Bio-ethanol Fuel Study on Spray Characterization Using High Speed Digital Camera

By

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AHMAD SYAUFIK B MOHD YUSOFF

ABSTRACT

Fuel spray characteristic is very important in the entire internal combustion engine. Today, researchers try to improve on the fuel which will produce less emission and also improve the fuel consumption. Some of the new type of fuel is introduced such as the ethanol which mainly extract from the crop. By introducing an alternative for the gasoline, we mainly want to be fewer dependants for the fossil fuel which will be depleted. So a study will be conducted to see the spray characteristic of these new fuels. The fuel that wants to be studied is bio-ethanol, which are E10 and E85. Bio-ethanol has been identified as the possible future fuel. This project is looking for the development of bio-ethanol. Baseline characterization of the spray pattern is required prior to advance studies in spray-guided direct injection process. By using the ethanol, we can produce cleaner combustion with lower emissions which is very important aspect in today's world. This study is mainly to compare the characteristic of neat gasoline and the ethanol-gasoline blend which is E10 and E85 in term of their spray tip penetration length and the spray tip velocity.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND STUDY

Today, people in this world depend on fossil fuels for energy production. But the reserves of these petroleum-based fuels are rapidly depleted. The researches on finding the new fuels must also include the emission produced. Researchers nowadays try to find the new alternative fuels which can substitute the fossil fuels and also can reduce the emission of CO_2 and other pollutants. Alcohols, such as ethanol which is colorless liquid with mild characteristics odor have high octane rating which has antiknock properties that will improves engine efficiency and gives higher compression ratios. Alcohols, principally methanol and ethanol have the potential to displace a substantial portion of the domestic petroleum consumption used either neat or in blends with petroleum fuels.Ethanol also has higher heat of vaporization than that in gasoline. This means that freezes the air allowing more mass to be drawn into the cylinder and increases the power output.

Numerous attempts had been done to study this new alternative fuel. Since the spray properties play an important role on engine air fuel mixing and subsequent combustion, an in depth research of the spray characteristics of the ethanol-gasoline blends is of necessity and significance. . The spray characteristic of the fuels will be analyzed by using the Schlieren optic and also High Speed Digital Camera. These devices are used to catch the picture of the spray geometry during the injection of the fuel inside the internal combustion engine. The variation of spray geometry will be evaluated and presented for different fuels which are neat gasoline, E10 and E85. The results will show the different patterns developed by different type of fuels by using the injector provided. The experimental results of spray properties including the spray structure, the main spray tip penetration and the spray angle but the paper will be more focused to the main spray tip penetration length of the spray.

1.2 PROBLEM STATEMENT

In the modern days of automobile nowadays, we still depend on gasoline which is a fossil fuel to power up our vehicle. This kind of fuel will not last long and will be depleted. That is why the ethanol has been introduced as the alternative fuels to replace the fossil fuel. It is also well known that the future availability of energy resources as well as the need of reduced emissions of CO_2 and pollutants promote an increased utilization of regenerative fuels.

Ethanol is mainly extracted from plant and easily can get. So by using ethanol, we will reduce the dependant to the fossil fuel. Also nowadays, there had been increasing price for the crude oil. This means that the price of the gasoline also increases. So, we must minimize the usage of the gasoline as the source to power up the vehicle by introducing other types of fuel which is ethanol. Afar from that, we also want to produce cleaner combustion which minimizes the effect to the environment.

1.3: SIGNIFICANCE OF STUDY

We are searching for a new alternative fuel to replace the fossil fuel. Experimentation on the new fuel that is possibly be the substitute for the fossil fuel are required to determine whether this new fuel can be used as the fuel for the vehicle. It also very important to conduct the experiment which will determine the performance and efficiency of the engine that used bio-ethanol as fuel. In this project, we want to study the spray characteristic of the ethanol which is also a part of the experiment to find whether it is suitable or not.

Although, there has been a lot of development on the use of bio-ethanol-gasoline as fuel for vehicle, these are limited to conventional fuelling systems such as carburator and the port injection system and not the direct injection. The development of bio-fuel technology in Malaysia also depends on this project which will result whether it is possible to develop this new fuel in Malaysia. Furthermore, the result that obtained from this project also important on enhancing the combustion process and also engine performance by using the bio-ethanol as the alternative fuel to power up the engine.

1.4: OBJECTIVES

The objectives of the project are to perform experimental work to study about the neat gasoline and bio-ethanol fuel (E10 and E85). This project is also performing spray characterizations of injectors using the method of High Speed Digital Camera to study the characteristic of the spray produced by different types of fuel which are neat gasoline, E10(10% ethanol + 90% unleaded gasoline) and E85(85% ethanol + 15% unleaded gasoline). This experiment also performed to compare the characteristics shown by the neat gasoline and also the ethanol-gasoline blends which are E10 and E85.

1.5: SCOPE OF WORK

The scope of work will be basically on studying the spray characteristic of different fuel which is neat gasoline, E10, and E85. These characteristic will be studied using the equipment High Speed Digital Camera. The equipment will take the picture of the spray produced by different fuel and display it through the computer. The spray characterization investigation will be conducted at atmospheric pressure on 4 injectors. The study will include the different spray angle and main spray tip penetration between neat gasoline, E10 and also E85.

