DEVELOPMENT OF THE PREMIXING INJECTOR IN BURNER SYSTEM

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ABSTRACT

The alternative fuel is good attention especially for renewable and prevention energy such as biodiesel. Biodiesel fuel (BDF) has a potential for external combustion. BDF is one of the hydrocarbon fuels. Palm oil Biodiesel is free from sulfur and produced by esterification and transesterification reaction of vegetable oil with low molecular weight alcohol, such as ethanol or methanol. The objectives of this research are design the mixing injector fuel and water-fuel emulsion with air for open burner and analyze the behavior of mixture spray formation between fuel (DF and BDF) and water-fuel emulsion. Premix injector use for external combustion especially open burner system. The disadvantages of BDF are high toxic emissions such as NOx, CO and particular matter (PM) and but it can reduced the performance of burner system. High toxic emission can be solved by using a new concept injector with mixing fuel-water emulsion and air. The additional water for combustion process can reduce the NOx emissions, soot, and the flame temperature. This research focuses the Spray angle, penetration, and flame length with secondary and without secondary air. CPO biodiesel has longer penetration length and spray area than diesel, but the spray angle is smaller than diesel. The different of flame Image between pure fuel and water mix with fuel is the flame color. Water mix with fuel has brightness color and shorter flame than pure fuel.

ABSTRAK

Bahan api alternatif merupakan satu isu yang penting bagi mengantikan bahanapi yang sedia ada dan diperbaharui seperti contoh bahan api biodiesel.Bahan api Biodiesel (BDF) mempunyai potensi bagi sistem pembakaran luar. BDF merupakan bahan api jenis hydrocarbon. Biodiesel daripada kelapa sawit bebas daripada belerang dan ia terhasil daripada proses kimia (esterification dan transesterification) bertindakbalas dengan alkohol bermolekul rendah seperti ethanol atau methanol. Objektif dalam kajian ini ialah merekabentuk penyuntik semburan untuk campuran bahan api dan air secara emulsi bagi ‘Open burner’ dan menganalisis bentuk semburan bagi bahan api (Diesel dan Biodiesel) dan campuran bahan api dengan air. Kelemahan bahan api biodiesel ialah pelepasan toksid yang tinggi seperti NOx, CO dll dan ia juga boleh mengurangkan prestasi system pembakaran. Pelepasan toksid yang tinggi boleh dikurangkan menggunakan penyuntik semburan yang baru yang mempunyai konsep mencampurkan bahan api dengan air. Campuran air didalam bahan api boleh menggurangkan kuantiti NOx , jelaga dan suhu api pembakaran. Kajian ini tertumpu kepada sudut semburan, pemanjangan semburan dan panjang api nyalaan. Biodiesel daripada minyak mentah kelapa sawit (CPO) mempunyai bentuk semburan yang panjang dan sudut semburan yang kecil berbanding dengan diesel. Dari segi api nyalaan bahan api bercampur dengan air tidak terang jika dibandingkan dengan nyalaan bahan api yang asli.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	Percentage
Φ	Equivalent Ratio
AFR	Air fuel Ratio
B0	Biodiesel 0 %
B5	Biodiesel 5 % & Diesel 95 %
BDF	Biodiesel Fuel
BFD	Block Flow Diagram
CME	Canola Methyl Ester
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPO	Crude Palm Oil
DF	Diesel Fuel
DSLR	Digital Single-lens Reflex
EC	External Combustion
FAME	Fatty Acid Methyl Ester
HC	Hydrocarbons
ICE	Internal Combustion Engine
NO_x	Nitrogen Oxide
OH	Oxygen Hydrogen
PM	Particulate Matter
PPM	Part Per million
RBDPO	Refine, Bleach and Deodorized Palm Oil

RPE	Rape seed Methyl Ester
SME	Soy Methyl Ester
SMEs	Small and Medium Sized Enterprises
W0	Water 0% & Fuel 100%
W10	Water 10% & Fuel 90%

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CHAPTER 1

INTRODUCTION

1.1. Background of Study

Today, global warming is the biggest issues due the increasing of emissions from diesel fuel in transportation and manufacturing sectors. The solution for this issue is by using Biodiesel fuel as alternative fuel in both sectors. Malaysia government has introduced the Biodiesel (B5) in the diesel engine for transportations [1]. Biodiesel fuel (BDF) in alternative fuel and renewable energy but it has low quality of fuel and can reduce the performance compared to the diesel fuel (DF). BDF can be used in external combustion for burner and internal combustion for diesel engine. The main issue is BDF has high toxic emission such as Nitrogen Oxides (NOx) but it decreases the other gases. This research studied a new concept for injector in burner system. This injector can combine the water-fuel emulsion and air by using suitable ratio in mixing chamber for combustion process.

The purpose of water-fuel emulsion in the combustion process is to reduce the gas emission especially NOx, soot, flame temperature and flame phenomena. This research also studied the spray characteristic such as spray penetration and spray angle to compare fuel (DF and BDF) with water and without water. The spray characteristic can be analyzed by image processing technique.

1.2. Problems Statement

In combustion process could emitted into the atmosphere, Nitrogen oxide (NOx) react with water and other compounds to form various acidic compounds, fine particles, and ozone. These pollutants can remain in the air for days or even years. Effects of NOx are decreases in lung function, resulting in difficulty breathing, shortness of breath, and other symptoms.

Increase or decrease (NOx) in biodiesel emission is depending on the testing procedures. But results from more researchers found that NOx emission from biodiesel is increase. For examples, Mekhilef, Siga, and Saidur (2011) reported that Palm oil has more oxidation stability than Jatropha and other biodiesel feedstock. The palm biodiesel would increase NOx emission [2]. Labeckas and Slavinskas (2011) analyzed the emission characteristics of four stroke, four-cylinder, direct injection, unmodified, naturally aspirated diesel engine when operating on neat rapeseed methyl ester (RPE) and its 5%, 10%, 20% and 35% blends with diesel fuel. They found that carbon monoxide, hydrocarbon and visible emissions had decreased while an oxide of nitrogen emissions increased for methyl ester compared to diesel [3].

1.3. Objectives

The objectives of this research are:

I. to design the mixing injector fuel and water-fuel emulsion with air for open burner.
II. to analyze the behavior of mixture spray formation between fuel (DF and BDF) and water-fuel emulsion.

1.4. Scope of the project

The scopes of this project are:

I. the capacity of mixing chamber in injector between 5 to 8 cc and 8 holes with diameters of 1 mm.

II. using direct image to analyze flame and spray characteristic such as spray angle and penetration by the operating parameters :

   a. Diesel fuel.
   b. Bio-diesel ratio (B5, B10, and B15).
   c. Equivalent ratio (0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8 and 2.0).
   d. Water-fuel emulsion (W5, W10 and W15).
   e. Air Pressure at nozzle (0.1bar- gauge pressure).
   f. Secondary air pressure (1 bar- gauge pressure)
   g. Ambient temperature.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This study aimed to develop biodiesel fuel especially from palm oil to open burner. It is involves in the development injector for burner system. Kidoguchi, Yatsufusa, and Nakagawa (2011) was designed this premix injector. Premix injector mix the air, fuel and water in combustion process to reduce NOx emissions [4].The role of SMEs in the development of the economic sector and intraregional trade and investment is attracting the policy makers throughout the Association of South East Asian Nations (ASEAN) country. According to Small and Medium Industries Development Corporation (SMIDEC), an enterprise is consider as an SME in each of the representative sectors based on the annual sales turnover or the numbers of full time employees. SMEs are divided into two sectors; manufacturing, manufacturing related services and agriculture industries; and services (including ICT) and primary agriculture [5].

