BACHELOR THESIS AND COLLOQUIUM - ME184841

The Effect Of Heating Of B20 Fuel To The Spray Characteristic And Combustion On The Diesel Engine Based On Experiment

Faris Mishbahul Muhammad
NRP 0421 15 41 0000 09

Supervisor 1:
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APROVAL FORM

THE EFFECT OF HEATING OF B20 FUEL TO THE SPRAY CHARACTERISTIC AND COMBUSTION ON THE DIESEL ENGINE BASED ON EXPERIMENT

BACHELOR THESIS

Submitted to Comply One of The Requirements to Obtain a Bachelor of Engineering Degree in Double Degree of Marine Engineering (DDME) Program Department of Marine Engineering – Faculty of Marine Technology

Institut Teknologi Sepuluh Nopember
Departement of Maritime Studies

Hochschule Wismar, University of Applied Sciences

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on
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DECLARATION OF HONOUR

I hereby who signed below declare that:

This thesis has been written and developed independently without any plagiarism act. All contens and ideas drawn directly from internal and external sources are indicated such as cited sources, literatures, and other professional sources.

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Departement	: Double Degree of Marine Engineering

Surabaya, July 2019

Faris Mishbahul Muhammad

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Name of Student : Faris Mishbahul Muhammad

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ABSTRACT

According to Bank Indonesia, the current account deficit of Indonesia. In the second quarter of 2018 increased to USD 8.0 billion. One of the government's programs to reduce the current account deficit is by implementing B20 biodiesel policy. The increasing percentage of biodiesel in fuel blends tends to decrease the quality of spray atomization, where it indicated by longer droplet breakup, spray penetration, droplet lifetime, and bigger droplet diameter. Higher viscosity causes a decrease in the quality of the spray from the injector. In 2018, research conducted by Abdullah bin-Mahfouz, Khaled Mahmoud, and Mohammed Mourad proves that the inlet temperature of the fuel can make the performance of small diesel engine slightly better. The research was conducted using petrodiesel and biodiesel fuel by varying inlet temperature of 50^{o}C and 70^{o}C. Based on that this research is conducted to understand the effect fuel heating to macroscopic spray characteristic and engine combustion process. The result of the spray characteristic shows that for every temperature increase, the spray tip penetration decreased, the spray cone angle increased and the average spray velocity decreased. For combustion characteristic it is shown that generally maximum pressure is increased for every increase of fuel temperature. The heat release shows a decreasing trend for every increase of fuel temperature. Knock detection shows that generally when the fuel temperature increased the knocking is also increased. The increasing fuel temperature shows little effect on ignition delay except for higher temperature of 60^{o}C and 70^{o}C where the ignition delay is the lowest and closest to that of a dexlite fuel.

Key Word: Biodiesel B20, Combustion Process, Experiment, Heat Exchanger, Spray Characteristic,

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FOREWORD

All praise to Allah SWT for all His blessings, gifts and guidance so that the author can complete the Thesis with the title **"The Effect of Heating of B20 Fuel to The Spray Characteristic and Combustion on The Diesel Engine Based on Experiment".** This bachelor thesis is a requirement to obtain Bachelor degree in Marine Engineering from Marine Engineering Department, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya.

On the completion of this Bachelor Thesis, there are a lot of supports from many people. For this reason, author want to thank to those who supported the completion of this bachelor Thesis, those people are:

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Author wished this bachelor thesis can be useful by readers and can be improved by juniors who are taking bachelor thesis in the later year so it can be better bachelor thesis idea.

May Allah SWT give His blessings and mercy to all of us and hopefully all the assistance given so far can be recorded as good deeds and received a reward multiplied by Allah SWT. Aamiin

Surabaya, Juli 2019

Faris Mishbahul Muhammad

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CHAPTER I
INTRODUCTION

1.1. Background

According to Bank Indonesia, the current account deficit of Indonesia. In the second quarter of 2018 increased to USD 8.0 billion. One of the government's programs to reduce the current account deficit is by implementing B20 biodiesel policy. This policy is expected to reduce oil imports and can save national budget for imports, thus reducing the current account deficit. The policy officially replaces the pure diesel fuel (B0) with Bio Solar (B20) since September 1^{st}, 2018 through ministerial decree 1936 K / 10 / MEM / 2018 about the procurement of biodiesel fuel starting from September 2018.

Biodiesel fuel has advantages compared to diesel fuel. According to Dainis and Ligita (2014) these advantages are made from renewable sources, better emissions, and better lubricating property. The disadvantage of Biodiesel are more expensive than fossil fuel, less suitable for low temperatures, and have higher viscosity than the pure diesel fuel. According to Lia and Listiana (2017) the kinematic viscosity of diesel fuel (B0) produced by Pertamina was tested at 40^oC is 3.59 cSt, and the Biodiesel B100 produced by PT. Smart Tbk. was tested at 40^oC is 4.35 cSt. In which if the B20 is blend of 80% diesel fuel and 20% biodiesel the viscosity is expected to be in between 3.59-4.35 cSt at 40^oC.

Both viscosity B0 and B100 are still complying with the standard of diesel fuel of SNI 7182:2015 the range of kinematic viscosity of biodiesel is between 2.3 to 6.0 cSt. Higher viscosity means that the biodiesel will have worse spray characteristic than the diesel fuel in which it can lead to performance decrease. The increasing percentage of biodiesel in fuel blends tends to decrease the quality of spray atomization, where it indicated by longer droplet breakup, spray penetration, droplet lifetime, and bigger droplet diameter. (Bambang *et al*, 2007).

Higher viscosity causes a decrease in the quality of the spray from the injector. This can be overcome by reducing the viscosity of the B20 fuel that is used in this study. To reduce or vary the viscosity of B20 biodiesel is by using a heat exchanger. Therefore viscosity can be varied and the best temperature for fuel inlet can be found in this research.

1.2. Problem Statement

Biodiesel B20 is a fuel that officially replaces pure diesel (B0) since September 1^{st} 2018. Biodiesel has its advantages and disadvantages. One of the advantages of biodiesel is producing lower emissions than diesel fuel. While one of the disadvantages of biodiesel is higher viscosity than normal diesel fuel. In combustion, diesel engine fuel viscosity also determines fuel efficiency, if the fuel viscosity is too high, it can cause a larger fuel droplet so the time needed to burn out per fuel droplet is getting longer. The easiest way to change the viscosity of a fuel is to change the temperature. Therefore, in the research the problem statement was raised as follows:

1. How are the characteristics of fuel spray with variation fuel temperature by the heat exchanger?
2. How are the results of the combustion process produced by variation of fuel temperature from the heat exchanger?

1.3. Research Limitation

In order to focus the research analysis, the problem boundary is given as follows:

1. The Engine used is Mitsubishi 4D30.
2. The fuel used is Biodiesel B20 bought from Pertamina.
3. Temperature variable is done by heat exchanger powered by engine cooling system with outlet fuel temperature from heat exchanger of, 40^{o}C, 50^{o}C, 60^{o}C, and 70^{0}C.
4. The RPM variable of the Engine will be 1800, 2000 and 2200 RPM with 100% load.
5. The parameter of the combustion analysis will be ignition delay, maximum pressure, heat release, and knocking
6. Analysis of combustion process is using TMRInstrument sensor and SYSMONSoft as data acquisition.
7. For Spray Anaysis the parameters observed are Spray tip Penetration and spray cone angle.

1.4. Research Objectives

To answer the questions given by the problem statement above. This research is has aim as follows:

1. To understand the B20 fuel spray characteristic by varying the temperature outlet of the Heat exchanger.
2. To understand the combustion process of the B20 fuel produced by variation of fuel temperature from heat exchanger. Which includes ignition delay, maximum pressure, rate of heat release, and knocking.

1.5. Benefits

The benefits can be attained from this research are as follows:

1. This research can give information of the effect to combustion process of the B20 fuel with temperature variation.
2. This research can give information of the effect to spray characteristic of the B20 fuel with temperature variation.

CHAPTER II

LITERATURE STUDY

2.1. Biodiesel

Biodiesel is chemically referred to as methyl ester or ethyl ester of fatty acids produced from plant vegetable oils or animal oils. Biodiesel derived from vegetable oil is made by converting triglycerides into fatty acids, using the catalyst in the esterification process. Biodiesel has the same physical and chemical properties as conventional diesel fuel. In general, biodiesel has an energy content that is almost close to diesel fuel. So it can be used to power engines for transportation and for agricultural purposes. (Bode, 2002)

Indonesia is the biggest producer of Crude Palm oil in the world, has a very good opportunity to produce biodiesel. Beside crude palm oil, there are some resouces that can be used as source of biodiesel like Jathropa with 557,842,000 barrels per year, algae with 258,867,000 barrels per year and some other resources. It is predicted that with these supplies Indonesia can withstand energy crisis up to 2101 (Semin et al, 2013). Biodiesel fuel is already used as B20 fuel for general use for diesel engines from transportation to production. Starting from September 1st 2018, by ministerial decree 1936 K / 10 / MEM / 2018 about the procurement of biodiesel fuel September to December 2018, Indonesia started to effectively be commercialized the B20 fuel through several company as producer and suppliers. This is done to reduce diesel fuel import budget for Indonesia.

The advantage of biodiesel compared to diesel fuel are: (1) made from renewable sources, (2) better emissions in which it doesn't contain any sulfur and fewer particulates can degrade easily (Bode, 2002), and (3) better lubricating property (Dainis & Ligita, 2014). Where the disadvantage of Biodiesel are (1) more expensive than fossil fuel, (2) less suitable for low temperatures, and (3) have higher viscosity than the pure diesel fuel (Dainis & Ligita, 2014).

2.2. SNI Standards

Biodiesel is utilized to be able to make a significant contribution to national energy diversification, especially as a substitute fuel for diesel engines. Therefore in order to maintain its position as a reliable source of energy because of quality, standards need to be made to ensure the quality of biodiesel made in Indonesia. To guarantee the quality of biodiesel, SNI launches the biodiesel quality standard which is a revision from SNI 04-7182-2006 namely SNI 7182: 2015.

The standard establishes the quality requirements and test methods for biodiesel as substitute fuel or blend with diesel fuel that meet the specification requirements set by the authorized standards. The standards from SNI are shown in table 2.1.

Table 2.1 SNI Standards for Biodiesel (SNI 7182:2015)

No.	Characteristic	Units /min/max	Requirements
1	Density at 40°C	Kg/m^3	850-890
2	Kinematic Viscosity at 40°C	cSt	2.3-6.0
3	Cetane Number	Min	51
4	Flash Point	°C, min	100
5	Evaporation Point	°C, max	18
6	Corrosion of copper plate (3 hours at 50°C)		No. 1
7	Carbon Residue	% of mass, max	
	-in original sample		-0.05
	-in 10% residue of distillation		-0.3
8	Water and Sediment	% of volume, max	0.05
9	Distillation temperature at 90%	°C, max	360
10	Sulfur ash	% of mass, max	0.02
11	Sulfur	mg/kg, max	50
12	Phosphorous	mg/kg, max	4
13	Acid Number	mg-KOH/g, max	0.5
14	Free Glycerol	% of mass, max	0.02
15	Glycerol total	% of mass,max	0.24
16	Ester Methyl	% of mass,min	96.5
17	Iodine Number	% off mass (g-l$_2$/100g), max	115
18	Oxidation stability	Minute	
	-Induction period rancimat method		-480
	-Induction period petro oxy method		-36
19	Monoglyceride	% of mass, max	0.8

2.3. Biosolar Fuel Properties

Biosolar is the product name released by PT. Pertamina (Persero) for B20 fuel. It is implemented on September 1st, 2018. The biodiesel is supplied from some companies that is regulated in ministerial decree 1936 K / 10 / MEM / 2018.

To ensure the quality of the biosolar, PT. Pertamina (Persero) create more strict specification for its product which is shown by table 2.2.

Table 2.2 Biosolar Specification (Pertamina)

No	Characteristic	Units	Limits	
			Minimum	Maximum
1	Cetane Number	-	48	-
	Cetane Index	-	45	-
2	Density @15°C	Kg/m^3	815	860
3	Viscosity @40°C	mm^3/sec	2.0	4.5
4	Sulphur Content	%m/m	-	0.25
5	Distilation 90% evaporation	°C	-	370
6	Flash Point	°C	52	-
7	Pour Point	°C	-	18

8	Carbon Residue	%m/m	-	0.1
9	Water Content	mg/kg	-	500
10	Biological Growth	-	-	-
11	FAME Content	% v/v	-	-
12	Methanol Content	% v/v	-	-
13	Ash Content	% v/v	-	0.01
14	Sediment Content	% m/m	-	0.01
15	Strong Acid Number	mgKOH/gr	-	0
16	Total Acid Number	mgKOH/gr	-	0.6
17	Particulate	mg/l	-	-
18	Visual Appearance	-	Bright and clear	
19	Color	No.ASTM	-	30
20	Lubricity	micron	-	460

2.4. Combustion Process

Diesel engine is an engine in which the combustion occurs inside the combustion chamber of the engine. The combustion occurs by compressing air inside the combustion chamber making the air have higher pressure and temperature, at the same time the fuel is injected through an injector into the combustion chamber, because the combustion chamber has high temperature the fuel ignites and combustion occurs. This combustion leads to higher pressure in the combustion chamber thus pushing the piston downward and then cranking the crankshaft (Achmad, 2018).

There are several factors like ignition delay, knocking, Rate of heat release, and pressure that affecting the combustion process of the combustion chamber. Each of these factors is caused by different variables whether it's the fuel calorific value, fuel cetane number, fuel spray pattern, injection timing etc. All of those factors can affect the performance of the engine.

A. Ignition Delay

Theoretically the combustion process in a diesel engine starts when the piston compresses the air in the combustion chamber, then when the piston reaches Top Dead center, the fuel is injected which will burn by itself because the temperature of the combustion chamber has reached the flash point of the fuel. In fact there is a delay since the start of fuel injection with the occurrence of combustion. This delay is called Ignition delay (Arifin & Mawardi, 2013).

The main reason for ignition delay depends on the cetane number (CN) of the fuel used. Cetane number is a number that provides a measure of ignition characteristics of a diesel fuel when it is burnt in diesel engine (Oxford dictionary). Fuel which has lower cetane number has longer ignition delay characteristics (S. Rabl et al, 2014).

B. Maximum Pressure

One of the factors of combustion process is the pressure produced by the combustion. In diesel engine, the peak pressure of the combustion chamber depends on the fraction of fuel burned during premixed burning phase, i.e initial stage of combustion. The pressure of the cylinder characterizes the ability of the fuel to mix well in the air and burn (Qi et al., 2010)

C. Rate of Heat Release

Rate of heat release is defined as the heat released from a chemical in a given time. By knowing heat release rate parameter, some of the combustion phenomena in the engine cylinder can be analyzed. Phenomena parameters such as combustion duration and intensity can be easily estimated from heat release rate diagram (Tesfa, et al. 2011). In this study the chemical is biodiesel B20.

D. Knocking

Sometimes Diesel engines can experience abrupt cylinder pressure raise due to rapid increase of fuel combustion rate. This is sometimes because of the fuel has longer ignition delay, the burning of the first droplets is longer, and more fuel is accumulated in the combustion chamber. Then when the ignition occurs, it burns violently and create pressure oscillations. This phenomenon is called knocking (Jakub, 2016).