CHAPTER 2
LITERATURE REVIEW

2.1 Ethanol

From the definition of Tony Radich [5], ethanol or Ethyl Alcohol is a clear colourless liquid which is biodegradable, low toxicity and causes little environmental pollution. Ethanol burns to produce carbon dioxide and water. Ethanol is a high octane fuel and used to replace lead as the octane enhancer in gasoline. By blending the ethanol with the gasoline, we also can make the mixture of it burns more completely thus decreasing polluting emissions.

Ethanol offers a number of benefits to us in term of our vehicles, economy, environment and national security [10]:

- It can be used as gasoline substitute
- Adds oxygen to gasoline resulting much more cleaner combustion
- Reduces the nation's expensive dependence on imported oil
- Creates jobs and investment across nation by the increasing demands on crop for ethanol.
- Can improves the octane rating of the fuel
- All cars can use 10% ethanol (E10) and the warranty is still covered by the respective car manufacturers.

Despite of its advantages, it also had some disadvantages which is one gallon of ethanol has just 2/3 energy of one gallon of neat gasoline [10]

Every major car makers in the world approves the uses of 10% ethanol-E10 under warranty. By giving one example of the automakers, "BMW- Fuels containing up to and including 10% ethanol...will not void the applicable warranties..." and also "Honda – You may use gasoline containing up to 10 percent ethanol by volume. Some conventional gasoline is being blended with alcohol or an ether compound. This gasoline is collectively referred to as oxygenated fuels. To meet clean air standards, some areas of the United States and Canada use oxygenated fuels to help reduce emissions."

Jian Gao et al 2007 stated that by blending the ethanol and also the gasoline, it will increase two to three points of octane number to gasoline, helping improve the engine performances. Ethanol also helps keep the fuel injector clean and lowering the level of toxic emissions. By blending the gasoline and ethanol we can also oxygenate the fuel mixture so it will burn completely and reduces polluting emissions which is what we are trying to do nowadays which is reducing the emissions produce by the vehicles that use fossil fuel.

Studies had shown that ethanol [10]:

- Reduces tailpipe carbon monoxide emissions by as much as 30 percent
- Reduces exhaust volatile organic compound by 12 percent
- Reduces toxic emissions by 30 percent
- Reduces particulate matter emissions by more than 25 percent.

Research by the U.S. Department of Energy's Argonne National Laboratories shows that ethanol has the ability to significantly reduce greenhouse gas emissions. According to Argonne, the production and use of 4.9 billion gallons of ethanol in 2006 reduced carbon dioxide-equivalent greenhouse gas emissions by about 8 million tons

2.2 High Speed Digital Camera

Chang Chan Teng stated that High Speed Digital Camera is used to study the spray characteristic. It is stated that, in the first phase, an optical setup of High Speed Digital Camera was used to obtain sequential high speed photographs of transient sprays in a constant volume chamber. The spray images were analyzed with a light extinction technique to provide spray characteristics which include the spray tip penetration length, spray angles, spray dispersion, and overall spray size

John Fuller [11] mentions that High Speed Photography is a science of taking pictures at very fast phenomena. High speed digital camera that will be used is needed to be adjusted to obtain the perfect image which will show the different between the 3 different fuels which are the neat gasoline, E10 and E85. The right adjustments are needed to get the best picture as these pictures will be used to study its main spray tip penetration length and also calculation can be done to find its spray tip velocity. The high speed digital camera will give the range motion of the injection in a sequence of time. A series of photographs may be taken at a high sampling frequency or frame rate. The first requires a sensor with good sensitivity and either a very good shuttering system or a very fast strobe light. The second requires some means of capturing successive frames, either with a mechanical device or by moving data off electronic sensors very quickly.

2.3 Fuel Characterization of Gasoline Direct Injection

There were many literature reviews which explained about how to analyze the spray pattern. Spray characterization is a preliminary research for the further analysis of the internal mixture formation, and consequent combustion using the ethanol-gasoline blends into SI engines (J.Gao et al 2007)

Chang Sik Lee et al(2001) says that spray characteristics of the direct injection engine such as the mean drop size, spray tip penetration, velocities and spray cone angle have influence upon the air-fuel mixing rate, the distribution of mixture concentration and the wetting of cylinder liner and piston head. It is known that spray characteristics and spray structure in the direct injection engine have important role in the improvement of engine performance and the reduction of emissions. So, to improve the performance of the engine, researchers can develop

J.Gao et al (2007) says that fuel spray shape, spray tip penetration and spray angle are usually used to characterize the overall spray structure. Generally, the images of ethanol-gasoline blend's spray are similar to those of gasoline. Precisely, for all tested blended fuels, it shows that a hollow cone spray with wide spread angle is formed in the case of low ambient pressure and an initial spray slug appears in the front of the main spray.

From the literature review, it is predicted that the characteristics of the ethanol-blend and neat gasoline is closely identical. It is assume that ethanol-blend will give the same characteristic during combustion processes. The definition of spray tip penetration according to J Gao et al (2007)is from the nozzle tip of injector until the end of the spray.

