release rate is lower than diesel fuel, while it is not significantly different in the combustion pressure and cumulative heat release. With a higher blended ethanol ratio, the ignition delay period is longer and better atomization, affecting the better combustion process. As shown in a higher combustion pressure, cumulative heat release, and heat release rate. The engine performances show that the indicated specific fuel consumption is increased by around 18% for pure biodiesel fuel and 12% for blended ethanol fuel compared to diesel fuel. The brake specific fuel consumption of blending ethanol fuel increased by around 18% for diesel fuel and 2% for pure biodiesel fuel. The indicated specific energy consumption is decreased by blending ethanol around 6% to 8% compared to diesel and biodiesel fuel. The brake specific energy consumption is not significantly different. The indicated thermal efficiency increased with blending ethanol fuel by around 5% to 8% compared to diesel and biodiesel fuel. While brake thermal efficiency is not significantly different. The emissions show that the smoke intensity is reduced by increasing biodiesel concentration to around 20% for B20 and 70% for B100 compared to B10. Blending ethanol could reduce the smoke intensity by around 90% for diesel fuels and 70% for pure biodiesel fuel. NO<sub>x</sub> emission increases with a higher ethanol concentration by around 60% for diesel fuel and 70% for pure biodiesel fuel. Carbon monoxide emission decreases with blending ethanol fuel by around 50% for diesel fuel and 25% for pure biodiesel fuel. Carbon dioxide emission decreases with blending ethanol fuel by around 10% to 12% for diesel and biodiesel fuel. The agglomerate particle size of blended ethanol fuel is reduced by around 30% to 40% for diesel fuel and 20% for pure biodiesel.

Furthermore, the diesel vehicle test was tested on a chassis dynamometer with the virtual driving cycle based on the New European Driving Cycle. The diesel vehicle test investigated the emitted emissions in the urban driving and highway driving cycle. As the results of the diesel vehicle test, the emission reduction shows that particulate number and particulate mass are decreased by around 30% to 40% when using biodiesel and biodiesel blended with ethanol fuel in both cases with and without the DOC system.

The advantage of blending ethanol could improve combustion and emission reduction. Ethanol has the properties such as lower cetane number, shorter evaporation duration, and higher burning rate. By shorter evaporation duration indicates a higher vaporization rate and better combustible mixture formation. A lower cetane number indicates a longer ignition delay period which affects to increase in the accumulated premixed fuel. And higher burning rate indicates a shorter combustion duration in the higher amount of fuel which results in higher combustion pressure. The above reasons affect increasing the combustion pressure, heat release rate, and cumulative heat release as shown in the experimental results. From higher combustion pressure which is related to the indicated power and from lower specific energy consumption. Resulting in the higher indicated thermal efficiency. The higher indicated thermal efficiency indicates better combustion resulting in lower emissions.

Finally, the results of this research show that using biodiesel and biodiesel-ethanol blended fuel in the proper proportion could be reduced particulate matter emissions by 30% to 40% compared to diesel fuels. The suitable blending fraction is approximately 10% of ethanol into pure biodiesel fuel because the viewpoint of specific energy consumption and thermal efficiency of blending ethanol approximately 5% to 10% is not significantly different. While the emissions and the agglomerate particle size decrease by around 10%.

## REFERENCES

- [1] Key world energy statistics. Int. Eng. Agency (IEA), 2020, <https://www.iea.org/reports/key-world-energy-statistics-2020>.
- [2] Key energy statistics, Thailand. Int. Eng. Agency (IEA), 2019, <https://www.iea.org/countries/thailand>
- [3] Energy Balance of Thailand Report, 2020, [https://www.dede.go.th/ewt\\_news.php?nid=47340](https://www.dede.go.th/ewt_news.php?nid=47340).
- [4] C. ChooChuay, S. Pongpiachan, D. Tipmanee, O. Suttinun, W. Deelaman, Q. Wang, L. Xing, G. Li, Y. Han, J. Palakun and J. Cao, "Impacts of PM2.5 sources on variations in particulate chemical compounds in ambient air of Bangkok, Thailand.", *Atmospheric Pollution Research*, Vol. 11(9), pp. 1657-1667, 2020.
- [5] Zielinska, B., Sagebiel, J., Arnott, W. P., Rogers, C. F., Kelly, K. E., Wagner, D. A., ... & Palmer, G. (2004). Phase and size distribution of polycyclic aromatic hydrocarbons in diesel and gasoline vehicle emissions. *Environmental Science & Technology*, 38(9), 2557-2567.
- [6] May, A. A., Nguyen, N. T., Presto, A. A., Gordon, T. D., Lipsky, E. M., Karve, M., ... & Robinson, A. L. (2014). Gas-and particle-phase primary emissions from in-use, on-road gasoline, and diesel vehicles. *Atmospheric Environment*, 88, 247-260.
- [7] R. Zhu, C. S. Cheung, Z. Huang and X. Wang, "Regulated and unregulated emissions from a diesel engine fueled with diesel fuel blended with diethyl adipate," *Atmospheric Environment*, vol. 45, p. 2174–2181, April 2011.
- [8] P. Verma, S. Stevanovic, A. Zare, G. Dwivedi, T. C. Van, M. Davidson, T. Rainey, R. J. Brown and Z. D. Ristovski, "An Overview of the Influence of Biodiesel, Alcohols, and Various Oxygenated Additives on the Particulate Matter Emissions from Diesel Engines," *Energies*, vol. 12, p. 1987, May 2019.
- [9] Proctor, C. Lafayette and Armstrong, Lloyd Van Horn (2021, February 21), diesel engine, *Encyclopedia Britannica*, <https://www.britannica.com/technology/diesel-engine>

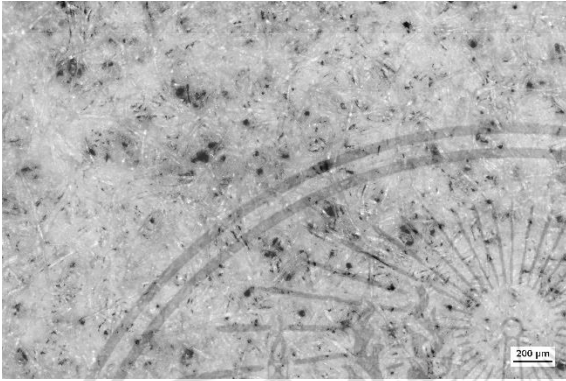

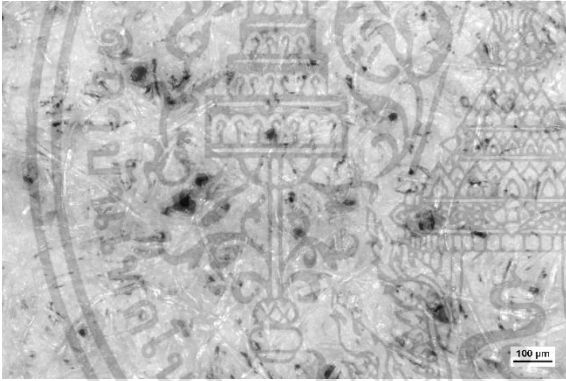
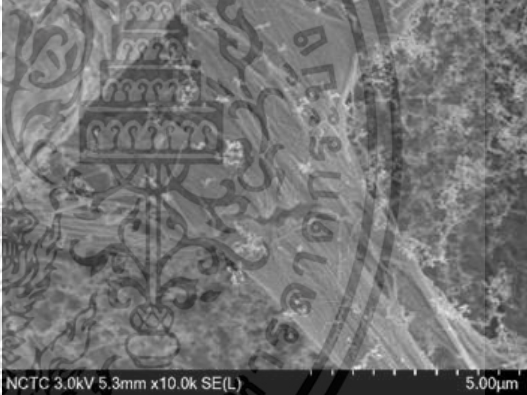

- [10] J. Heywood, Internal Combustion Engine Fundamentals 2E, McGraw Hill Professional, 2018.
- [11] Dec, J. (1997). A conceptual model of DI diesel combustion based on laser-sheet imaging. SAE Paper No. 970873.
- [12] Industry Outlook 2021-2023: Biodiesel, 2021, <https://www.krungsri.com/en/research/industry/industry-outlook/Energy-Utilities/Biodiesel/IO/io-biodiesel-21>
- [13] Biodiesel, 2016, <http://www.bangchakbiofuel.co.th/products/biodiesel>
- [14] S. H. Yoon and C. S. Lee, "Experimental investigation on the combustion and exhaust emission characteristics of biogas–biodiesel dual-fuel combustion in a CI engine," Fuel Processing Technology, vol. 92, p. 992–1000, May 2011.
- [15] A. Tripatara and P. Karin and W. Phairote and C. Charoenphonphanich and M. Masomtob and N. Chollacoop and H. Kosaka, "Effect of biodiesel on compression ignition engine's combustion behavior and particle emission," Journal of Research and Applications in Mechanical Engineering (JRAME), vol. 8, p. 92–100, 2020.
- [16] M. Lapuerta, J. Rodríguez-Fernández, D. Fernández-Rodríguez and R. Patiño-Camino, "Modeling viscosity of butanol and ethanol blends with diesel and biodiesel fuels," Fuel, vol. 199, p. 332–338, July 2017
- [17] C. Zhan, Z. Feng, W. Ma, M. Zhang, C. Tang and Z. Huang, "Experimental investigation on effect of ethanol and di-ethyl ether addition on the spray characteristics of diesel/biodiesel blends under high injection pressure," Fuel, vol. 218, p. 1–11, April 2018.
- [18] L. Geng, Y. Xie, J. Wang, W. Liu, C. Li and C. Wang, "Experimental and numerical analysis of the spray characteristics of biodiesel–ethanol fuel blends," SIMULATION, vol. 97, p. 703–714, August 2019
- [19] Q. Fang, J. Fang, J. Zhuang and Z. Huang, "Effects of ethanol–diesel–biodiesel blends on combustion and emissions in premixed low temperature combustion," Applied Thermal Engineering, vol. 54, p. 541–548, May 2013.

- [20] C. Sayin, "Engine performance and exhaust gas emissions of methanol and ethanol–diesel blends," *Fuel*, vol. 89, p. 3410–3415, November 2010.
- [21] M. M. Jackson, K. C. Corkwell and C. C. Degroote, "Study of Diesel and Ethanol Blends Stability," in *SAE Technical Paper Series*, 2003
- [22] P. Kwanchareon, A. Luengnaruemitchai and S. Jai-In, "Solubility of a diesel–biodiesel–ethanol blend, its fuel properties, and its emission characteristics from diesel engine," *Fuel*, vol. 86, p. 1053–1061, May 2007.
- [23] A. Chotwichien, A. Luengnaruemitchai and S. Jai-In, "Utilization of palm oil alkyl esters as an additive in ethanol–diesel and butanol–diesel blends," *Fuel*, vol. 88, p. 1618–1624, September 2009.
- [24] M. Tongroon, P. Saisirirat, A. Suebwong, J. Aunchaisri, M. Kananont and N. Chollacoop, "Combustion and emission characteristics investigation of diesel–ethanolbiodiesel blended fuels in a compression-ignition engine and benefit analysis," *Fuel*, vol. 255, p. 115728, November 2019.
- [25] AVL DITEST, 2016, <http://www.avl-hitec.com/getProductById.action?productId=2>
- [26] K. Thakkar, S. S. Kachhwaha, P. Kodgire and S. Srinivasan, "Combustion investigation of ternary blend mixture of biodiesel/n-butanol/diesel: CI engine performance and emission control," *Renewable and Sustainable Energy Reviews*, vol. 137, p. 110468, March 2021.
- [27] R. J. Donahue and D. E. Foster, "Effects of Oxygen Enhancement on the Emissions from a DI Diesel via Manipulation of Fuels and Combustion Chamber Gas Composition," in *SAE Technical Paper Series*, 2000.
- [28] L. Zhu, C. S. Cheung, W. G. Zhang and Z. Huang, "Combustion, performance and emission characteristics of a DI diesel engine fueled with ethanol–biodiesel blends," *Fuel*, vol. 90, p. 1743–1750, May 2011.
- [29] Donahue R, Foster DE. Effects of oxygen enhancement on the emissions from a DI diesel via. Manipulation of fuels and combustion chamber gas composition. *SAE Tec Pap Ser* 2000; No. 2000-01-0512