E. Fuel Spray characteristic

Injection characteristic has an important role on engine performance, emission and efficiency. These are directly related to fuel economy in which will affect the operational fuel cost of the engine. Generally good injection characteristic is when the injector can inject smaller droplets of fuel, the smaller droplets can have more overall surface area than bigger droplets with the same volume of fuel injected. This can be achieved by increasing the injection pressure. It is proven that by increasing the injection pressure there is an increase in engine power because of better combustion (R.A Bakar, 2008). Better spray quality means better and more efficient combustion characteristic of the engine. The second way to improve this is to add the number of nozzle hole for better spray distribution and improving hole geometry of the nozzle. This way it is computationally proved that more nozzle hole and improved hole geometry has better effect on performance of a diesel engine (Semin, 2008). This concept is also proven to be good on CNG marine Engine (Semin, 2008.The other way to make the droplets of fuel become smaller is by varying the temperature of the fuel which can make the viscosity of the fuel become lower (Park, 2010).

Viscosity is a very important property of a fluid especially fuel. Viscosity is a resistance of a fluid to move (Nanang et al, 2012). In theory viscosity value of a fluid in this case is fuel can be reduced by increasing the temperature. This is due to the molecular structure of liquid. The molecules in the liquid has cohesive force, by heating the liquid the cohesive force is reduce thus the resistance of the fluid become lower and as a result the viscosity decreased (Donal F. Young, 2004). As explained before that viscosity has very important role in fuel injection and combustion process, higher the viscosity leads to worse atomization by the injector (Nanang et al, 2012).

On macroscopic level, the characteristic of the injection are Spray tip Penetration, Spray Angle, and Breakup length. Spray tip penetration is the distance travelled by the fuel spray in a controlled volume of injection. This is determined by momentum of quantity of the fluid that is injected and resistance of the air present in the combustion chamber. Spray angle is defined as the angle formed by the spray from the nozzle orifice and tangent of the spray outline. The average range of cone angle is around 10^o to 25^o (Prabkhara Rao, 2015). Breakup length is the length from nozzle orifice to the area where the first breakup occur (Martinez et al, 2010).

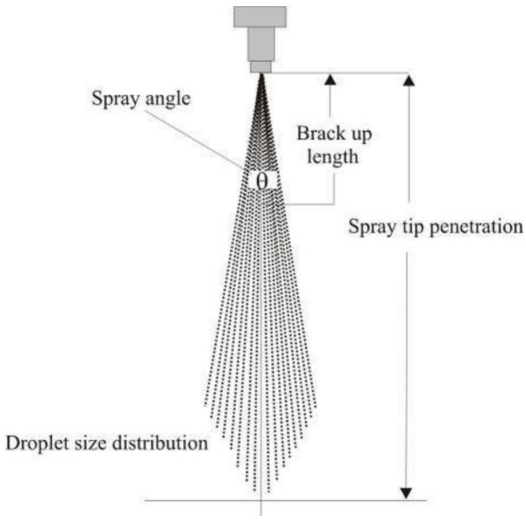

Figure 2.1 Characteristic of Injection on macroscopic level (Martinez et al, 2010)

One of the factor affecting the fuel spray characteristic is fuel properties. According to research conducted by Bambang *et al*(2007), the properties of the fuel that will affect the spray characteristic are density, viscosity and surface tension. The increasing amount of those properties leads to longer droplet breakup, longer droplet life time, more spray penetration and bigger sauter mean diameter. For surface tension, research conducted by (*Anh Tuan,* 2019) on straight coconut oil (SCO) shows that increasing temperature leads to lower surface tension, density and kinematic viscosity of the fuel oil.

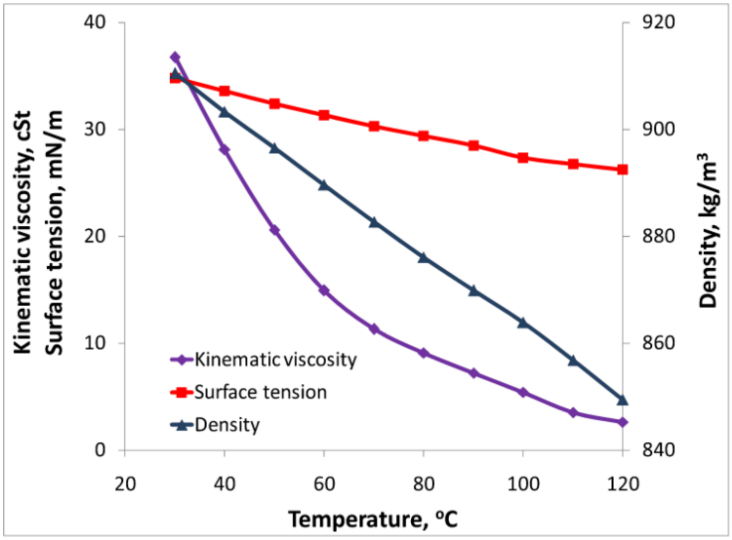

Figure 2.2 Kinematic Viscosity, Surface Tension and Density per temperature of SCO (*Anh Tuan*, 2019)

Reduced surface tension and kinematic viscosity is due to decreasing of cohesion force between fuel molecules as the temperature increase. Fuel spray characteristics played important role in combustion and emission characteristic. Bad fuel spray characteristic leads to inefficient engine performance and worse emission due to incomplete combustion.

2.5. Heat Exchanger

In General heat exchanger is a device that function to transfer heat between two or more fluids at different temperature. Heat exchanger is used in many sectors such as Power plant, chemical industry, refrigeration (Sadik et al, 2012). Heat exchanger is also used in a ship, it is used in cooling system and lubricating system.

2.4.1 Heat exchanger based on its flow direction

There are many types of heat exchanger. According to its flow path configurations commonly heat exchanger are categorized (Zohuri, 2017):

A. Parallel Flow
In parallel Flow as the name implies the fluids is having the same direction as both fluids flow inside the heat exchanger.

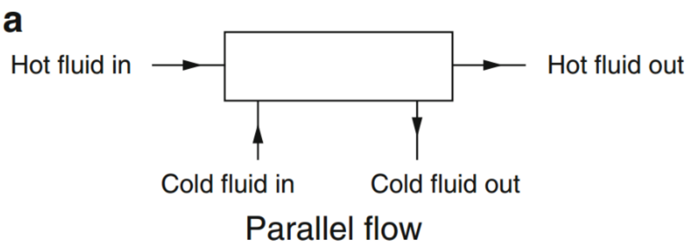

Figure 2.3 Parallel Flow Heat exchanger (Zohuri, 2017)

B. Counter Flow

In the counter Flow heat exchanger, the fluids move in the opposite direction, so if one working fluid is flowing from left to right, then the other working fluid is flowing right to left.

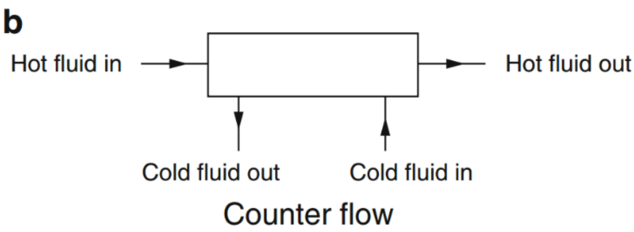

Figure 2.4 Counter Flow Flow Heat exchanger (Zohuri, 2017)

C. Single-Pass Cross Flow

In this type the fluid direction is crossing each other at an angle.

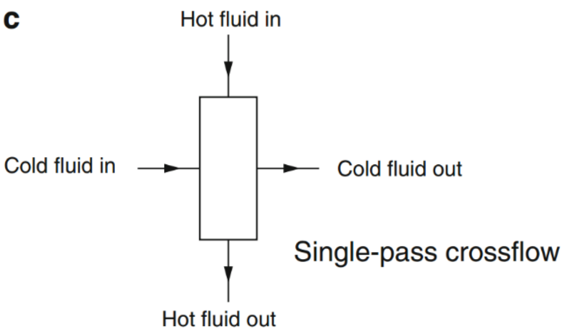

Figure 2.5 Single-Pass Cross Flow Heat exchanger (Zohuri, 2017)

D. Multipass crossflow

In this type, one of the working fluid is flowing back and forth inside the heat exchanger before going out from the heat exchanger.

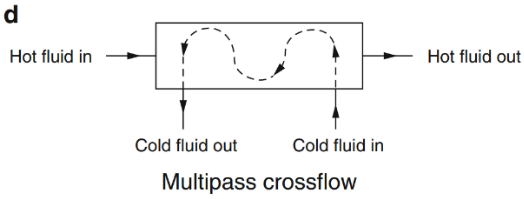

Figure 2.6 Multipass Crossflow Heat Exchanger (Zohuri, 2017)

2.4.2 Heat exchanger based on its construction

Based on its construction heat exchanger has many classification, this is due to its demand that is varied so much depending at what system it is placed or at what kind of industry it is in. Here are the types of heat exchanger based on its construction (Sadik et al, 2012):

A. Tubular Heat Exchanger

Tubular Heat exchangers are comprised of tubes where one fluid flow inside the tube and other fluid flow outside the tube. The design of this kind of heat exchanger are usually quite flexible due to its flexibility by changing the diameter of tube, number of tubes, and the tube arrangement. Generally tubular heat exchanger can be further classified to spiral tube heat exchanger, shell and tube heat exchanger, and double pipe heat exchanger.

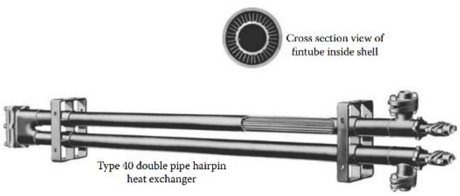

Figure 2.7. Double pipe heat exchanger(left) and Shell and tube Heat exchanger(right) (Brown Fintube and Alfa Laval)

B. Plate Heat Exchanger

Plate Heat exchangers are plates that has hollow construction used for fluid flow channel. In the plates usually there are 2 hollow channel for different fluid temperatures, these channel is separated by smooth plates that consist of corrugated fins. This kind of heat exchanger is used for combination of gas or liquid streams. Plate heat exchanger can be further classified to gasketed plate heat exchanger, spiral plate, or lamella.

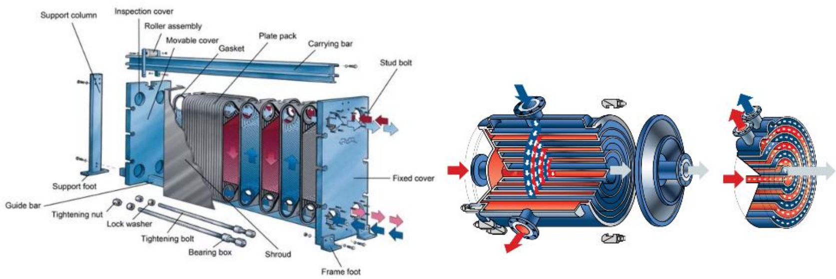

Figure 2.8. Gasketed heat exchanger (left) and Spiral Plate heat exchanger (right) (Alfa Laval)

2.6. Research Relating to the Topic

A. Research about Fuel inlet temperature and its relation with engine performance

In 2018, research conducted by Abdullah bin-Mahfouz, Khaled Mahmoud, and Mohammed Mourad proves that the inlet temperature of the fuel can make the performance of small diesel engine slightly better. The research was conducted using petrodiesel and biodiesel fuel by varying inlet temperature of 50°C and 70°C and observing the effect on engine brake thermal efficiency and brake specific fuel consumption.

The research shows that the effect of fuel temperature on brake thermal efficiency of the biodiesel at inlet temperature of ambient temperature, 50°C and 70°C. It is shown that there is an increase of brake thermal efficiency as shown in the figure 2.8.

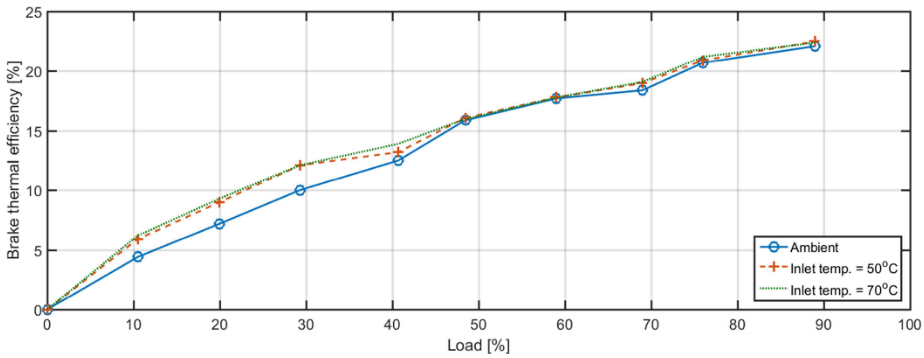

Figure 2.9 Brake Thermal Efficiency vs load (Abdullah et al, 2018)

The increase of Brake Thermal Efficiency is due to the weakening fuel chain hence better combustion can be achieved. With better combustion, it is expected that the performance of the engine is increased. On Brake Specific Fuel Consumption (BSFC), there is a slight reduction of BSFC in both petrodiesel and Biodiesel at inlet temperature 70°C as shown in the figure 2.9. Based on that, this research is conducted to know the effect of heat exchanger in order to increase the temperature inlet of the engine from the Combustion Process point of view.

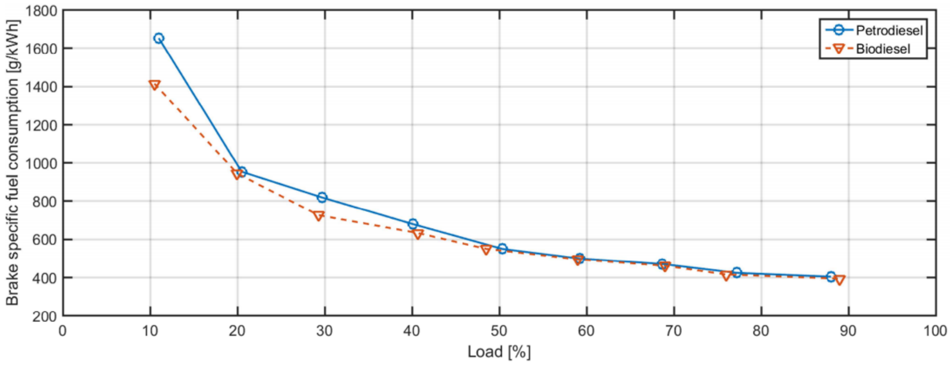

Figure 2.10 Brake Specific Fuel Consumption vs Load (Abdullah et al, 2018)

B. Research about Fuel Injection Temperature to Spray Characteristics

In 2010, a research conducted by Su Han Park, Hyung Jun Kim and Chang Sik Lee prove that by varying the temperature of the fuel can make the injection spray characteristic different. By increasing the fuel temperature the spray tip penetration decreased (figure 2.10) due to reduction of spray momentum because to density of the fuel become lower. The Spray cone angle is showing an increasing trend in the experiment and calculation.

