Calorific Value Measurements and Optimization of Waste Cooking Oil Bio-Diesel, Crude Plastic Oil and Their Blends for the Synthesis of Low Cost High Energy Fuels

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Abstract—

Plastic is an artificial polymer which is having a wide application in manufacturing industries and consumer products as it is light weight, economical, strong, convenient and durable. Plastic is a non-biodegradable material because of which it is very harmful to the environment. Plastics have use in various spheres of economy – infrastructure, construction, agriculture, consumer goods, telecommunications, packaging, etc. Because of growing plastic industries the amount of plastic waste has also increased which is a major problem in front of environmental researchers. Currently worldwide accepted technology used for plastic disposal is incineration which releases extremely toxic compounds leading to environmental issues if not handled carefully. Hence an alternate solution to the exponentially growing plastic waste is being analyzed across the globe. Plastic waste can well be handled with pyrolysis, a thermochemical decomposition method. Pyrolysis, a Plastic to Fuel (PTF) technology, is done at a temperature of 420- 440°C. Oil derived from PTF technology has a complex chemical composition but can be used as a fuel conveniently because of its higher energy density. The bio-diesel obtained from the waste cooking oil is blended in different proportions with crude plastic oil obtained from the pyrolysis process of the plastic waste using ultrasonic vibrator. The calorific values of diesel, Crude plastic oil, Standard bio-diesel and bio-diesel obtained from waste cooking oil are 45,457kJ/kg, 25,353 – 43,496 kJ/kg, 39,011kJ/kg and 37,120.16kJ/kg respectively. Bio-diesel from waste cooking oil synthesized by conventional route blended with crude plastic oil obtained after pyrolysis in different proportion was analyzed for its calorific value and was tested with constant speed 4- stroke diesel engine to study the fuel blend performance.

Keywords: Plastic to Fuel, pyrolysis, biodiesel, crude plastic oil, calorific value

I. INTRODUCTION

Plastics are high molecular weight synthetic or semi-synthetic organic polymers most commonly derived from petrochemicals containing Oxygen, Sulfur and Nitrogen with an average of 20% by weight additives (fillers, stabilizers, plasticizer, colorants) for improving their performance and properties [1]. In spite of the wide range of applications plastic materials have in almost all sectors, they are a major threat to environmental scientists owing to their non-degradable nature. The increase in plastic material usage has also contributed to a proportional increase in the waste generated. Plastic wastes generated at both domestic and industrial levels are potent sources of toxic chemicals like polychlorinated dibenzo para dioxins and furans. With extensive research initiatives several technologies are being proposed to manage the serious problems hoisted by the disposed plastic wastes. Amongst which incineration has gained significant selection over the decades especially in communities facing dwindling landfill capacity and increasing tipping cost. However, incineration of plastics emits gases of the toxic pollutants that contribute to global warming and climate change [2].

Stringency in environmental regulations and waste management scenario has brought front recycling as an alternate to technologies that add on the existing pollutant levels to the atmosphere. Segregation at source and recycling of plastic waste without dumping has proved instrumental in reduction of emission from the non-degradable plastics. Pyrolysis a thermo chemical decomposition method is one such successful recycling technology where the plastic waste is processed in an oxygen free environment at a temperature of about 420 - 440°C in the presence or absence of a catalyst [3] to get crude plastic oil (CPO) of high calorific value. The product of pyrolysis can further be distilled at varying boiling point ranges to get a variety of fuel fractions comparable to petroleum crude. Crude plastic oil thus obtained without further distillation can also be used directly replacing the petroleum based fuel. Though crude plastic oil has energy density it will disseminate oxides of Sulfur and Nitrogen along with carbon monoxide comparable to petroleum based fuels preventing its usage in the engines. To exploit the benefits of high energy density of crude plastic oil and to simultaneously reduce the emission related problems, attempts have been taken to study the performance of the fuel blending formulated by pyrolysed plastic oil with the transesterified waste cooking oil (that has low energy density).