SMEs sector is a key component of the economy, accounting for 99.2% of all total business establishments (SME Annual Report, 2006). In view of this staggering figure, SMEs expected to adopt "green technology" to improve global warming problem. Global warming problem, can seriously affect on the world's sustainability or even humankind's survival. Scientists, academic researchers, and influential world leaders from the world's biggest economies such as United States, China, Germany, and Japan have called for concerted efforts to arrest global warming problem before it is too late [6]

2.2 Global Warming

Global warming is one of the environmental issues since 1958(Mark Maslin, 2004). The definition of global warming is referring to the increased temperature of earth surface and it can give negative effect to the green house. Green house gasses are carbon dioxide (CO_2), carbon monoxide (CO), water vapor (H_2O), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). CO2 is the main gas in green house and it is an unavoidable product of economic activities and human's life hoods [7].

The potentially of global warming are from burning of fossil fuel, deforestation, transportations, etc. Transportation emissions especially from diesel engine can contribute to direct warming impact (carbon dioxide) and indirect Impact (Nitrogen oxide, carbon monoxide etc). Table 2.1 is shown as global warming impact of alternative technology vehicles [8].

Table 2.1: Global warming impacts of alternative technology vehicles [8]

Vehicle	**Mean emission (g/km)**			
	CO2	***CO***	***THC***	***NOx***
R15-04	151	6.1	1.27	2.7
Three-way catalyst	180	0.87	0.13	0.13
Lean burn	132	8.2	1.1	1.5
Oxidising catalyst	144	4.5	0.5	0.65
IDI diesel	131	0.43	0.23	0.46
DI diesel	126	0.53	0.73	1.1
LPG	192	37	0.86	1.4

Effects of global warming are rise in global temperature, rise in sea level, impact on weather, food production, and the economy. So, one of the solution is to reduce the use of fuel especially diesel change to biodiesel as a renewable energy.

2.3 Biodiesel as a Renewable Energy

Palm oil Biodiesel is free from sulfur and produced by esterification and transesterification reaction of vegetable oil with low molecular weight alcohol, such as ethanol or methanol. It is also biodegradable and non-toxic fuel. This fuel is obtaining from vegetable oils (typically palm oil, soybean, rapeseed, or sunflower) with changes the properties of the oil significantly.

Malaysia is a country of palm oil producers in the world and the main raw stock for biodiesel. Palm oil biodiesel give advantages for the economical and environmental issue in the Malaysia. Since 1982, Malaysia had developed palm oil as renewable fuel and use of palm oil biodiesel blend (B5) for the industrial and transportation sector [2]. Biodiesel fuel can be used for external and internal combustion because it less emission and pollutant. Biodiesel also be used in the transportation for reduction of pollutant emissions of automotive Diesel engines [9]. It can be proved by the research of "Biodiesel as alternative fuel: Experimental analysis and energetic evaluations" by Carraretto (2004). The test engine was a four-cylinder with direct injection diesel engine, which was model UNIC 8220.12.; 125 mm bore, 130 mm stroke, compression ratio of 17: 1 and a maximum output of 158 kW/2,600 rpm.

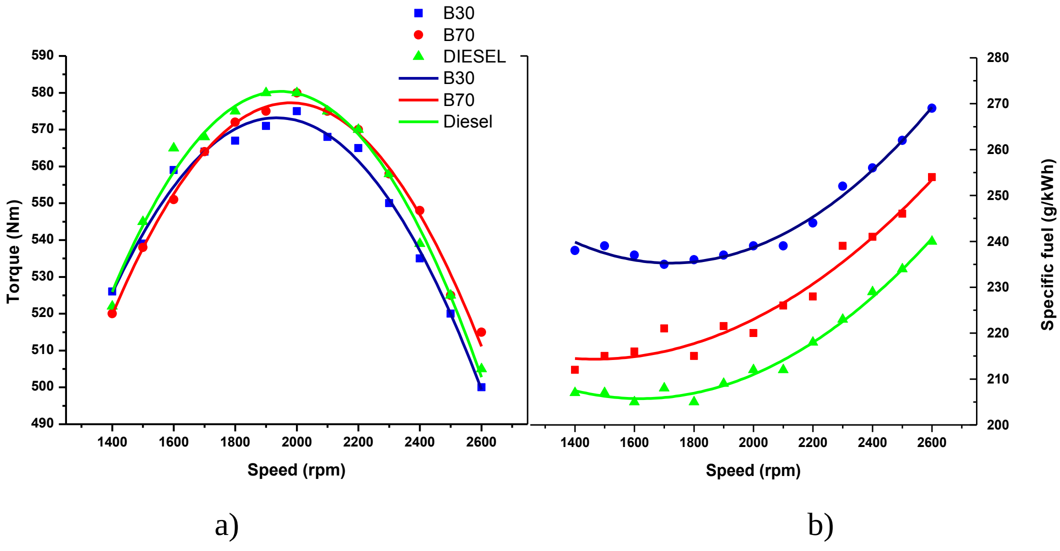


Figure 2.1 : a) Torque and b) fuel consumption for diesel oil and different oil-biodiesel blends [9]

Comparison between diesel oil with oil biodiesel blends start from speed 1400 to 2000 rpm diesel oil the torque higher than oil biodiesel blends (figure 2.1), but after speed 2000 rpm, the torques is similar with oil biodiesel blends. The increase of biodiesel percentage in the blend involves a slight decrease of both power and torque over the entire speed range [9].

2.3.1. Biodiesel

Biodiesel is defining by ASTM as "a fuel comprised of mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats, designated B100." Another name for biodiesel is fatty acid methyl esters (FAME) [10].

The main advantages of using biodiesel are such as:(1)lower dependence on crude oil, (2) renewable fuel, (3) favorable energy balance,(4) reduction in green house gas emission,(5) lower harmful emission, (6) biodegradable and nontoxic,(7) the use of agricultural surplus and (8) safer handling (higher flashpoint than conventional diesel fuel) [11].

2.3.2. Biodiesel Properties

Chemical properties of biodiesel are carbon, hydrogen, and oxygen. Common chemical name of biodiesel is Fatty acid (m) ethyl ester and chemical formula range C_{14}–C_{24} methyl esters or $C_{15–25}$ $H_{28–48}$ $O_{2.}$. The definition of Density is as mass per unit volume and kinematic viscosity is the ratio of absolute or dynamic viscosity to density. Kinematic viscosity can be obtained by dividing the absolute viscosity of a fluid with its mass density (Yunus A. Çengel, Michael A. Boles).

Kinematic viscosity range at 40^oC and density range at 15^oC are 3.3 to 5.0 mm^2/s and 860 to 900 kg/m^3 [12].Table 2.2 is besides the Malaysian palm diesel specifications and Malaysian petroleum diesel standards [11]. There are different types of biodiesel. Table 2.3 is comparison of density and kinematic viscosity for various types of biodiesel.