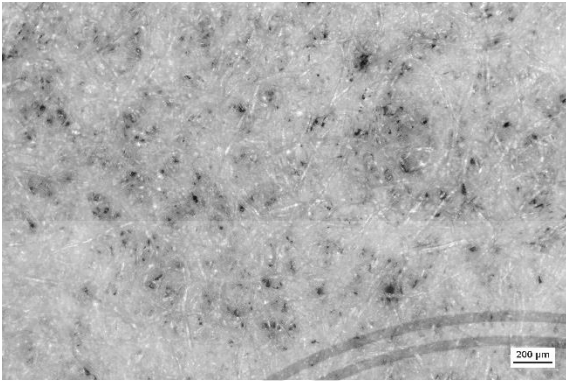


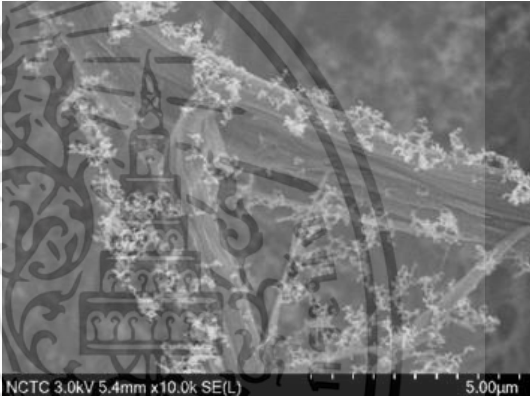

- [30] K. Gopal, R. Karupparai, "Effect of pongamia biodiesel on emission and combustion characteristics of DI compression ignition engine," *Ain Shams Engineering Journal*, 2014.
- [31] H. Kuszewski, A. Jaworski and A. Ustrzycki, "Lubricity of ethanol–diesel blends – Study with the HFRR method", *Fuel*, vol. 208, pp. 491-498, 2017.
- [32] M. Yasin, R. Mamat, A. Yusop, R. Rahim, A. Aziz and L. Shah, "Fuel Physical Characteristics of Biodiesel Blend Fuels with Alcohol as Additives", *Procedia Engineering*, vol. 53, pp. 701-706, 2013.
- [33] Ö. Can, İ. Çelikten and N. Usta, "Effects of ethanol addition on performance and emissions of a turbocharged indirect injection Diesel engine running at different 26 injection pressures," *Energy Conversion and Management*, vol. 45, p. 2429–2440, September 2004.
- [34] Z. Xiao, N. Ladommatos and H. Zhao, "The effect of aromatic hydrocarbons and oxygenates on diesel engine emissions," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 214, p. 307–332, March 2000.
- [35] F. Payri, J. Benajes, J. Arrègle and J. M. Riesco, "Combustion and Exhaust Emissions in a Heavy-Duty Diesel Engine with Increased Premixed Combustion Phase by Means of Injection Retarding," *Oil & Gas Science and Technology*, vol. 61, p. 247–258, March 2006.
- [36] Z. Zhang et al., "Effects of Different Diesel-Ethanol Dual Fuel Ratio on Performance and Emission Characteristics of Diesel Engine", *Processes*, vol. 9, no. 7, p. 1135, 2021.

# APPENDIX A

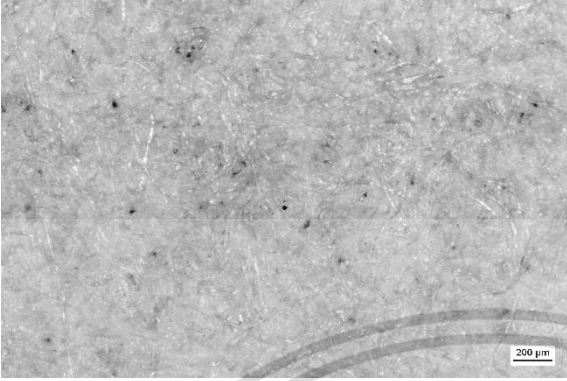


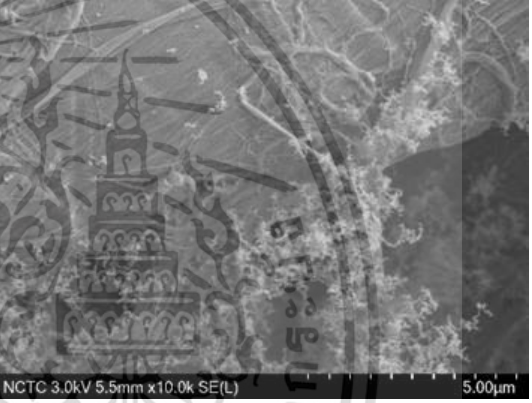

## OPTICAL MICROSCOPE AND SCANNING ELECTRON MIRCROSCOPE

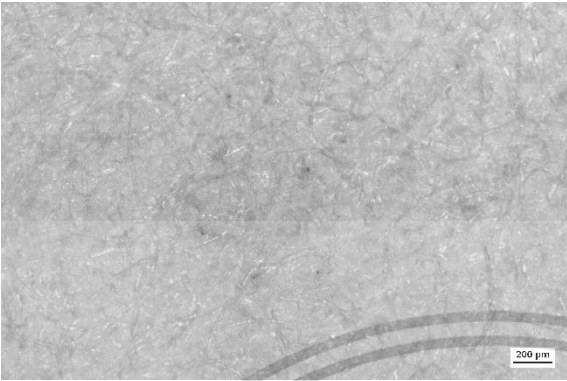


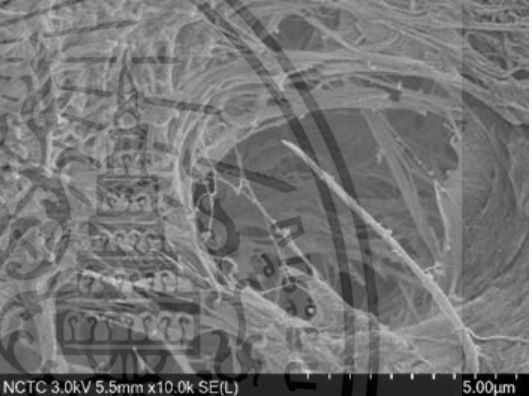

Fuel	Optical Microscope	Scanning Electron Microscope
	 <p data-bbox="467 835 711 869">50x magnification</p>	 <p data-bbox="1024 846 1300 879">1,000x magnification</p>
Diesel B10	 <p data-bbox="467 1297 711 1331">100x magnification</p>	 <p data-bbox="1016 1308 1308 1341">10,000x magnification</p>
	 <p data-bbox="467 1759 711 1793">200x magnification</p>	

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

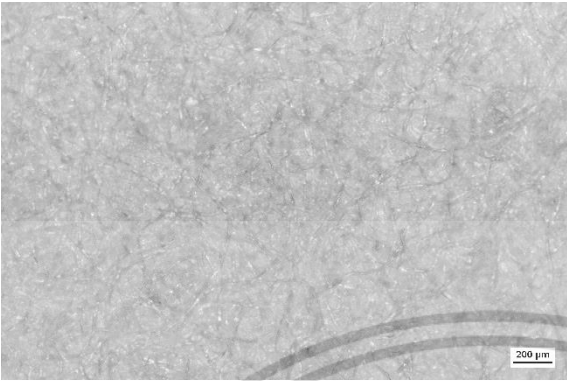
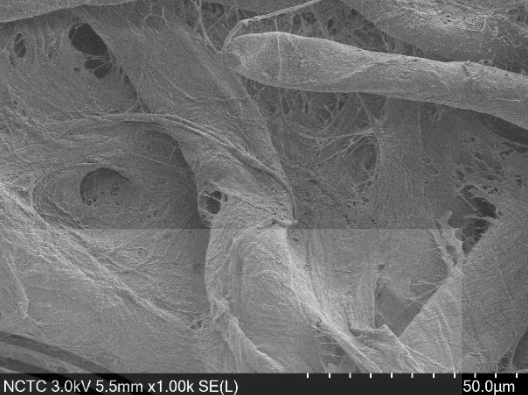

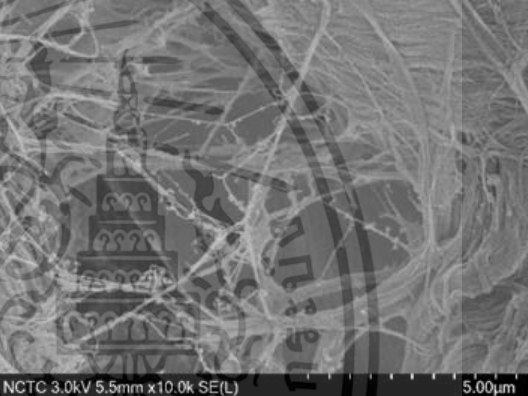

Fuel	Optical Microscope	Scanning Electron Microscope
	 <p data-bbox="467 646 711 682">50x magnification</p>	 <p data-bbox="1024 653 1300 688">1,000x magnification</p>
Diesel B20	 <p data-bbox="467 1108 711 1144">100x magnification</p>	 <p data-bbox="1013 1115 1312 1150">10,000x magnification</p>
	 <p data-bbox="467 1570 711 1606">200x magnification</p>	

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

Fuel	Optical Microscope	Scanning Electron Microscope
	 <p data-bbox="488 653 727 684">50x magnification</p>	 <p data-bbox="1040 663 1325 695">1,000x magnification</p>
Biodiesel B100	 <p data-bbox="480 1115 735 1146">100x magnification</p>	 <p data-bbox="1032 1125 1333 1157">10,000x magnification</p>
	 <p data-bbox="480 1577 735 1608">200x magnification</p>	

Fuel	Optical Microscope	Scanning Electron Microscope
	 <p data-bbox="488 653 727 684">50x magnification</p>	 <p data-bbox="1040 659 1321 690">1,000x magnification</p>
Biodiesel Blended with Ethanol B100E5	 <p data-bbox="480 1115 735 1146">100x magnification</p>	 <p data-bbox="1032 1121 1330 1152">10,000x magnification</p>
	 <p data-bbox="480 1577 735 1608">200x magnification</p>	

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

Fuel	Optical Microscope	Scanning Electron Microscope
	 <p data-bbox="488 646 727 682">50x magnification</p>	 <p data-bbox="1040 653 1323 688">1,000x magnification</p>
Biodiesel Blended with Ethanol B100E10	 <p data-bbox="483 1108 738 1144">100x magnification</p>	 <p data-bbox="1036 1115 1333 1150">10,000x magnification</p>
	 <p data-bbox="483 1570 738 1606">200x magnification</p>	

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า ไม่ว่าจะกรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

# APPENDIX B

## TEST RESULTS



ISO 9001 : 2015 Certified

Focuslab Ltd

		Sample Information	
Customer Code	: 20010	Unit ID /	
Customer Name	: KMITL	Sample Information	: <b>B10</b>
Address	: 3 Moo 2, Chalongkrung Road Ladkrabang Bangkok 10520	Identification	
		Unit type	: FUEL
		Oil type	: DIESEL B10
		Sampling Date	: 22-Jun-21
		Received Date	: 22-Jun-21
Test Code	: 811A		

### Test Report Sample No 21063747

Test Description	Test Method	Test Result	Limit (a)
<b>Appearance</b>			
Color	Visual Inspection	Bright and Clear	Bright and Clear
<b>Diesel Fuel</b>			
Density at 15 C , g/cm <sup>3</sup>	ASTM D4052	0.835	0.81 - 0.87
Cetane Index	ASTM D976	54.9	Min 50
Distillation , C	ASTM D86		
Initial Boiling Point		180.0	
90%vol. Recovered		344.2	Max 357
Flash Point	ASTM D93	66.0	Min 52
Fatty Acid Methyl Ester, %vol	EN 14078	10.2	9 - 10
Pour Point , °C	ASTM D97	0.0	Max 10
<b>Flow Properties</b>			
Viscosity at 40 C , cSt	ASTM D445	3.0	1.8 - 4.1
<b>Cleanliness</b>			
Total Contamination, mg/kg	EN 12662	6.2	Max 24.0
Micro Carbon Residue (MCR) , %mass	ASTM D4530	<0.01	Max 0.3
Ash , %wt	ASTM D482	<0.001	Max 0.010
Total Sulfur Content , mg/kg	ASTM D5453	24.4	Max 50
Water Content , mg/kg	ASTM D6304	691	Max 200
Water and Sediment , %Vol.	ASTM D2709	<0.01	Max 0.05

#### Interpretation of the Test Result

- Test results are based on received fuel sample , submitted and identified by client.
- Data is provided above.

#### Recommendation

- No recommendation for R&D.

