THE STUDY OF SPRAY CHARACTERISTICS BY USING VIDEO IMAGE PROCESSING

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ABSTRACT

This thesis deals with video image processing analysis study of gasoline ethanol blends as the fuel. The objective of this study is to study about spray characteristics. Investigation of these spray from three type of fuel mixture such as pure gasoline (E0), gasohol (E50) and pure ethanol (E100) at different pressure. The pressures used in this study are 10 MPa and 20 MPa. Spray characteristics focus only on spray penetration and spray cone angle. The video from previous experiment is using to compare. From the video, image is captured frame by frame from start time until finished injection. Time taken for the spray is from 0.03 s to 0.12 s. Video imaging has been analyzed and the result is compared according spray evolution. At the 10 MPa, for E0, produced spray penetration is 120.3 mm at 0.06 s and cone angle 2.89° as the accurate result because at that time are shows the overall spray image. E50, produced the penetration 142.2 mm and cone angle 8.31°. E100, produced over than 120.2 mm penetration while the cone angle is 3.99 °. At the high pressure, result shows for E0 is 131.5 mm penetration and 3.71° of cone angle. E50 shows the penetration length 149 mm and cone angle is 10.87° and for E100 show the penetration and cone angle are over 150 mm and 5.75°. Comparing these result indicate higher pressure better penetration and reduce the cone angle because the density of fuel are used is different. It can conclude the physical properties are related with the spray pattern.

ABSTRAK

Tesis ini membentangkan tentang pemprosesan video imej bagi campuran petrol dan ethanol untuk di analisis. Tujuan kajian ini dijalankan adalah untuk mengkaji ciri-ciri semburan. Penyiasatan untuk ciri-ciri semburan ini melibatkan tiga jenis minyak yang digunakan di dalam ujikaji ini adalah seperti gasoline (E0), ampuran gasoline dengan ethanol (E50) dan ethanol (E100) untuk tekanan yang berlainan. Tekanan yang digunakan di dalam ujikaji ini adalah 10 MPa dan 20 MPa. Ciri-ciri semburan yang di uji di dalam ujikaji ini adalah panjang keseluruhan semburan dan sudut semburan sahaja. Video yang direkod digunakan untuk analisis semburan terhasil dari ujikaji sevelum ini untuk dibandingkan. Dari video tersebut, imej diambil mengikut frem ke frem yang lain dari mula semburan sehingga siap. Masa yang diambil untuk imej dari 0.03 s sehingga 0.12 s. pada tekanan 10 MPa, untuk E0 menunjukkan panjang semburan adalah 120.3 mm pada 0.06 s dan sudut semburan adalah 2.89° sebagai hasil yang paling tepat kerana keseluruhan imej dapat dilihat pada masa ini. E50 pula menghasilkan lebih dari 142.2 mm panjang dan sudut 8.31°. E100 menunjukkan 120.2 mm panjang dan sudut semburan sebanyak 3.99°. bagi tekanan tinggi pada 20 MPa pula, E0 sebanyak 131.5 mm panjang dan 3.71° sudut semburan. E50 menunjukkan panjang semburan 149 mm dan sudut sebanyak 10.87° dan untuk E100 menunjukkan panjang dan sudut semburan adalah melebihi 150 mm dan 5.75°. Perbandingan hasil yang diperolehi menunjukkan perbezaan panjang dan sudut semburan mempunyai hubungan dengan ketumpatan minyak yang digunakan.

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LIST OF SYMBOLS

°	Degree
%	Percentage
mm	Milimeters
kPa	Kilo Pascal
fps	Frame per Second
MPa	Mega Pascal
K	Kelvin
mL	Mililitres
s	Second
L/s	Litre per Second
ms	Milisecond

LIST OF ABBREVIATIONS

GDI	Gasoline Direct Injection
E0	Pure Gasoline
E50	Blended Fuel (Gasoline 50% + Ethanol 50%)
E100	Pure Ethanol
LISA	Linearized Instability Sheet Atomization
RON	Research Octane Number
SMD	Sauter Mean Diameter

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Ethanol can be blend with gasoline at low concentrations without any modification to be used in SI engine [1]. Gasoline-ethanol blends (gasohol) can be used as fuel in order to substitute some part of gasoline in engine applications [2].

Besides that, ethanol also has higher heat of vaporization compared to gasoline which means that freezes the air allowing more mass to be drawn into the cylinder and increases the power output. Besides that, ethanol also has anti-knock properties that improves engine efficiency and gives higher compression ratios [2].