Table 2.2: Different standards and specifications for palm biodiesel [11]

Property	Unit	Biodiesel standards		Palm biodiesel			
		EN14214	ASTM D6751	Normal point	Low pour point	PLPO/PD B5[a]	MS123:1993[b]
Ester content	% (m/m)	96.5 >	–	98.50	99.5	–	–
Density at 15 °C	Kg/m^3	860–900	–	878.3	870–890	841.9–845.9	–
Viscosity at 40 °C	mm^2/s	3.5–5.0	1.9–6.0	4.415	4–5	4.136–4.549	1.5–5.8
Flash point	°C	120 <	130.0 <	182	150–200	75–81	60 <
Cloud point	°C		Report[c]	15.2	−18 to 0	14–16	18
Pour point	°C			15	−21 to 0		15
Carbon residue (on 10% distillation residue)	% (m/m)	0.3 >	0.50 >	0.02	0.02–0.03	0.2	0.2 >
Acid value	mg KOH/g	0.5 >	0.80 >	0.08	0.3 >	–	–
Cetane index	–	51 <	47 <	58.3	53.0–59.0	51–57	47 <
Sulphur content	% (m/m)	0.001 >	0.0015 >	0.001 >	0.001 >	0.00017–0.00018	0.005 >
Sulphated ash content	% (m/m)	0.02 >	0.020 >	0.01 >	0.01 >	–	–
Water content	mg/kg	0.05 >	0.05 >	0.05 >	0.05 >	0.001 >	0.001 >
Copper strip corrosion (3 h at 50 °C)	Rating	1a	3a >	1a	1a	1a	1a
Iodine value	–	120 >	–	52	56–83	–	–
Linolenic acid methyl ester	% (m/m)	12 >	–	0.5 >	0.5 >	–	–
Polyunsaturated (≥4 double bonds) methyl esters	% (m/m)	1 >	–	0.1 >	0.1 >	–	–
Methanol content	% (m/m)	0.2 >	–	0.2 >	0.2 >	–	–
Monoglyceride content	% (m/m)	0.8 >	–	0.4 >	0.4 >	–	–
Diglyceride content	% (m/m)	0.2 >	–	0.2 >	0.2 >	–	–
Triglyceride content	% (m/m)	0.2 >	–	0.1 >	0.1 >	–	–
Free glycerol	% (m/m)	0.02 >	0.02 >	0.01 >	0.01 >	–	–
Total glycerol	% (m/m)	0.25 >	0.24 >	0.01 >	0.01 >	–	–
Phosphorous content	mg/kg	10 >	10 >	–	–	–	–
Distillation temperature (90% recovered)	°C	–	360 >	–	–	363.7–367.8	370

[a] PLPO/PD B5: 5% processed liquid palm oil (PLPO)+95% petroleum diesel (PD).
[b] MS123:1993: Malaysian Standard for Diesel Fuel (Malaysia Biodiesel Standard, 2007).
[c] The cloud point of biodiesel is generally higher than that of petroleum based diesel and should be taken into consideration when blending.

Various types of biodiesel (B100) have differents value of densities and kinematic viscosities depend on temperature. For example, maximum and minimum values of density are 897 kg/m^3 for biodiesel from waste cooking oil and 882.1 kg/m^3 for biodiesels from Grapeseed oil methyl ester (GOME) and soybean.

Table 2.3: Comparison of density and kinematic viscosity for various types of biodiesel [9],[13]-[20]

Types of biodiesel	Chemical formula	Test method	Kinematic viscocity at 40°C (mm^2/s)	Test method	Density (kg/m^3)	Test method	References
Sunflower oil methyl ester (SOME2)	$CH_{1.82}O_{0.11}$	calculation	5.8	ASTM D445	893.4 @60°C	ASTM D1298	(Carraretto et al., 2004)
Corn oil methyl ester (COME)	$CH_{1.84}O_{0.11}$	calculation	5.5	ASTM D445	884 @60 °C	ASTM D1298	(Carraretto et al., 2004)
Ricebran oil methyl ester (ROME)	$CH_{1.85}O_{0.11}$	calculation	6	ASTM D445	889.5 @60 °C	ASTM D1298	(Carraretto et al., 2004)
Olive oil methyl ester (OOME)	$CH_{1.87}O_{0.11}$	calculation	5.3	ASTM D445	887.6 @60 °C	ASTM D1298	(Carraretto et al., 2004)
Grapeseed oil methyl ester (GOME)	$CH_{1.82}O_{0.11}$	calculation	5.2	ASTM D445	882.1 @60 °C	ASTM D1298	(Carraretto et al., 2004)
Rapeseed Methyl Ester (RME)	-	-	4.478	ASTM D445	883.7 @ 15C	ASTM D4052	(L. K. S. Teo. 2002)
Soybean	-	-	5.8	ASTM D445	882.1 @60 C	ASTM D1298	(Afshin Ghorbani, 2011)
Fatty acid (m)ethyl ester (FAME)	C14–C24 methyl esters $C_{15\text{–}25}H_{28\text{–}48}O2$	-	3.3–5.2	EN 14214	860–894 @15	EN 14214	(Demirbas A.,2009)
Palm oil bio diesel (PBO)	-	-	4.71	ASTM D445	864.42@25C	ASTM D1298	(Pedro Benjumea., 2007)
Palm biodiesel (palm methyl ester)	-	-	4.5	-	855 @ 40C	-	(Jawad Nagi., 2008)
Biodiesel from waste cooking oil	-	-	5.3	-	897 @ 15C	-	(Ayhan Demirbas., 2009)
Soybean crude oil	-	-	5.2	-	870@20C	-	(D.H. Qi et al., 2009)
Waste cooking oil	-	-	4.56	ASTM D445	866 @60 C	ASTM D1298	(G.R. Kannan et al., 2011)
Animals' fats	$C_{53}H_{102}O_6$	-	6	-	870 @60 C	-	(Imdat TAYMAZ., 2010)

2.3.3. Biodiesel Blends

Biodiesel blends such as B5, B10, B15, and B20 have different values of density and kinematic viscosity as shown in Figure 2.2. B0 stands for diesel fuel and B100 for pure biodiesel. B5 is 5% biodiesel and 95% diesel fuel, B20 is 20% biodiesel and 80% diesel. Refined, Bleached and Deodorized Palm Oil (RBDPO) has high value of density at 40^{o}C compare with soy metyl and palm oil, but lower value of kinematic velocity.