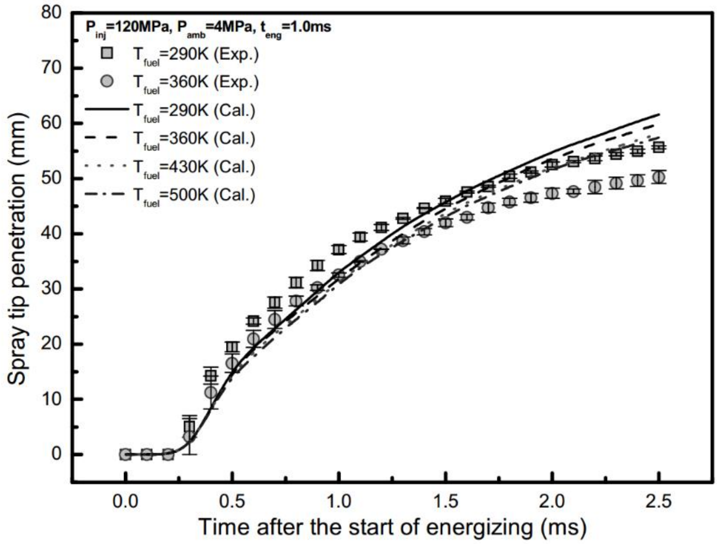

Figure 2.11 Spray tip Penetration of heated fuel Experiment and calculation (Park, 2010)

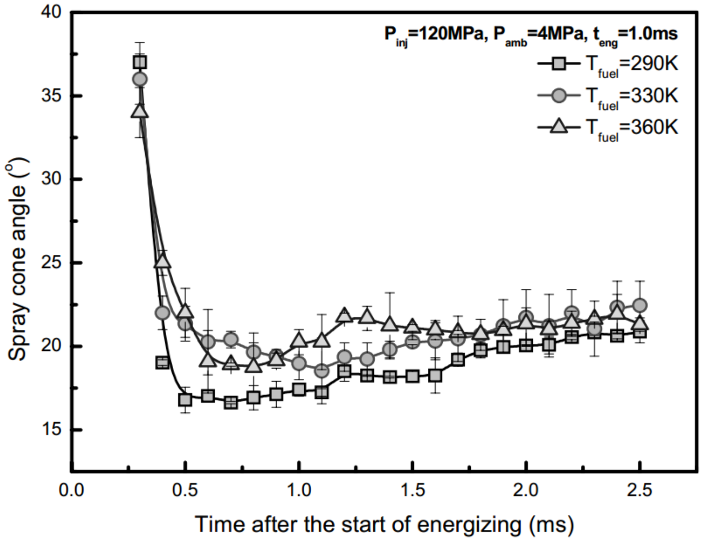

Figure 2.12 Spray Cone Angle of heated fuel Experiment and calculation (Park, 2010)

In the research the droplet sizes are also calculated and it turns out that the droplet sizes decreases by the increase of the fuel temperature. This is due to the decrease of kinematic viscosity and surface tension.

C. Research Relating to Biodiesel Fuel spray characteristics and Combustion Characteristics

In 2007 there was a research titled "The Atomization and Combustion Characteristics of Biodiesel and Fossil Diesel Fuel Blend" conducted by (Bambang, *et al*). In the research the fuel used was diesel fuel (B0) and Biodiesel (B100). It is proved that the more amount of Biodiesel in the fuel used tends to worse quality of spray indicated by longer spray tip penetration, bigger droplets and its lifetime.

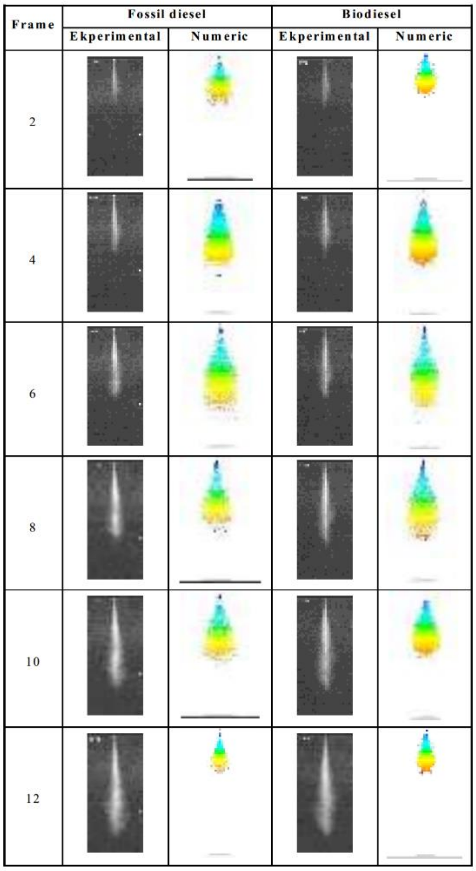

Figure 2.13 Spray Characteristic comparison between diesel fuel and biodiesel (Bambang *et al*, 2007)

In the research the combustion characteristic of both fuel were also analyzed. The result, were quite significant, by using Biodiesel (B100) the ignition delay is increased by 4 degrees and the total heat release is decreased until 26% compared to pure diesel fuel.

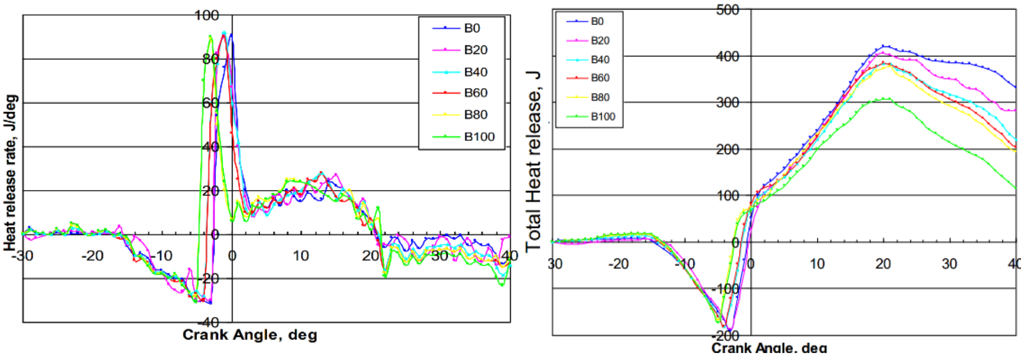

Figure 2.14 Heat Release rate and Heat release diagram in the research (Bambang *et al*, 2007)

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CHAPTER III

METHODOLOGY

3.1. Problem identification

Problem Identification on this thesis is to understand the effect of Heat Exchanger as the Heater of B20 Fuel to the Spray Characteristic and Combustion on the Diesel Engine Based on Experiment.

3.2. Literature study

Literature study is done by learning from some sources like books, journal, paper, thesis and internet. The purpose of this is to learn the theories to provide the knowledge in order to support the making of this bachelor thesis.

3.3. Preparing Tools and materials

In this stage the tools like engine, test tools, heat exchanger, etc are being prepared. The tools used are also tools on the marine power plant laboratorium. The B20 fuel is also needed to be bought in order to support the experiment. In this research, the tools and material needed are:

Experiment 1 (Combustion Test):

- Mitsubishi 4D30 Engine.
- Biodiesel B20
- Heat Exchanger
- Laptop, TMRInstrument sensor and SYSMONSoft software.

In the experiment, the engine used is Mitsubishi 4D30. The fuel is then heated by a heat exchanger in which the heat is obtained from the cooling system of the engine. Temperature control is done by a solenoid valve. Here are the Engine specification.

Table 3.1 Engine Specification (Manual Book Mitsubishi 4D30)

No.	Desciption	Parameter	Unit
1	Manufacturer	Mitsubishi	
2	Model	4D30	
3	Type	Inline 4, Water Cooled, 4-stroke Diesel Engine	
4	Valve Mechanism	Over Head Valve	
5	Type of combustion chamber	Swirl Chamber	
6	Bore x Stroke	100 x 105	mm
7	Displacement	3298	cc
8	Max Power	90	PS
9	Max Torque	22	kgfm
10	Fuel Injection Pressure	120	Kg/cm^2

Figure 3.1 Mitsubishi 4D30

Figure 3.2 Heat Exchanger Set

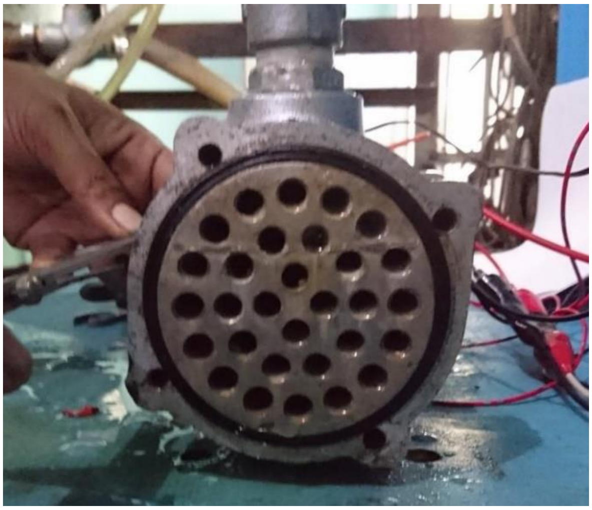


Figure 3.3 Cross sectional view of heat exchanger used in this experiment

Figure 3.4 Solenoid Valve for temperature control

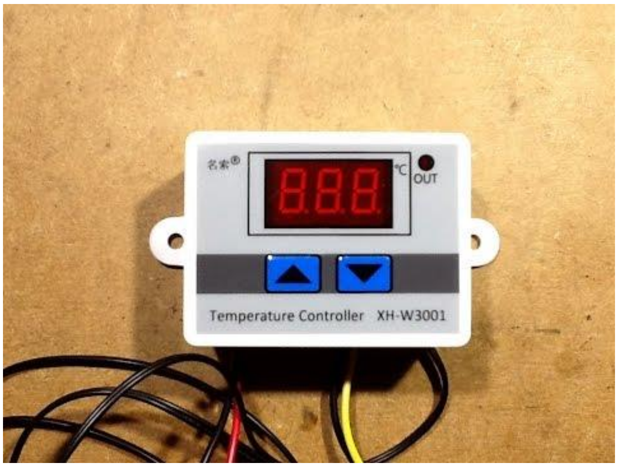


Figure 3.5 Thermostat

Before the Experiment begin, it need to be noted that the engine need to have some preparation such as drilling a hole plug for combustion sensor/pressure transducer, valve clearance check, and some repairs on the supporting system.

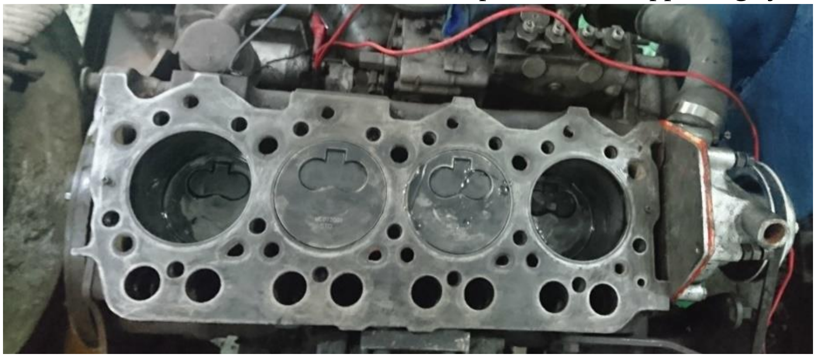


Figure 3.6 Upper view of engine block

Figure 3.7 Checking the viability for drilling the cylinder head for pressure transducer

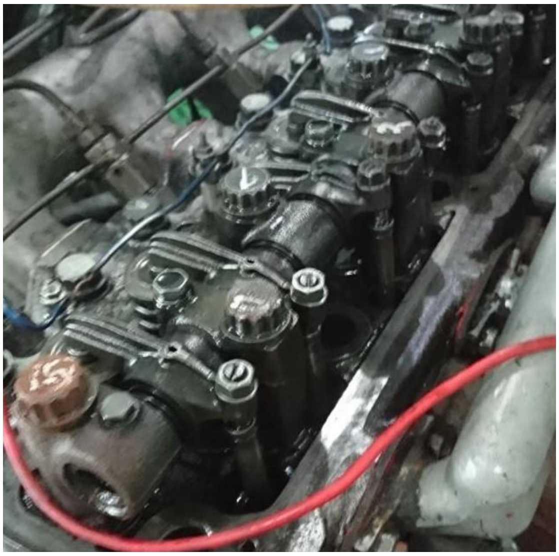


Figure 3.8 Valve clearance check

Figure 3.9 Water Brake cooling pump needs a bearing change

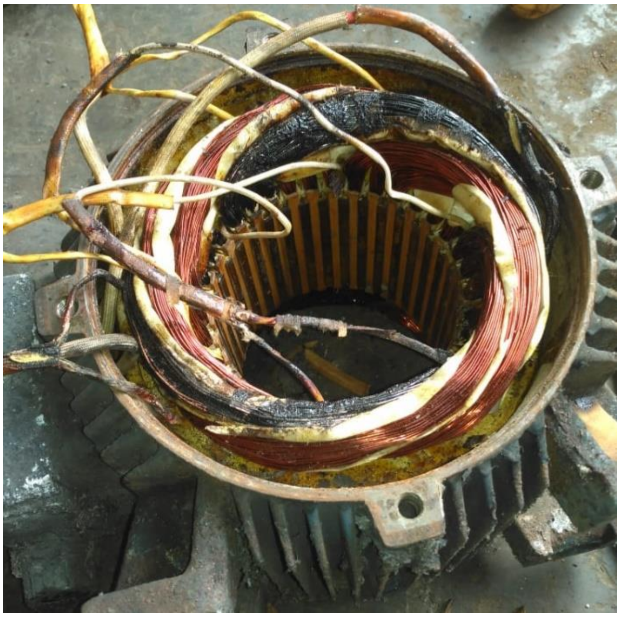


Figure 3.10 Water brake cooling pump motor needs rewiring

Figure 3.11 Water Brake Load Valve needs Bearing change

Experiment 2 (Spray Characteristics test):

- Biodiesel B20
- Measuring cups
- Electric heater
- High Speed camera (240 FPS and 720p Resolution)
- Injector Tester

Figure 3.12 Injector of Mitsubishi 4D30

Figure 3.13 Injector Tester

Figure 3.14 Electric heater for Spray Test Experiment

In the test there will be several variables to be used, some of these variables are:

A. RPM Variable
   - 1800RPM with 100% Load
   - 2000 RPM with 100% Load
   - 2200 RPM with 100% Load
B. Fuel Temperature Variables (for Spray Characteristic)
   - Ambient Temperature
   - Temperature 35°C
   - Temperature 40°C
   - Temperature 45°C
   - Temperature 50°C
   - Temperature 55°C
   - Temperature 60°C
   - Temperature 65°C

- Temperature 70°C

C. Fuel Temperature Variables (for Combustion Process)
   - Ambient Temperature
   - Temperature 40°C
   - Temperature 50°C
   - Temperature 60°C
   - Temperature 70°C

D. Control Variables
   - Analog Set up
   - Engine Set up
   - Angle sensor set up
     - Thermodynamics set up
     - Knock Detection Set up
     - Top Dead Center Detection
     - Maximum Pressure Set up

E. Result Variables
   - Ignition Delay
   - Maximum Pressure
   - Heat Release
   - Knocking detection
   - Spray Characteristics

3.4. Experiment setup

Before collecting the data, the engine will be checked by running test to understand the current condition and the basic performance of the engine. The engine that will be used in the research will be MITSUBISHI 4D30. After the engine condition and performance is checked then the engine will be set up Experiment 1 in which in schematic it will look like this.