#### Remark

- ( a ) Diesel fuel is from Thailand Diesel Specification - MOE - 2563

Tested and Issued By

Kanjana K.  
Lab Technologist

Approved and Authorised by

Somchai J.  
Machine Lubricant Analyst

2/57 Bangna Complex Office Tower, 12 th Fl. , Soi Bangna- Trad 25, North Bangna, Bangna, Bangkok 10260, Thailand  
http://www.focuslab.co.th  
FL-6.7

Tel : ( 66 2 ) 3618600-3 Fax : ( 66 2 ) 3618567

Page 1 of 2

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

Customer Code : 20010  
Customer Name : KMITL  
Address : 3 Moo 2, Chalongkrung Road  
Ladkrabang  
Bangkok 10520

Test Code : 811A

Sample Information

Unit ID / :  
Sample Information : **B10**  
Identification :  
Unit type : FUEL  
Oil type : not given  
Sampling Date : 22-Jun-21  
Received Date : 22-Jun-21



เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

Customer Code : 20010  
Customer Name : KMITL  
Address : 3 Moo 2, Chalongkrung Road  
Ladkrabang  
Bangkok 10520

Unit ID /  
Sample Information : **B20**  
Identification  
Unit type : FUEL  
Oil type : DIESEL B20  
Sampling Date : 22-Jun-21  
Received Date : 22-Jun-21

Test Code : 811A

**Test Report Sample No 21063748**

Test Description	Test Method	Test Result	Limit (a)
<b>Apperance</b>			
Color	Visual Inspection	Bright and Clear	Bright and Clear
<b>Diesel Fuel</b>			
Density at 15 C , g/cm <sup>3</sup>	ASTM D4052	0.827	0.81 - 0.87
Cetane Index	ASTM D976	60.0	Min 50
Distillation , C	ASTM D86		
Initial Boiling Point		177.4	-
90%vol. Recovered		348.4	Max 357
Flash Point	ASTM D93	66.0	Min 52
Fatty Acid Methyl Ester, %vol	EN 14078	22.5	19 - 20
Pour Point , °C	ASTM D97	9.0	Max 10
<b>Flow Properties</b>			
Viscosity at 40 C , cSt	ASTM D445	3.1	1.8 - 4.1
<b>Cleanliness</b>			
Total Contamination , mg/kg	EN 12662	4.2	Max 24.0
Micro Carbon Residue (MCR) , %mass	ASTM D4530	<0.01	Max 0.3
Ash , %wt	ASTM D482	<0.001	Max 0.010
Total Sulfur Content , mg/kg	ASTM D5453	142	Max 50
Water Content , mg/kg	ASTM D6304	1183	Max 300
Water and Sediment , %Vol.	ASTM D2709	<0.01	Max 0.05

**Interpretation of the Test Result**

- Test results are based on received fuel sample , submitted and identified by client.
- Data is provided above.

**Recommendation**

- No recommendation for R&D.

**Remark**

- ( a ) Diesel fuel is from Thailand Diesel Specification - MOE - 2563

Tested and Issued By

Kanjana K.  
Lab Technologist

Approved and Authorised by

Somchai J.  
Machine Lubricant Analyst

Customer Code : 20010  
Customer Name : KMITL  
Address : 3 Moo 2, Chalongkrung Road  
Ladkrabang  
Bangkok 10520

Test Code : 811A

Sample Information

Unit ID /  
Sample Information : **B20**  
Identification :  
Unit type : FUEL  
Oil type : DIESEL B20  
Sampling Date : 22-Jun-21  
Received Date : 22-Jun-21





## Analysis Report

Sample Biodiesel  
Sample owner King Mongkut's Institute of Technology Ladkrabang  
Objective To analyse heating value of combustion  
Instrument Automatic Bomb Calorimeter ; Leco model AC - 500  
Job ID 640707-9246  
Analysis Date July 28, 2021

### Results

Sample name	Heating value of combustion (MJ/kg)		
	#1	#2	Average
Biodiesel B7	45.26	45.24	45.25
Biodiesel B10	45.80	45.46	45.63
Biodiesel B20	44.89	45.01	44.95
Biodiesel B100	39.84	40.03	39.94
Biodiesel B20E5	43.90	43.99	43.95
Biodiesel B20E10	42.66	42.78	42.72
Biodiesel B20E20	40.61	40.45	40.53


  
(Mrs. Aree Limnirandorn)

Analyst

## Analysis Report

Sample Biodiesel and Ethanol  
Sample owner King Mongkut's Institute of Technology Ladkrabang  
Objective To analyse heating value of combustion  
Instrument Automatic Bomb Calorimeter ; Leco model AC - 500  
Analysis Date September 20, 2021  
Results

Sample name	Heating value of combustion (MJ/kg)		
	#1	#2	Average
Biodiesel B10E5	44.37	44.39	44.38
Biodiesel B10E10	43.27	44.03	43.65
Biodiesel B10E20	42.60	41.50	42.05
Biodiesel B100E5	39.21	39.42	39.31
Biodiesel B100E10	37.88	38.25	38.07
Biodiesel B100E20	38.15	38.01	38.08
EthanolE100	27.88	28.22	28.05

  
(Mrs. Aree Limnirandom)  
Analyst

EagerSmart

Method name : CHNS  
Method filename : E:\...\65-002\CHNS.mth

Detection and integration parameters

Time base : (s)  
Peak width : 10  
Peak threshold : 1  
Minimum area : 1500  
Skim ratio : 10  
Next sample to acquire : 19  
Real time plot scale : 10  
Real time plot offset : 0

Time events table

#	Time	Events type	New value
1	.1	Disable integration	
2	35	Enable integration	
3	160	Change peak threshold	.1
4	160	Change skim ratio	1
5	160	Change peak width	40
6	500.3922	Disable integration	

Calculation and report parameters

Calibration method : Linear fit  
Heat Value calc. : No  
CO2 Emission Factor calc. : No  
Protein calc. : No  
Report on : None  
Peak option : Only calibrated peaks  
Report format : Default  
Report publisher : No  
Calibration report : Yes  
Concentration unit :  
Stripchart format : None  
Autoscaling : ---  
Stripchart full scale : 10  
Stripchart scale offset : 0  
Stripchart initial time : 0  
Stripchart end time : 600  
Append for summarize : Element %  
Signal to noise report : Yes  
Signal peak name :  
Noise evaluation from/to : 0.0-0.0(s):

Custom report

Component table

#	Component name	Ret.T.	Window	Min. %	Max. %
1	Nitrogen	47	10		
2	Carbon	67	14		
3	Hydrogen	194	60		
4	Sulphur	412	88		

Calibration factors

#	Component name	Kb	Kc
1	Nitrogen	1995673	0
2	Carbon	4763351	0
3	Hydrogen	1.488643E+07	0
4	Sulphur	2078495	0

Standard table

Sample Num.4 Sample name: STD1 (BBOT 1.5 mg)  
Filename: File004 STD1 (BBOT 1\_5 mg) Std name: BBOT

#	Component name	Concentration	Valid
1	Nitrogen	6.53	Yes
2	Carbon	72.58	Yes
3	Hydrogen	6.1	Yes
4	Sulphur	7.41	Yes

Sample Num.5 Sample name: STD2 (BBOT 2 mg)  
Filename: File005 STD2 (BBOT 2 mg) Std name: BBOT

#	Component name	Concentration	Valid
1	Nitrogen	6.53	Yes
2	Carbon	72.58	Yes
3	Hydrogen	6.1	Yes
4	Sulphur	7.41	Yes

Sample Num.6 Sample name: STD3 (BBOT 2.5 mg)  
Filename: File006 STD3 (BBOT 2\_5 mg) Std name: BBOT

#	Component name	Concentration	Valid
1	Nitrogen	6.53	Yes
2	Carbon	72.58	Yes
3	Hydrogen	6.1	Yes
4	Sulphur	7.41	Yes

Sample Num.7 Sample name: STD4 (BBOT 3 mg)  
Filename: File007 STD4 (BBOT 3 mg) Std name: BBOT

#	Component name	Concentration	Valid
1	Nitrogen	6.53	Yes
2	Carbon	72.58	Yes
3	Hydrogen	6.1	Yes
4	Sulphur	7.41	Yes

Operator ID/info

Operator ID :  
Company name :  
Column type :  
Column length :  
Date packing :  
Comment :



เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้



เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
 ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้



เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้



เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

EagerSmart Summarize Results

Date : 11/08/2021 at 15:52:41

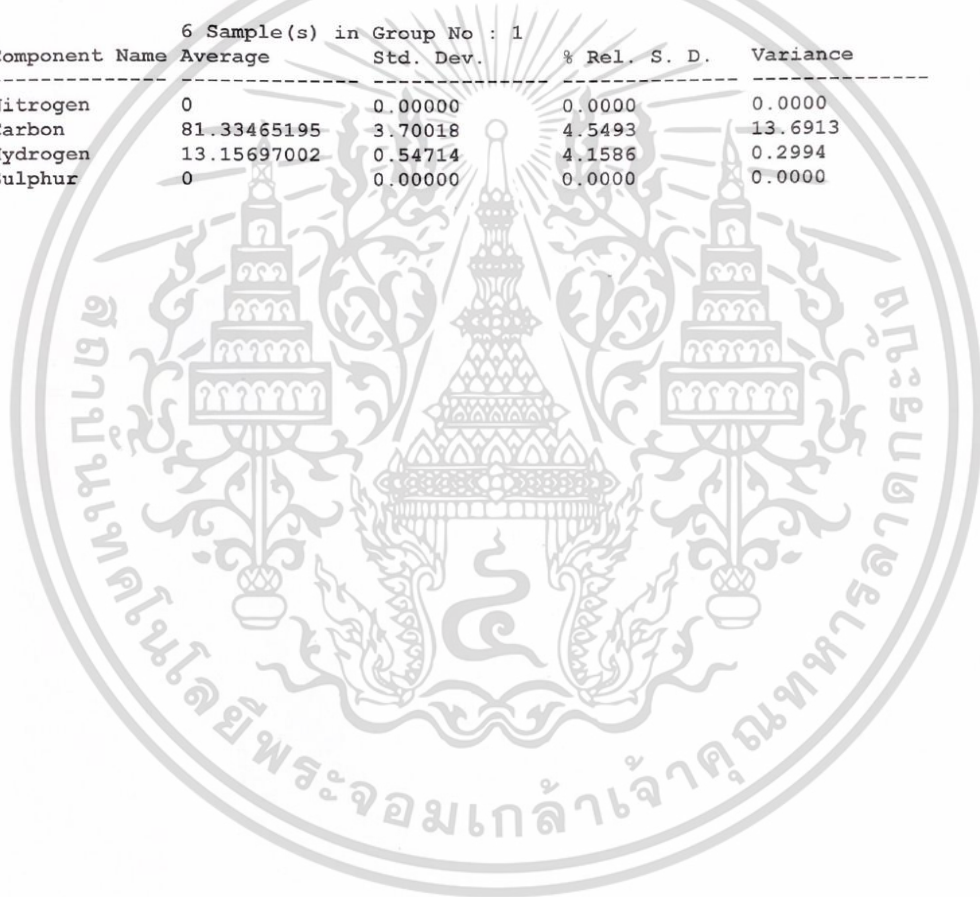
Method Name : CHNS

Method Filename : CHNS.mth

Group No : 1	Element %			
Sample Name	Nitrogen	Carbon	Hydrogen	Sulphur
B100_1	0	76.40828705	12.38687801	0
B100_4	0	77.04006958	12.53007603	0
B20_2	0	82.24542999	13.38155937	0
B20_3	0	82.98455048	13.52551937	0
B10_1	0	84.58450317	13.53221703	0
B10_2	0	84.74507141	13.58557034	0

6 Sample(s) in Group No : 1

Component Name	Average	Std. Dev.	% Rel. S. D.	Variance
Nitrogen	0	0.00000	0.0000	0.0000
Carbon	81.33465195	3.70018	4.5493	13.6913
Hydrogen	13.15697002	0.54714	4.1586	0.2994
Sulphur	0	0.00000	0.0000	0.0000



EagerSmart Summarize Results

Date : 11/08/2021 at 15:52:55

Method Name : CHNS

Method Filename : CHNS.mth

Group No : 1	Element %			
Sample Name	Nitrogen	Carbon	Hydrogen	Sulphur
B100_2	0.05251986906	76.13822174	0	0
B100_3	0.04693116993	76.21728516	0	0

2 Sample(s) in Group No : 1

Component Name	Average	Std. Dev.	% Rel. S. D.	Variance
Nitrogen	0.04972551949	0.00395	7.9472	0.0000
Carbon	76.17775345	0.05591	0.0734	0.0031
Hydrogen	0	0.00000	0.0000	0.0000
Sulphur	0	0.00000	0.0000	0.0000



# APPENDIX C

## PUBLICATION



**RCM & MAMIP 2021**  
Emerging Materials for Future Technology

**1st - 2nd December 2021**  
The 14<sup>th</sup> AUN/SEED-Net Regional Conference on Materials  
&  
The 4<sup>th</sup> International Postgraduate Conference on Materials, Minerals and Polymer

**REGISTER NOW**  
<http://rcmmamip2021.eng.usm.my>

**Conference Secretariat**  
RCM & MAMIP 2021  
School of Materials and Mineral Resources Engineering,  
Engineering Campus, Universiti Sains Malaysia.