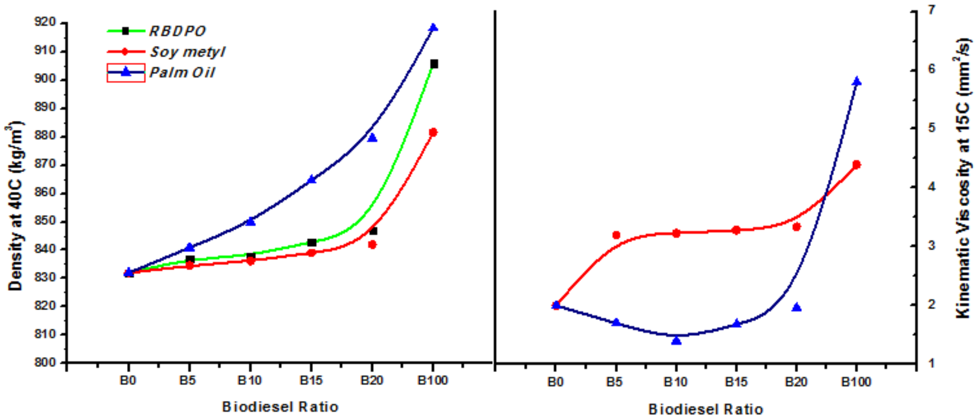


Figure 2.2: Density, Kinematic viscosity vs Biodiesel ratio for RBDPO [15], Soy metyl [16] and Palm oil [17]

P. Benjumea (2007) was studied the basic properties of several palm oil biodiesel–diesel fuel blends according to the corresponding ASTM standards. Fig. 2.3 shows the effect of temperature on density (ρ) for pure fuels and B5 and B20 blends [18]. If the temperature increases, the density of fuel will decrease. S. H. Yoon (2008) was investigated the fuel density of diesel and biodiesel fuel in the temperature range from 0 to 200 °C. Test fuels used were a conventional diesel, neat biodiesel (100% methyl ester of soybean oil), and their blends with blending ratios of 20%, 40%, 60%, and 80% [19]. Figure 2.4 as showed the Relation between density and fuel temperature of diesel, biodiesel, and blended fuels (B20–B80).

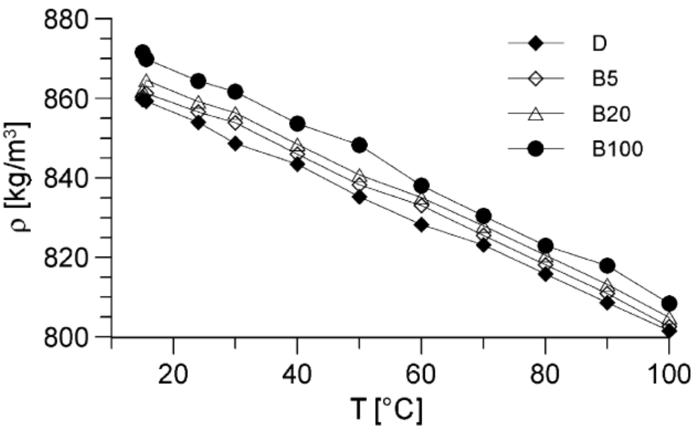


Figure 2.3: Variation of blend density with temperature [18]

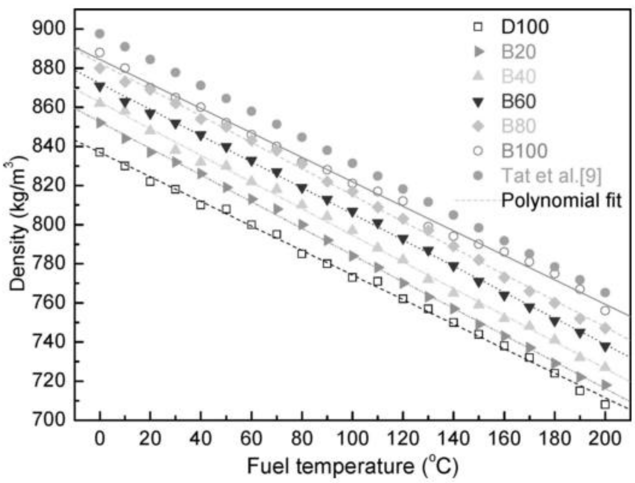


Figure 2.4: Relation between density and fuel temperature of diesel, biodiesel, and blended fuels (B20–B80) [19]

2.4 Water-Fuel Emulsion

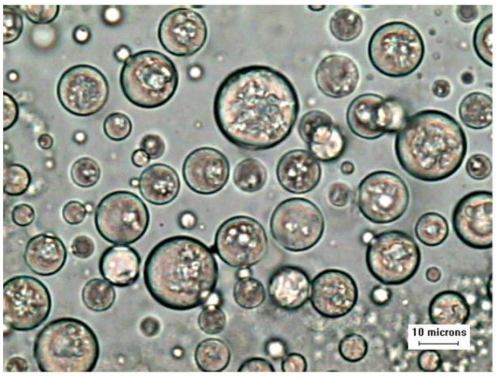
Water additional into hydrocarbon fuel such as methane, kerosene, diesel, and biodiesel has potential to reduce pollutant emission (NOx, Sox and soot) depending on the type of experiment methods. Many studies on emulsion fuels reveal that they have various benefits, including improvement in combustion efficiency and a reduction in particulate matter (PM) and nitrogen oxide (NOx) emissions.

Indeed, water particles vaporize and explosively spread when emulsion fuels are igniting in an internal combustion engine and a boiler. The oil particles surrounding the water particles are also scattered and become finer with smaller particle sizes. Oil particles have more contact area with oxygen, and as a result, incomplete combustion suppressed and combustion efficiency is improved. Therefore, PM emissions are also reducing. Cherng-Yuan Lin has discussed a variable on fuel properties of two and three-phase biodiesel emulsions. The results showed that the burning of neat biodiesel produces the least amount of carbon residue. In addition, the existence of water content causes an increase in specific gravity and kinematic viscosity of the biodiesel emulsion. The emulsification stability of the oil-water-oil (O/W/O) biodiesel emulsions, if compare with water oil (W/O) biodiesel. The O/W/O biodiesel is found to produce larger mean droplet size and volumetric fraction than those of the W/O biodiesel emulsion. The isolated water phase has to envelop the inner oil phase completely, as shown in Figure 2.5. Figure 2.5.(a) is for O/W/O emulsion has a larger mean droplet diameter than that of the W/O emulsion in Figure 2.5.(b) [20].

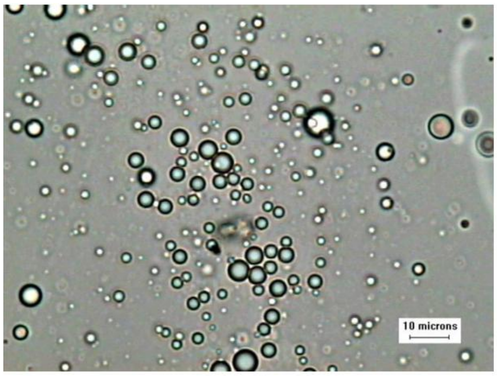
Water-in-kerosene emulsion combustion was investigated using a co-annular spray burner designed for aerospace turbojet combustors by Toncu [21]. The result is NOx level decreased by adding water, due to the change in thermal range and a subsequent modification of the formation mechanism. Figure 2.6 as shown as Microscopy of water-in-kerosene emulsion with 20% water prepared with 20% water and 1% SPAN 80 at magnitude 100.

2.4.1. Internal Mixing (Application for Burner)

Water used free of emulsification to reduce toxic emission. A new injector was first developed by Kidoguchi [4]. Water, atomizing air, and fuel are mix inside the mixing chamber. The mixture composes of three-fluids injected as spray into a flame stabilizer of burner. Figure 2.7 (a) as shown as fuel-water internally rapid mixing and figure 2.7 (b) is external mixing type. External mixing type injector is mix fuel and air by separately.