To analyze these spray characteristics according to the injection duration under ambient pressure conditions and the injection timing in the visualization engine are significant. Averaging many spray images is a typical quantification method for spray characteristics. However, if quantitative spray characteristics are to be obtained from so many images by an averaging method, a considerable amount of time and stable conditions that provide repeatability are needed [3].

While the study focused about the ethanol properties and the advantages it offers, others resource about the contribution to environmental pollution from internal combustion engine are the major issues that led to increasing demand for efficient and eco-friendly energy management schemes to be implemented in industrial, commercial and domestic sectors. For this study, it will be analysis, research and finding the result from properties of ethanol and gasoline blend during spray and the side effect of the different ratio each sample.

1.2 PROBLEM STATEMENT

The quantification of the characteristics of sprays from gasoline fuel injectors is a very important, but specialized, area measurement. The injection of fuel in an engine is a very rapid, transient event of a few milliseconds duration, and the resultant spray of atomized liquid fuel is not easily characterized. Parameters such as the mean drop diameter, the spray tip penetration, the fuel mass distribution and the cone angle (or spray angle for G-DI) are critical to the selection of an injector for a given application. Recently, digital imaging and image processing tasks are conducted to measure macroscopic spray and flame characteristics. These macro spray characteristics include the spray tip penetration, near- and far-field angles, tip velocity, and average fuel area density.

1.3 RESEARCH OBJECTIVES

The objectives of this study are:

i. To investigate about spray characteristics in penetration and cone angle

ii. To analyzed spray using video image processing

1.4 SCOPE OF STUDY

The scopes of the study are:

i. Choosing video of fuel mixture (ethanol with gasoline) from previous research to analyzed. From previous research have three video are taken which is using different fuel
   - Ethanol 100% (E100)
   - Gasoline 100 % (E0)
   - Ethanol 50% + Gasoline 50% (E50)

ii. Image processing method to analyzed spray characteristics from a high speed camera using Matlab R2011b software.

iii. Describe spray characteristic such as spray angle and spray tip penetration

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This literature review had been taken with reference from sources such as journal, books, thesis and internet in order to gather all information related to the title of this project. This chapter covers about the previous experiment doing by researcher and to go through the result by experimental and numerical.

2.2 ALTERNATIVE FUEL

Around the world today, has use the fossil energy for energy production and its call, fuel that produced by reserves of petroleum. It is also well known that this energy resources as well as the need of reduced emissions of CO_2 and pollutants promotes an increased utilization of regenerative fuels. One of the type of Alcohols named ethanol which is a colorless liquid with mild characteristic odor and can be produced from coal, natural gas or biomass, have high octane rating and can be used as one of the realistic alternative fuels. Besides that, ethanol have higher heat of vaporization compared to gasoline, that's means that freezes the air allowing more mass to be drawn into the cylinder and increase the power output. Then, other thing about ethanol is it has antiknock properties that improves engine efficiency and gives higher compression ratios. All things about ethanol and fuel that can be various ration both of it are the current interest and numerous attempts have been done on this topic by researchers around the world in the past decade. Then, the spray properties play an important role on engine air –fuel mixing and subsequent combustion when spray, can be understanding of the characteristic by doing the experimental different ratio of fuel- ethanol blends is of necessity and significance [4]

2.2.1 Ethanol

Ethanol is also known as ethyl alcohol or grain alcohol. Ethyl ethanol is an alcohol made from grain. Ethanol was first used to extend gasoline supplies during the gasoline shortage of the 1970s. Ethanol has an oxygen content of approximately 35%. Thus 10% concentration adds about 3.5% oxygen to mixture. Like gasoline, ethanol contains hydrogen and carbon, but ethanol also contains oxygen in its chemical structure. The addition of oxygen makes for a cleaner burning fuel than gasoline. Another benefit of ethanol is that it increases the octane rating fuel. A 10% ethanol will raised an 87% octane fuel by at least 2.5 octane numbers. However, the alcohol added to the base gasoline also raised volatility of the fuel about 0.5 psi or 3.5 kPa. Most automobile manufactures permit up to 10 percent ethanol if drivability problems are not experienced. According to [5] in his journal title the use of ethanol-gasoline blends as a fuel in an SI engines, characteristics of ethanol and gasoline is distinguish by viewpoint of formula, molecular weight, density, specific gravity and so on.

