Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879

Performance of Sludge Palm Oil Combustion Using Waste Oil Burner

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Muhammad Ahmar Zuber[1], Ahmad Muhsin Ithnin[1,*], Wira Jazair Yahya[1], Ahmad Danish Abd Wahab[1], Mohamad Azrin Ahmad[1]

[1] Advance Vehicle System, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia Kuala Lumpur, Jalan Sultan Yahya Petra, Kampung Datuk Keramat, 54100 Kuala Lumpur, Wilayah Persekutuan Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 14 April 2018
Received in revised form 25 June 2018
Accepted 4 July 2018
Available online 2 September 2018

Keywords:
Sludge palm oil, waste oil burner, flame, emission, waste to energy

ABSTRACT

Sludge palm oil (SPO) is one of the wastes produced during the activity of palm oil milling process. The most common method to synthesise biodiesel from SPO is through a chemical process known as esterification and transesterification. The chemical process required additional cost and time. Hence this paper aims to evaluate the utilisation of SPO directly as fuel in burner system and compare with conventional diesel. The SPO studied contain free fatty acid (FFA) content about 30 %, density and viscosity at 0.982 g/cm^3 and 67.76 mm^2/s respectively which is higher than diesel. The maximum combustion temperature achieved was 869 °C lower than diesel, 891 °C. Lower CO, CO2 and NOx emission during combustion compare to diesel around 34 %, 6% and 90 % reduction respectively. The low combustion temperature, flame length and emission due to the high viscosity of SPO compare to diesel. Fuel spray and flow was affected by viscosity which lowers the combustibility and consumption of SPO. SPO show great properties and combustion performance as fuel for burner system and improvement can make it even better.

1. Introduction

Palm oil industry has grown over the year producing edible oil, by-product and waste along the process. The vast waste produces from the palm oil process is a threat to the environment as the waste can be harmful and need a massive area of land for disposal. This waste can be reduced through the chemical or physical process and converted into useful product. Converting waste into product and energy is aligned with the purpose of producing green and renewable energy especially from waste.

The waste and by-product produced from palm oil industry are categorized into two type namely solid and liquid waste. Each type of waste produces from the palm oil milling process can be identified at each stage as depicted in Fig. **1**. Oil Palm Frond (OPF), Empty Fruit Bunch (EFB), Fiber and Palm Kernel Shell (PKS) are the solid waste while wastewater is the liquid waste. The wastewater usually

* *Corresponding author.*
E-mail address: ahmadmuhsin@utm.my (Ahmad Muhsin Ithnin)

contains residual oil that leaches together during the discharging process. The wastewater is known as Palm Oil Mill Effluent (POME) which contain many impurities and oil. After a while in the cooling pond, the residual oil can be found floating on top of POME and this oil is known as Sludge Palm Oil (SPO).