(a) Photograph of optical electron microscope of O/W/O biodiesel



(b) Photograph of optical electron microscope of W/O biodiesel

Figure 2.5: The isolated water phase has to envelop the inner oil phase completely [20]

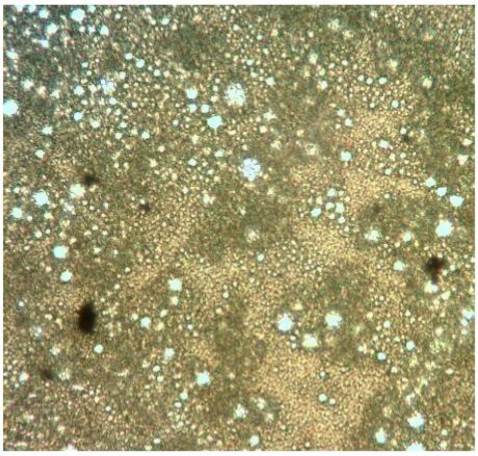
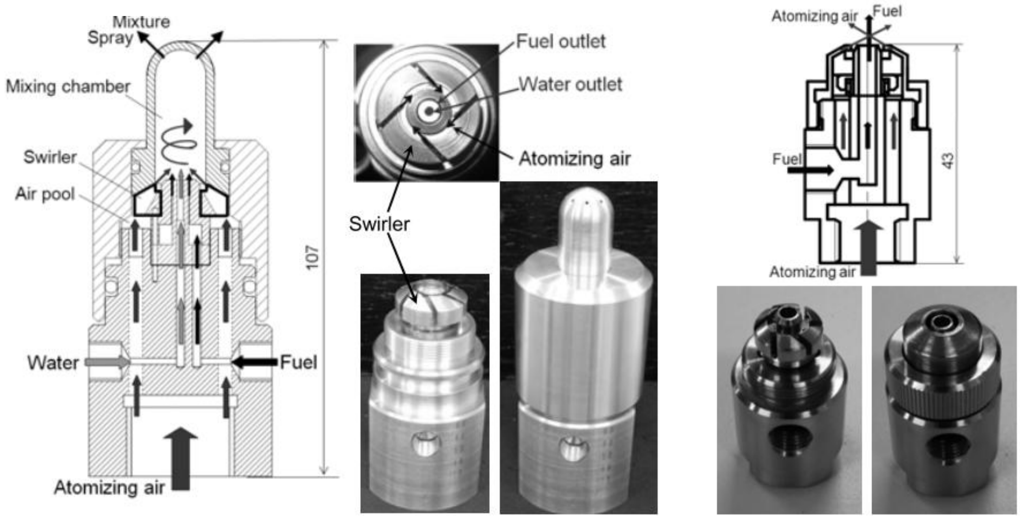


Figure 2.6: Microscopy of water-in-kerosene emulsion with 20% water prepared with 20% water and 1% SPAN 80 at magnitude 100 [21]



(a) (b)

Figure 2.7: (a) Fuel-water internally rapid mixing type, (b) External mixing type, Configuration of injector [4]

Gallagher was designed water in oil emulsifier and oil-burner boiler system. This emulsifier comprises a Venturi for an inlet for receiving oil, an oil-water emulsion outlet and opening extending there through from inlet to outlet shown in Figure 2. 8. The objective is to provide water-into oil emulsifier which has no moving parts is simple and inexpensive to manufacture and maintenance [22].

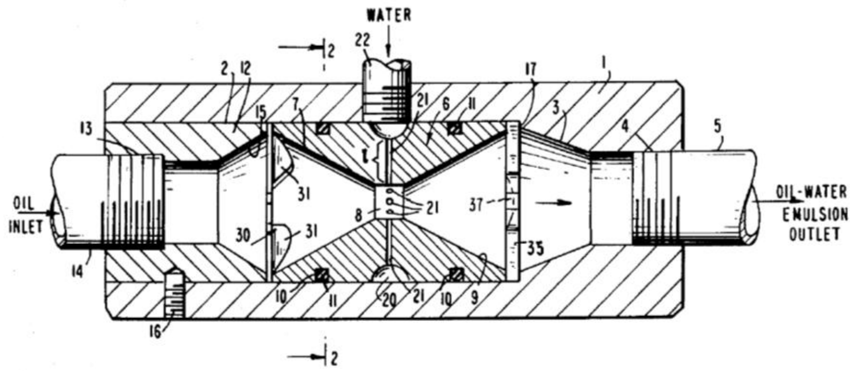
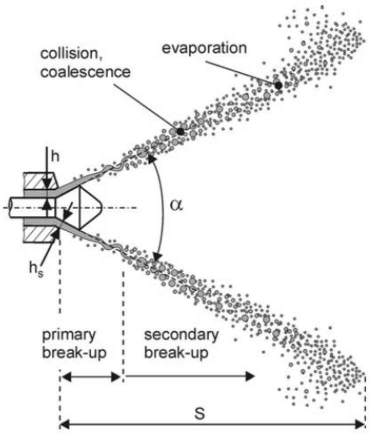


Figure 2.8: Cross-sectional view for water- oil emulsifier (Internally rapid mixing) [22]

2.5 Spray Characteristics

Spray characteristics depend on the type of liquids, pressure, density, temperature, and the design of injector. The basic Function of spray are to generate surface area for evaporation or combustion (heat and mass transfer), and transfer momentum to a surface or a gas. Figure 2.9 shows spray formation using a hollow cone nozzle. Figure 2.9 (a) is hollow-cone spray. α is the initial spray cone angle. The spray angle is the angle between the lines drawn on the edge of different contrast, and D is the diameter of nozzle hole. S is spray penetration.



(a) Hollow-cone spray. Example: outwardly opening nozzle

(b): Image of spray formation using a hollow cone Nozzle Sowing sheet breakup

Figure 2.9: Spray Formation by hollow cone nozzle [23]

C.D. Bolszo reported that atomization, vaporization, combustion, and emissions in operation 30 kW of gas turbine used biodiesel (soybean oil) as a reference compare with diesel fuel (DF). Previous work illustrated that the atomization and fuel dispersion characteristics of DF and B99 are substantially different due to the variation in liquid properties The spray generated at the DF engine injector air to fuel ratio for both liquids is show in Fig. 2.10 and exhibits obvious differences in spray angle and general appearance. Spray angle for biodiesel is bigger than DF [24].

