# DEVELOPMENT OF THE PREMIXING INJECTOR IN BURNER SYSTEM

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**SPECIAL GRATITUDES TO:**

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Hj.Sies Bin Hj.Tukimon with Hjh.Jawiah Binti Hj.Sulaiman

*For their supports in whole of my life*

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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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| | |
|---|---|
| % | Percentage |
| $\Phi$ | 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]

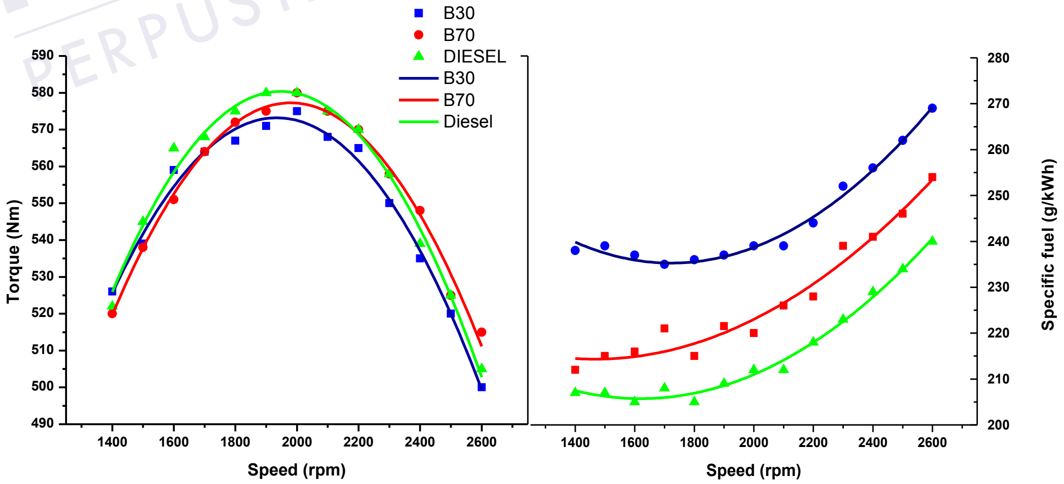
| ***Vehicle*** | **Mean emission (g/km)** | | | |
|---|---|---|---|---|
| | ***CO2*** | ***CO*** | ***THC*** | ***NOx*** |
| R15-04 | 151 | 6.1 | 1.27 | 2.7 |
| Three-way catalyst | 180 | 0.87 | 0.13 | 0.13 |
| Lean burn | 132 | 8.2 | 1.1 | 1.5 |
| Oxidising catalyst | 144 | 4.5 | 0.5 | 0.65 |
| IDI 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.




a) b)

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$^o$C and density range at 15$^o$C 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 viscosity 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<br>$C_{15\text{–}25}H_{28\text{–}48}O2$ | - | 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.

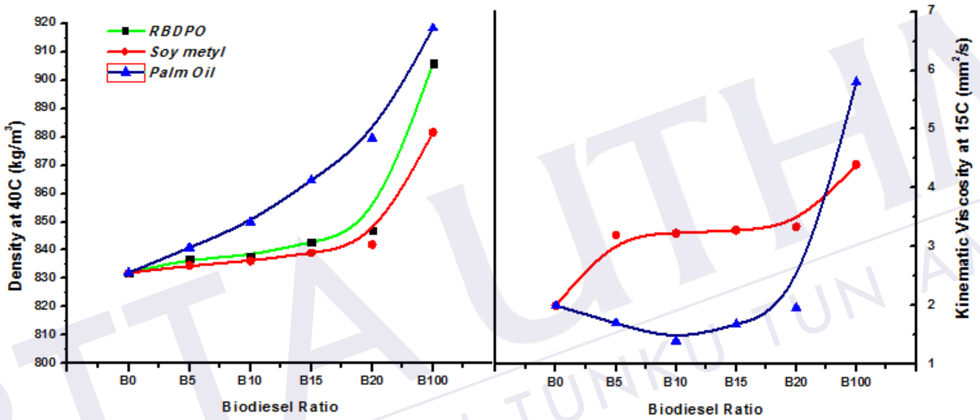



Figure 2.2: Density, Kinematic viscosity vs Biodiesel ratio for RBDPO [15], Soy metyl [16] and Palm oil [17]

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).

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