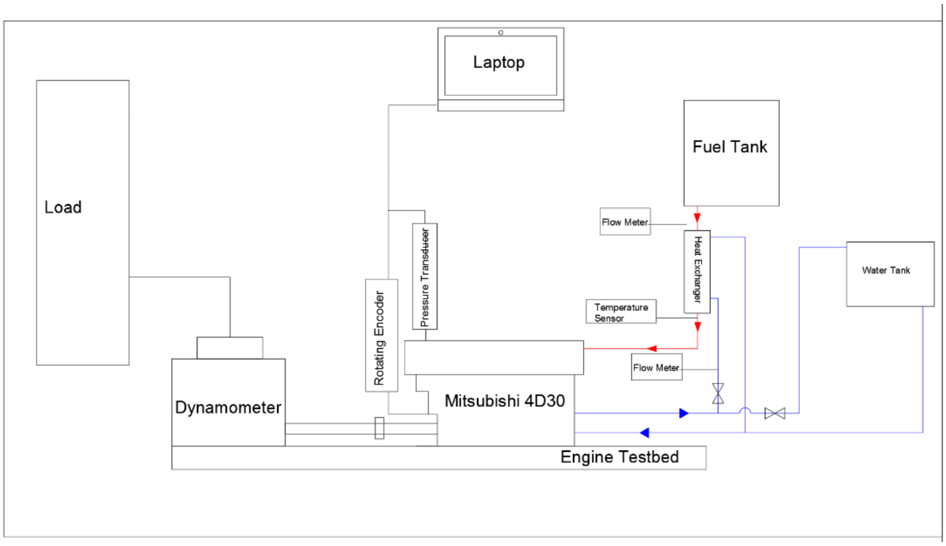


Figure 3.15 Experiment 1 Schematic Setup

Figure 3.16 Real Setup of Experiment 1

For the experiment 2 the test will be using injector tester, thermometer, and high speed camera. It is need to be noted that the test is done at ambient pressure. For the fuel temperature, it is done by heating fuel using coil in the injector tester tank. The configuration of the experiment 2 is shown below.

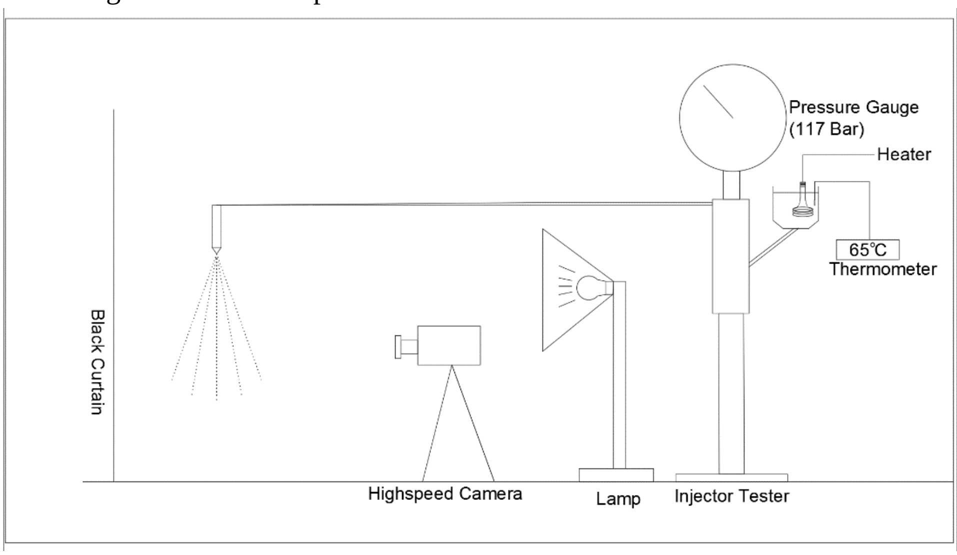


Figure 3.17 Experiment 2 Schematic Setup

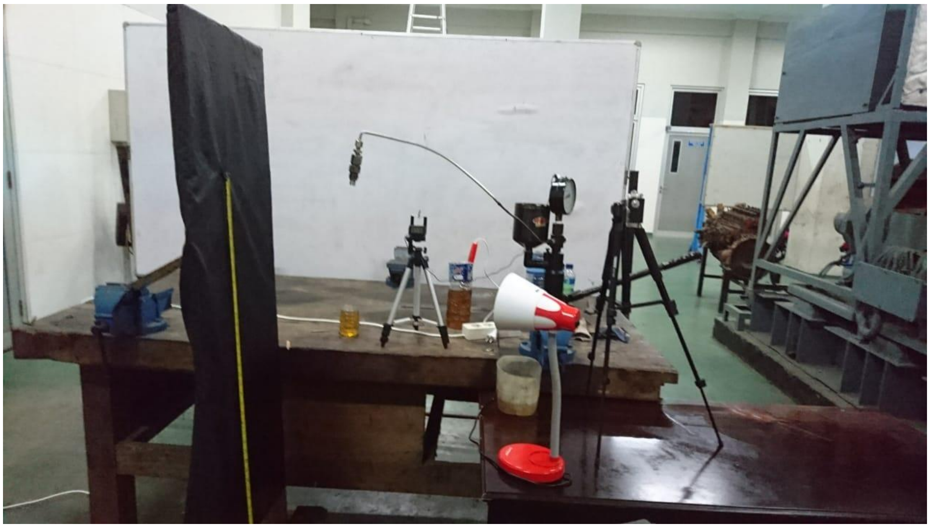


Figure 3.18 Real Setup of Experiment 2

3.5. Experiment

- Experiment 1: Combustion Process data Acquisition

From figure 3.1 it is known that the engine needs to be modified in order to install the pressure transducer and rotating encoder in order to get the data. For pressure transducer, normally the cylinder head needs to be drilled. In this case trilling the cylinder head is not viable because there is water jacket around the preferable location and can create coolant leak to combustion chamber. The solution of this is to get the data from swirl chamber/pre-chamber. The sensor/pressure transducer is installed replacing the glow plug in one of the cylinder. For this a connector is made.

Figure 3.19 Connector for glow plug hole and Pressure transducer

Figure 3.20 Connector for Rotating Encoder

- The first Experiment will be done when the engine set up is finished and ensuring that components will be safe for the test. The test will be done in Marine Power Plant Laboratory in Marine Engineering department ITS. The goal of this experiments is collecting data of the engine combustion process.

The second experiment will be Spray test using the injector of the 4D30 Engine. The test will include a high speed camera to capture the spray of the injector to get the data in detail.

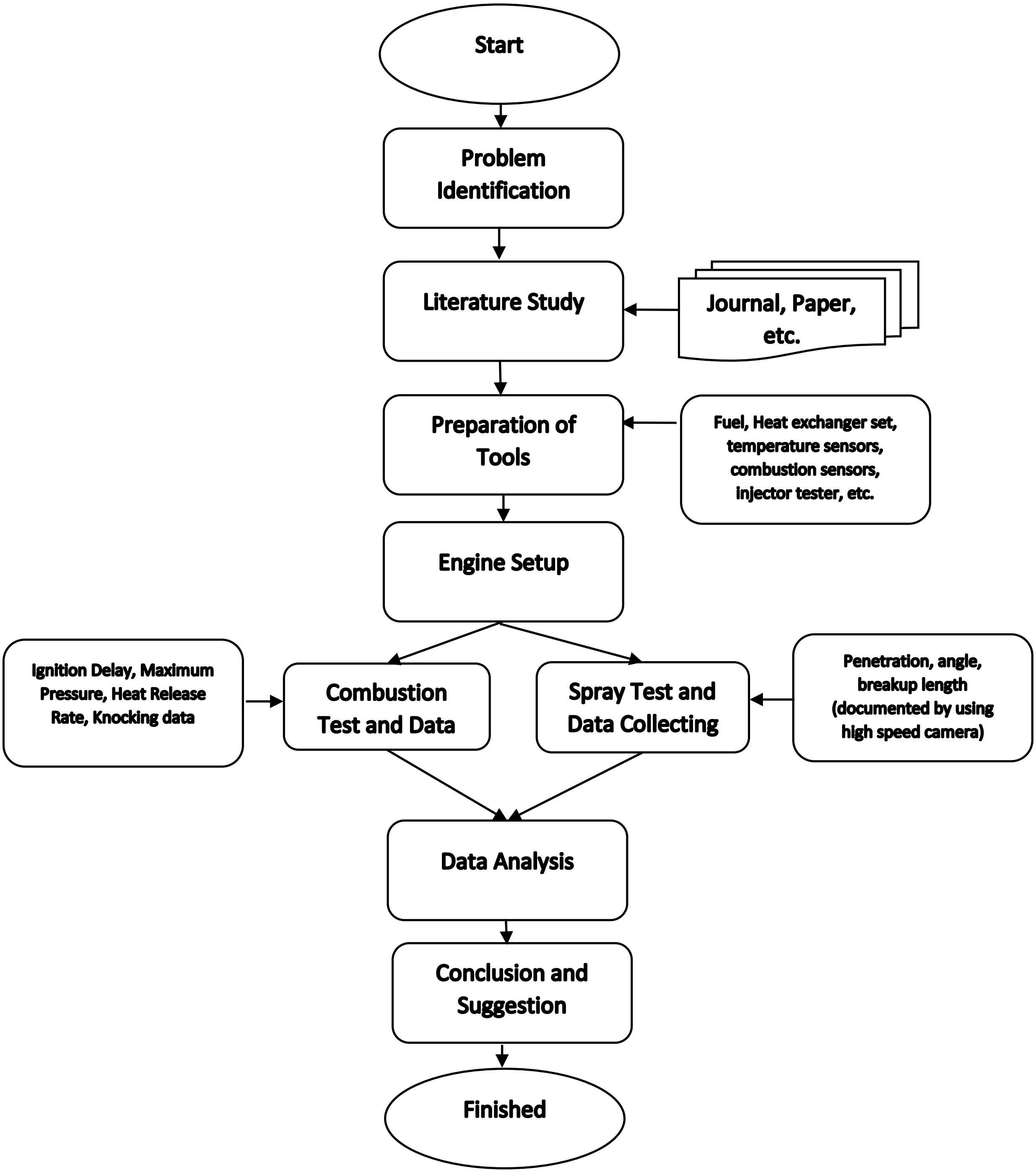
3.6. Analysis and Discussion

After the data is collected, the data is then processed and analyzed. The data will be analyzed by comparing the results of the temperature variables in each combustion parameters for each RPM.

3.7. Conclusion and Suggestions

After all data has been analyzed, conclusions can be made. The conclusion will satisfy the problem statement of the thesis. And suggestion is also can be made to perfect the next research regarding the same topic so, the process can be more accurate and efficient.

In this Thesis the method that will be used will be experiment based method. Here is the flow chart diagram of the method that will be used in the thesis:



CHAPTER IV

DATA ANALYSIS

4.1. Spray Characteristic Test Results

In this research the spray characteristic of the B20 fuel with temperature variation is observed. In the research, it is using the injector of Mitsubishi 4D30 by using an injector tester, portable heater, thermometer and high speed camera (240 FPS). In this test the Spray tip penetration, cone angle, and average velocity of the spray can be determined. It is need to be noted that all the picture of the spray taken is t= 0.1s after injection, the reason is that the time of the injection in the test are averaging at 0.1s. The temperature variation of the test would be 30ºC (ambient temperature), 35ºC, 40ºC, 45ºC, 50ºC, 55ºC, 60ºC, 65ºC and 70ºC.

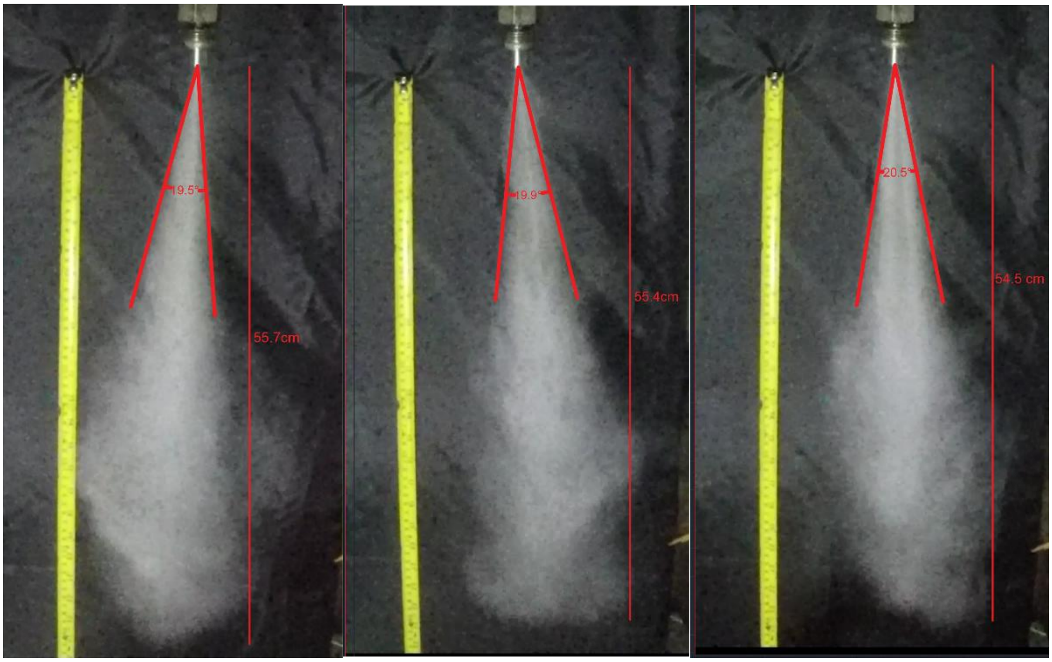


Figure 4.1 Spray Visualization of 30ºC, 35ºC and 40ºC (from left)

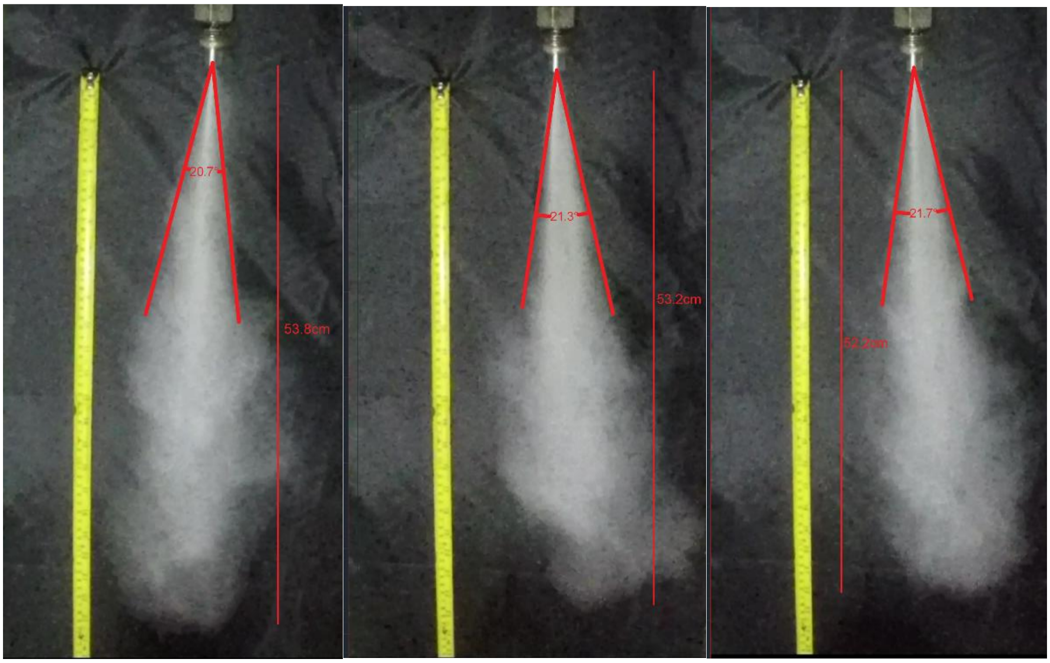


Figure 4.2 Spray Visualization of 45ºC, 50ºC and 55ºC (from left)