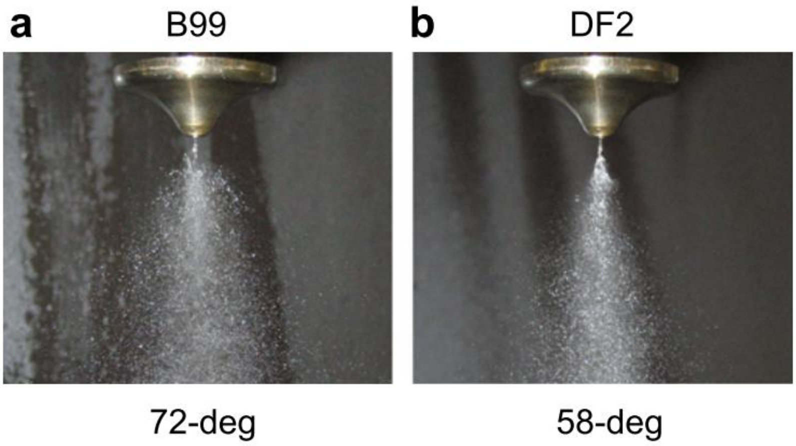


Figure 2.10: Comparison of B99 and DF Sprays at Baseline Condition [24]

Nazri studied the spray characteristics of refined bleached and deodorized palm oil and diesel blends. The objective of this research is to characterize the spray of the refined, bleached, and deodorized palm oil (RBDPO) and diesel blends. Five blends B5, B10, B15, B20, and B25 were physically blended using lab scale dynamic double propeller mixer and the main physical properties the results is the blends B5 and B10 was used in the power engines without fuel system modification. The fuel flow rate is 0.60 l/min for diesel and RBDPO blends. Spray angle will decrease when the ratio of biodiesel is increase. Figure 2.11 shows the photograph spray angle with biodiesel blend B0, B5, B10, B15, B20, and B25. The conclusion is the atomization characteristics of the lower mixing ratio RBDPO blends B5 and B10 comparable to that of the diesel fuel can be used directly to the power generation engines without any engine modification [25].

Kegl was reported that Optimization of a Fuel Injection System for Diesel and Biodiesel Usage. The tested biodiesel (B100) is produce from rapeseed oil. Figure 2.12 shows the spray comparison for Diesel (D2) and B100. It can see that the biodiesel penetration length is somewhat larger than that of D2 [26].

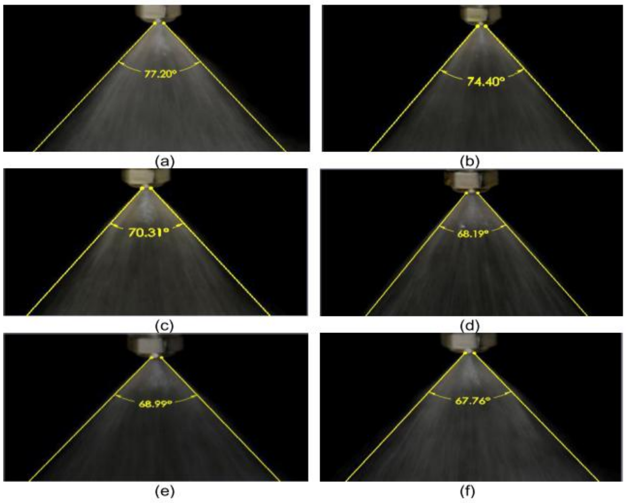


Figure 2.11: Photographs of (a) B0, (b) B5, (c) B10, (d) B15, (e) B20, and (f) B25 sprays. The fuel flow rate was maintained at 0.60 l/min for diesel and RBDPO blends [25]

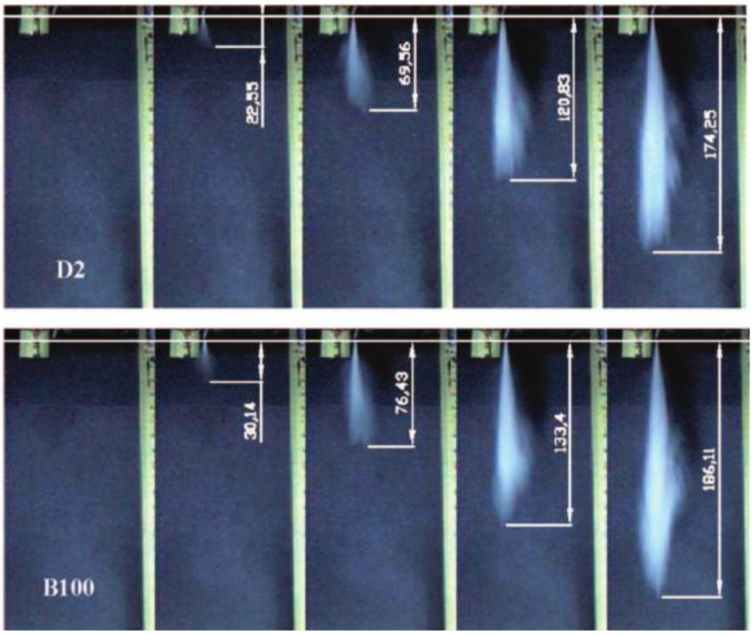


Figure 2.12: Fuel spray development of Diesel (D2) and B100 [26].

2.6 Combustion Process

The combustion process is a chemical chain reaction that requires fuel, oxygen, and an ignition heat source. Combustion of biodiesel alone (B100) provides over a 90% reduction in total unburned hydrocarbons, and a 75-90% reduction in aromatic hydrocarbons. Biodiesel further provides significant reductions in particulates and carbon monoxide than petroleum diesel fuel. Biodiesel produces either a slight increase or a slight decrease in nitrogen oxides, depending on engine design and testing procedures.

Effect of water-oil emission will be producing Micro-explosion in oil fuel. It can produce of diesel blend consisting in fuels with different vapor pressures in emulsify and combustion. In case water-in-oil emulsions, water has a higher vapor pressure compare with diesel. When the water phase reaches superheated conditions, water droplets surrounded by the diesel phase explode resulting in the dispersion of the big oil globule into very fine particles. Figures 2.13 and 2.14 are shows the difference between pure fuel and emulsified fuel combustion [27].

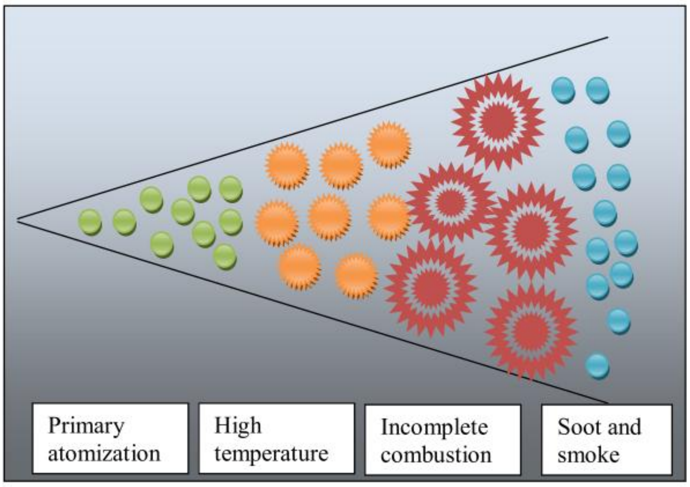


Figure 2.13: Regular fuel oil combustion [27]

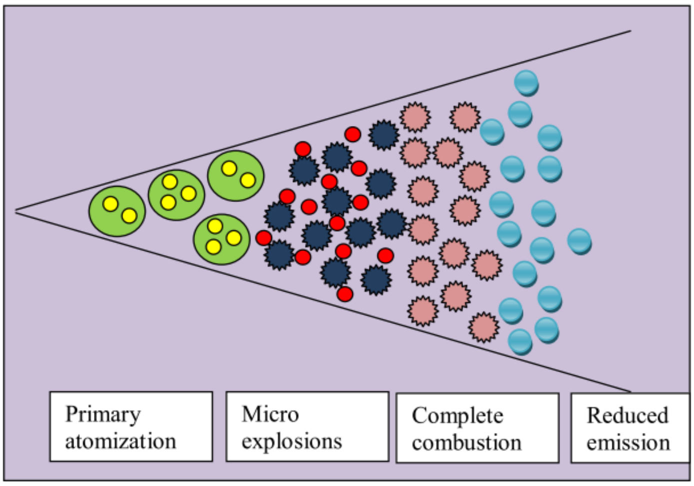


Figure 2.14: Emulsified fuel combustion [27]

2.6.1 Oil Burner System

An oil burner is a combustion machine to mixing heating oil with air, then blowing and igniting this mixture in a boilers fire port. There are several types of burner such as vaporizing pot type, low-pressure gun type, high-pressure gun type, and rotary type.The process of oil burner combustion can be seen in the following steps; the oil must be vaporized and mixed with air, the temperature of the mixture must be increased above the ignition temperature, air and fuel must be supply continuously, and flame or product combustion must be remove from the combustion chamber [28]. Figure 2.15 show the oil burner system.