This study thus focused on redirecting the waste cooking oil (another major liquid waste) which when drained into the soil and water causes enormous health impacts (by decreasing the oxygen levels in the water bodies) for biodiesel production via transesterification route to formulate a fuel blend. The cooking oil is a plant based; the biodiesel made from it will thus not emit sulfur oxide on combustion, which is a positive point from the environmental point of view. Bio-diesel is very valuable renewable resource as it can be used in the diesel engine without any modification. Using bio-diesel in place of diesel reduce the emission of carbon monoxide and oxides of sulfur up to 75 – 85%.

II. MATERIALS AND METHODS

A. Production of bio-diesel from waste cooking oil

The waste cooking oil collected from Sathyabama University mess operating for more than 10,000 people per day was collected as raw material for transesterification reaction to make bio-diesel. The conditions for bio-diesel preparation were optimized with conventional methanol reactant and sodium hydroxide catalyst. The transesterification reactions were checked for repeatability of result and the reaction conditions were fixed. About 88 – 90% bio-diesel yield was observed after washing of the transesterification product obtained with reactions carried out at oil and ethanol molar ratio of 1:6, 0.5 gram of sodium hydroxide at a temperature of 60ºC with the speed of 350 rpm. Bio-diesel obtained was characterized for its viscosity, density, fire point, calorific value, pH, Sulfur content, copper corrosion and water content. Hence, the most important variables affecting the ester yield during the transesterification are the molar ratio of alcohol to waste cooking oil and reaction temperature.

B. Production of crude oil from plastic waste

The non-biodegradable plastic waste was segregated from municipal solid waste to obtain crude plastic oil upon pyrolysis carried out at 420 - 440ºC at M.K. Aromatic, Alathur, Tamil Nadu. Though the process is energy intense it is the only feasible option to recycle waste plastic to a fuel that has characteristics close to crude petroleum that can further be distilled to various carbon fractions. The properties of crude plastic oil were comparable to the previously reported values [8].

C. Ultrasonication of oil

The bio-diesel transestrified from the waste cooking oil and crude oil obtained by pyrolysis of plastic waste were blended in different proportion of 5%, 10%, 20% and 50% using ultrasonicator. Each blend of the oil was kept for 10 minutes in the ultrasonicator for homogeneous blending of the oil.

D. Calorific value measurement

The calorific value of any fuel is the amount of heat released by a unit weight or unit volume of a substance during complete combustion. The term calorific value of the fuels is very important as selection of fuel for the diesel engines is done on the basis of calorific value of the fuel. If the fuel has higher calorific value it will have tendency to produce more power in the engine. The fuels with less calorific value tend to burn inefficiently thus causing lot of exhaust and air-pollution. The calorific values for different blends of oil were determined using bomb calorimeter and the values are reported in Table III.

E. Engine performance test

The ultrasonificated blends of crude plastic oil and waste cooking oil bio-diesel were tested for their performance in a constant speed diesel engine and parameters like Specific Fuel consumption (SFC), Mechanical Efficiency (ME), Brake thermal Efficiency (BTE), Indicated Thermal Efficiency (ITE) were determined for varying load condition and are reported in Table III to Table VI.

III. RESULT AND DISCUSSION

On analyzing the oil samples as shown in Table I, it is observed that the properties of waste cooking oil bio-diesel are comparable with that of diesel. The acidity of the waste cooking oil bio-diesel is much higher than that of diesel but comparable to that of standard bio-diesel which implies that it can be used safely in a diesel engine. The flash point of waste cooking oil bio-diesel is higher in comparison to diesel which makes it safer for storage and transportation purpose. The pour point and cloud point of bio-diesel is lesser than that of diesel hence makes it suitable for engine operation at lesser temperature. The viscosity values of waste cooking oil methyl esters decrease sharply after transesterification.