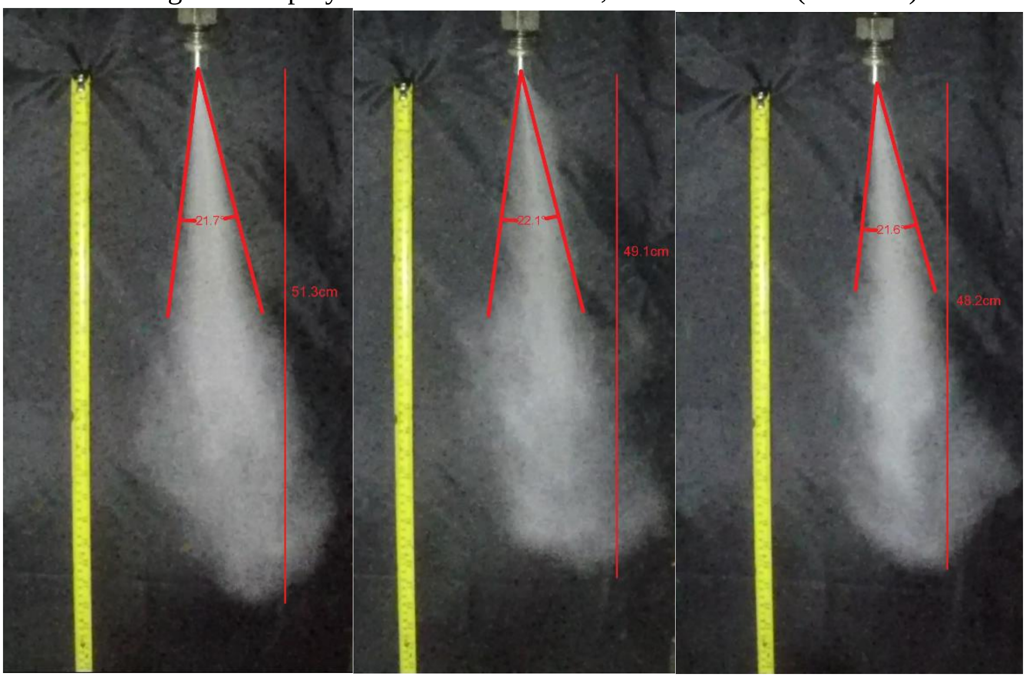


Figure 4.3 Spray Visualization of 60ºC, 65ºC and 70ºC (from left)

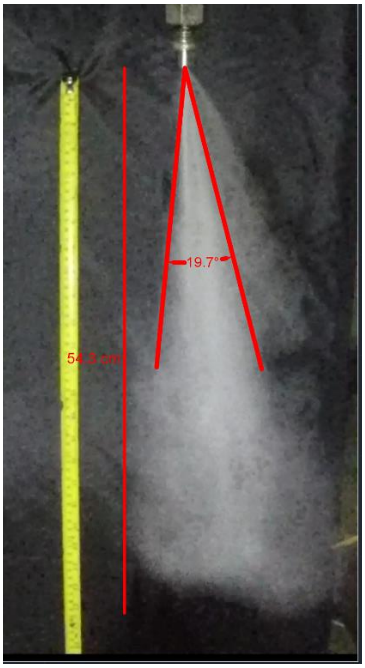


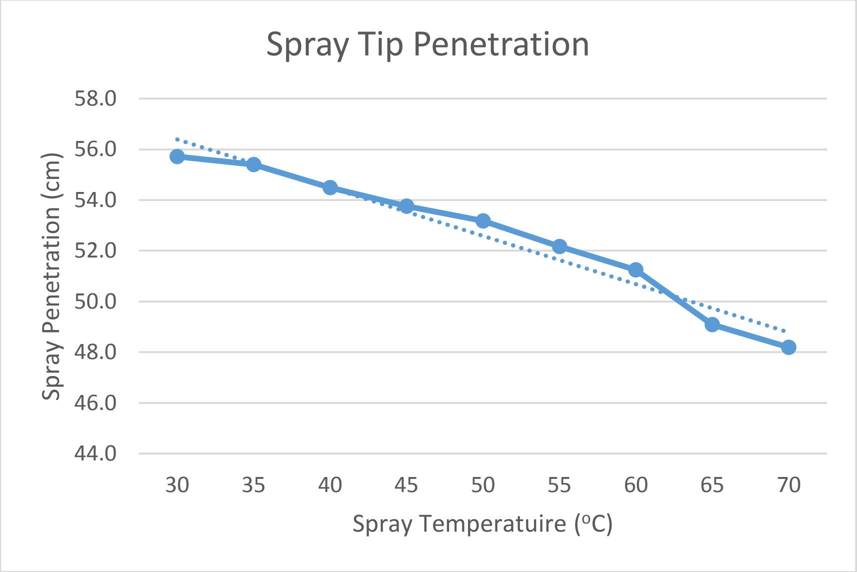
Figure 4.4 Dexlite at 31°C (ambient) for comparison

Based on the spray visualization on Figure 4.1, 4.2, 4.3 and 4.4 the spray characteristic parameters can be compared for each temperature. In the table 4.1 all parameters that need to be observed are summarized. After that it is followed by the graph 4.1, 4.2 and 4.3 to see the trend of each parameter.

Temperature	Spray tip Penetration (cm)	Cone Angle (degree)	Average Velocity (m/s)	Capture time (s) (after injection)
30	55.7	19.5	5.57	0.1
35	55.4	19.9	5.54	0.1
40	54.5	20.5	5.45	0.1
45	53.8	20.7	5.38	0.1
50	53.2	21.3	5.32	0.1
55	52.2	21.7	5.22	0.1
60	51.3	21.7	5.13	0.1
65	49.1	22.1	4.91	0.1
70	48.2	21.6	4.82	0.1
Dexlite 31°C	54.3	19.7	5.43	0.1

Table 4.1 Summary of Spray Characteristic Results

a. Spray Tip Penetration

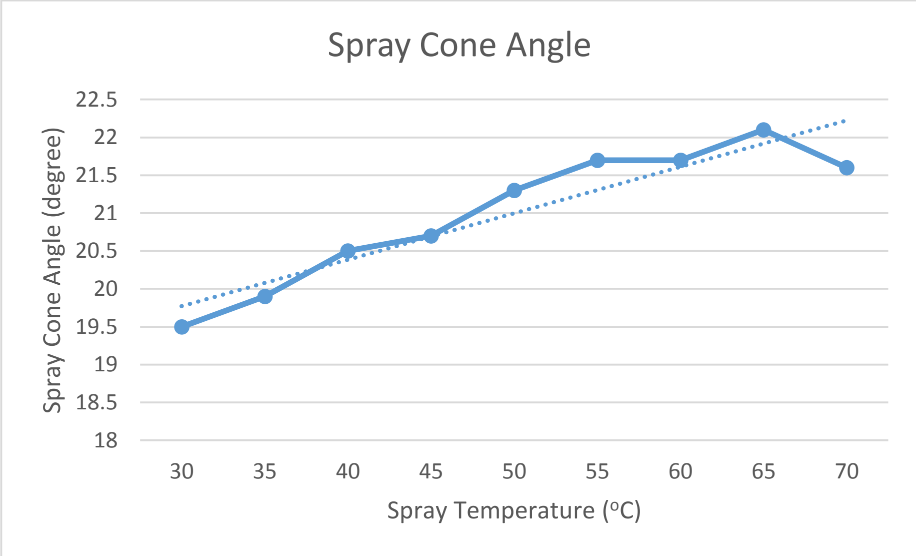


Graph 4.1 Effect of temperature to spray tip penetration

From the figure 4.1 it can be seen that the spray tip penetration at 30°C is 55.7cm then the spray goes slightly nearer at 55.4 cm at 35°C. At 40°C the spray tip penetration is decreased by 0.9 cm compared to spray tip penetration at 35°C. The trend shows that the spray tip penetration of the fuel is shorter for every increase of temperature. At 65°C the spray tip penetration is 49.1cm, compared to the ambient temperature which is 30°C, the spray tip penetration at 65°C is 6.6 cm shorter then at 70°C the spray tip penetration become even shorter at 48.2 cm. As a comparison, at 30°C Dexlite fuel has 54.3 cm of spray tip penetration.

The explanation of this is due to the lower viscosity of the fuel for every temperature increase. The lower temperature of the B20 fuel cause viscosity become lower thus the flow momentum of the fuel to be lower. So when higher temperature fuel is injected at the same pressure, due to its lower momentum compared to the ambient temperature fuel, the fuel will have shorter spray tip penetration. On the other hand, when the lower fuel is injected at the same pressure, it has higher viscosity, hence the fuel flow momentum is higher so the spray tip penetration will become longer.

b. Spray Cone Angle

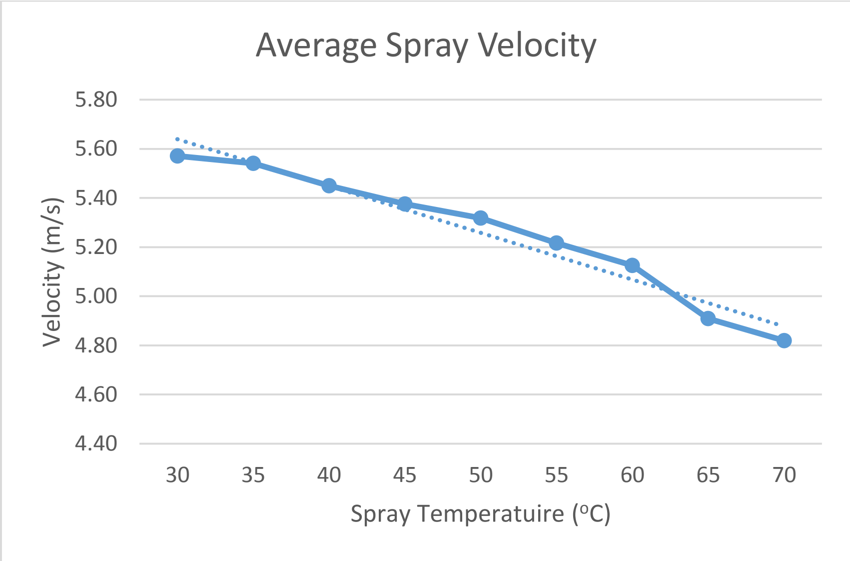


Graph 4.2 Effect of temperature to spray cone angle

From the figure 4.2 it is shown that the spray cone angle at 30°C is 19.5°, then at 35°C the spray cone angle is increased to 19.9°. Then the spray cone angle at 40°C is increased by 0.6°. At 45°C the spray cone angle only slightly increase about 0.2° and increasing again at 50°C become 21.3°. Then the trend keep increasing until 65°C. At 65°C the spray cone angle become 22.1°. Then at 70°C the spray cone angle become slightly reduced at 21.6°. For comparison, Dexlite has Spray 19.7° at 31°C (ambient).

The increasing trend of spray cone angle is due to lower density and lower surface tension for every increasing temperature. The increasing temperature will make the density and surface tension become lower. It is well known that the lower surface tension due to increasing temperature is because of the weakening cohesive force between fuel molecules. This can create better degree of evaporation of the fuel which indicated by bigger spray cone angle

c. Average Spray Velocity



Graph 4.3 Effect of temperature to average spray velocity

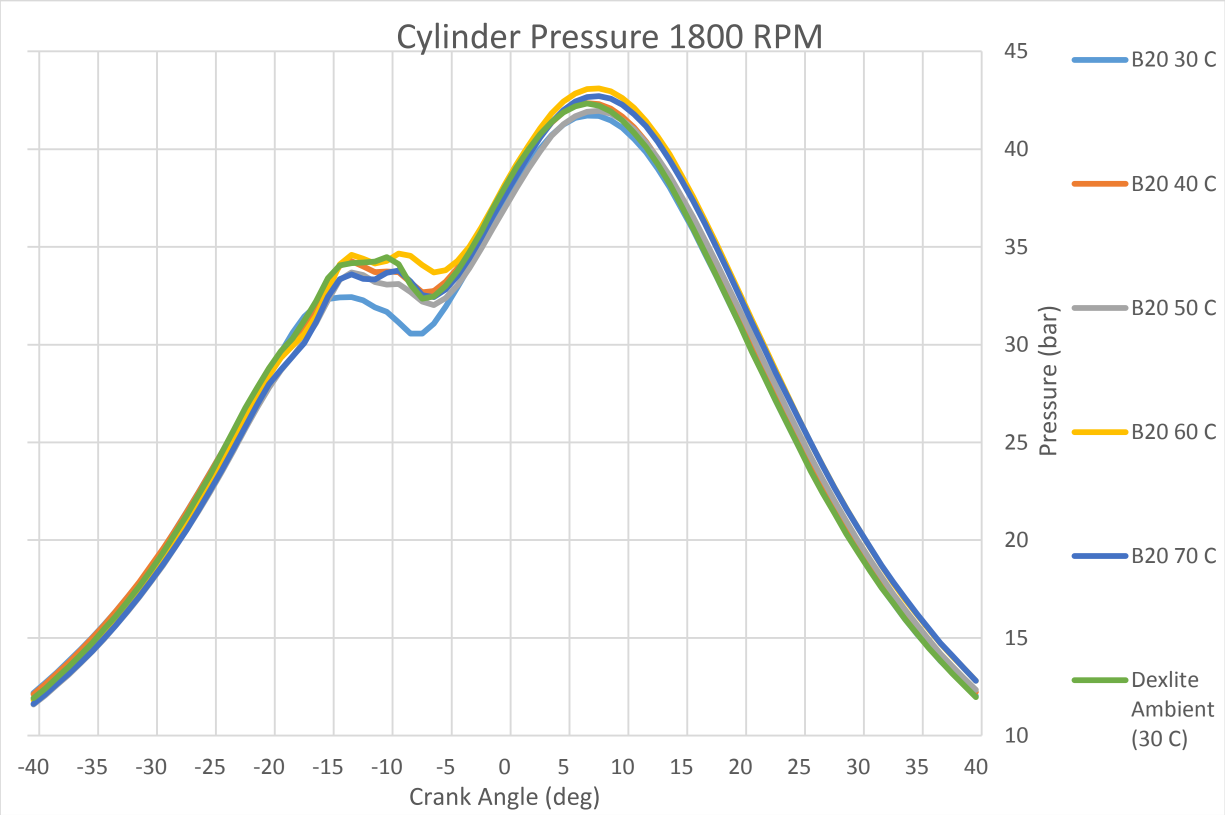
From Figure 4.3 the average spray velocity is 5.57 m/s at 30ºC, 5.54 m/s at 35ºC. The trend keep decreasing until the highest temperature of 65ºC in which the average spray velocity becomes 4.91 m/s. Compared to average spray velocity at 30ºC, the average spray velocity at 65ºC is 0.66 m/s slower. Then the average spray velocity at 70ºC become even slower at 4.82 m/s. As a comparison Dexlite fuel has 5.43 m/s of average spray velocity

The decreasing trend is due to the difference of the fuel flow momentum. The higher the temperature, the lower the fluid flow momentum. So when injected at the same pressure, the fuel that has higher temperature tends to decelerate quicker compared to the fuel with lower temperature so the distance travelled at the same time is nearer thus making the average speed become lower. It is need to be noted that all fuel spray characteristic is captured at 0.1s, because it is the average time of the injection of fuel in the test, in which the picture is taken just before the injection ends.