[rcmmamip@usm.my](mailto:rcmmamip@usm.my)  
04-5996907

Associate Professor Ir. Ts. Dr. Zuratul Ain Abdul Hamid  
(srzuratulain@usm.my | 04-5996153/017-3320778)  
Associate Professor Ir. Ts. Dr. Anasyida Abu Seman  
(anasyida@usm.my | 04-599 5216)

Dr. Nurazreena Ahmad  
(nurazreena@usm.my | 04-599 6117)  
Mrs. Fauziatun Dahari  
(eefauzia@usm.my | 04-599 6104)

<http://rcmmamip2021.eng.usm.my>

**Post Publication**  
Publication in Materials Today Proceeding indexed by Scopus

**Important Date**

**Abstract Submission Deadline**  
8<sup>th</sup> November 2021

**Notification of Abstract Acceptance**  
12<sup>th</sup> November 2021

**Payment Deadline**  
15<sup>th</sup> November 2021

**Full Paper Submission**  
24<sup>th</sup> November 2021

**Fees**

**Local Student/ Participant**  
RM400

**International Participant**  
USD150

**Who should attend?**  
Local & international delegates, academics, postgraduate students, scientists, researchers, engineers, managers, product developers, business leaders and professionals.

The development of emerging, novel and advanced materials with superior functionalities on design, production and fundamental understanding are evolving rapidly. It has always been of great interest and challenge to tune materials functionalities to meet the demand of current advancement.

This event is packed with talks and discussions from distinguished and renowned speakers globally of various research areas.

The conference covers the following areas but is not limited to:

- Advanced Materials
- Biomaterials
- Nanomaterials
- Functional Materials
- Materials Manufacturing
- Materials Characterization
- Recycling and Waste Management
- Coatings and Surface Engineering

RCM-MAMIP 2021 intends to provide an interdisciplinary and multidisciplinary forum for researchers, industrial professionals, and postgraduates as an avenue to share and discuss their current innovations, issues and challenges faced in the field of emerging materials.

Logos: USM, APEX, AUN/SEED-Net, JICA

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้



Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: [www.elsevier.com/locate/matpr](http://www.elsevier.com/locate/matpr)

## Influence of ethanol biodiesel blends on a diesel engine's efficiency and exhaust emission characteristics

Phobkrit Kanokkhanarat<sup>a,\*</sup>, Preechar Karin<sup>a</sup>, Nattawoot Depaiwa<sup>a</sup>, Veerayut Wongpattharaworakul<sup>a</sup>, Chadchai Srisurangkul<sup>b</sup>, Masaki Yamakita<sup>c</sup>

<sup>a</sup> School of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand

<sup>b</sup> National Metal and Materials Technology Center, National Science and Technology Development Agency, Pathum Thani 12120, Thailand

<sup>c</sup> School of Engineering, Tokyo Institute of Technology, Tokyo 152-8550, Japan

### ARTICLE INFO

Article history:  
Available online xxx

Keywords:  
Biodiesel  
Ethanol  
Diesel engine  
Combustion  
Emissions

### ABSTRACT

The harm caused by polluted air occurs from dust, smoke, or soot. One of the main causes of pollutions is exhaust emission that comes from diesel engines of cars, trucks, buses, heavy machines, or generators for industrial because their thermal efficiency, torque, and performance are higher than the other engines. To reduce the emission from diesel engines, the fuel substitute for biodiesel which is made from based palm oil is one of the alternatives to use. So, the purpose of this paper is an experimental investigation of the engine performance, combustion characteristics, and smoke intensity of commercial biodiesel fuels (B10 and B20), pure biodiesel fuel (B100), and pure biodiesel blended with ethanol fuels (B100E5 and B100E10), which were performed at various loads (56, 84, 112, and 140Nm) and conducted at constant engine speeds (1000, 1500, and 2000 rpm). The experimental results show that pure biodiesel fuel (B100) and pure biodiesel blended with ethanol fuels (B100E5 and B100E10) have engine performance and combustion characteristics similar to commercial biodiesel fuels (B10 and B20). However, pure biodiesel fuels (B100) and pure biodiesel blended with ethanol fuels (B100E5 and B100E10) can reduce the emissions as the smoke intensity from commercial biodiesel (B10 and B20) is more than 50%.

Copyright © 2022 Elsevier Ltd. All rights reserved.

Selection and peer-review under responsibility of the 14th AUN/SEED-Net Regional Conference on Materials and 4th International Postgraduate Conference on Materials, Minerals and Polymer (RCM & MAMIP 2021).

### 1. Introduction

A diesel engine is widely used in industry, agriculture, and transportation, resulting in high diesel fuel usage. Because it is one of the highest thermal efficiency engines among internal combustion engines. However, diesel engines have the disadvantage of emitting a lot of pollution, which causes global pollution or particulate matter (PM), which is directly harmful to human health [1]. Therefore, much research studied alternative fuels derived from renewable sources, such as biodiesel which has physical properties similar to diesel fuel. It can use by unnecessary to modify the engine. Previous research discovered that biodiesel derived from palm has slightly different combustion characteristics from diesel fuel due to its high cetane number, higher viscosity, and higher density, including a lower calorific value. Which results in a shorter

ignition timing delay. Furthermore, the engine has been designed by the manufacturer to be more suitable for diesel fuel than biodiesel fuel. When using biodiesel fuel, the start of combustion process begins before the optimum setup point. This has an effect on heat release rate and thermal efficiency reduces. However, the advantages of biodiesel can reduce engine emissions when compared to diesel fuel [2,3].

Another alternative fuel derived from agricultural products is ethanol. There is an approximate amount of oxygen mixed in, 34% by weight. The ethanol's properties have a low viscosity density, allowing for efficient atomization, including the low cetane number [4]. Previous research discovered biodiesel blended with ethanol. It was observed that biodiesel blended with ethanol is better atomized while injecting fuel [5,6]. There is an increase in the duration of the ignition delay when biodiesel was blended with ethanol at various ratios because of the low cetane number of the ethanol. The longer premixed duration and higher oxygen content in the biofuel result in more complete combustion and the

\* Corresponding author.

E-mail address: [k.phobkrit@gmail.com](mailto:k.phobkrit@gmail.com) (P. Kanokkhanarat).

<https://doi.org/10.1016/j.matpr.2022.06.532>

2214-7853/Copyright © 2022 Elsevier Ltd. All rights reserved.

Selection and peer-review under responsibility of the 14th AUN/SEED-Net Regional Conference on Materials and 4th International Postgraduate Conference on Materials, Minerals and Polymer (RCM & MAMIP 2021).

Please cite this article as: P. Kanokkhanarat, P. Karin, N. Depaiwa et al., Influence of ethanol biodiesel blends on a diesel engine's efficiency and exhaust emission characteristics, Materials Today: Proceedings, <https://doi.org/10.1016/j.matpr.2022.06.532>

start of the combustion process being close to the optimum setup point, resulting in lower exhaust emissions [7].

The goal of this study is to observe the impact of biodiesel (B10 and B20), pure biodiesel (B100), and biodiesel blended with ethanol (B100E5 and B100E10) on soot emissions and thermal efficiency. The process of comparing engine performance such as thermal efficiency, specific fuel consumption, specific energy consumption, and combustion characteristics such as heat release rate by using an unmodified engine. As well as an analysis of the soot emission at various engine loads (56, 84, 112, and 140 Nm) and constant engine speeds (1000, 1500, and 2000 rpm).

## 2. Research and methodology

### 2.1. Fuel and test condition

To investigate and compare the engine performance, combustion characteristic, and the emission of biodiesel (B10 and B20), pure biodiesel (B100), and biodiesel blended with ethanol (B100E5 and B100E10). Biodiesel (B10 and B20) are obtained in a commercial form which contains 10% and 20% pure biodiesel mixed in diesel fuels respectively. Pure biodiesel (B100) production is conducted from based palm oil via the acid-esterification and transesterification with methanol. Biodiesel blended with ethanol (B100E5 and B100E10) contain approximately 5% and 10% ethanol by weight mixed in pure biodiesel. The fuel properties were shown in Table 1. Operating conditions of this experiment are performed on various engine loads (56, 84, 112, and 140Nm) at constant engine speeds (1000, 1500, and 2000 rpm).

### 2.2. Experimental setup

The experiment focuses on the effects of biodiesel (B10, B20, and B100) and biodiesel blended with ethanol (B100E5 and B100E10) on the engine's performance, combustion characteristics, and exhaust emission. An engine specification of direct injection diesel engine (Isuzu 4J1-TC) shows in Table 2. The engine was coupled with an Eddy Current Dynamometer (Tokyo Plant Model ED-150-LC) as shown in Table 3. In addition, a pressure sensor was installed in the combustion chamber to measure the pressure by a piezoelectric sensor (Kistler 6052C31, 250Bar, sensitivity:  $\pm 0.5\%$ ), and a crank encoder is used to count the revolutions of the engine (CA-RIE-360, resolution: 360 pulses/rev), as well as

**Table 1**  
Properties of biodiesel and ethanol.

Properties	B10	B20	B100	Ethanol
Carbon (% mass)	84.6	82.6	76.7	52.2
Hydrogen (% mass)	13.5	13.4	12.4	13.0
Oxygen (% mass)	1.9	4.0	10.9	34.8
Low heating value (kJ/g)	43.1	42.4	37.4	25.5
Cetane Number	53.7	54.5	62.1	8
Flash Point ( $^{\circ}\text{C}$ )	66	66	184.5	17
Density at 15 $^{\circ}\text{C}$ ( $\text{kg}/\text{m}^3$ )	835	827	875	792
Viscosity at 40 $^{\circ}\text{C}$ ( $\text{mm}^2/\text{s}$ )	3.0	3.1	4.5	1.2

**Table 2**  
Engine specification.

Items	Details
Engine Model	Isuzu 4J1-TC
Engine Type	Diesel
Injection Type	Direct Injection
Displacement Volume	2,999 cc
Compression Ratio	18.3: 1
Bore $\times$ Stroke	95.4 mm $\times$ 104.9 mm
Related Power	52 kW/2000 rpm

**Table 3**  
Eddy current dynamometer specification.

Items	Details
Model	Tokyo Plant ED-150-LC
Maximum Brake Horsepower	150 PS/3000 rpm
Maximum Brake Torque	35.81 kgm
Maximum Speed	3000 rpm

using DewesoftX software to acquire data. The exhaust emission quantity was measured by a smoke intensity meter, which optically evaluates soot collected on smoke paper filters by the light reflection method. All the equipment is set up, as shown in Fig. 1.

## 3. Calculation method

### 3.1. Combustion characteristic

#### 3.1.1. Heat release rate

Heat release rate (HRR) represents the effects of the fuel injection system, premixed mode, and late combustion. The heat release rate is obtained from the first law of thermodynamics. It is calculated by the following equation.

$$\text{Heat Release Rate (HRR)} = \left[ \frac{k}{k-1} \right] \cdot \frac{PdV}{d\theta} + \left[ \frac{1}{k-1} \right] \cdot \frac{VdP}{d\theta}$$

### 3.2. Engine performance

The engine performance is described by brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC), and brake thermal efficiency (BTE) are determined by the following equations.

#### 3.2.1. Brake specific fuel consumption

The rate of fuel consumption to the power produced by an engine, measured in kg/kWh, is referred to as BSFC.

Brake Specific Fuel Consumption (BSFC)

$$\text{Fuel Consumption Rate} = \frac{\dot{m}_f}{\text{Brake Power}} = \frac{\dot{m}_f}{4\pi\tau \cdot \frac{N}{60} \cdot \frac{1}{2}}$$

#### 3.2.2. Brake specific energy consumption

The rate of energy consumption to the power produced by an engine, measured in kJ/kWh, is referred to as BSEC.