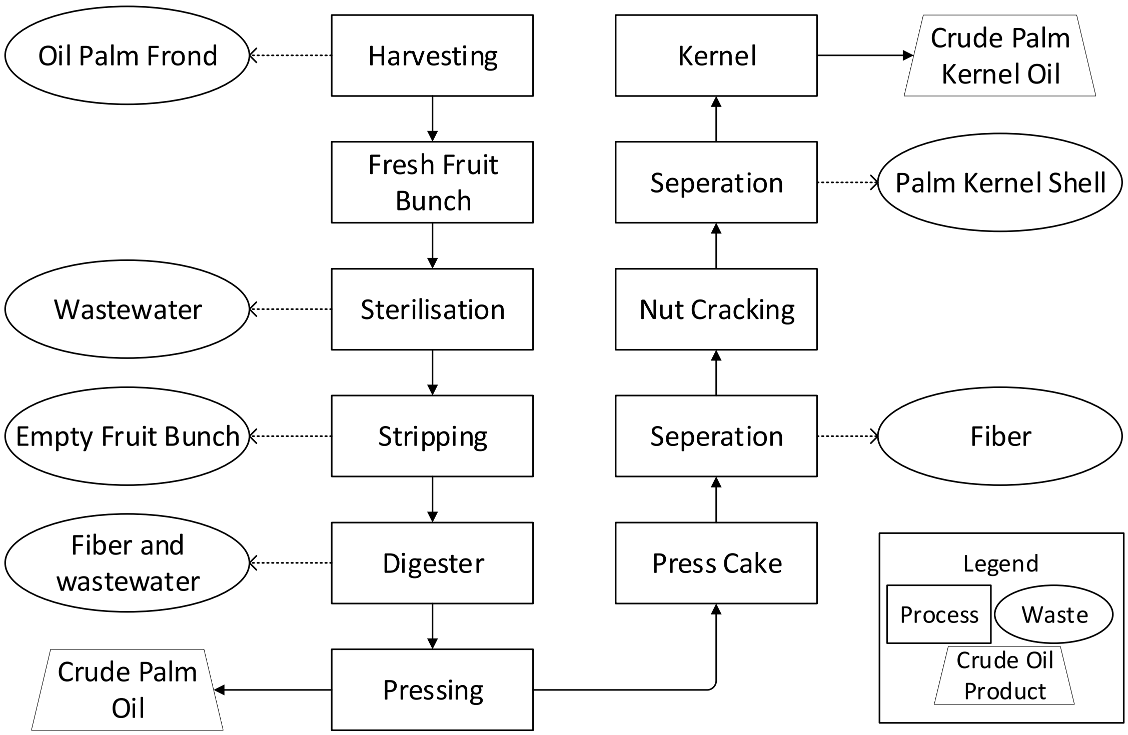

Fig. 1. Palm oil milling process and waste produce

SPO is one of the liquid waste product due to oil loss during the milling process and can be recovered as low-quality oil [1,2]. Currently, SPO being used as soap formulation and not as a food source due to low-quality oil. Refined SPO can be used as biodiesel raw material, fuel for burner and soap industry replacing palm fatty acid distilled [3]. Due to the abundant resource available and lower price of SPO, most researchers focusing on using SPO as a raw material for biodiesel production. A suitable process for SPO conversion into biodiesel can be determined based on the properties and characterization of SPO.

Physically SPO is a yellowish brown semi-solid at room temperature with strong unpleasant odor. The properties of SPO as shown in Table 1 and has different value even from same milling plant due to various factors such as different process parameter and environment condition. SPO has a high content of Free Fatty Acid (FFA) around 20-80 %, and it is undesirable for producing biodiesel. Low moisture and water content in SPO is suitable for biodiesel production which can reduce the hydrolysis of triglyceride into glycerol. The impurities contents are not affecting the biodiesel process directly but must be reduced and eliminated to ensure no contamination during biodiesel production process. SPO has high density, and kinematic viscosity value compares to diesel but lowers in calorific value.

Table 1
SPO properties

Parameters	Values
Free fatty acid (FFA) (%)	22.33 [1], 22.33±0.77 [4], 5-45 [5], 7.529[6], 21-25 [7], 16 [8], 50 [9], 51.64±0.59 [10], 23.2±0.7567 [11], 36.7 [12]
Moisture content (%)	1.243 [1], 1.20±0.06 [4], <2 [5], 0.02 [6], 1.20 [7], 1.00±0.04 [10], 0.873±0.5 [11]
Impurities (%)	0.05±0.007 [4], 0.007±0.071 [11]
Density (kg/l) @ 40 °C	0.8598 [1], 0.913 [9], 0.90 [12]
Calorific value (MJ/kg)	40.14 [1]
Kinematic viscosity (mm^2/s) @ 40 °C	46.63 [12]

Transesterification is the most commonly used chemical method for producing biodiesel [13]. There are three types of catalyst can be used in the transesterification process namely alkalis, acids and enzymes. The alkalis were mostly used as a catalyst as it is having lower cost, shorter reaction time and less corrosive compared to the others. However, this method only applicable for raw material with low FFA content around or lower than 2 % [14]. Since SPO has a high content of FFA, it is not recommended to use transesterification process due to soap produced. The researcher has experimented with converting SPO into biodiesel using esterification process to reduce the FFA and followed by esterification process.