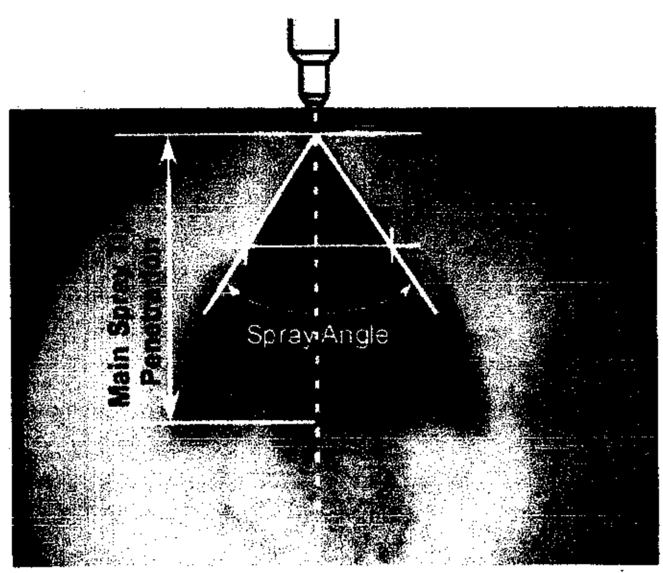

Figure 2.1: The definition of main spray tip penetration and spray angle

J.Gao et al (2007) [8] says that for increase ethanol content, the main spray tip penetration will decrease and the spray angle will increase. This shows that, when the ethanol fraction in the ethanol-gasoline blend is increase, it will reduce the length of the main spray tip penetration. In the same time, the spray angle will increase and the spray will be shaped like a cone. The increase of the spray angle maybe resulted from the evaporation of the ethanol thus reducing the volume at the spray tip.

Jiro Senda et al also stated the relation of the spray penetration with the angle of the spray. The spray angle has the large value at the initial stage of the injection due to large shearing force between the ambient. The value of spray angle for one particular fuel is quite small which resulted to the large penetration in B100 spray.

Jiro Senda et al stated that for the experiment of spray characterization, spray penetration and maximum dispersion width in radial direction are measured at each elapsed time from the injection start. It is understood that, at each elapsed time, measurements must be taken. After all the data had been collected, it will be compared to see the differences between the 3 different types of fuels. It also stated that the magnitude of spray angle will decreases gradually with the increase of ethanol fraction in the ethanol-gasoline blend. This maybe contributed by the different value for specific enthalpy of vaporization and droplet surface tension for the 2 fuels.

J gao et al (2007) stated that a compact spray pattern which is relatively shorter penetration is presented in the case of high ambient pressure and the vortexes are also produced in the middle part of the spray. By increasing the ambient pressure, it will cause high ambient density and a large drop drag force and the fuel evaporation is suppressed and insufficient. Thus it will affect overall spray structure.

CHAPTER 3
METHODOLOGY

3.1: PROCEDURE IDENTIFICATION

The project is mainly about studying and analyzing the spray characteristic for each different fuel. This can be done by using the equipment such as the Schlieren Imaging and High Speed Digital Camera to capture and display the pattern of each spray from each different fuel. We then will compare 3 types of fuel which are E10, E85 and neat gasoline. It is predict that different types of fuel will give different result because of the properties of the fuel.

The experiment of spray characterization of ethanol-gasoline blend also needed some equipment. The equipments that will be used to conduct this experiment are the Powertrain Control EEC-V and also the High Speed Digital Camera. The Powertrain Control EEC-Valso needed some adjustment to ease with the experiment which needed us to monitor the spray characteristic and also taking photograph of it.

For this experiment High Speed Digital camera needed to be studied first to understand the working criteria of the machine. It is also needed to understand how the Powertrain EECV working to ease with the experiment. The images of the experiment will be stored in the computer for further analysis. The image that captured will be studied about its main spray tip penetration length. Prior to this result, the velocity of the spray also can be obtained.

3.2: RESEARCH METHODOLOGY

Steps taken to complete the project

1. Literature review and reading about bio-ethanol and High Speed Digital Camera
2. Planning and design concept for the equipment.
3. Moving the Powertrain EECV to the Central Automotive Laboratory
4. Modification of the Powertrain by taking out the injector and also the oil pump and put it inside the new box.
5. Synchronization of the High Speed Digital Camera prior to the timing of the Powertrain.
6. Conducting the experimental work
7. Data and result acquisition
8. Analysis of the result
9. Recommendation and conclusion

The above steps are the method for completion of the project. The important thing among the steps is the modification of the Powertrain. A new design of the test chamber will be needed for the experiment. This test chamber is a constant volume which operates under ambient pressure and temperature. This test chamber will be needed to place the pump inside it and connected to the Powertrain.

After obtaining the data from the experiment, 2 criteria will be studied from the spray which is the main spray tip penetration length and also the tip velocity of the spray. The main spray tip penetration length is obtained from the result itself. The length is measure by using a ruler which had been captured using the high speed digital camera at the same setting when the experiment is conducted.

3.2 DESIGNING THE TEST CHAMBER

By using the Catia, the design of the test chamber is made. The test chamber which is used to contain the fuels that will be used for the experiment must be visible so the imaging can be done. The thickness of the wall for the test chamber is made allowable to let the light passes which is important for the capturing the image using the High Speed Digital Camera