Table 2.1: Properties of Pure Ethanol

Properties	**Amount**
Density @ 15°C (kg/L)	0.794
Reid vapor pressure (mbar)	159
Research octane number	107
Boiling point (°C)	78.5
Stoichiometric Air Fuel Ratio	9.0
Enthalpy of combustion (MJ/kg. liq.)	-26.8
Heat of vap. (MJ/kg)	0.925
H/C ratio	3
O/C ratio	0.5
Adiabatic flame temperature (K)	2258

Source: Longfei Chen et al (2010)

The range of ethanol blended fuels used in this study was 10%, 20%, 50%, 70% and 85% volumetric percentage of ethanol; properties of pure ethanol are listed in Table 2.1. It is worth noting that the latent heat of evaporation for a stoichiometric mixture of ethanol is about 4.5 times that of the gasoline – this could make evaporation of gasoline/ethanol blends more difficult and hence lead to higher heterogeneity of the mixture than that for the gasoline. The lower stoichiometric Air Fuel Ratio of ethanol caused by its lower energy density requires about 1.5 times more ethanol to achieve the same energy input [6].

2.2.2 Gasohol

Gasohol is a mixture combination between gasoline and ethanol. It is introduce in 1990s and mostly use in Brazil. It is usually a mixture of 10% ethyl alcohol and 90% unleaded gasoline. Ethyl alcohol is made from sugar, grain or other organic living material. It is believe that the use of gasohol ease the demand of crude oil. Gasohol reduces the use of gasoline with no modification needed to automobile engine. [4] says that gasoline blended with 10% alcohol or less does not require changes to the fuel system. However vehicles burning any amount of gasohol may require that the fuel filter be changed more often. This is due to the cleaning effect that alcohol has on the vehicle's fuel tank. Oxygenates suspend water in fuel and tend to keep it from accumulating in the gas tank. One gallon of gasoline can hold only 0.5 teaspoon of water. As a result, the water separates and accumulates at the bottom of the tank.

Table 2.2: Table of Properties Gasoline and Ethanol

Properties	Gasoline	Ethanol
Chemical formula	C_8H_{18}	C_2H_5OH
Molecular weight	100-106	46
Oxygen (mass %)	0-4	34.7
Net lower heating value (MJ/kg)	43.5	27
Surface Tension (dynes/cm)	20	22.27
Latent heat (kJ/L)	223.2	725.5
Stoichiometric air/fuel ratio	14.6	9
Vapor pressure at 23.5°C (kPa)	60-90	17
Boiling point (K)	399	351
RON	97	111

Source: A.K. Amirruddin,(2009)

2.3 FUEL INJECTION AND SPRAY RESEARCH

The typical spray structure of a direct injection fuel spray is introduced into the engine cylinder through a nozzle. As the liquid jet leaves the nozzle, it becomes turbulent and the other surface of the jet breaks up into droplets. In turbulent mixing processes, the turbulent eddies formed in the shear layer will hit the surrounding fluid in the jet core, and mixing subsequently takes place on the molecular level at the two-fluid interface.

The physics of spray atomization and its influence on combustion, pollutant formation, and fuel efficiency are not well understood unfortunately, and final tuning of the engine is a trial-and error procedure. The development of several novel diagnostic techniques that use x-rays to study the detailed structure of fuel sprays have been developed by Argonne scientist. X-rays are highly penetrative in materials with low atomic numbers; therefore they do not encounter the multiple scattering problems typical of diagnostic methods that use visible light. From research of Advanced Photon Source by Gurpreet Singh, 2010 he said that Argonne has developed a non-intrusive absorption technique that yields a highly quantitative characterization of the dynamic mass distribution in the spray from both diesel and gasoline engine injectors by using highly time-resolved monochromatic x-rays generated.

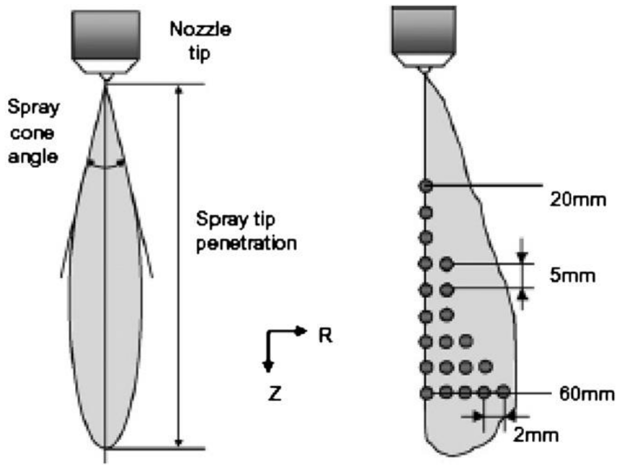

Figure 2.1: The definition of macroscopic spray characteristic

Source; Suh et. (2009)

2.3.1 Fuel Injection

Fuel injection is a system for mixing two substances which are fuel and air in an internal combustion engine. It has becomes the primary fuel delivery system used in automotive petrol engines, having almost completely replaced carburetors in the late 1980s. A fuel injection system is designed and calibrated specifically for the type of fuel it handled. The main difference between carburetor system and fuel injection system is that fuel injection atomizes the fuel by forcibly pumping it through a small nozzle under high pressure, while a carburetor relies on low pressure created by intake air rushing through it to add the fuel to the airstream.