4.2. Combustion Process

4.2.1 Max Pressure Analysis at 1800 RPM 100% load

Analysis done is comparison of maximum pressure of B20 with inlet temperature variation ranging from 30°C to 70°C at 1800 RPM with dexlite as comparison.

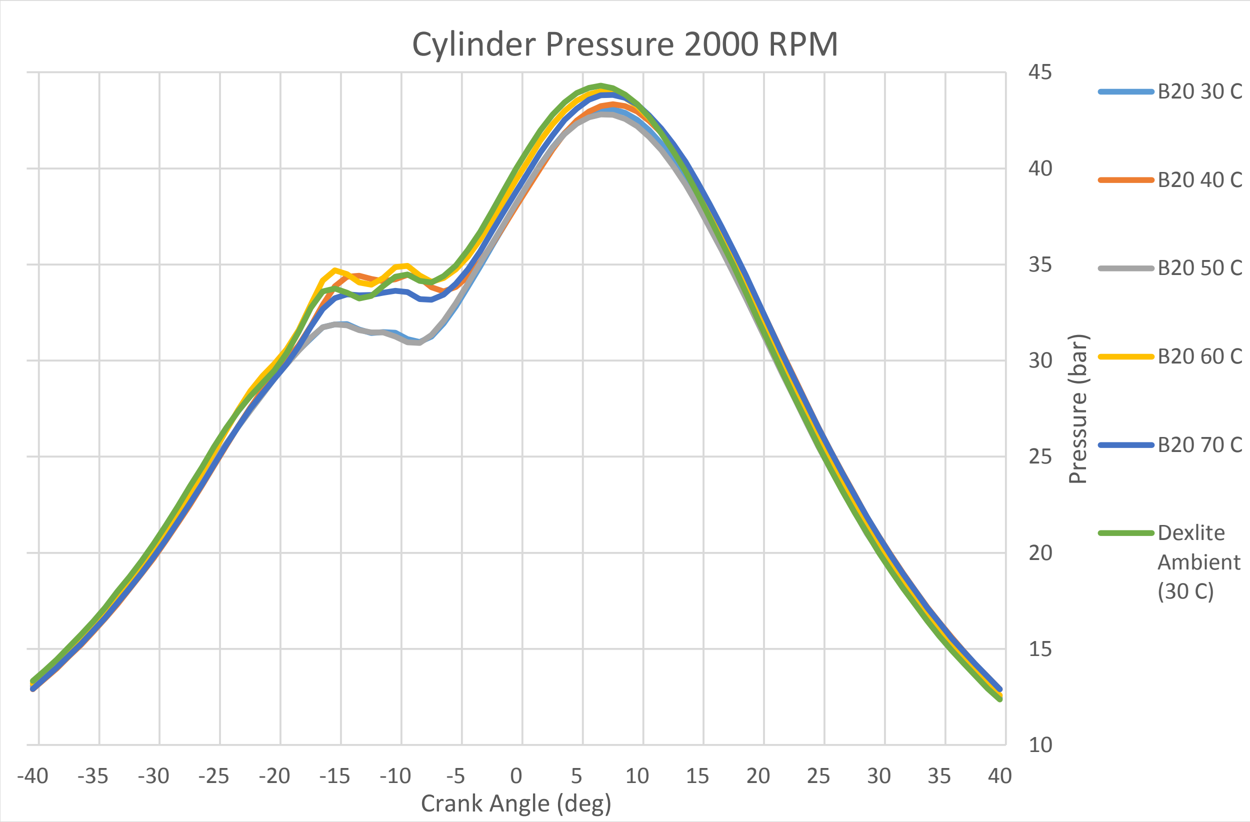


Graph 4.4 Max Pressure Graph analysis at 1800 RPM

Graph 4.4 is showing the max Pressure graph analysis at 1800 RPM for B20 fuel with fuel variation and dexlite as comparison. It can be observed that B20 fuel at 30°C can achieve 41.71 bar of maximum pressure at 7° angle after TDC. Then B20 at 40°C can achieve 42.34 bar of maximum pressure at 7° angle after TDC. For B20 at 50°C can achieve 41.96 bar of maximum pressure at 8° angle after TDC. B20 at 60°C can achieve 43.09 bar of maximum pressure at 8° angle after TDC. Then B20 at 70°C can achieve 42.71 bar of maximum pressure at 8° angle after TDC. As for comparison dexlite can achieve 42.33 bar of maximum pressure at 7° angle after TDC. The value of Maximum Pressure and the angle it's achieve is depending on how long the fuel burnt and the ignition delay time. The longer the ignition delay time means the top most point will be having more distance from the injection point at 14° before TDC.

4.2.2 Max Pressure Analysis at 2000 RPM 100% load

Analysis done is comparison of maximum pressure of B20 with inlet temperature variation ranging from 30ºC to 70ºC at 2000 RPM with dexlite as comparison.

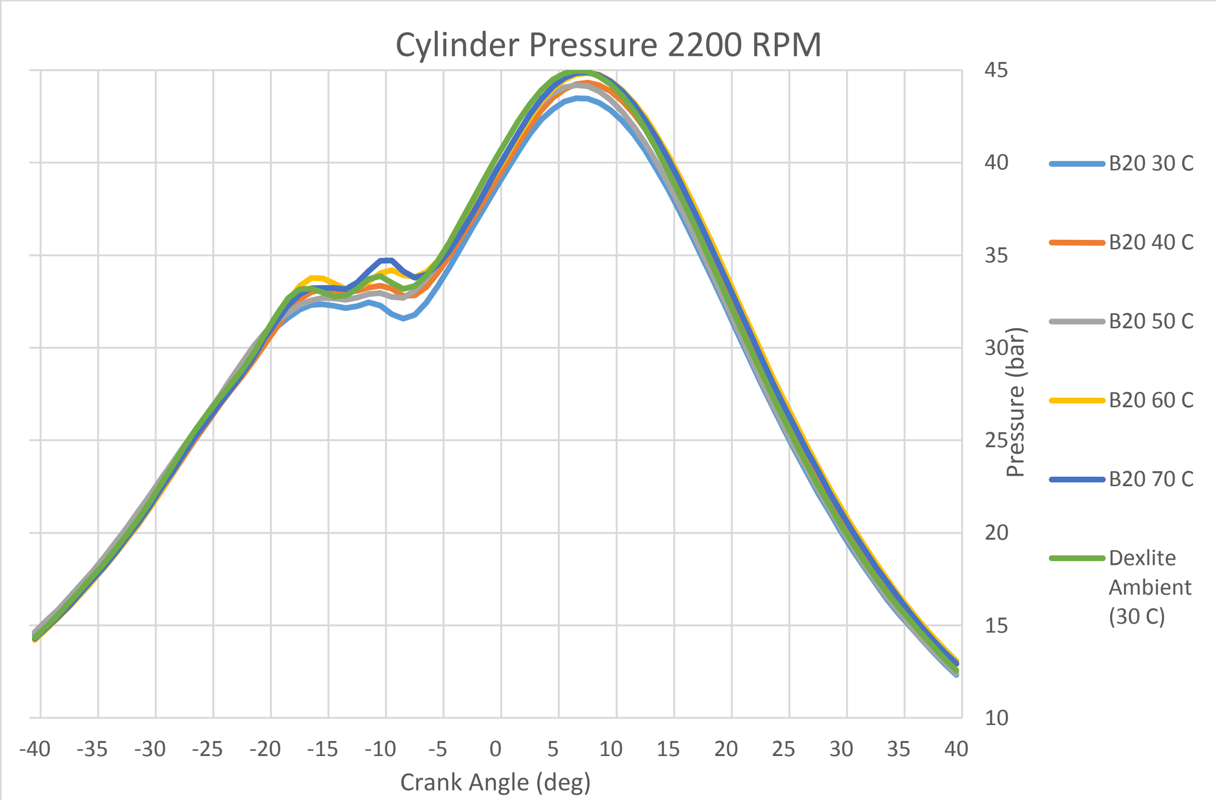


Graph 4.5 Max Pressure Graph analysis at 2000 RPM

Graph 4.5 is showing the max Pressure graph analysis at 2000 RPM for B20 fuel with fuel variation and dexlite as comparison. It can be observed that B20 fuel at 30ºC can achieve 43.07 bar of maximum pressure at 8º angle after TDC. Then B20 at 40ºC can achieve 43.30 bar of maximum pressure at 8º angle after TDC. For B20 at 50ºC can achieve 42.81 bar of maximum pressure at 7º angle after TDC. B20 at 60ºC can achieve 44.0 bar of maximum pressure at 7º angle after TDC. Then B20 at 70ºC can achieve 43.82 bar of maximum pressure at 8º angle after TDC. As for comparison dexlite can achieve 44.30 bar of maximum pressure at 7º angle after TDC. The value of Maximum Pressure and the angle it's achieve is depending on how long the fuel burnt and the ignition delay time. The longer the ignition delay time means the top most point will be having more distance from the injection point at 14º before TDC.

4.2.3 Max Pressure Analysis at 2200 RPM 100% load

Analysis done is comparison of maximum pressure of B20 with inlet temperature variation ranging from 30ºC to 70ºC at 2200 RPM with dexlite as comparison.

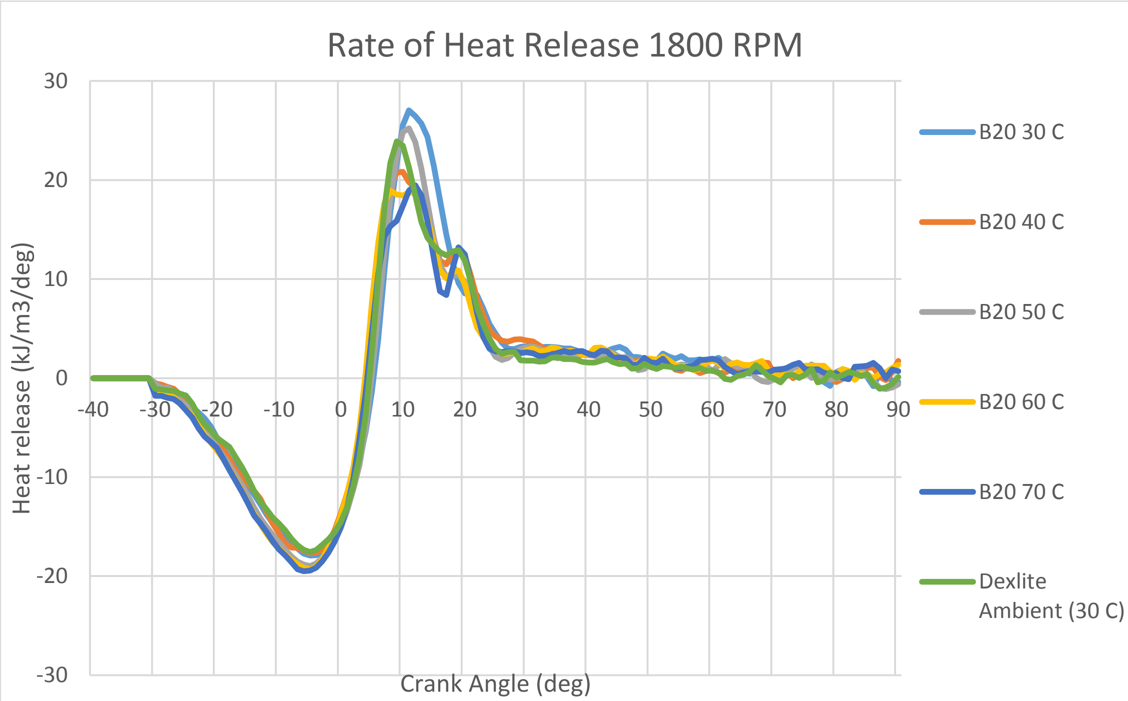


Graph 4.6 Max Pressure Graph analysis at 2200 RPM

Graph 4.6 is showing the max Pressure graph analysis at 2200 RPM for B20 fuel with fuel variation and dexlite as comparison. It can be observed that B20 fuel at 30ºC can achieve 43.47 bar of maximum pressure at 7º angle after TDC. Then B20 at 40ºC can achieve 44.31 bar of maximum pressure at 8º angle after TDC. For B20 at 50ºC can achieve 44.19 bar of maximum pressure at 7º angle after TDC. B20 at 60ºC can achieve 44.84 bar of maximum pressure at 8º angle after TDC. Then B20 at 70ºC can achieve 44.87 bar of maximum pressure at 8º angle after TDC. As for comparison dexlite can achieve 44.95 bar of maximum pressure at 7º angle after TDC. The value of Maximum Pressure and the angle it's achieve is depending on how long the fuel burnt and the ignition delay time. The longer the ignition delay time means the top most point will be having more distance from the injection point at 14º before TDC.

4.2.4 Rate of Heat Release Analysis at 1800 RPM 100% load

To understand the result of combustion process, then analysis of Rate of heat release is done. Rate of heat Release is the average release of heat from fuel and air during the combustion process. In this analysis the influence of fuel preheating can be known.