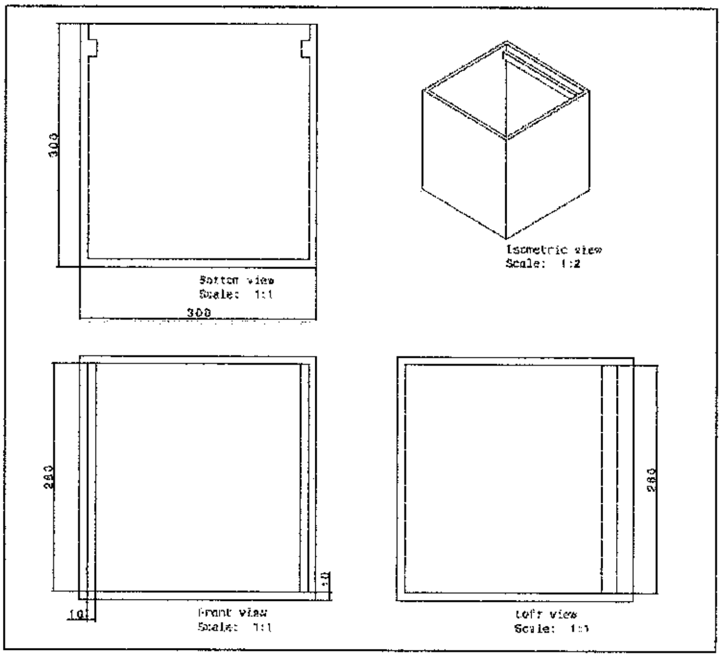

Figure 3.1: Engineering drawing of the test chamber

The above figure is the design that had been made for the test chamber. The thickness of the wall must be designed to allow the light moving through it.

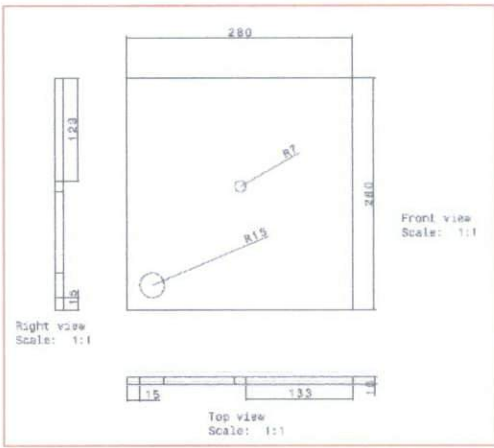

Figure 3.2: Top cover of the test chamber

The holes at the top cover are made for the passage to locate the fuel hose from the pump into the fuel rail. It also used to locate on of the injector from the fuel rail.

Figure 3.3: Finished design of the test chamber body

After several runs for the experiment, it is impossible to place just one injector on top of the test chamber. This is because the connection that had been made manually from the fuel pump to the injector is not feasible to cater the pressure develops by the pump. Few minor adjustments had to be made for the top cover of the test chamber. By using the fuel rail obtained from the Powertrain, 4 holes needed to be made instead of one. This is to allowed all the injector place at the top cover but only one injector will be used.

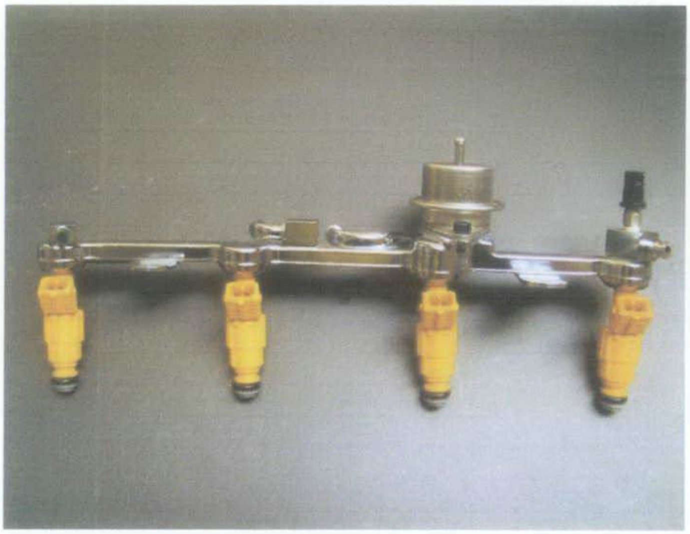

Figure 3.4: 4 injectors and fuel rail

Figure 3.5: Minor adjustment for the top cover of the test chamber

3.3 EQUIPMENT AND APPARATUS

Figure 3.6: Powertrain Control EECV

The Powertrain Control EECV will be used to gives signals to injector so the injector will start injecting the fuels. The Powertrain Control EECV also can be used to vary the injector speed and also other variables such as the temperature and also the speed of the engine cycle. The works that had been done to the powertrain is basically to disassemble its original test chamber, injectors and pump.

The experiment also needs a test chamber which will be the place to place the fuel. It is designed to be closed loop as the fuel will circulate back into the test chamber using the pump from the Powertrain. The pressure will be maintained at ambient pressure which is 1 atm. So the pressure will not be affecting the results from the injector. Also, the temperature will be maintained at ambient temperature which is at the room temperature. So the pressure and temperature will not be the factors that affecting the results obtained from the experiment.

The fuel rail and injector will be mounted on the test chamber and the camera will be placed at the side of the test chamber. For the experiment, only one injector used as it is sufficient enough to study the characteristic using one injector.