Brake Specific Energy Consumption (BSEC) = BSFC  $\cdot$  LHV

#### 3.2.3. Brake thermal efficiency

Brake thermal efficiency (BTE) is amount of power output from heat energy given to a system.

$$\text{Brake Thermal Efficiency (BTE)} = \frac{\text{Brake Power}}{\text{Energy Input}} = \frac{4\pi\tau \cdot \frac{N}{60} \cdot \frac{1}{2}}{\dot{m}_f \cdot Q_{LHV}}$$

where P is pressure in a cylinder (bar), V is volumetric ( $\text{m}^3$ ), N is engine speed (rev/min),  $\dot{m}_f$  is mass fuel consumption rate (g/s),  $Q_{LHV}$  is Energy input (kJ/kg), k is specific heat ratio, and  $\theta$  is angular displacement in a cylinder or Crank angle (deg) [8].

## 4. Result and discussion

### 4.1. Combustion characteristic

To investigate the behaviors, the pressure in the combustion chamber can be divided into two groups: biodiesel (B10, B20,

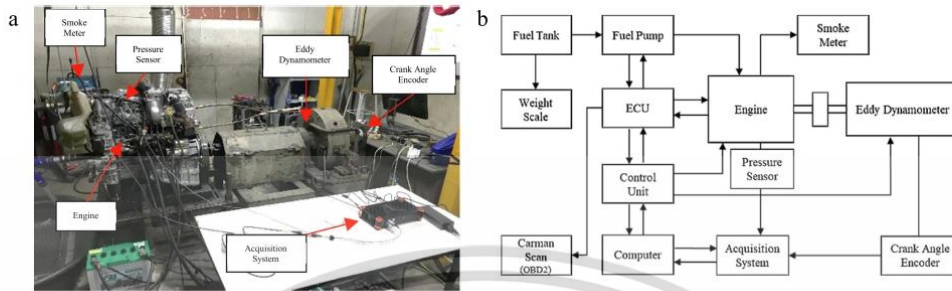


Fig. 1. (a) Experimental Setup and (b) Schematic diagram.

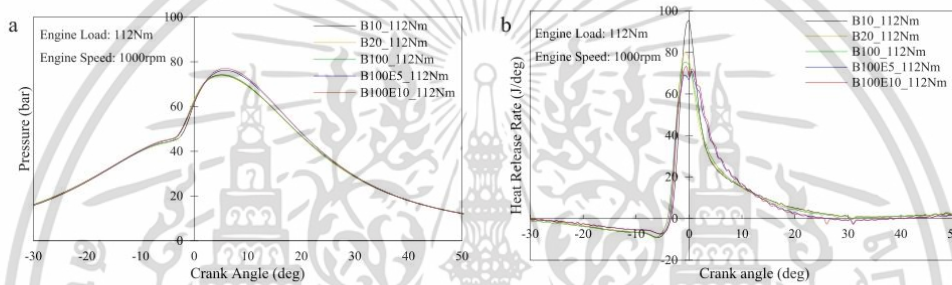


Fig. 2. (a) Pressure-Crank Angle and (b) Heat Release Rate at load 112Nm and engine speed 1000 rpm.

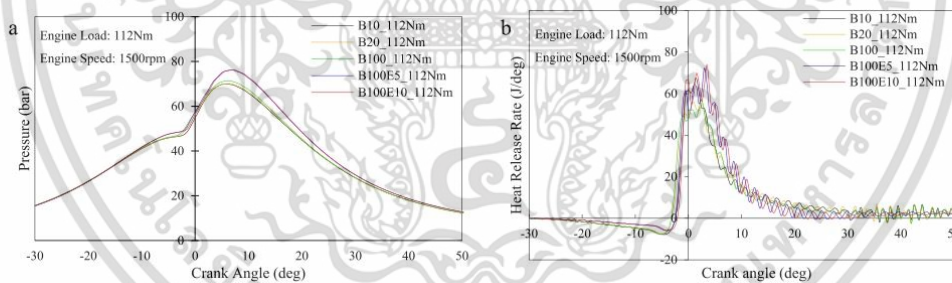


Fig. 3. (a) Pressure-Crank Angle and (b) Heat Release Rate at load 112Nm and engine speed 1500 rpm.

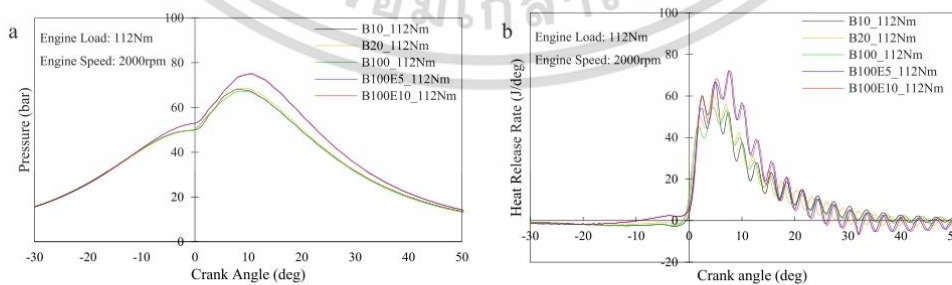


Fig. 4. (a) Pressure-Crank Angle and (b) Heat Release Rate at load 112Nm and engine speed 2000 rpm.

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า  
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ดัดแปลงเนื้อหา และต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

and B100) and biodiesel blended with ethanol (B100, B100E5, and B100E10). The combustion pressure rise, and heat release rate diagram of all fuels at engine load 112Nm of each engine speed (1000, 1500 and 2000 rpm) are represented in Figs. 2 to 4. The first group, B100 has a slightly shorter ignition than B10 and B20 in low engine speed conditions because of the higher cetane number which has

an effect on the ignition. At high engine speed conditions, all fuels have similar ignition behavior due to the fast-operating combustion. Furthermore, as seen in the combustion pressure rise and combustion heat release rate diagrams, each biodiesel has a similar combustion behavior. The second group is biodiesel blended with ethanol, such as B100, B100E5, and B100E10. The ignition timing

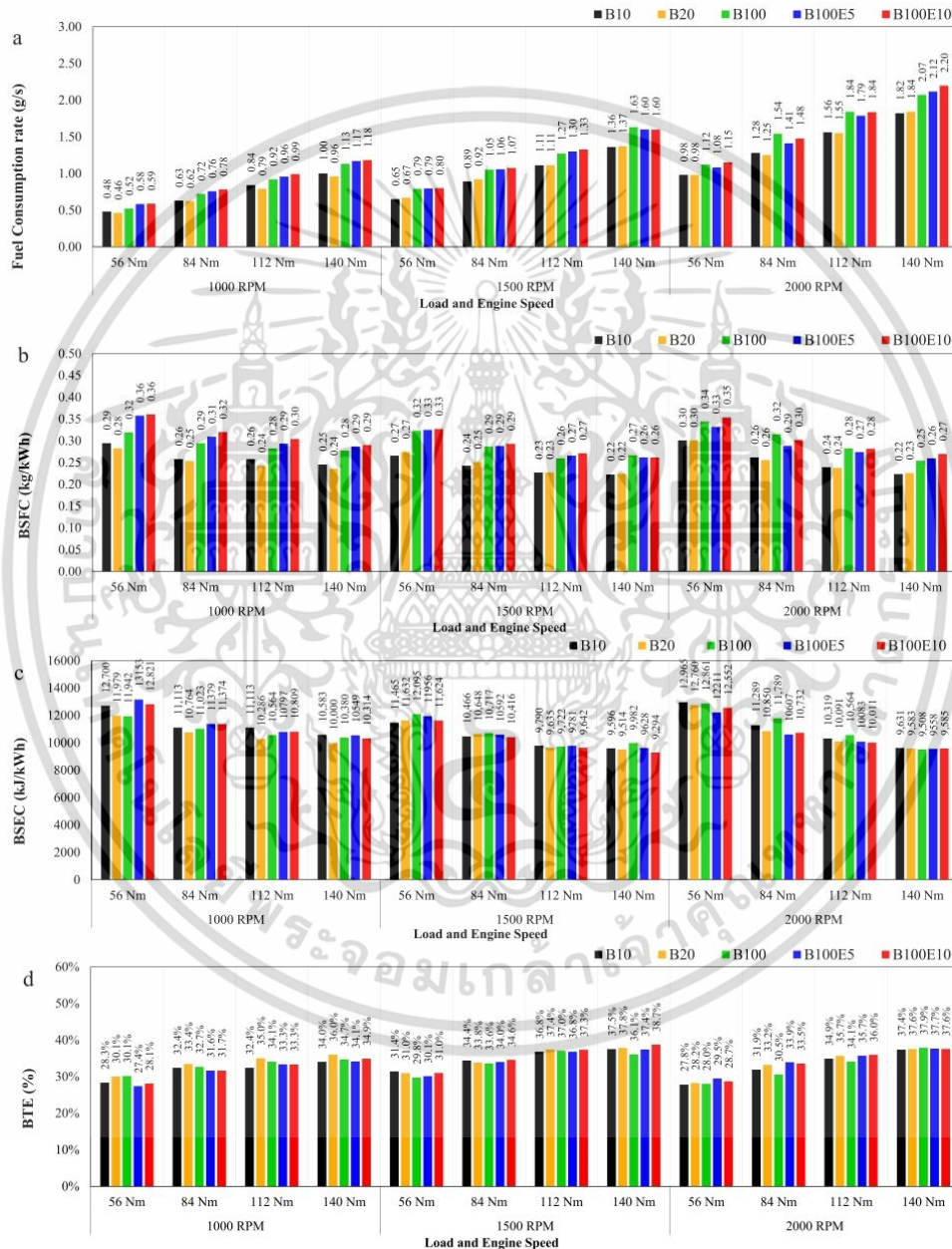


Fig. 5. (a) Fuel consumption rate; (b) Brake Specific Fuel Consumption; (c) Brake Specific Energy Consumption; (d) Brake Thermal Efficiency.

of B100E5 and B100E10 is longer than B100 because ethanol has a lower cetane number blended into the fuel. The pressure of biodiesel blended with ethanol in-cylinder pressure and heat release rate is higher than biodiesel because of the fuel properties such as the high autoignition temperature and higher heat of vaporization of ethanol can prolong the air-fuel mixing time. The combustion quality of biodiesel blended ethanol performs better than biodiesel in terms of power output, combustion pressure rise, and combustion heat release rate [9,10].

4.2. Engine performance

The engine performance characteristics are described as brake specific fuel consumption (BSFC in units of kg/kWh), brake specific energy consumption (BSEC in units of kJ/kWh), and brake thermal efficiency (%). Biodiesel blended with ethanol group has higher fuel consumption rate than the biodiesel group because the ethanol blended has a lower heating value, as shown in Fig. 5(a). Thus, the amount of fuel supplied to the engine must be greater. At the same amount of brake power, biodiesel blended with ethanol as B100E10 has the highest brake specific fuel consumption (BSFC) in all load and engine speed conditions, as shown in Fig. 5(b), because of the lowest lower heating value. At constant engine speed, BSFC decreases as engine load increases because at low load conditions, there is more time of heat loss from heat radiation to the chamber cylinder wall than at higher loads. That affect total heat energy reduces. Therefore, the system have to inject more fuel to achieve the same amount of power. When evaluated at the same quantity of brake thermal energy, biodiesel blended with ethanol as B100E10 has the lowest brake specific energy consumption (BSEC) in all load and engine speed conditions, as shown in Fig. 5(c). The brake thermal efficiency (BTE) of B100 is almost the lowest in all load conditions because of the larger molecular structure, worse vaporization, higher viscosity, and higher cetane number,

resulting in advancement in start the combustion and the lowest heat release rate. However, adding ethanol, which has low viscosity and cetane number, can improve this problem. As a result, the BTE of biodiesel blended with ethanol is higher than the biodiesel group, as shown in Fig. 5(d) [11].

4.3. Exhaust emission

Exhaust emissions directly impact on pollution or particulate matter (PM). An opacity smoke intensity meter can be used to measure exhaust emissions as smoke intensity. According to the results of smoke intensity in Fig. 6(a) and optical microscope (OM) images and scanning electron microscope (SEM) images of soot filter paper in Fig. 7, biodiesel B100 has lower smoke intensity than biodiesel B10 in all load conditions because B100 has a higher oxygen content to promote complete combustion [12]. Incomplete combustion from injected fuel causes high smoke intensity in high load and low engine speed conditions. When the engine load increases, the engine increases the injection quantity, and when the engine speed increases, the engine increases the injected pressure. As a result, when more fuel is injected at a lower pressure, the fuel break-up and atomization quality are lower and larger droplets of fuel which are difficult to evaporate. Therefore, it can be improved by adding ethanol which has low density and viscosity. The higher proportion of ethanol in biodiesel, the less smoke emission. Due to higher oxygen content, easier break-up atomization while spraying from lower density, and longer premixed phase from lower cetane number. As a result, the smoke intensity can be reduced by more than 50% from B100, as shown in Fig. 6(a). NOx emission increase as engine load increases, as shown in Fig. 6(b). In particular, biodiesel blended with ethanol has a higher oxygen content which reacts with the nitrogen content of the atmosphere [13,14].