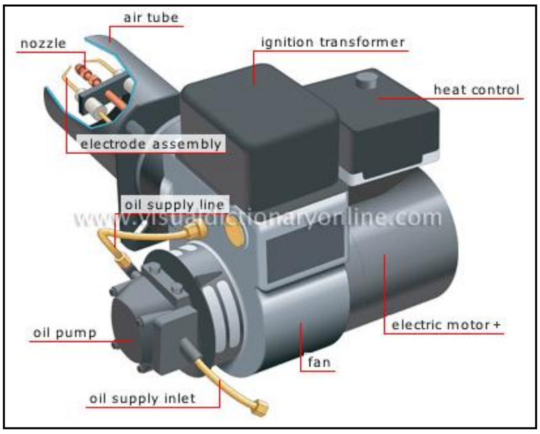
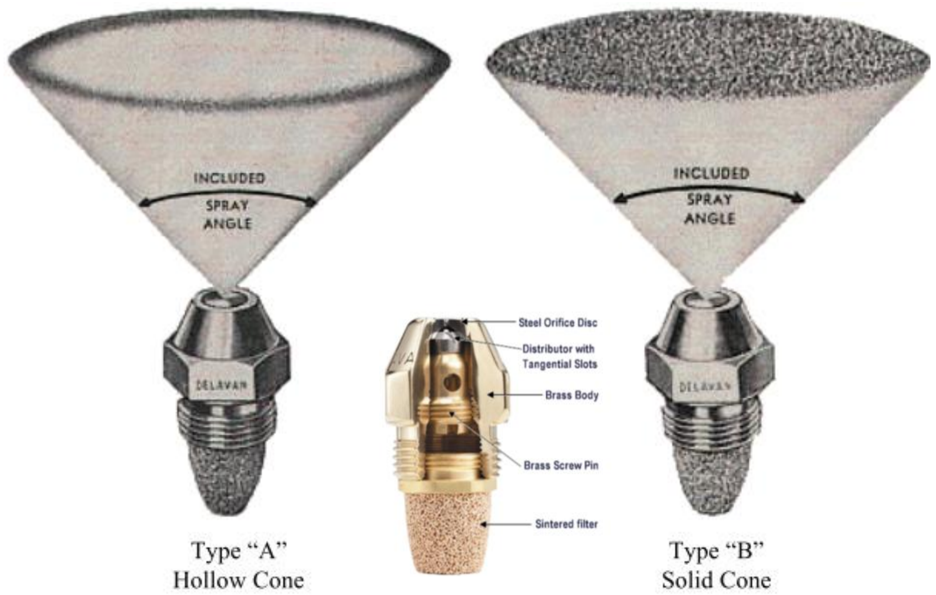


Figure 2.15: Burner system [50]

2.6.2 Fuel Nozzles for Oil Burner

The function of nozzle is to break up the fuel to very small droplet for the performance of burner. Oil separation into small droplet requires the application of energy is supply in the form of pressure. There have two different types of spray patterns, hollow cone, and solid cone. Figure 2.16 are types of spray pattern [28].



Sources: Delavan Spray Technologies

Figure 2.16: Types of spray pattern [28] [51]

2.6.3 Stoichiometric

This research uses stoichiometric to determine the air fuel ratio for spray injector. The stoichiometric quantity of oxidizer is amount needed to completely burn a quantity of fuel. The stoichiometric oxidizer - (or air-) fuel ratio (mass) is determined by writing simple atom balances, assuming that the fuel reacts to form an ideal set of products.

Stoichiometric combustion is complete combustion and no O_2 in product. Hydrocarbon fuel especially diesel given by C_xH_y, the stoichiometric relation can be expressed [29] as

$$C_x H_y + a(O_2 + 3.76N_2) \rightarrow xCO_2 + \left(\frac{y}{2}\right) H_2O + (3.76\,a)N_2 \qquad \textbf{(2.1)}$$

Where $a = x + {}^{y}/_{4}$

Assume the simplified composition for air is 21 percent O_2 and 79 percent N_2 (by volume), i.e., for each mole of O_2 in air, and 3.76 moles of N_2.

The stoichiometric air-fuel-ratio can be found as

$$(A/F)_{stoich} = \left(\frac{m_{air}}{m_{fuel}}\right)_{stoich} = \frac{4.76a}{1}\frac{MW_{air}}{MW_{fuel}} \qquad \textbf{(2.2)}$$

Where, $MW_{air} = molecular\ weight\ of\ the\ air$

$MW_{fuel} = molecular\ weight\ of\ the\ fuel$

The equivalent ratio, Φ is used to indicate quantitatively of a fuel-oxidizer mixture is rich, lean, or stoichiometric. The equivalent ratio is define as

$$\phi = \frac{(A/F)_{stoich}}{(A/F)_{exp}} \qquad \textbf{(2.3)}$$

If, $\phi > 1\ for\ fuel - rich\ mixture$

$\phi = 1\ for\ stoichiometric$

$\phi < 1\ for\ fuel - lean\ mixture$

For Biodiesel fuel assuming a general chemical formula $C_xH_{2y}O_{2z}$. The chemical equation for stoichiometric combustion can found as follows studied in 2.4 [30] :

$$C_x H_{2y} O_{2z} + a(O_2 + 3.76N_2) \rightarrow xCO_2 + yH_2O + (3.76\,a)N_2 \qquad \textbf{(2.4)}$$

Where $a = x + \frac{y}{2} - z$

The stoichiometric air-fuel ratio for biodiesel is:

$$(A/F)_{stoich,bio} = \frac{a[32 + 3.76\,(28)]}{12x + 2y + 32z} = 34.32\,\left(\frac{2x + y - 2z}{6x + y + 16z}\right) \qquad \textbf{(2.5)}$$

2.7 Biodiesel Flame

Santos has investigated the performance of biodiesel from waste vegetable oil in a flame tube furnace. The heat transfer rate analyzed in several sections along the furnace and the performance of the biodiesel compared to that of diesel oil. The heat flow from fuel burning in the direction to the walls of the combustion chamber evaluated under the same fuel injection pressure. Figure 2.17 (a) and 2.17 (b) shows that at the same injection pressure (686 kPa), the diesel oil flame has a more dispersed and shorter for- mat than biodiesel flame, providing higher temperatures in the areas closer to the injector nozzle. Flame temperature is the main factor of heat transfer rate. It is possible to observe in Fig. 2.18 that the flame temperature of the diesel oil is higher than the biodiesel, which explains the higher heat transfer rate of the diesel oil in the parts of the furnace that were near the body of flame [31].