Fuel injector is a nozzle that injects a spray of fuel into the intake air. They are normally controlled electronically for modern engines. A metered amount of fuel is trapped in the nozzle end of the injector and a high applied to it. At proper time, the nozzle is opened and fuel is sprayed into the surrounding air. The amount of fuel injected each cycle is controlled by injector pressure and time duration of injection. An electronic fuel injector consists of the following basic components like valve housing, magnetic plunger, solenoid coil, helical spring, fuel manifold and needle valve. When activated, the electric solenoid coil is excited which move plunger and connected needle valve. This opens the needle valve and allows fluid from the manifold to be injected out of the valve orifice. The valve can either be pushed opened by added pressure from the plunger or it can be opened by being connected to plunger, which then releases the pressurized fuel. Each valve can have one several orifice openings, each having diameter of about 0.2-1.0 mm. the fuel exits the injector at velocities greater than 100 m/s and flow rate of 3-4 gm/sec.[7]

2.4 SPRAY CHARACTERISTICS

The microscopic spray characteristic including axial spray penetration, spray width and spray angle are shown in figure 2.5**.** The spray tip penetration and spray width were defined as maximum distance from the nozzle tip of the side view spray image and maximum radial distance from the bottom view, respectively. Also the spray cone angle is defined as the interval which is formed by the nozzle tip and two straight lines wrapped with the maximum outer side of the spray. Amirruddin, et al. (2009) says that when the ethanol percentage is higher the spray spread faster, produce longer penetration distance.

Figure 2.2: Definition of Spray angle and Spray tip Penetration

2.4.1 Gasoline Spray

Gasoline Direct Injection (GDI) engines are the new in US market. These engines inject the fuel directly into the engine cylinder rather than into the intake port. These engines also can achieve higher fuel efficiency, but they depend on a precise fuel or air mixture at the spark plug to initiate ignition. These things lead to more stringent requirements on spray quality and reproducibility. Gasoline Direct Engine also enables new combustion strategies for gasoline engines. Such "learn burn" engines may achieve efficiencies near that of a diesel while producing low emissions. This advanced combustion a strategy relies on precise mixing of the fuel and air to achieve clean, efficient power generation.

Argonne's fuel injection and spray researchers are studying the process of gasoline injection to enable these advanced combustion strategies. They have performed the first quantitative, dynamic three-dimensional reconstruction of a fuel spray, which revealed the striking asymmetry of sprays from a prototype gasoline injector. They also have worked with several US manufactures to help them understand the performance of their injectors, and have assisted in the development of a new GDI injection system, from prototype to final production design (Gurpreet Singh, 2010)

Argonne's researchers are studying the fuel injection process using fuels such as biodiesel, vegetables oil, ethanol, butanol, with the goal of understanding how changes in fuel properties affect the spray, combustion, and ultimately, the operation of the engine. The researcher's experiments have discovered structural differences between sprays of conventional fuels and biodiesels, revealing that biodiesel sprays require more time to atomize and produce more compact sprays with higher density (Gurpreet Singh, 2010)

2.5 PHYSICAL PROPERTIES

Physical properties are related with the spray characteristics. Balram S., et al. (2013) stated the butanol and gasoline spray are different because the physical properties of it are different. Table 2.3 shows the physical properties of butanol, ethanol and gasoline.

Table 2.3: Physical properties of fuel

Properties	Gasoline	Butanol	Ethanol
Density [kg/m^3] (20°C)	729*	809	794
Viscosity [cP](25°C)	0.4-0.8	3.64	1.08
Surface tension [mN/m] (20°C)	25.8	25.4	22.4
Energy density [MJ/kg]	44	37	29
Boiling point [°C]	30-190	117.2	78.5
Latent heat of vaporization [MJ/kg] (25°C)	0.364	0.43	0.902

*For current study gasoline density is taken as 760 kg/m^3

Source: Balram S., et al. (2013)

Soid S. N., et al. (2012) state the higher viscosity would significantly affect to the fuel spray structure due to poor atomization. The higher main spray tip penetration is the lowest of the density is shown in the result in Figure 2.4.