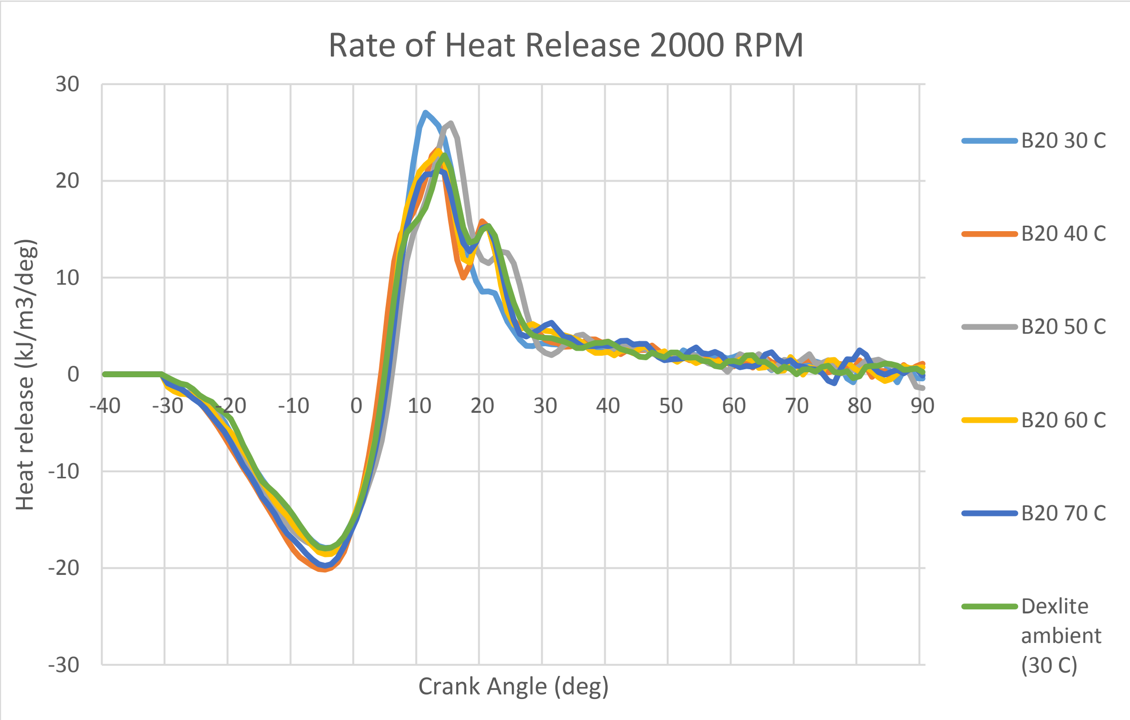


Graph 4.7 Rate of Heat Release analysis at 1800 RPM

From the graph 4.7 the result can be known. From Rate of heat release graph ignition delay can be known. The injection timing for Mitsubishi 4D30 is 14^o before TDC. It then can be observed that B20 at 30^{o}C has earliest combustion at 2^o before TDC and has highest heat release at 11^o after TDC with the value of 27.05 kJ/m^3/deg. Then B20 at 40^{o}C has earliest combustion at 2^o before TDC and has highest heat release at 10^o after TDC with the value of 20.84 kJ/m^3/deg. Then B20 at 50^{o}C has earliest combustion at 3^o before TDC and has highest heat release at 11^o after TDC with the value of 25.21 kJ/m^3/deg. Then B20 at 60^{o}C has earliest combustion at 3^o before TDC and has highest heat release at 8^o after TDC with the value of 18.9 kJ/m^3/deg. Then B20 at 70^{o}C has earliest combustion at 3^o before TDC and has highest heat release at 12^o after TDC with the value of 19.46 kJ/m^3/deg. Then Dexlite for comparison has earliest combustion at 4^o before TDC and has highest heat release at 9^o after TDC with the value of 23.9 kJ/m^3/deg.

4.2.5 Rate of Heat Release Analysis at 2000 RPM 100% load

To understand the result of combustion process, then analysis of Rate of heat release is done. Rate of heat Release is the average release of heat from fuel and air during the combustion process. In this analysis the influence of fuel preheating can be known.

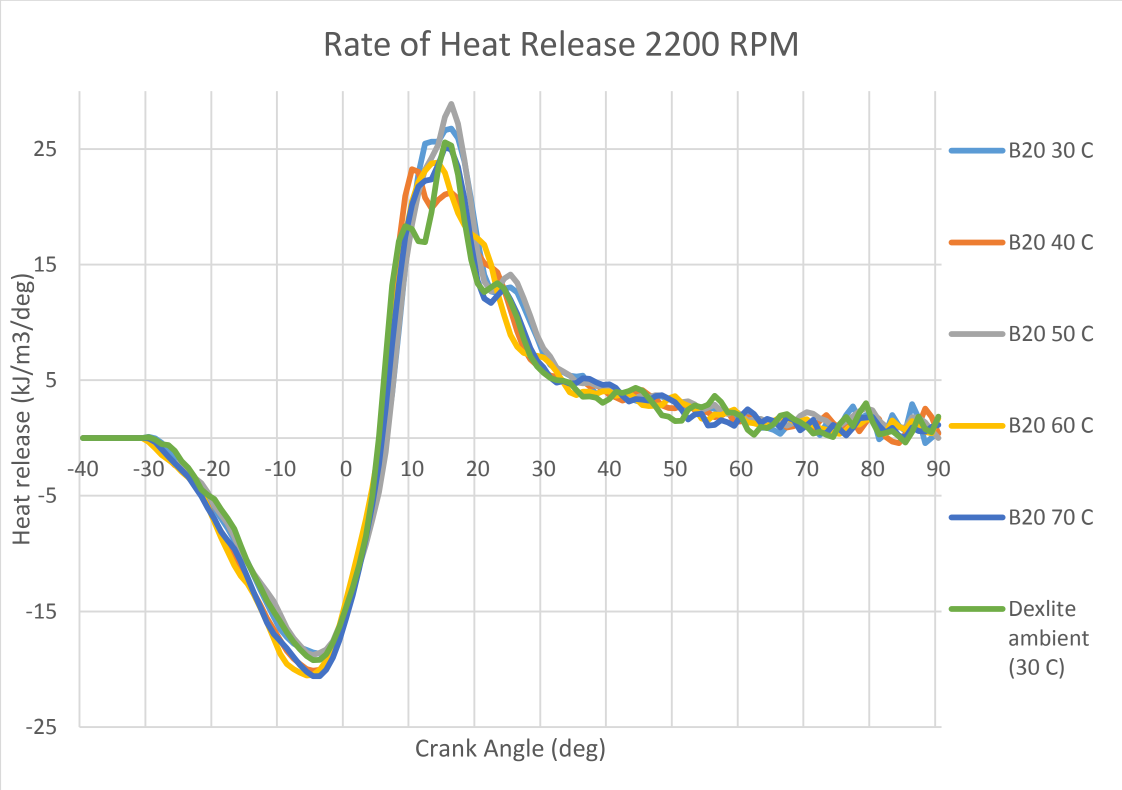


Graph 4.8 Rate of Heat Release analysis at 2000 RPM

From the graph 4.8 the result can be known. From Rate of heat release graph ignition delay can be known. The injection timing for Mitsubishi 4D30 is 14^o before TDC. It then can be observed that B20 at 30^{o}C has earliest combustion at 3^o before TDC and has highest heat release at 11^o after TDC with the value of 27.41 kJ/m^3/deg. Then B20 at 40^{o}C has earliest combustion at 2^o before TDC and has highest heat release at 13^o after TDC with the value of 23.35 kJ/m^3/deg. Then B20 at 50^{o}C has earliest combustion at 1^o before TDC and has highest heat release at 15^o after TDC with the value of 25.95 kJ/m^3/deg. Then B20 at 60^{o}C has earliest combustion at 3^o before TDC and has highest heat release at 13^o after TDC with the value of 23.1 kJ/m^3/deg. Then B20 at 70^{o}C has earliest combustion at 4^o before TDC and has highest heat release at 15^o after TDC with the value of 25.16 kJ/m^3/deg. Then Dexlite for comparison has earliest combustion at 4^o before TDC and has highest heat release at 14^o after TDC with the value of 22.62 kJ/m^3/deg.

4.2.6 Rate of Heat Release Analysis at 2200 RPM 100% load

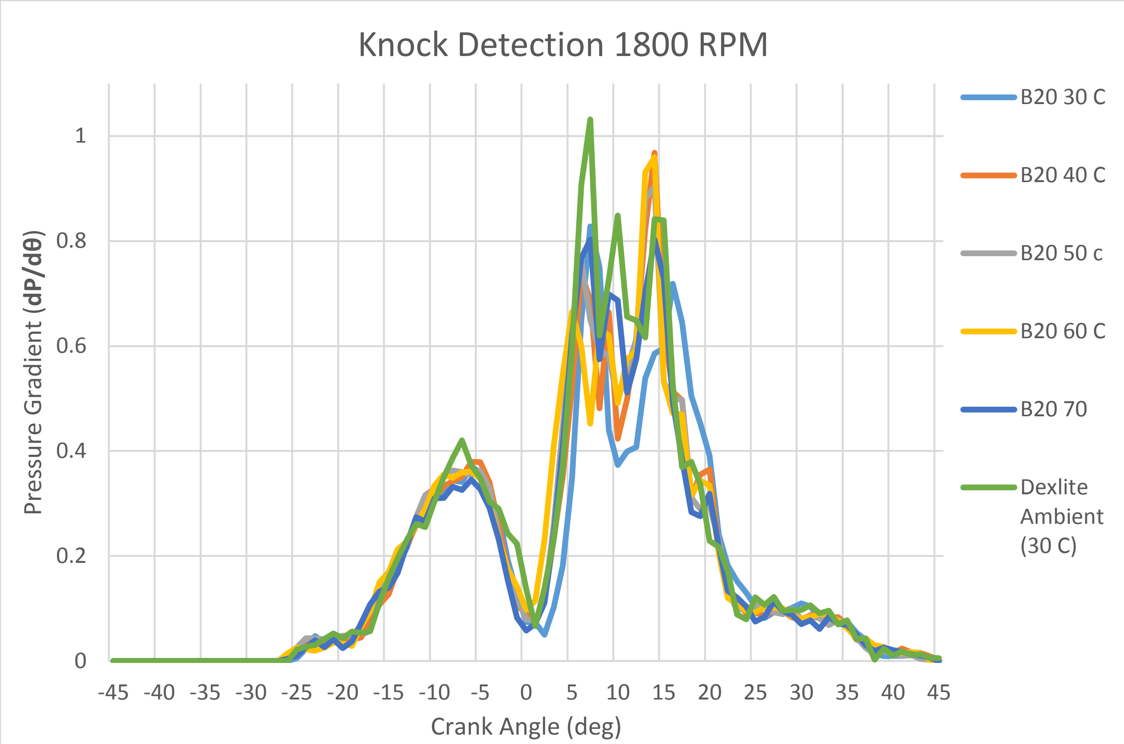
To understand the result of combustion process, then analysis of Rate of heat release is done. Rate of heat Release is the average release of heat from fuel and air during the combustion process. In this analysis the influence of fuel preheating can be known.



Graph 4.9 Rate of Heat Release analysis at 2200 RPM

From the graph 4.9 the result can be known. From Rate of heat release graph ignition delay can be known. The injection timing for Mitsubishi 4D30 is 14^o before TDC. It then can be observed that B20 at 30^{o}C has earliest combustion at -3^o before TDC and has highest heat release at 16^o after TDC with the value of 26.76 kJ/m^3/deg. Then B20 at 40^{o}C has earliest combustion at 3^o before TDC and has highest heat release at 10^o after TDC with the value of 23.24 kJ/m^3/deg. Then B20 at 50^{o}C has earliest combustion at 2^o before TDC and has highest heat release at 16^o after TDC with the value of 28.88 kJ/m^3/deg. Then B20 at 60^{o}C has earliest combustion at 4^o before TDC and has highest heat release at 14^o after TDC with the value of 23.83 kJ/m^3/deg. Then B20 at 70^{o}C has earliest combustion at 3^o before TDC and has highest heat release at 15^o after TDC with the value of 25.16 kJ/m^3/deg. Then Dexlite for comparison has earliest combustion at 4^o before TDC and has highest heat release at 15^o after TDC with the value of 25.57 kJ/m^3/deg.

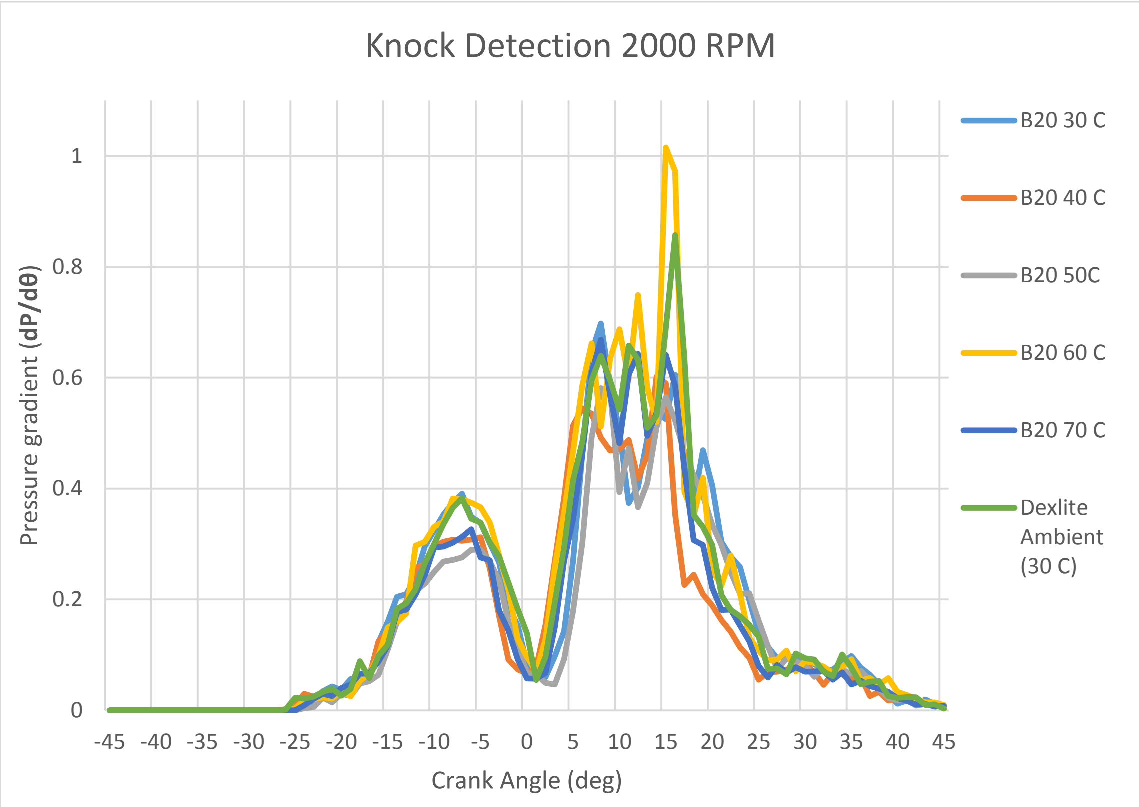
4.2.7 Knock Detection Analysis at 1800 RPM 100% load



Graph 4.10 Knock Detection analysis at 1800 RPM

Graph 4.10 is the knock Detection graph analysis at 1800 RPM. The graph shown the knock detection for B20 inlet temperature ranging from 30ºC to 70ºC and Dexlite for comparison. B20 fuel at 30ºC has highest point of knocking at 0.82 at 7º after TDC. B20 fuel at 40ºC has highest point of knocking at 0.96 at 14º after TDC. B20 fuel at 50ºC has highest point of knocking at 0.90 at 14º after TDC. B20 fuel at 60ºC has highest point of knocking at 0.96 at 14º after TDC. B20 fuel at 70ºC has highest point of knocking at 0.80 at 14º after TDC. Dexlite for comparison has highest point of knocking at 1.03 at 7º after TDC.