The quality was also determined using gas chromatography technique the result of which is represented in Table II. Comparable to diesel fuel, all waste cooking oil are methyl esters are slightly viscous. The flash point value of waste cooking oil methyl esters is significantly lower than those of waste cooking oil. There is high regression between the density and viscosity values of waste cooking oil methyl esters. The relationships between viscosity and flash point for waste cooking oil methyl ester are considerably regular.

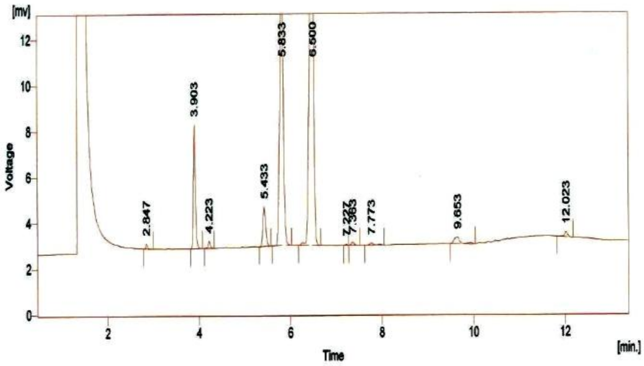

Fig. 1 Gas Chromatography analysis for Waste cooking oil

Table 1 ANALYSIS RESULT OF THE WASTE COOKING OIL, DIESEL AND BIO-DIESEL

Sl. No.	Tests	Waste cooking oil	Bio-diesel	Diesel
1	Acidity Inorganic	Nil	Nil	Nil
2	Acidity as mg of KOH/gm	0.49	0.37	0.03
3	Water content	0.15%	0.17%	0.02%
4	Density @ 15°C in gm/cc	0.9243	0.8874	0.8324
5	Specific Gravity @ 15°C/15°C	0.9251	0.8874	0.8331
6	Kinematic Viscosity @ 40°C	30.8	4.63	2.9
7	Ash content	Less than 0.01%	Less than 0.01%	Less than 0.01%
8	Conradson Carbon Residue	0.89%	0.09%	Less than 0.01%
9	Insoluble in Hexane	Less than 0.01%	Less than 0.01%	Less than 0.01%
10	Flash point	256°C	172°C	58°C
11	Fire point	268°C	184°C	66°C
12	Copper strip corrosion @ 100°C for 3 hours	Not worse than No. 1	Not worse than No. 1	Not worse than No. 1
13	Pour point	Below minus 12°C	Minus 10°C	Below minus 12°C
14	Cloud point	Minus 10°C	Minus 5°C	Minus 6°C
15	Calorific value in kJ/kg	37170	39011	42345
16	Sulfur content	30 ppm	20 ppm	Less than 10 ppm
17	Calculated Cetane Index	33	47	62

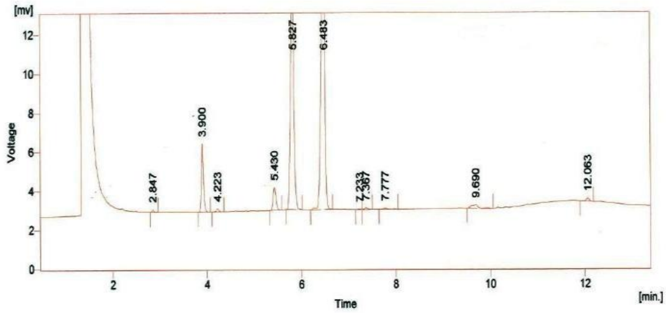

Fig. 2 Gas Chromatography analysis for Bio-diesel

Table 2 Composition Of Fatty Acids From Gas Chromatography Analysis

	Composition (%)		
	Stearic	Oleic	Linoleic
Waste cooking oil	3.205	36.038	50.900
Bio-diesel	3.493	32.324	53.246

Fig 1, Fig 2 and Table II shows the gas chromatography analysis of sunflower oil and waste cooking oil. Based on the gas chromatography analysis, there is not much change in the composition of bio-diesel and waste cooking oil. However, a significant change was observed in oleic and Linoleic acid content after transesterification.