Since SPO contains a large percentage of FFA, esterification process was used to reduce the FFA and followed by transesterification to complete the synthesis of biodiesel. Esterification process can reduce the FFA to 2 % using alcohol as reactant and acid as catalyst. Esterification process using sulfuric acid (H_2SO_4) and methanol showed FFA reduction from 50 % to 1.5 % [9]. Esterification process showed a reduction of FFA content to the acceptable FFA limit for transesterification (>2 %). Several types of research have focused on the conversion of SPO into biodiesel using two-step process namely esterification and transesterification. Abdullah *et al.,* [12] used methanol as reactant and alum ($Al_2(SO_4)_3 \cdot 14H_2O$) as a catalyst for esterification and Potassium hydroxide (KOH) as a catalyst for transesterification. Others using methanol, P-toluene sulfonic acid (PTSA) and KOH [1], methanol, trifluoromethanesulfonic acid (TFMSA) and KOH [8], methanol, sulfuric acid, and KOH [11], and ethanol, PTSA and sodium hydroxide (NaOH) [3], methanol, PTSA and KOH [4]. Instead of using base and acid as catalyst, Nasaruddin *et al.,* [10] used Candida cylindracea lipase enzyme as catalyst and ethanol as a reactant for both esterification and transesterification process.

The one-step process of converting SPO into biodiesel using only transesterification process was achieved with the addition of Deep Eutectic Solvent (DES) into the process [6]. DES was derived from the reaction of choline chloride and glycerol. The biodiesel yield was higher with the addition of DES compare to transesterification without DES. Besides, with the addition of DES, no soap produced, and the biodiesel produced does not emulsify with glycerol making the purification process easier. All the biodiesel derived from SPO through esterification and transesterification previously meet the American and European standard for biodiesel, ASTM 6751 and EN 14214 respectively. However, the presence of saturated fatty acids gives biodiesel fuel advantages regarding a higher cetane number and better oxidation stability but show disadvantages such as the fuel having higher cloud point and pour points.

Roughly the main component in vegetable oil that reacts with the alcohol is triglyceride producing methyl ester and glycerol. The esterification is the process to reduce the FFA in SPO using strong acid as a catalyst such as sulfuric acid and react with alcohol, either methanol or ethanol. The process can reduce FFA content to become less than 2 % and produced fatty acid methyl ester (FAME). Then transesterification process using alkaline such as KOH or NaOH as the catalyst in the presence of reactant (methanol or ethanol) to convert the remaining FFA into FAME, glycerol, and water. Then the biodiesel or FAME produced will be purified, to separate biodiesel from glycerol and water to produce clean biodiesel.

The process of producing biodiesel need a significant amount of resource and time. Hence this paper aims to use SPO directly as fuel in the burner to cut source and time for producing fuel. This method will eliminate the need for resource and time considerably and make SPO more attractive as a source of biofuel as it is cheap, and no process need.

2. Materials and Methodology

2.1 Sludge Palm Oil

Budi Oil Enterprise Sdn. Bhd. Supplied the SPO and collected from the pond in milling plant. The collected SPO is yellowish, semi-solid at room temperature and has a strong unpleasant odor. Several tests were conducted to determine the density, viscosity, calorific value and FFA percentage. Pycnometer and viscometer (Fungi Lab Expert Series Rotational Viscometer) were used to determine the density and viscosity. Calorific value was determined by using bomb calorimeter. Chemical titration method based on the standard method of American Oil Chemical Society (ACS) Ca 5a-40 was used to calculate the percentage of FFA. Diesel was used for comparing the properties and combustion performance of SPO and obtain from the Petronas gas station with grade EURO 2 standard.

The chemical titration method used to determine the FFA content in SPO based on titration of NaOH into the mixture of SPO sample with Iso-Propanol and three drops of Phenolphthalein indicator. The titration stops when the color change from orange to pink (retain at least for 10 seconds). The formula to calculate the FFA percentage as in equation 1 and 25.6 is the palmitic acid molar mass.

$$FFA,\% = \frac{25.6 \times M \times V}{m_s} \tag{1}$$

where; M = molarity of NaOH (M)
V = volume of titrated NaOH (ml)
m_s = mass of SPO sample (g)

2.2 Burner

The burner system used to test the SPO is waste oil burner system with the specification as in Table 2. The burner can burn a wide range of waste oil if the waste oil has a minimum calorific value of 33 MJ/kg. The performance of SPO combustion will be measure using thermocouple probe at five different points with data logger for the collection of data in real time. Emission analyzer (Testo 350) was used to measure the emission of the combustion at the sampling port according to the United States Environmental Protection Agency (USEPA) Method 17. The emission measured were NO_x, CO and CO_2.