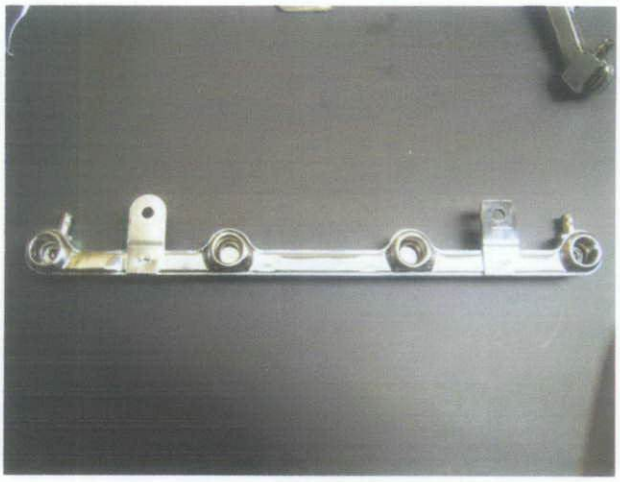

Figure 3.7: Fuel rail

Figure 3.8: Ford F6VE – A5A injector

Figure 3.9: High Speed Digital Camera

Table 3.1: Experimental conditions

Ambient temperature	300K
Ambient pressure	1 atm
Injector type	Ford F6VE – A5A
Injection duration	1.25ms
Injection pressure	3 bar
Engine speed	~1000rpm
No of injector used	1

Table 3.2: Setting for the High Speed Digital Camera

Shutter Speed	4000fps
Filter	yes (polarizer)
Light source	Spotlight

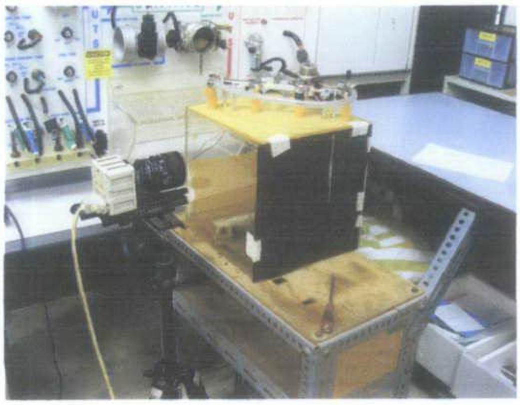

Figure 3.10: High Speed Digital Camera setup

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Results

Neat gasoline

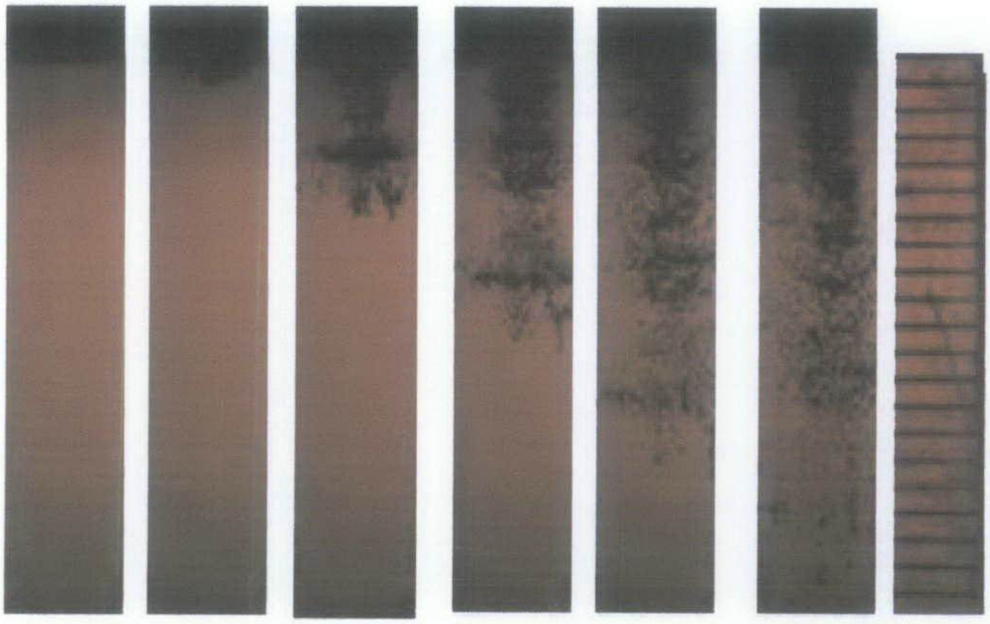

Figure 4.1: Images taken using neat gasoline

E10 (10% ethanol + 90% gasoline)

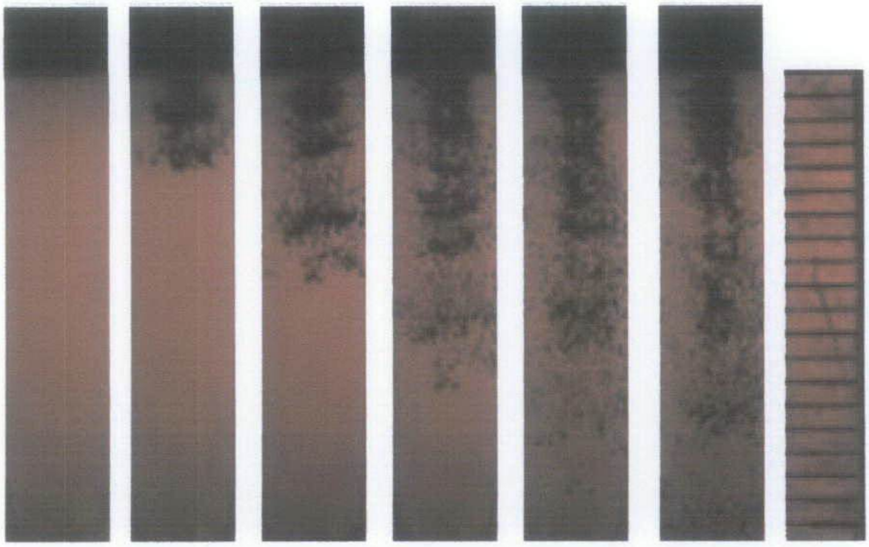

Figure 4.2: Images taken using E10

E85 (85% ethanol + 15%gasoline)