The change in the calorific value of the fuel was observed with the changing proportion of waste cooking oil bio-diesel and crude plastic oil. With the increase of the proportion of the crude plastic oil the increase in calorific value was observed which is shown in the Table III.

Table 3 Calorific value of bio-diesel and crude plastic oil

Sl. No	Percentage of bio-diesel	Percentage of crude plastic oil	Calorific value (kJ/kg)
1	5	95	43686
2	10	90	43440
3	20	80	42948
4	50	50	41471

Specific fuel consumption (SFC), describes the fuel efficiency. SFC is dependent on engine design, but differences in the SFC between different engines using the same technology tend to be quite small. The values obtained clearly signify that a different blend of biodiesel and crude plastic oil does not significantly alter the specific fuel consumption of an engine. It may hence be inferred that with no modification done to the engine, the biodiesel obtained from all the oil sources can be used as their specific fuel consumption values are close to diesel. From Table IV, it can be concluded that SFC is highest for the blend of 50% bio-diesel and 50 % crude plastic oil.

Table 4 Specific fuel consumption for different blends

Sl. No.	Load	5% Bio-diesel	10% Bio-diesel	20% Bio-diesel	50% Bio-diesel
1	1	1.04	0.99	0.99	1.01
2	9	0.17	0.16	0.15	0.17
3	18	0.11	0.11	0.12	0.12
4	24	0.10	0.11	0.11	0.15

Mechanical efficiency is the rating that shows how much of the power developed by the expansion of the gases in the cylinder is actually delivered as useful power. The factor which has the greatest effect on mechanical efficiency is friction within the engine. The friction between moving parts in an engine remains practically constant throughout the engine's speed range. Therefore, the mechanical efficiency of an engine will be the highest when the engine is running at the speed at which maximum BHP is developed. From the engine performance studies the mechanical efficiency for different blend of bio-diesel and crude plastic oil is found to be constant for a particular load and if found to increase with increasing load percentage (88.87% for maximum load condition). The observations of different blends are shows that variation in fuels blends does not significantly alter the mechanical efficiency of the engine.

Table 5 Break Efficiency For Different Blends

Sl. No.	Load	5% Bio-diesel	10% Bio-diesel	20% Bio-diesel	50% Bio-diesel
1	1	7.90	8.29	8.41	8.60
2	9	48.18	50.76	56.02	52.16
3	18	71.16	74.65	71.16	69.55
4	24	79.07	79.63	80.75	59.02

It is observed that the brake thermal efficiency increased with increase in load percent. This was due to reduction in heat loss and increase in power with increase in percent load. Table V shows the break thermal efficiency of the engine at different load with different blends of the fuel. It is observed that the break thermal efficiency of the engine is highest for the blend of 20% bio-diesel and 80% crude plastic oil for maximum load.

Thermal efficiency is the measure of the efficiency and completeness of combustion of the fuel, or, more specifically, the ratio of the output or work done by the working substance in the cylinder in a given time to the input or heat energy of the fuel supplied during the same time. Table VI shows that the indicated thermal efficiency of the engine is high for the blend of 20% bio-diesel and 80% crude plastic oil for maximum load.

Table 6 Indicated Thermal Efficiency For Different Blends

Sl. No.	Load	5% Bio-diesel	10% Bio-diesel	20% Bio-diesel	50% Bio-diesel
1	1	52.79	55.38	56.16	57.46
2	9	78.58	82.78	91.36	85.07
3	18	93.61	98.19	93.61	91.49
4	24	97.78	98.46	99.86	72.97

IV. CONCLUSION

The different samples of fuel obtained from the blending of crude plastic oil and bio-diesel from waste cooking oil at different proportions were tested for their performance in the diesel engine. After the comparison of specific fuel consumption, mechanical efficiency, break thermal efficiency and indicated thermal efficiency it is observed that the blend of 20% of bio-diesel from waste cooking oil and 80% of crude plastic oil gives the maximum efficiency compared to other sample fuel. The studies further recommended the choice of blend based on the emission resulting on fuel combustion.

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