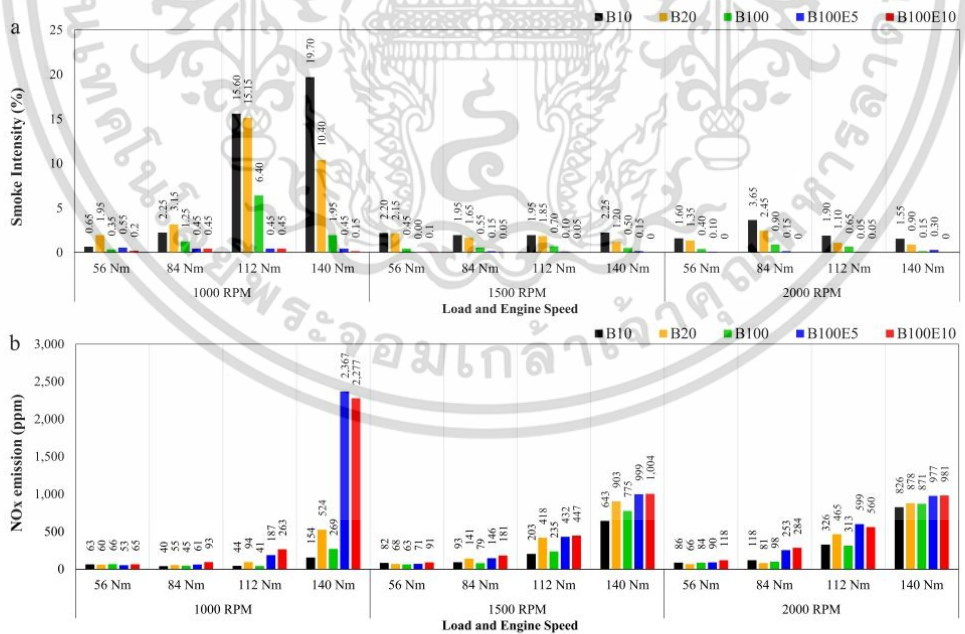


Fig. 6. (a) Smoke Intensity and (b) NOx emission.

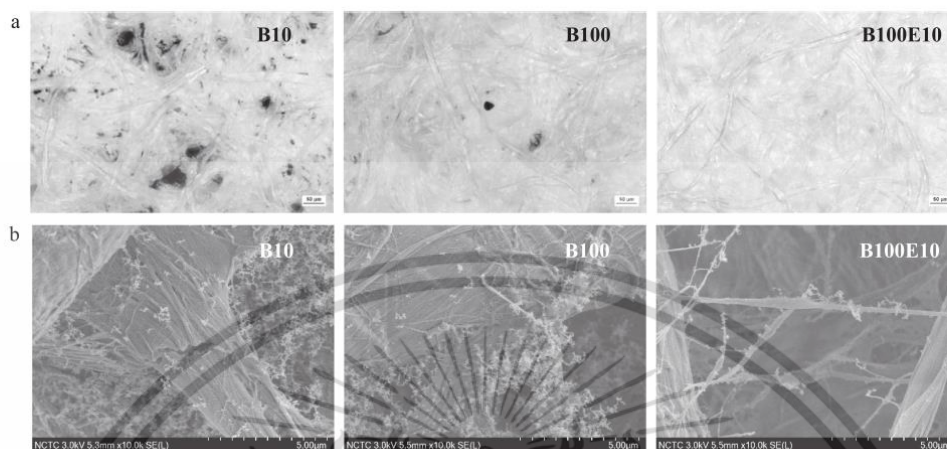


Fig. 7. (a) OM images and (b) SEM images of B10, B100 and B100E10.

## 5. Conclusion

Engine tests were performed in a diesel engine using biodiesel (B10, B20, and B100) and biodiesel blended with ethanol (B100E5 and B100E10) at various loads (56, 84, 112, and 140Nm) at each constant engine speed (1000, 1500, and 2000 rpm). As a result of combustion analysis, B100 has slightly advanced ignition than B10 and B20. Because larger molecular structure, poorer vaporization, higher viscosity, and higher cetane number lead to an advancement in start combustion timing and the lowest heat release rate, which affects brake thermal efficiency. This issue can be resolved by blending ethanol, which has a low cetane number, low density, and viscosity blended with biodiesel (B100). As a result, biodiesel blended with ethanol (B100E5 and B100E10) has a higher brake thermal efficiency and heat release rate than B100. Soot emissions or particulate matter (PM) from B10 and B20 can be reduced by more than half by using B100, which has a higher oxygen content to promote complete combustion. However, the smoke intensity was found to be higher under high load and low engine speed conditions due to incomplete combustion from injected fuel. After blending ethanol as biodiesel blended with ethanol has a higher oxygen concentration, lower density, and a longer premixed phase, resulting in more complete combustion in all load conditions.

## Data availability

No data was used for the research described in the article.

## Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Phobkrit Kanokkhanarat reports financial support was provided by King Mongkut's Institute of Technology Ladkrabang].

## Acknowledgements

The authors are grateful for research funding from National Research Council of Thailand (Diesel Engine's Particulate Matters

Reduction using Ethanol- Biodiesel- Diesel Blends and Particulate Filter 398/2563).

## References

- [1] K.A. Yu, B.C. McDonald, R.A. Harley, Evaluation of nitrogen oxide emission inventories and trends for on-road gasoline and diesel vehicles, *Environ. Sci. Technol.* 55 (10) (2021) 6655–6664.
- [2] S.H. Yoon, C.S. Lee, Experimental investigation on the combustion and exhaust emission characteristics of biogas-biodiesel dual-fuel combustion in a CI engine, *Fuel Process. Technol.* 92 (5) (2011) 992–1000.
- [3] V.H. Nguyen, M.Q. Duong, K.T. Nguyen, T.V. Pham, P.X. Pham, An extensive analysis of biodiesel blend combustion characteristics under a wide-range of thermal conditions of a cooperative fuel research engine, *Sustain.* 12 (18) (2020) 7666, <https://doi.org/10.3390/su12187666>.
- [4] M. Lapuerta, J. Rodríguez-Fernández, D. Fernández-Rodríguez, R. Patiño-Camiño, Modeling viscosity of butanol and ethanol blends with diesel and biodiesel fuels, *Fuel* 199 (2017) 332–338.
- [5] C. Zhan, Z. Feng, W. Ma, M. Zhang, C. Tang, Z. Huang, Experimental investigation on effect of ethanol and di-ethyl ether addition on the spray characteristics of diesel/biodiesel blends under high injection pressure, *Fuel* 218 (2018) 1–11.
- [6] L. Geng, Y. Xie, J. Wang, W. Liu, C. Li, C. Wang, Experimental and numerical analysis of the spray characteristics of biodiesel-ethanol fuel blends, *Simulation* 97 (10) (2021) 703–714.
- [7] Q. Fang, J. Fang, J. Zhuang, Z. Huang, Effects of ethanol-diesel-biodiesel blends on combustion and emissions in premixed low temperature combustion, *Appl. Therm. Eng.* 54 (2) (2013) 541–548.
- [8] J.B. Heywood, *Internal Combustion Engine Fundamental*, McGraw-Hill Series in Mechanical Engineering, Singapore, 1998.
- [9] M.R. Chow, J.B. Ooi, K.M. Chee, C.H. Pun, M.-V. Tran, J.C. Kong Leong, S. Lim, Effects of ethanol on the evaporation and burning characteristics of palm-oil based biodiesel droplet, *J. Energy Inst.* 98 (2021) 35–43.
- [10] L. Geng, L. Bi, Q. Li, H. Chen, Y. Xie, Experimental study on spray characteristics, combustion stability, and emission performance of a CRDI diesel engine operated with biodiesel-ethanol blends, *Energy Rep.* 7 (2021) 904–915.
- [11] P. Karin, P. Watanawongskorn, J. Boonsakda, E. Saenkhumvong, S. Rungsritanapaisan, S. Srivarocha, C. Charoiphonphanich, N. Chollacoop, K. Hanamura, Impact of biodiesel on small CI engine combustion behavior and particulate emission characteristic, *SAE Tech. Pap.* (2017).
- [12] A. Tripatara, P. Karin, W. Phairote, C. Charoiphonphanich, M. Masomtob, N. Chollacoop, H. Kosaka, Effect of biodiesel on compression ignition engine's combustion behavior and particulate emission, *J. Res. Appl. Mech. Eng.* 8 (2020) 92–100.
- [13] M. Tongroon, P. Saisirirat, A. Suebwong, J. Aunchaisri, M. Kananont, N. Chollacoop, Combustion and emission characteristics investigation of diesel-ethanol-biodiesel blended fuels in a compression-ignition engine and benefit analysis, *Fuel* 255 (2019) 115728, <https://doi.org/10.1016/j.fuel.2019.115728>.
- [14] M. Jamshaid, H.H. Masjuki, M.A. Kalam, N.W.M. Zulkifli, A. Arslan, A.A. Qureshi, Experimental investigation of performance, emissions and tribological characteristics of B20 blend from cottonseed and palm oil biodiesels, *Energy* 239 (2022) 121894, <https://doi.org/10.1016/j.energy.2021.121894>.

# ICERE 2022

School of Environmental Science and Technology  
(Hanoi University of Science and Technology) Vietnam

February 25-27, 2022



## CONTACT

Tel: +86-(0)28-88220101  
Mobile: +86-15908122414

Conference Secretary: Ms. Alice Lin  
icere@ieet.ac.cn

<http://www.icere.org/>

## SUBMISSION METHOD

★ Online Submission System:  
<http://confsys.iconf.org/submission/icere2022>

★ Email: [icere@ieet.ac.cn](mailto:icere@ieet.ac.cn)

## CALL FOR PAPER

Topics of interest for submission include, but are not limited to:

### Session A: Energy Science and Technology

- (01) Development and Utilization of Solar Energy
- (02) Development and Utilization of Biomass Energy
- (03) Development and Utilization of Wind Energy

### Session B: Environmental Science and Engineering

- (1) Environmental Chemistry and Biology
- (2) Environmental Materials
- (3) Environmental Safety and Health

### Session C: Motivation, Electrical Engineering and Automation

- (1) Engineering Thermodynamics
- (2) Thermal Engineering
- (3) Power Machinery and Engineering

### Session D: The Development and Utilization of Resources

- (1) Mineral Prospecting and Exploration
- (2) Mining Engineering
- (3) Mining Machinery Engineering

## CONFERENCE INTRODUCTION

ICERE 2022 is supported by School of Environmental Science and Technology (Hanoi University of Science and Technology), Vietnam, VNU-University of science and Beijing CAS Industrial Energy and Environment Technology Institute. As a leader in the global trend of scientific and technological innovation, China is creating an increasingly open environment for scientific and technological innovation, expanding the depth and breadth of academic cooperation, and building an innovation community. These efforts have made new contributions to advancing globalization and building a community with a shared future for mankind. In order to adapt to the changes of the world and the rapid development of China in the new era, the 2022 8th International Conference on Environment and Renewable Energy (ICERE 2022) will be held during February 25-27, 2022 in School of Environmental Science and Technology (Hanoi University of Science and Technology), Vietnam. The conference aims to facilitate the exchange of the latest and advanced information among scientists and engineers in a wide range of fields such as "environment" and "renewable energy". In particular, the Forum aims to promote exchanges and cooperation between basic researchers and those engaged in the development of practical technologies in related fields such as environment and renewable energy.

## PAPER PUBLICATION

For papers submitted to ICERE 2022, after the peer reviewing process by at least 2-3 experts, the accepted papers will be published into International Conference Proceeding, which is indexed by **El Compindex**, **Scopus**, Thomson Reuters (WoS), Inspec, et al.

## IMPORTANT DATE

Paper Submission	Before January 31, 2022
Notification of Acceptance	Before February 15, 2022
Authors' Registration	Before February 25, 2022
Conference Dates	February 25-27, 2022

PAPER • OPEN ACCESS

## Investigation of the Impact Bioethanol Blends into Biodiesel on Combustion Characteristics, Engine Performance, and Emissions of Diesel Engine

To cite this article: Phobkrit Kanokkhanarat *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1121** 012014

View the [article online](#) for updates and enhancements.