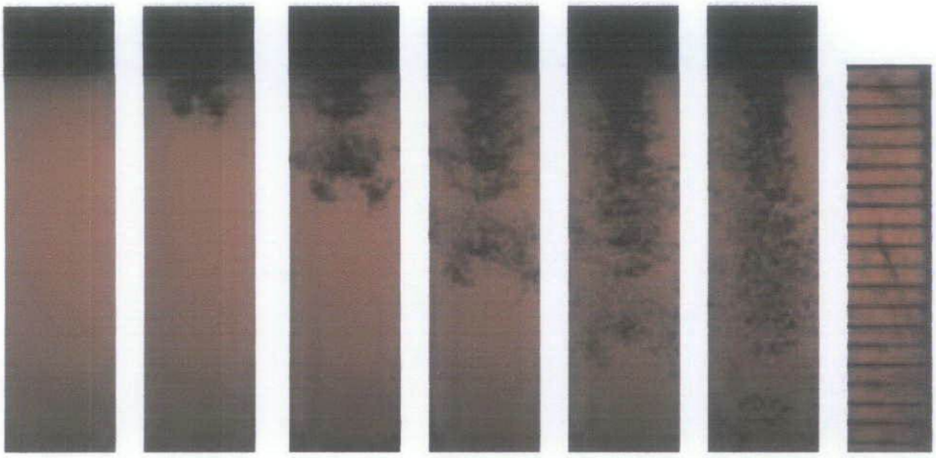

Figure 4.3: Images taken using E85

Table 4.1: Properties of Gasoline and Ethanol

Property	Gasoline	Ethanol
Chemical formula	C_4 to C_{12}	C_2H_5OH
Physical state	Liquid	Liquid
Molecular weight	100–105	46.07
Composition (weight %)		
Carbon	85–88	52.2
Hydrogen	12–15	13.1
Oxygen	0	34.7
Main fuel source(s)	Crude oil	Corn, grains, or agricultural waste
Specific gravity (60° F/ 60° F)	0.72–0.78	0.796
Density (lb/gal @ 60° F)	6.0–6.5	6.61
Boiling temperature (F°)	80–437	172
Freezing point (F°)	-40	-173.2
Autoiginition temperature (F°)	495	793
Reid vapor pressure (psi)	8–15	2.3

Fuel spray shape, spray tip penetration and spray angle are usually used to characterize the overall spray structure. In this experiment, the spray tip penetration will be measured by placing the ruler at the center of the injector and taking the picture of it at the same setting with the experiment. From the spray tip penetration length, velocity of the spray can be obtained at each elapsed time.

The 3 pictures above show the 3 different type of fuel used during the experiment which are neat gasoline, E10 and E85. The setting to obtain the pictures is done by setting the camera speed up to 4000fps which is sufficient enough to see the pattern clearly. The experiment also had been conducted at higher speed, but the results are very much the same compare to the current setting.

Comparing all the 3 types of fuel, the figure shows that E85 has the higher speed. It shows that during the same time frame, the E85 is longer compare to E10 and neat gasoline. These resulted from the different properties of the 3 different fuels. The ethanol had a slightly higher density compare to gasoline. In this case, pressure will not play a role in affecting the spray structure of each fuel as it is maintained at ambient pressure.

Thus, the higher ethanol fraction for the ethanol-gasoline blend will result in higher density compare to the neat gasoline. The higher ethanol fraction of ethanol-gasoline also resulted the higher density. The density and viscosity of the neat gasoline and also the ethanol-gasoline blend will also effect the spray tip penetration length which gives different result between neat gasoline, E10 and E85.

Table 4.2: Main spray tip penetration length for different type of fuels

		Tip penetration length (mm)		
Time(μs)	Time (s)	Neat gasoline	E10	E85
0	0	0	0	0
250	0.0025	1.5	2	2.5
500	0.005	8	7.5	9.4
750	0.0075	14.5	15	14.8
1000	0.01	20	20	20.5
1250	0.0125	26	25.5	25.5
1500	0.015	30	29.5	27.5
1750	0.0175	33	32	29.5
2000	0.02	36	35.5	31
2250	0.0225	39	38	32.5
2500	0.025	41.5	40.5	34
2750	0.0275	43.5	42	35.5
3000	0.03	45	43.5	37

As we can see from the table, up until the time is 0.015s, the penetration length is nearly the same for the neat gasoline, E10 and E85. Starting at that time forward, which is at time 0.0175s, the pattern for the 3 different fuels is started to differentiate. From the table, it shows that the neat gasoline has a high main spray tip penetration length compare to E10 and E85 at the same time frame. The graphical result of the table is shown in the Figure 4.4.