Table 2
Specification of waste oil burner

Model KV-03			
Oil consumption	2-4 L/H	Tube diameter	89 mm
Output power	14-50 kW	Heating pipe	1 kW
Maximum output power	15,000-40,000 Kcal/H (60,000-160,000 Btu/H)	Motor power	180 W
Nozzle	Brass syphon 1×1.0 mm	Power supply	220 V/50 Hz

3. Results

3.1 SPO Properties

Diesel fuel was used as the control parameter for the properties, combustion performance, flame temperature and emission to compare with SPO. The properties of SPO conducted as in Table 3. The density of SPO is 0.928 g/cm^3 slightly higher compare to diesel and other research[1,9,12]. While having higher density leads to the higher viscosity of SPO at 67.76 mm^2/s higher than 46.63 mm^2/s reported by Abdullah *et al.,* [12] and 15 times higher compared to diesel. The calorific value of SPO was recorded at 38 MJ/kg slightly lower than 40.14 MJ/kg reported by Hayyan *et al.,* [1] and diesel (44 MJ/kg). Since SPO has calorific value above 33 MJ/kg, SPO meet the requirement for combustion by the waste oil burner. FFA percentage in SPO was recorded at 30 % in the range of 20-80 % reported in the literature is quite low compared to others.

Table 3
SPO properties

Fuel	Density at 40 °C (g/cm^3)	Kinematic Viscosity (mm^2/s) at 40 °C	Calorific value (MJ/kg)	FFA (%)
SPO	0.928	67.76	38.00	30
D2	0.820	4.3	45.28	-

3.2 Combustion Performance

Since SPO has high density and viscosity, it will be affecting the flow and spray during the combustion. During the experiment, heat up SPO up to 130 °C show proper combustion, flame stabilization, and better ignition compare to below 130 °C, hence the optimum pre-heating was determined at 130 °C. The air optimum air pressure is around 0.5-1 bar with damper setting set on 2. The damper is the air-fuel ratio, in this case, was set at manufacturing setting, and air pressure is to control the spray and penetration length. Increasing or decreasing the air pressure and damper setting exhibit problems in the ignition, flame stability and combustion performance. Increasing the air pressure beyond the 1 bar will increase the penetration length, and the high pressure disturbs the ignition and extinguish the flame. Lower the air pressure causes the SPO not to ignite maybe due to the improper mixing of SPO with air and high droplet size. The damper setting was tested by increasing and decreasing the flow of air into the burner and the flame extinguish after few second due to the incorrect air-fuel ratio between air and SPO.

The temperature probes were placed at five different spots at the center of the flame, where 1 is at the closest to the flame and 5 is the furthest. Figure 2 shows the temperature in the combustion chamber between diesel and SPO. Diesel has higher temperature compare to SPO, this may be due to the lower calorific value and high viscosity of SPO compare to diesel. Inflame lengthwise, SPO flame length was shorter compared to diesel due to higher viscosity. The high density of SPO causes poor spray quality and fuel vaporization which affecting the ignition and combustion reducing the flame temperature and length [15].

The combustion temperature of SPO are slightly lower compared to diesel and SPO has better emission than diesel. Figure 3 shows the CO, CO_2 and NO_X emission between SPO and diesel. SPO has lower NO_X emission compare to diesel due to lower temperature compared to diesel. SPO has lower CO and CO_2 emission compare to diesel, due to the high viscosity that reduces the flow of SPO and limits the combustion compares to diesel. SPO show promising properties and performance as fuel for burner due to lower emission and acceptable combustion condition.