### You may also like

- [The effect of antioxidant additives on the growth of deposits on the use of biodiesel fuel \(B100\) at certain temperatures](#)  
B Sugiarto, M T Suryantoro, S Yubaidah et al.
- [Silicon dioxide nanoparticles have contrasting effects on the temporal dynamics of sulfonamide and -lactam resistance genes in soils amended with antibiotics](#)  
Xiujuan Zhang, Junjian Li, Dale Li et al.
- [The Disk Substructures at High Angular Resolution Project \(DSHARP\). IX. A High-definition Study of the HD 163296 Planet-forming Disk](#)  
Andrea Isella, Jane Huang, Sean M. Andrews et al.



**ECS Toyota Young Investigator Fellowship**

For young professionals and scholars pursuing research in batteries, fuel cells and hydrogen, and future sustainable technologies.

At least one \$50,000 fellowship is available annually.  
More than \$1.4 million awarded since 2015!

Application deadline: January 31, 2023

**Learn more. Apply today!**

This content was downloaded from IP address 110.169.138.161 on 30/12/2022 at 03:28

## Investigation of the Impact Bioethanol Blends into Biodiesel on Combustion Characteristics, Engine Performance, and Emissions of Diesel Engine

Phobkrit Kanokkhanarat<sup>1</sup>, Nattawoot Depaiwa<sup>1</sup>, Preechar Karin<sup>1</sup>, Veerayut Wongpattharaworakul<sup>1</sup>, Chadchai Srisurangkul<sup>2</sup>, and Masaki Yamakita<sup>3</sup>

<sup>1</sup> School of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand

<sup>2</sup> National Metal and Materials Technology Center, National Science and Technology Development Agency, Pathum Thani 12120, Thailand

<sup>3</sup> School of Engineering, Tokyo Institute of Technology, Tokyo, 152-8550, Japan  
E-mail: k.phobkrit@gmail.com

**Abstract.** Emissions from a diesel engine are dangerous to the environment and human health. Substitutable fuels from a renewable source are one of the alternatives to reduce emissions. Neat biodiesel from based palm oil (B100) can reduce emissions from higher oxygen content to be more complete combustion. The disadvantage of neat biodiesel is lower thermal efficiency from an advancement ignition. To improve this problem, adding bioethanol produced from agriculture products into neat biodiesel by weight ratio as B100E5 (95% B100 with 5% bioethanol) and B100E10 (90% B100 with 10% bioethanol). Hence, the focus of this research is to examine the combustion and emission characteristics, including engine performance, of bioethanol blends into neat biodiesel fuels (B100E5 and B100E10) compared with neat biodiesel (B100). All samples were tested at an engine load of 140 NM with constant engine speeds of 1000, 1500, and 2000 RPM on a diesel engine. The results of bioethanol blends into biodiesel fuels indicate that the pressure in the combustion cylinder and rate of heat release increase with increasing percentages of bioethanol. B100E10 shows the highest brake thermal efficiency. The smoke intensity of bioethanol blends into biodiesel fuels is reduced by more than 50% when compared to neat biodiesel fuel, and higher NOx emission from higher oxygen content in the fuels.

### 1. Introduction

The compression ignition engine is mostly utilized in heavy-duty vehicles, transportation, and industry since it is one of the most thermal efficiencies and fuel economy [1,2]. Nevertheless, the disadvantage of the compression ignition engine is the high smoke emissions, which contribute to the negative impact on human health and pollution as particulate matter (PM) [3]. One of the renewable energy alternatives is biodiesel, which approaches diesel fuel in terms of the physical characteristics. Many researchers have discovered agricultural products to produce biodiesel, such as palm oil, which derives from an esterification process blended into diesel fuel known as biofuels. The properties of palm oil have a higher density, viscosity, cetane number, and lower calorific value. As a result, the delay of ignition duration is reduced. In comparison, the combustion behavior is almost similar to the commercial diesel [4]. The shorter ignition delay from using biodiesel fuel leads to the combustion process starting to begin before the engine's optimization point, which is set up by the manufacturer for commercial diesel fuel. The above reason influences thermal efficiency and the rate of heat release decrease. Furthermore, the benefit of biodiesel fuel is a better reduction of smoke emissions than commercial diesel fuel [5]. Agricultural

products, including sugarcane juice, molasses, and cassava, are the other sources of renewable energy to produce bioethanol. The properties of bioethanol have a low density and viscosity, which affect better atomization and combustion. Bioethanol also has a high amount of oxygen, about 34% by weight, which can help reduce smoke emissions [6,7]. With bioethanol's low cetane number and better atomization, the ignition delay in the premixed phase gets longer as the bioethanol ratio increases. As a result, the combustion process starts to get close to the engine's optimization point. There are contributing to improving combustion, thermal efficiency, and emissions [8,9]. The miscibility and stability are the most difficult aspects of blending bioethanol into diesel fuel. There are depending on the duration, temperature, and bioethanol mix ratio during the blending. Previous research investigated whether miscibility and stability could be improved by increasing the palm methyl ester (PME) fraction [10]. The focus of this research is to examine the impact of neat biodiesel fuel (B100) made from base palm oil and bioethanol blends into neat biodiesel fuels (B100E5 and B100E10) in terms of combustion and emissions by testing with an unmodified diesel engine. The pressure in the combustion chamber was examined for the combustion characteristics. The results of fuel consumption and brake parameters such as brake specific fuel consumption, brake specific energy consumption, brake thermal efficiency, and emissions were utilized to evaluate the engine's performance.

## 2. Methodology

### 2.1. Experimental setup and condition

The experimental setup and schematic diagram are shown in Figure 1. An Isuzu 4JJ1-TC engine is used to perform in this experiment. The engine's specification is shown in Table 1. The engine is mounted with a Tokyo Plant eddy current dynamometer (ED-150-LC) to input the loads, and the eddy current dynamometer's specification is shown in Table 2. Monitoring all engine parameters by using the Carman scan or OBD2 and controlling the ECU by the control unit. Installed a piezoelectric pressure sensor (Kistler-6052C31, sensitivity 0.5%, 250Bar) to estimate the pressure in the cylinder. A crank encoder (CA-RIE-360, resolution 360 pulses/rev) is used to count the engine revolution. The acquisition of data is by Dewesoft software. BOSCH smoke intensity measures the smoke intensity. AVL exhaust gases analyzer analyzes the emissions. The experimental conditions are examined at constant engine speeds of 1000 RPM, 1500 RPM, and 2000 RPM with a constant engine load of 140 NM [11].

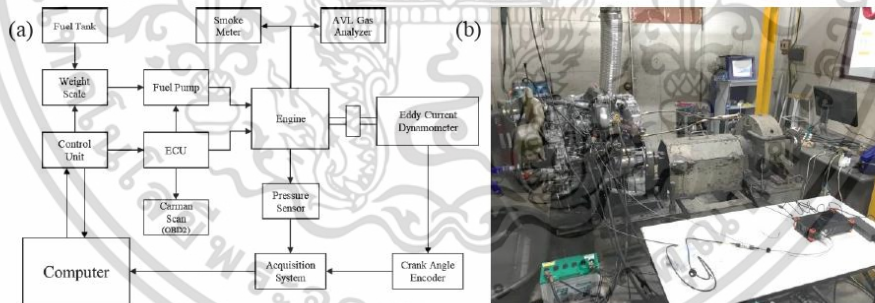


Figure 1. (a) Schematic Diagram and (b) Experimental Setup

### 2.2. Experimental sample

To investigate and evaluate the combustion characteristics, engine performance, and emissions of bioethanol blends into biodiesel and neat biodiesel fuels. The acid-esterification and transesterification with methanol process, also known as palm methyl ester (PME), is used to produce neat biodiesel (B100) from base palm oil. Adding bioethanol into B100 is blended in percent weight ratio. Two more samples are prepared in the experiment as B100E5 (bioethanol 5% and biodiesel 95%) and B100E10 (bioethanol 10% and biodiesel 90%). They are blended by stirring manually for around 30 minutes at surrounding temperature to be the homogeneous mixture. The properties of the samples are represented in Table 3.

**Table 1.** Specifications of Engine

Items	Details
Engine Type	Diesel
Model Type	Isuzu 4JJ1-TC
Injection Type	Common rail Direct Injection
Displacement Volume	3000 cc
Stroke x Bore	104.9 mm x 95.4mm
Compression Ratio	18.3: 1
Maximum Power	107 kW at 3600rpm

**Table 2.** Specifications of Eddy Current Dynamometer

Items	Details
Model Type	Tokyo Plant ED-150-LC
Maximum Brake Horsepower	150 PS at 3000rpm
Maximum Brake Torque	35.81 kgm
Maximum Speed	3000rpm

**Table 3.** Properties of Biodiesel and Bioethanol

Properties	Biodiesel	Bioethanol
Carbon (% mass)	76.7	52.2
Hydrogen (% mass)	12.4	13.0
Oxygen (% mass)	10.9	34.8
Calorific value (kJ/g)	37.4	25.5
Cetane Number	62.1	8
Flash Point (°C)	184.5	17
Density at 15°C (kg/m <sup>3</sup> )	875	792
Viscosity at 40 °C (mm <sup>2</sup> /s)	4.5	1.2

### 3. Results and Discussions

#### 3.1. Combustion Characteristics

The combustion characteristics are evaluated by the measured pressure inside the cylinder. The combustion pressure versus crank angle and rate of heat release diagrams of the examined results at constant engine speeds of 1000 RPM, 1500 RPM, and 2000 RPM with a constant engine load of 140 NM are shown in Figures 2 to 4. At low engine speed conditions, the beginning combustion of B100 is slightly more advanced than B100E5 and B100E10 since its higher cetane number. Furthermore, the rate of heat release of bioethanol blends into biodiesel fuels is greater than the neat biodiesel fuel since better atomization, higher oxygen fraction, and longer premixed. All of the testing samples exhibited almost the same behavior when the engine speed was higher. This was because the higher speed of combustion affected less time to lose the total energy from the cooling system and heat radiation. The

neat biodiesel has high density and viscosity, thus affecting difficulty breaking the drops of fuel. Adding bioethanol which has a lower density and viscosity can improve the atomization while injected with the same pressure injection. Higher heat vaporization and better atomization of bioethanol blended fuels have efficient combustion and better air and fuel mixing. Hence, B100E10 is the highest rate of heat release and the combustion pressure as shown in the figures [12,13].

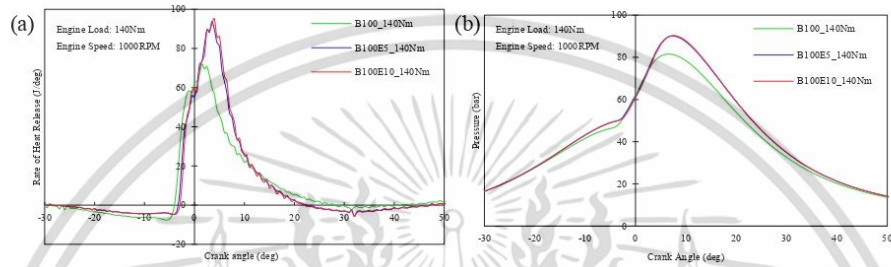


Figure 2. (a) Rate of Heat Release and (b) Pressure vs Crank Angle at load 140 NM with 1000 RPM

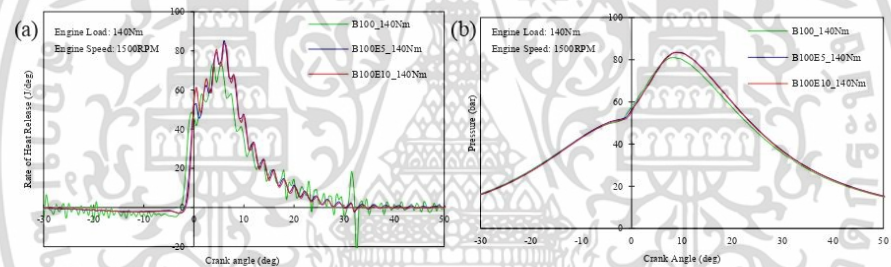


Figure 3. (a) Rate of Heat Release and (b) Pressure vs Crank Angle at load 140 NM with 1500 RPM

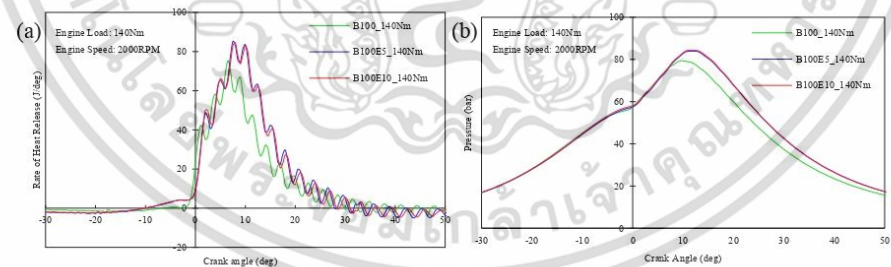


Figure 4. (a) Rate of Heat Release and (b) Pressure vs Crank Angle at load 140 NM with 2000 RPM

3.2. Engine Performance

The fuel consumption rate (g/s), brake specific fuel consumption (kg/kWh), brake specific energy consumption (kJ/kWh), and brake thermal efficiency (percentage %) are utilized to evaluate the engine performance characteristics. The engine performance’s results are described in Figure 5. Figure 5(a) represents the fuel consumption rate increases with the bioethanol proportion increase, due to its lower calorific value. Figure 5(b) demonstrates the brake thermal efficiency of bioethanol blends into biodiesel fuels is higher than biodiesel fuel. Figure 5(c) illustrates that B100E10 is the highest brake specific fuel consumption when considering the equal quantity of brake power. When evaluating the equal quantity

of energy inputs, brake specific energy consumption (BSEC) decreases with the bioethanol proportion increases. Thereby, Figure 5(d) shows that B100E10 is the lowest BSEC in every condition. However, the properties of bioethanol could resolve the issue of biodiesel fuel, which has a high density and viscosity, with proper blending proportions. [14,15].