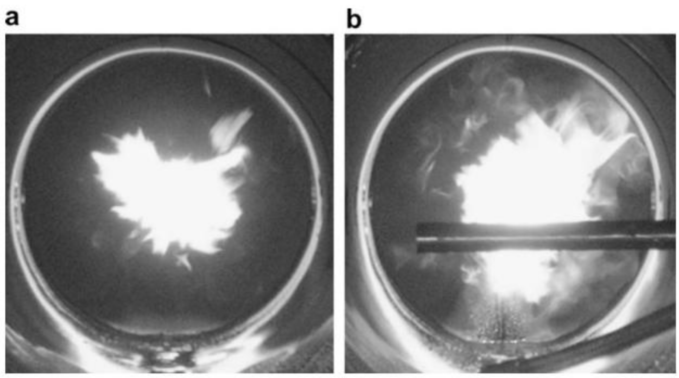


Figure 2.17: (a) Biodiesel flame. (b) Diesel oil flame [31]

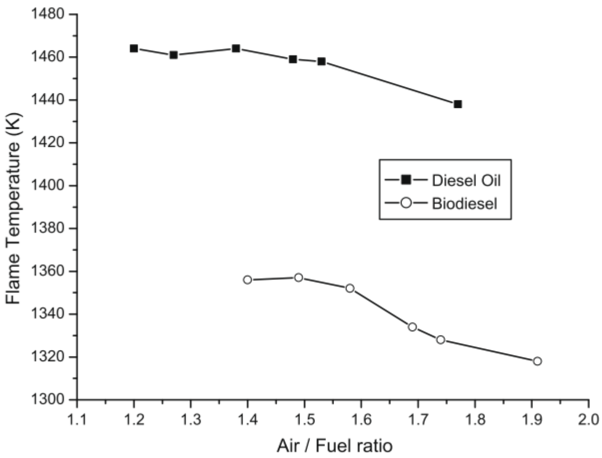


Figure 2.18: Flame temperature [31]

Botero presented the results of droplet combustion for Ethanol, Diesel, Castor Oil Biodiesel, and their mixtures. The results show that adding biodiesel to diesel significantly reduces the extent of soot formation while it slightly reduces the burning rate. In addition, higher soot production of methyl oleate than that of castor biodiesel observed suggesting strong oxidation propensity of the OH (oxygen hydrogen) function group in castor biodiesel. Figure 2.19 shows representative flame streaks of a burning droplet stream of diesel (figure 2.19a), castor oil biodiesel (figure 2.19 e), and their mixtures (figure 2.19 b-d). It can see that the diesel flame has a strong yellow brightness indicating the presence of soot, which is primarily due to the presence of aromatic components in the fuel blend. If biodiesel ratio increased, the yellow luminosity reduces visually, the reduction becomes drastic, and yielding a blue flame with a smaller dimension [32].

Figure 2.19: Flame streak images of mixtures of diesel and (castor oil) biodiesel:(a) diesel (b) D75B25, (c) D50B50, (d) D25B75, (e) biodiesel [32]

The analysis by Jha et al, flame temperature analysis of biodiesel blends and components of biodiesel performed to evaluate the effect of unsaturated level and the hydrocarbon chain length on the flame temperature. In figure 2.20, the saturated methyl esters resulted has greater flame temperatures if compare with unsaturated methyl esters. It can reveal that shorter chained fatty acid methyl esters lead to higher flame temperatures as compared to its longer chained counterparts and higher tendency for thermal NO_x formation. With the increase in the degree of unsaturated, the fuel consumption rate increased. Figure 2.20 is the thermal images of flames of different fuels [30] .

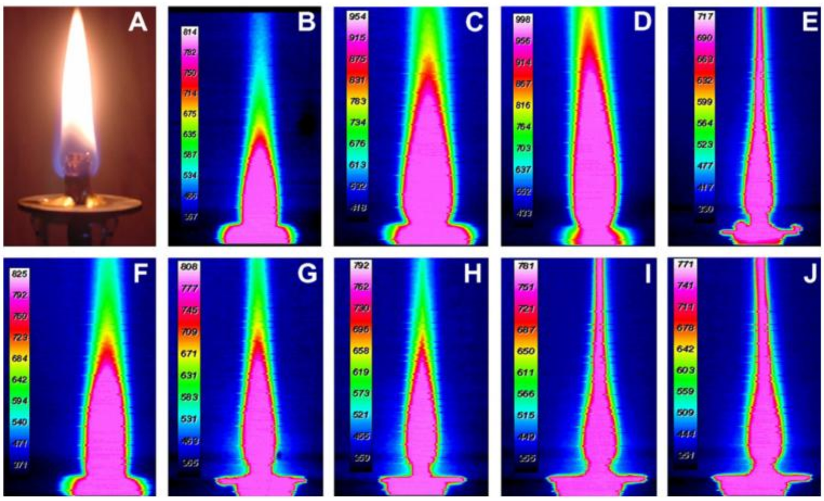


Figure 2.20 :Thermal image of flames (A. Flame arrangement; B. Soybean biodiesel; C. Ethanol; D. Methyl Acetate; E. Diesel; F. Methyl Palmitate; G. Methyl Stearate; H. Methyl Oleate; I. Methyl Linoleate; and J. Methyl Linolinate) [30]

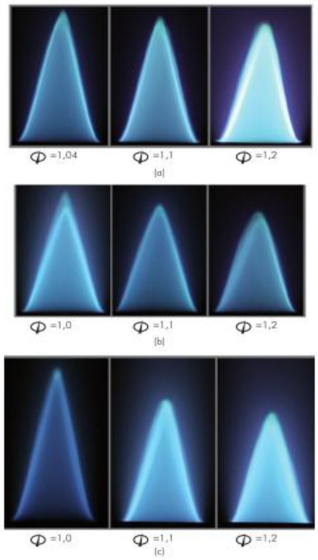


Figure 2.21: Photographs of laminar flames of various fuels. (a) Diesel, (b) Canola Methyl Ester (CME), (c) Soy Methyl Ester (SME) [33]

Kidoguchi was studied laminar flame speed of soy and canola biofuels. This paper investigates the flame speed values determined experimentally for laminar premixed flames of the vapors of two biofuels in air. Typical pictures of the flames of the different fuels presented in Figure 2.21 at different equivalence ratios (ϕ). The flames appear blue due to the predominance of the homogeneous gas-phase reactions at these conditions. The flames are laminar with a well-defined conical shape [33] .

2.7.1. Effect Water-Oil Emulsions

Kidoguchi was studied the improvement of emissions and burning limits in burner combustion using an injector on the concept of fuel-water internally rapid mixing. Figure 2.22 provides the example of flame images at high load condition of φ=1.2 using gas oil as fuel. Considering that bright flame is mainly luminescence of soot, water addition by both emulsified and water mixing has strong effect on soot reduction. In particular, internally rapid mixing injector shows little luminous flame in the case of introducing water [4].

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