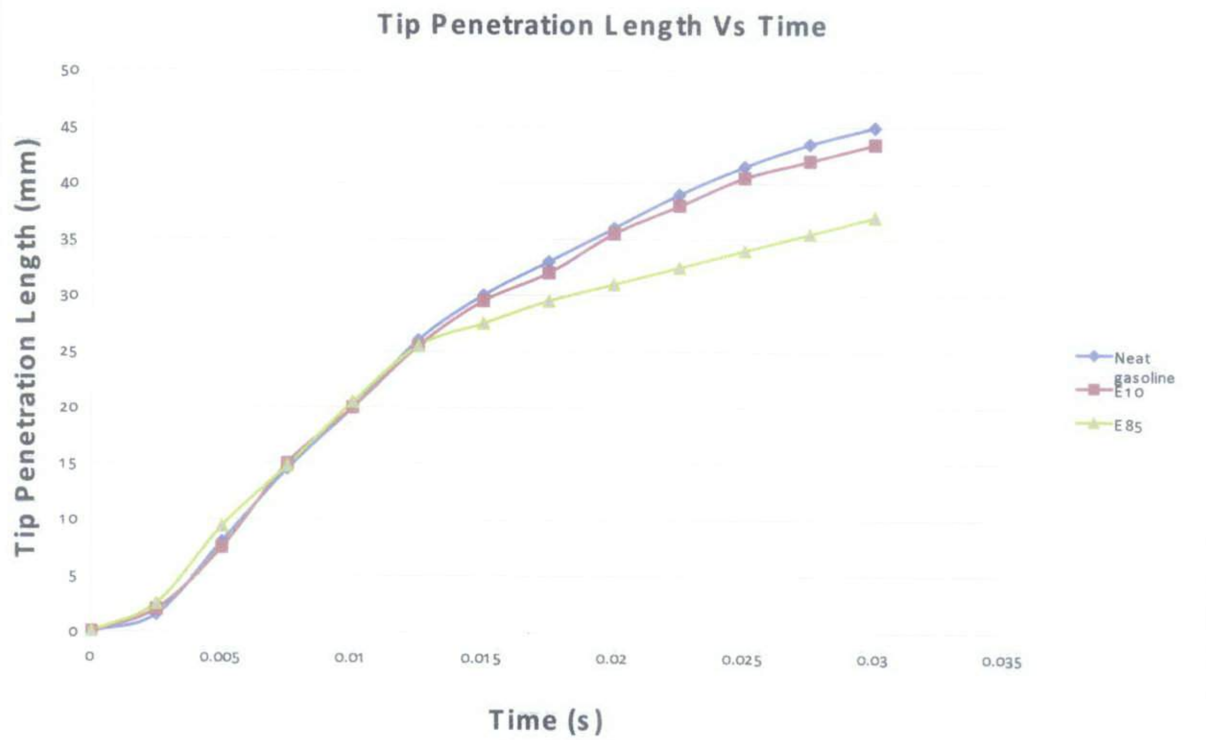

Figure 4.4: Graph of Tip Penetration Length vs Time

From the figure, it shows that neat gasoline has higher main spray tip penetration compare to E10 and E85. It is stated in the literature review that when the ethanol fraction in the ethanol-gasoline blend is high, the main spray tip penetration will reduced. This is because, the ethanol is easily evaporated and less volume at the end comparing to the neat gasoline. The shorter penetration shows that a better vaporization is occurring Corresponding to this, one more influence can be observed in the spray images is that more liquid phase remain in the spray at higher gasoline ratio whereas less liquid droplets is detectable for the blend of higher ethanol fraction in the same time frame.

This might be happen because gasoline comprises of mixture of many component from C_4-C_{12} with various carbon atoms and structures. So, its vapor pressure will largely contributes to the components with relatively low boiling point which evaporate easier and faster, and the other components with higher boiling point will evaporate more slowly. This is why the penetration length of gasoline is longer. As for ethanol, it is only comprised of only one component C_2H_5OH and has only one boiling point. So, the fraction of ethanol will easily evaporate and resulted less penetration length. Better vaporization will result better formation inside the combustion chamber. It is easier to burn the fuels which will release less unburned fuel after the ignition.

Table 4.3: Tip Velocity of the Spray for Different Fuels

		Velocity (m/s)		
Time(µs)	Time (s)	Neat gasoline	E10	E85
0	0	0.000	0.000	0.000
250	0.0025	0.600	0.800	1.000
500	0.005	1.600	1.500	1.880
750	0.0075	1.933	2.000	1.973
1000	0.01	2.000	2.000	2.050
1250	0.0125	2.080	2.040	2.040
1500	0.015	2.000	1.967	1.833
1750	0.0175	1.886	1.829	1.686
2000	0.02	1.800	1.775	1.550
2250	0.0225	1.733	1.689	1.444
2500	0.025	1.660	1.620	1.360
2750	0.0275	1.582	1.527	1.291
3000	0.03	1.500	1.450	1.233

The tip velocity of the neat gasoline, E10 and also E85 is obtained from the penetration length of each fuel. By each time frame, for given data that is obtained from the experiment, calculation can be made to obtain the velocity for each fuel.