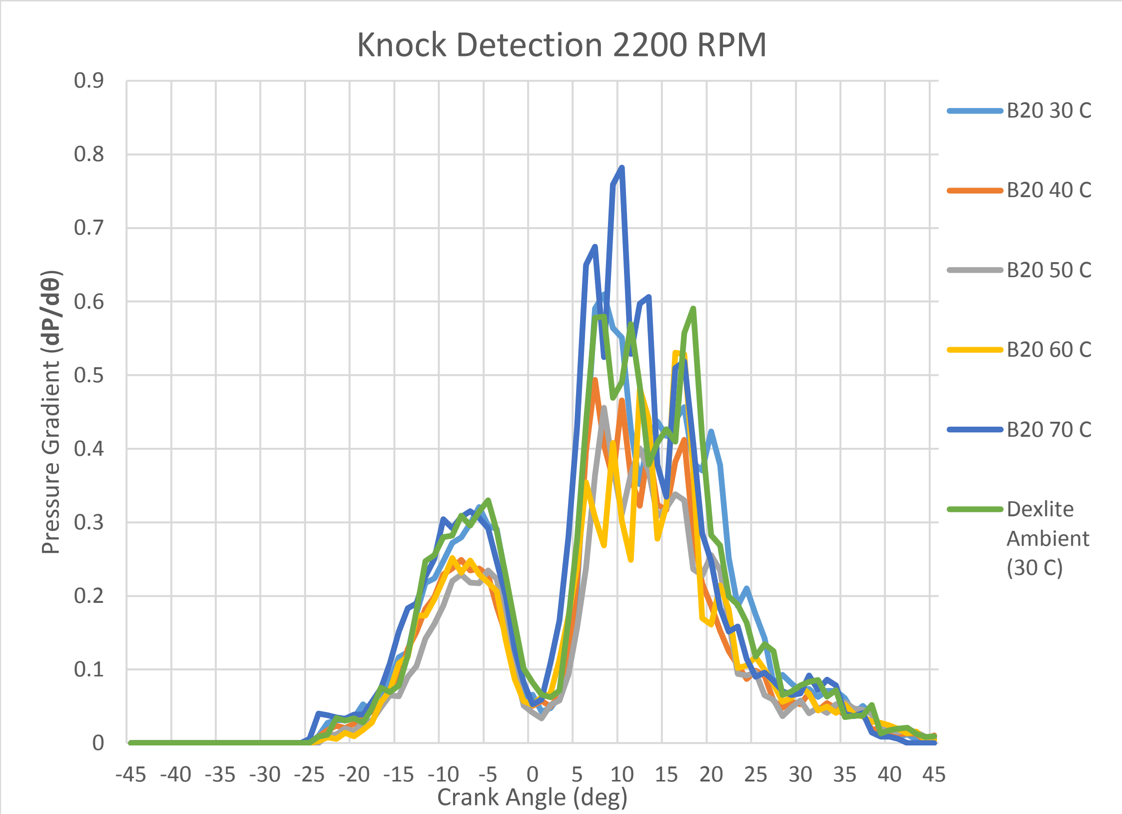
4.2.8 Knock Detection Analysis at 2000 RPM 100% load



Graph 4.11 Knock Detection analysis at 2000 RPM

Graph 4.11 is the knock Detection graph analysis at 2000 RPM. The graph shown the knock detection for B20 inlet temperature ranging from 30ºC to 70ºC and Dexlite for comparison. B20 fuel at 30ºC has highest point of knocking at 0.69 at 8º after TDC. B20 fuel at 40ºC has highest point of knocking at 0.60 at 14º after TDC. B20 fuel at 50ºC has highest point of knocking at 0.58 at 8º after TDC. B20 fuel at 60ºC has highest point of knocking at 1.01 at 15º after TDC. B20 fuel at 70ºC has highest point of knocking at 0.66 at 8º after TDC. Dexlite for comparison has highest point of knocking at 0.85 at 16º after TDC.

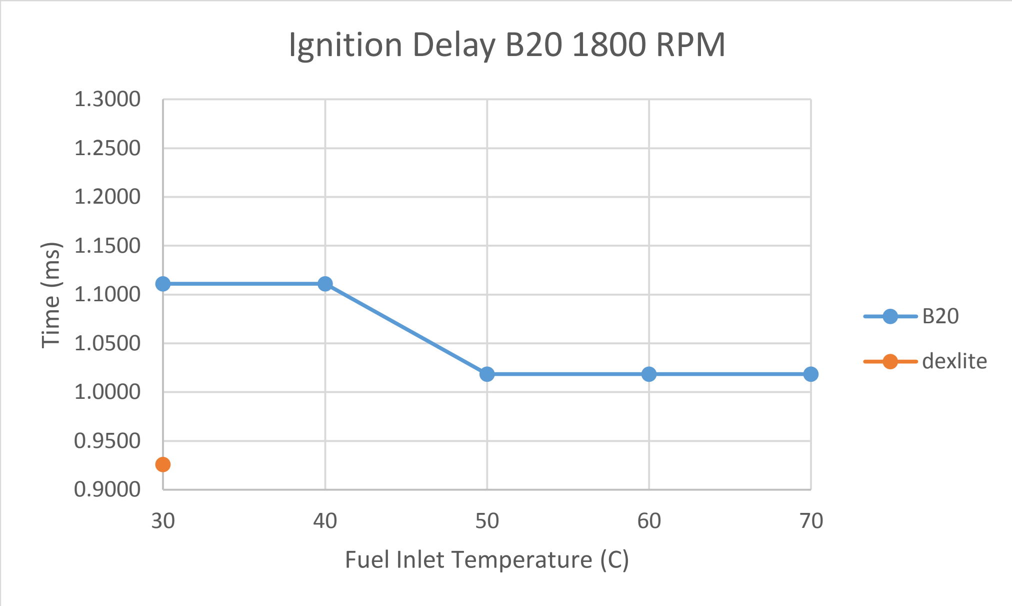
4.2.9 Knock Detection Analysis at 2200 RPM 100% load



Graph 4.12 Knock Detection analysis at 2200 RPM

Graph 4.12 is the knock Detection graph analysis at 2200 RPM. The graph shown the knock detection for B20 inlet temperature ranging from 30ºC to 70ºC and Dexlite for comparison. B20 fuel at 30ºC has highest point of knocking at 0.60 at 8º after TDC. B20 fuel at 40ºC has highest point of knocking at 0.49 at 7º after TDC. B20 fuel at 50ºC has highest point of knocking at 0.45 at 8º after TDC. B20 fuel at 60ºC has highest point of knocking at 0.53 at 16º after TDC. B20 fuel at 70ºC has highest point of knocking at 0.78 at 10º after TDC. Dexlite for comparison has highest point of knocking at 0.59 at 18º after TDC.

4.2.10 Ignition Delay Analysis at 1800 RPM 100% load

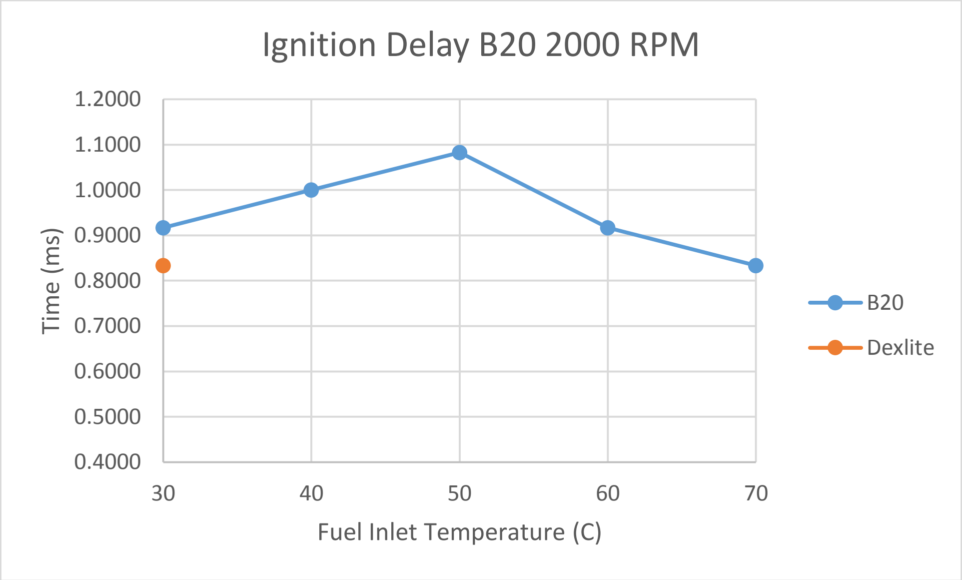


Graph 4.13 Ignition Delay analysis at 1800 RPM

Graph 4.13 is showing the ignition delay of B20 fuel for every inlet temperature. The ignition delay for B20 at 30ºC inlet temperature is 1.111 ms. Ignition delay for B20 at 40ºC inlet temperature is 1.111 ms. Ignition delay for B20 at 50ºC inlet temperature is 1.018 ms. Ignition delay for B20 at 60ºC inlet temperature is 1.018 ms. Ignition delay for B20 at 70ºC inlet temperature is 1.018 ms. While Dexlite achieve the lowest ignition delay at 0.925 ms.

Ignition delay time depends on the value of cetane number of the fuel. the higher the cetane number of a fuel, the faster the time takes for the fuel to ignite. Therefore higher cetane number means shorter ignition delay. In this case Dexlite has shorter ignition delay. This is due to the fact that Dexlite has cetane number of 51. While B20 (Biosolar) has cetane number of 48.

4.2.11 Ignition Delay Analysis at 2000 RPM 100% load

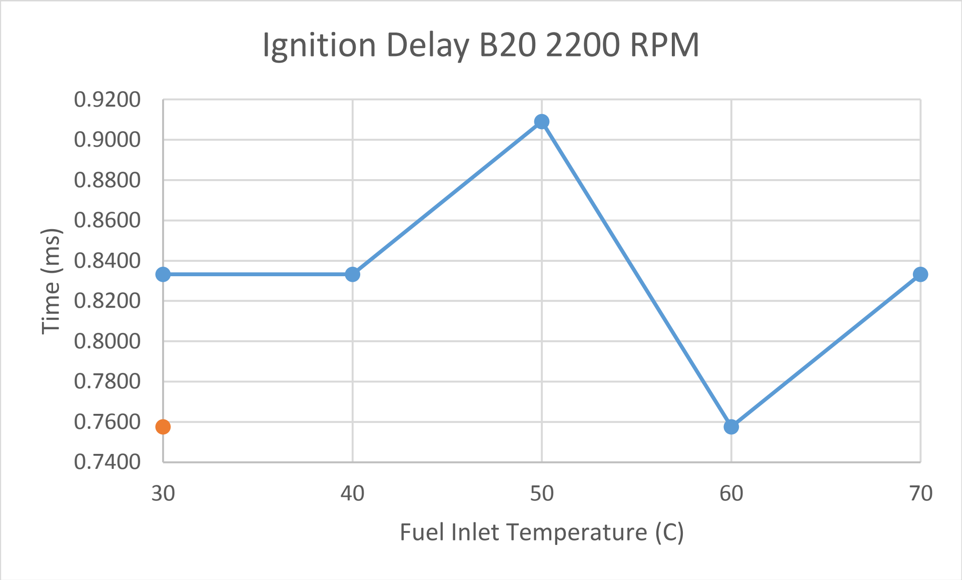


Graph 4.14 Ignition Delay analysis at 2000 RPM

Graph 4.14 is showing the ignition delay of B20 fuel for every inlet temperature. The ignition delay for B20 at 30ºC inlet temperature is 0.916 ms. Ignition delay for B20 at 40ºC inlet temperature is 1 ms. Ignition delay for B20 at 50ºC inlet temperature is 1.083 ms. Ignition delay for B20 at 60ºC inlet temperature is 0.916 ms. Ignition delay for B20 at 70ºC inlet temperature is 0.833 ms. While Dexlite achieve the lowest ignition delay at 0.833 ms.

Ignition delay time depends on the value of cetane number of the fuel. the higher the cetane number of a fuel, the faster the time takes for the fuel to ignite. Therefore higher cetane number means shorter ignition delay. In this case Dexlite has shorter ignition delay. This is due to the fact that Dexlite has cetane number of 51. While B20 (Biosolar) has cetane number of 48.

4.2.12 Ignition Delay Analysis at 2200 RPM 100% load



Graph 4.15 Ignition Delay analysis at 2200 RPM

Graph 4.15 is showing the ignition delay of B20 fuel for every inlet temperature. The ignition delay for B20 at 30ºC inlet temperature is 0.833 ms. Ignition delay for B20 at 40ºC inlet temperature is 0.833 ms. Ignition delay for B20 at 50ºC inlet temperature is 0.90 ms. Ignition delay for B20 at 60ºC inlet temperature is 0.757 ms. Ignition delay for B20 at 70ºC inlet temperature is 0.833 ms. While Dexlite achieve the lowest ignition delay at 0.757 ms.

Ignition delay time depends on the value of cetane number of the fuel. the higher the cetane number of a fuel, the faster the time takes for the fuel to ignite. Therefore higher cetane number means shorter ignition delay. In this case Dexlite has shorter ignition delay. This is due to the fact that Dexlite has cetane number of 51. While B20 (Biosolar) has cetane number of 48.

CHAPTER V

CONCLUSION AND SUGGESTIONS

5.1. Conclusion

Based on Experiment result and Analysis that has been done relating to The Effect of Heating Of B20 Fuel To The Spray Characteristic and Combustion On The Diesel Engine Based On Experiment, therefore can be concluded as follows:

1. B20 Temperature can affect the spray characteristics with detail as follows
    - Spray Tip Penetration becomes shorter when the inlet fuel temperature is higher. Higher the fuel temperature lowers the density of the fuel thus lowering the momentum of the fuel. Lower momentum make the fuel spray to decelerate quicker. So the spray tip penetration become shorter.
    - Spray Cone Angle becomes wider when the inlet fuel temperature is higher. Higher fuel temperature lowers the surface tension and kinematic viscosity. The lower surface tension and kinematic viscosity make the fuel easier to spread thus making the spray angle wider.
    - Average Spray Velocity becomes slower as the temperature of fuel inlet becomes higher. The lowering value of average spray velocity is due to the spray tip penetration decreased when the temperature becomes higher in the same amount of capture time,
2. B20 Temperature can affect the combustion characteristics with detail as follows:
    - Based on Maximum pressure graph, it is shown that there is an increasing trend of pressure when the fuel inlet temperature is increased. But the trend goes downward on high temperatures like 60^{o}C and 70^{o}C. The result also shows that there is little effect on the crank angle of highest pressure is achieved. The highest pressure is always achieved at 7 to 8 degrees after TDC.
    - Based on Heat Release rate graph, it is shown that there is decreasing trend on the peak value of heat release rate for when the fuel inlet temperature is increased. This is due to the fact that increasing temperature of fuel inlet causing the fuel density to goes down while the plunger of the injection system has the same volume, so the fuel mass per injection goes into the combustion chamber goes down. The result also shows that mostly the crank angle of highest heat release rate is farthest from after TDC when the fuel inlet temperature is 50^{o}C for every RPM.

- Based on Knock Detection Graph, it is shown that the knocking is generally higher when the temperature of the fuel inlet is increased. The crank angle of the highest point of knocking is varied between first peak at 7^o-8^o Before TDC or 14^o-15^oC after TDC.
- Based on Ignition delay graph, it is shown that the temperature increase only give a slight effect on ignition delay. The closest temperature and condition to approach the value of dexlite is at higher temperatures of 60^oC to 70^oC.

5.2. Suggestion

Based on the analysis and the entire process that has been done by the author to finish this research. There are some things to note, such as:

1. Camera installation need to be carefully adjusted to avoid angle bias making the data not precise. Higher frame rate camera is also recommended for more precise result for the next research.
2. Next research with the same topic need to be conducted on direct injection engine to see the difference or how significant the fuel inlet temperature to the engine combustion characteristic with different type of combustion chamber.

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