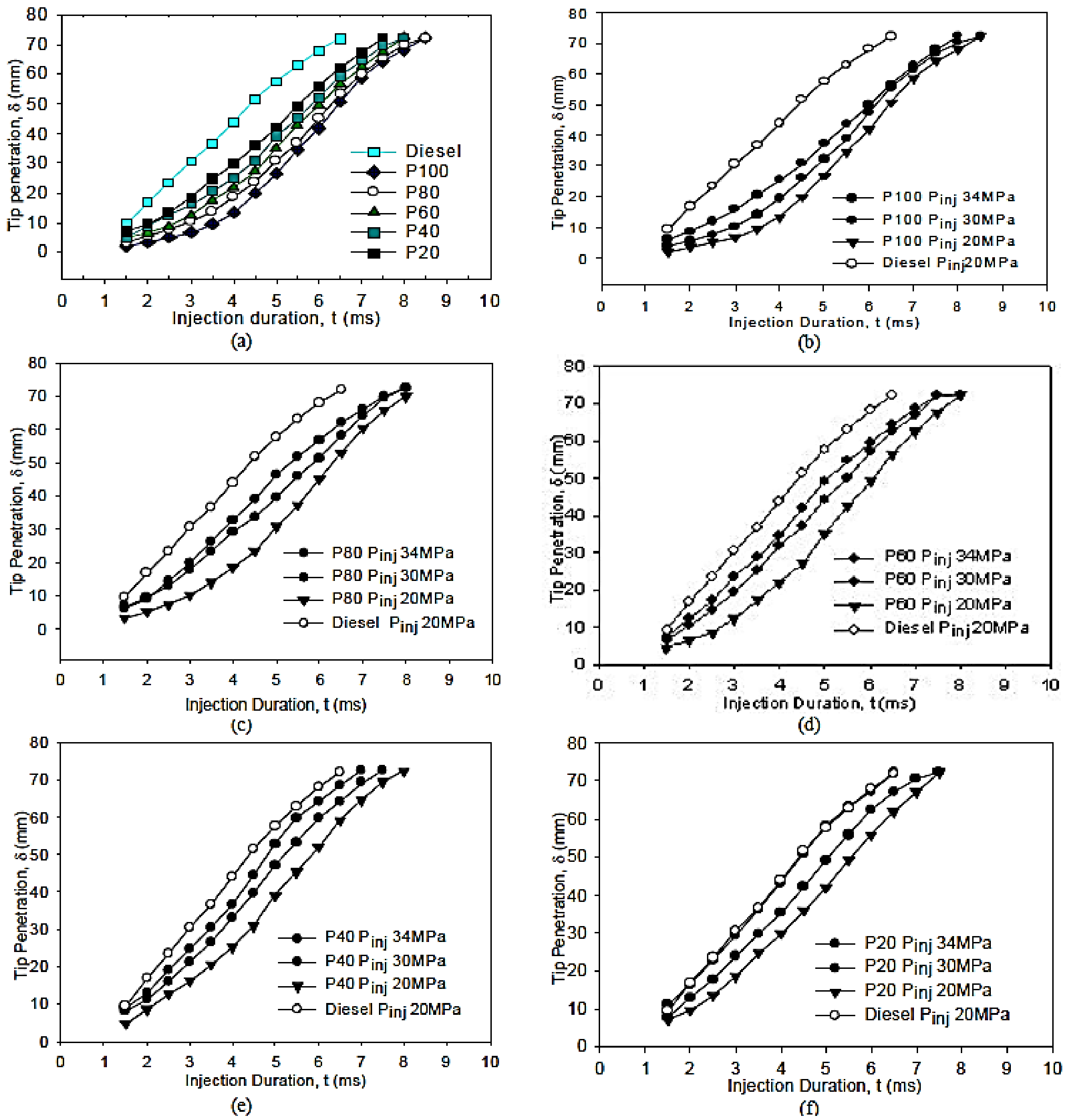

Figure 2.3: Spray tip Penetration (a) Comparison between palm oil blends and diesel at 20 MPa injection pressure and blends tip penetration at various injection pressure for (b) P100, (c) P80, (d) P60, (e) P40 and (f) P20

Source: Soid S. N., et al. (2012)

For the spray cone angle, Soid S. N., et al. (2012) stated the magnitude of spray cone angle of blends decrease with increase of palm oil fraction in diesel fuel. The changes of cone angle for palm oil blends are obvious due to different