Calculations for the spray tip velocity

$$v = \frac{\lambda}{t}$$

λ= main spray tip penetration length

t = time for each phases of the spray

$$v = \frac{0.0015}{0.0025}$$

$$v = 0.6\, m / s$$

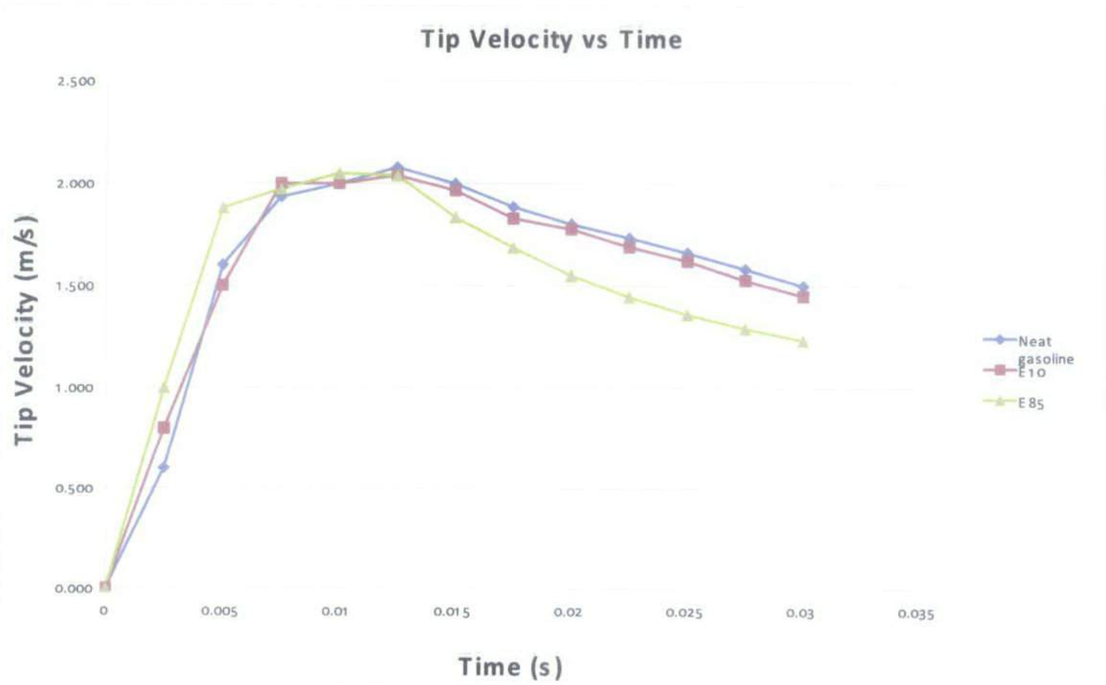

Figure 4.5: Spray Tip Velocity vs. Time

From the Figure, it shown that the E85 has higher velocity changes compare to the neat gasoline and E10. This is shown from the steep of the line produced by the E85. At the later part of the injection, the velocity is dropped and E85 shows a lot faster drop than neat gasoline and E10. The reduced velocity can be explained by comparing to the spray tip penetration length, which is shorter penetration length for the E85 compare to the neat gasoline and E10. This involves the evaporation of the E85 and the spray will spread more towards the side. The same thing also happen to the E10 which the spray will evaporate and left a few liquid phase of the spray at the later part of the spray.

CHAPTER 5

CONCLUSION

When the experiment of the ethanol-gasoline blend had done, similar spray pattern will be developed. By comparing the results, it shown that the main spray tip penetration is decreasing by the increasing of the ethanol fraction So when developing fuel blends which is ethanol and gasoline, similar patterns of blended fuels and pure gasoline are observed. The spray tip penetration decreases when ethanol fraction in ethanol-gasoline blend is high. This indicates a better vaporization. By developing new alternative energy, we need to develop its testing and study its properties whether it is suitable to replace the fossil fuel. Plus, we also will study the emission produced by using the bio-ethanol compare to the gasoline. One of the important criteria that need to be studied is the spray characteristic. If we found a new alternative fuel we can successfully decrease our dependant on the fossil fuel. Besides, full commitment towards completing the project tasks will be the most important factor in determining the success of the author. Through hard work and good engineering judgment, the objectives of this project can be fulfilled successfully. This study in believed as a preliminary research for the further analysis of internal mixture formation of the ethanol-gasoline blends in SI engines also this work is helpful to offer a comprehensive database for the spray properties studies for ethanol-gasoline blend. Further study can be made by using the equipment of Schlieren Imaging which will give the image clearly views of phases of the spray.

CHAPTER 6

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CHAPTER 7

APPENDIX

Appendix 1: Gantt Chart for the project

	Activities	Mth		1		2		3		4		5		6		7		8
		Wk	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
1	**Fuel Property study**																	
	a Fuel blending	2	■															
	b Fuel stability study	2		■														
	c Fuel property test	8			■	■	■	■										
	d Technical report	2							■									
2	**Engine component compatibility with E10 and E85**																	
	a Comp. char. using for neat gasoline	4						■	■									
	b Comp. char. for E10	4								■	■							
	c Comp. char. for E85	4										■	■					
	f Technical documentation.	2												■				
3	**Engine performance benchmark**																	
	a Engine ECU/fuel preparation	4		■	■													
	b Performance neat gasoline	4				■	■											
	c Performance neat gasoline with E10	4						■	■									
	d Performance neat gasoline with E85	4								■	■							
	e Technical documentation.	2										■						
4	**Spray characterization**																	
	a Setup/Calibration of spray test cell	4		■	■													
	b Schlieren Imaging E10 and E85	4				■	■											
	c PLIF/PIV for E10 and E85	8						■	■	■	■							
	d LDA/PDA for E10 and E85	8										■	■	■	■			
	e Technical documentation.	2														■		
5	**Overall project documentation**	4															■	■