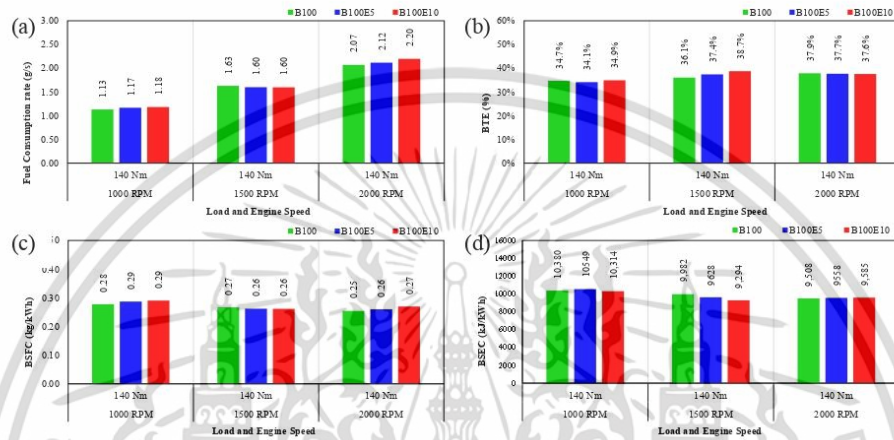


Figure 5. (a) Fuel consumption rate, (b) Brake Thermal Efficiency, (c) Brake Specific Fuel Consumption, and (d) Brake Specific Energy Consumption

### 3.3. Exhaust Emissions

NOx emission results, as shown in Figure 6(a), increases as bioethanol proportion increases because bioethanol consists of around 34% oxygen which can more react with the nitrogen content of the air inlet. Figure 6(b) shows the smoke intensity and Figure 7 shows optical microscope (OM) images of soot filter paper. B100E10 has the lowest smoke intensity because of its higher oxygenation, which promotes more complete combustion. The result of smoke intensity, bioethanol blended fuels can reduce more than 50% and around 90% at low engine speed. [16,17].

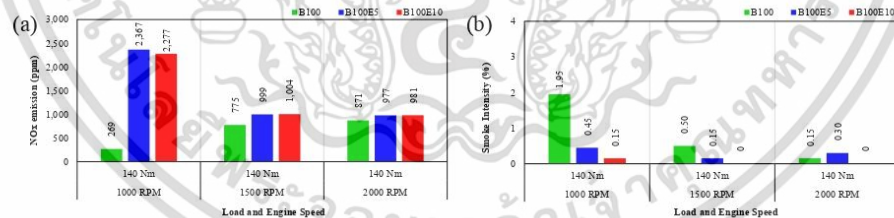


Figure 6. (a) NOx emission and (b) Smoke Intensity



Figure 7. OM images of B100, B100E5 and B100E10

### 3.4. Soot Morphology

Figure 8 shows the 10K magnification images of soot filter paper for the scanning electron microscope (SEM). The analysis is chosen and measured by a hundred agglomerate particles by using the ImageJ tool. Figure 9(a) shows the agglomerate particle size on average of B100, B100E5, and B100E10 is 0.17µm, 0.14µm, and 0.13µm, respectively. Most of the distribution of agglomerate particle size is found around 0.05 to 0.20µm, as shown in Figure 9(b).

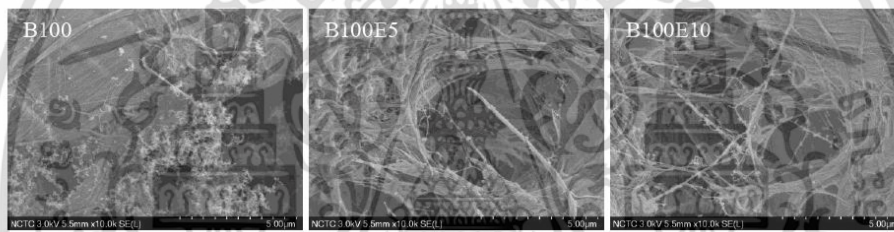


Figure 8. SEM images of B100, B100E5 and B100E10

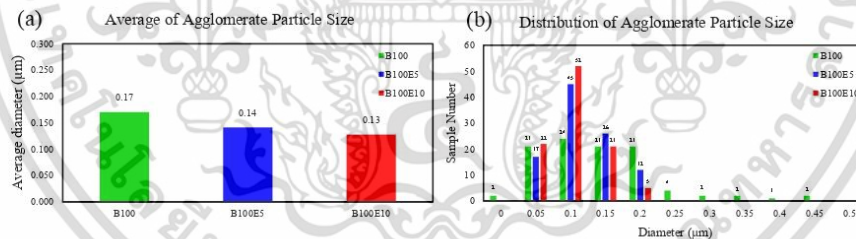


Figure 9. (a) Average of Agglomerate Particle Size and (b) Distribution of Agglomerate Particle Size

## 4. Conclusion

This research study investigated in neat biodiesel and bioethanol blended biodiesel fuels by testing on a commercial diesel engine at constant engine speeds of 1000 RPM, 1500 RPM, and 2000 RPM with a constant engine load of 140 NM. The results of pressure in combustion cylinder and rate of heat release of B100E5 and B100E10 are higher than B100. The fuel consumption rate increases with bioethanol proportion increase since its lower calorific value. Adding bioethanol into biodiesel fuel could reduce the density, viscosity, and cetane number of biodiesel fuel to be better atomization and longer premixed phase for improving air-fuel mixing and combustion. As a result of brake thermal efficiency of B100E10 is the highest. Moreover, adding ethanol could be reduced the smoke intensity by more than 50% and around 90% at low engine speed. The agglomerate particle size on average of B100, B100E5, and B100E10 is 0.17µm, 0.14µm, and 0.13µm respectively.

## 5. References

- [1] Askin A, Barter G, West T and Manley D. 2015 The heavy-duty vehicle future in the United States: A parametric analysis of technology and policy tradeoffs *Energy Policy* p 81:1-13
- [2] Yu K A, McDonald B C and Harley R A 2021 Evaluation of Nitrogen Oxide Emission Inventories and Trends for On-Road Gasoline and Diesel Vehicles *Environ. Sci. Technol.* **55** 6655–64
- [3] Englert N. 2004 Fine Particles and Human Health *A Review of Epidemiological Studies. Toxicology Letters* p 3:235-242
- [4] Nguyen V H, Duong M Q, Nguyen K T, Pham T V. and Pham P X 2020. An extensive analysis of biodiesel blend combustion characteristics under a wide-range of thermal conditions of a cooperative fuel research engine *Sustain. Sustainability* **12**(18):7666
- [5] Yoon S. H. and Lee C. S. 2011 Experimental investigation on the combustion and exhaust emission characteristics of biogas-biodiesel dual-fuel combustion in a CI engine *Fuel Process Technol* **92** p 992–1000.
- [6] Lapuerta M., Rodríguez-Fernández J., Fernández-Rodríguez D. and Patiño-Camino R. 2017 “Modeling viscosity of butanol and ethanol blends with diesel and biodiesel fuels” *Fuel* **199** p 332–8
- [7] Zhan C., Feng Z., Ma W., Zhang M., Tang C. and Huang Z. 2018 “Experimental investigation on effect of ethanol and di-ethyl ether addition on the spray characteristics of diesel/biodiesel blends under high injection pressure” *Fuel* **218** 1–11.
- [8] Sayin C. 2010 Engine performance and exhaust gas emissions of methanol and ethanol–diesel blends. *Fuel* **89**(11) p 3410-3415.
- [9] Fang Q., Fang J., Zhuang J. and Huang Z. 2013 “Effects of ethanol-diesel-biodiesel blends on combustion and emissions in premixed low temperature combustion” *Applied Thermal Engineering* **54** p 541–548
- [10] Chotwichien A., Luengnaruemitchai A., Jai-In S. 2009 Utilization of palm oil alkyl esters as an additive in ethanol–diesel and butanol–diesel blends. *Fuel* **88**(9) p 1618-1624.
- [11] Tripatara A., Karin P., Phairote W., Charoenphonphanich C., Masonfob M., Chollacoop N. and Kosaka H 2020 “Effect of biodiesel on compression ignition engine’s combustion behavior and particle emission” *Journal of Research Application in Mechanical Engineering* **8** p 92–100
- [12] Kim H.Y., Ge J.C., 2020 Choi N.J. Effects of ethanol–diesel on the combustion and emissions from a diesel engine at a low idle speed. *Applied Sciences* **10**(12) p 4153.
- [13] Geng L., Bi L., Li Q., Chen H. and Xie Y. 2021 “Experimental study on spray characteristics, combustion stability, and emission performance of a CRDI diesel engine operated with biodiesel–ethanol blends” *Energy Reports* **7** p 904–915.
- [14] Tongroon M, Saisirirat P, Suebwong A, Aunchaisri J, Kanantont M and Chollacoop N 2019 “Combustion and emission characteristics investigation of diesel-ethanol-biodiesel blended fuels in a compression-ignition engine and benefit analysis” *Fuel* **255** 115728
- [15] Karin P., Watanawongskorn P., Boonsakda J., Saenkhumvong E., Rungsritanapaisan S., Srivarocha S., Charoenphonphanich C., Chollacoop N. and Hanamura K. 2017 “Impact of biodiesel on small CI engine combustion behavior and particle emission characteristic SAE” *Tech. Pap.* P 8
- [16] Shahri N.S., Masjuki N.H., Kalam M.A., Imran A., Ashraf A.M. 2015 Performance and emission assessment of diesel– biodiesel–ethanol/bioethanol blend as a fuel in diesel engines *A review. Renewable and Sustainable Energy Reviews* **48** p 62-78.
- [17] Jamshaid M., Masjuki H. H., Kalam M. A., Zulkifli N. W. M., Arslan A. and Qureshi A. A. 2022 “Experimental investigation of performance, emissions and tribological characteristics of B20 blend from cottonseed and palm oil biodiesels” *Energy* **239** 121894.

## Acknowledgements

The authors are grateful for research funding from National Research Council of Thailand (Diesel Engine's Particulate Matters Reduction using Ethanol- Biodiesel- Diesel Blends and Particulate Filter 398/2563).

## AUTHOR BIOGRAPHY

**Author:** Mr. Phobkrit Kanokkhanarat

**Degree:** Master of Engineering

**Date of Graduation:**

**Date of Birth:** 12<sup>th</sup> June 1996

**Place of Birth:** Bangkok, Thailand

### Undergraduate and Graduate Education

Master of Engineering in Automotive Engineering,

King Mongkut's Institute of Technology Ladkrabang, Bangkok, 2023

Bachelor's degree in Mechanical Engineering,

Khon Kaen University, Bangkok, 2017

**Major:** Automotive Engineering

### Presentations and Publications:

- [1] P. Kanokkhanarat, P. Karin, N. Depaiwa, C. Srisurangkul, and M. Yamakita, "Influence of Ethanol Biodiesel Blends on a Diesel Engine's Efficiency and Exhaust Emission Characteristics.", 14th AUN/SEED- Net Regional Conference on Materials & 4th International Postgraduate Conference on Materials, Minerals and Polymer, 2021
- [2] P. Kanokkhanarat, P. Karin, N. Depaiwa, V. Wongpattharaworakul, C. Srisurangkul and M. Yamakita, "Investigation of the impact bioethanol blends into biodiesel on combustion characteristics, engine performance, and emissions of diesel engine", 8th International Conference on Environment and Renewable Energy, 2022