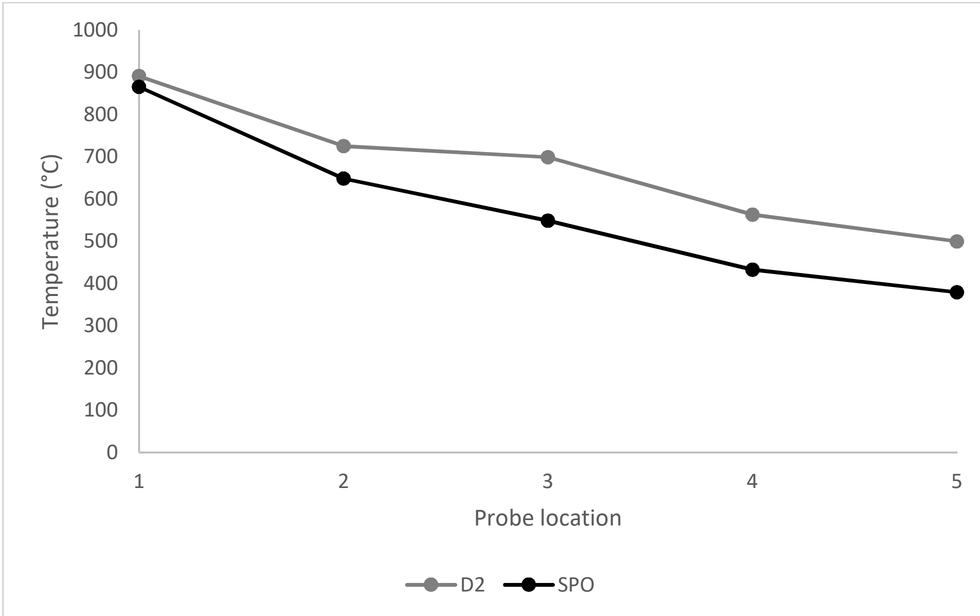

Fig. 2. Temperature at different location

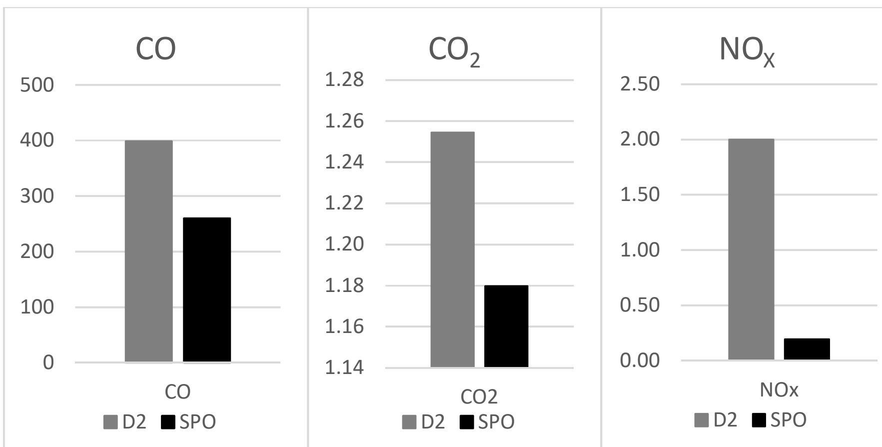

Fig. 3. CO, CO_2 and NO_X emission between SPO and diesel

4. Conclusions

SPO can be used as fuel directly in burner combustion system. Properties of SPO such as density is 0.928 g/cm^3, kinematic viscosity is 67.76 mm^2/s and calorific value is 38 MJ/kg. The density and viscosity can be reduced by heating the SPO to ensure better fuel flowability, spray, ignition and flame stability. The temperature of SPO combustion is lower than diesel, but the emission showed significant improvement compared to diesel especially NO_x emission. Further study on SPO combustion properties such as air-fuel ratio, air pressure, and fuel spray can affect the flame, performance and emission.

Acknowledgement
The authors would like to thank the personnel of Budi Oil Sdn. Bhd. for supplying the SPO. Highest appreciation was also given to the Malaysia-Japan International Institute of Technology, Universiti

Teknologi Malaysia (UTM) for providing the facilities to undertake this research. This research was funded by the Ministry of Higher Education

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