

Utilization of kitchen food waste for biodiesel production

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Abstract. Food waste has led to handling and disposal problems affecting human health and polluting environment. Land disposal is one of the ways of disposing food waste but it produces harmful leachate when rain water falls on it. Reuse of food waste for biodiesel production is one of the key steps to reduce food waste problem and also meet the energy demand. Food waste in the present study was collected from the kitchen of a hostel of an educational institute located in India. This waste was dried by various drying methods to dewater. Lesser is the moisture content, more will be the lipid extraction and hence increased biodiesel production. Lipids were extracted and fatty acids (caproic acid (6:1), lauric acid (12:0), myristic acid (14:0), palmitic acid (16:0), stearic acid (17:0) and oleic acid (18:0) were identified in gas chromatography-mass spectrometry (GC-MS). These fatty acids identified in lipid indicate the potential of food waste for biodiesel production. Transesterification of lipid was performed to produce biodiesel and concentration of fatty acid methyl ester was determined using gas chromatograph flame ionisation detector (GC-FID). Further, biodiesel properties were compared with various standards.

1. Introduction

Worldwide petroleum consumption has increased leading to fossil fuel crisis and energy problem in near future due to rapid urbanization and industrialization. Till now, energy crisis has been met by fossil fuel which is a limited resource. Increased demand of fossil fuel has led to increase in fuel price and serious environmental impacts such as global warming, acidification, deforestation, ozone depletion, eutrophication and photochemical smog. Global fossil fuel energy consumption has doubled in the last few decades. As fossil fuel is a limited source of energy, there is an urgent need to search for an alternative resource that would be economically efficient, socially equitable and environmental friendly [1].

Rapid urbanization and industrialization also generate huge amount of solid waste resulting in handling and disposal problem. Municipal solid waste (MSW) represents a small fraction of total solid waste but attracts more attention because people and environment are adversely affected [2]. In India during 2015, average MSW waste generation was 700 tons per day [3]. Municipal solid waste contains a considerable amount of food waste. Several billion gallons of food wastes are produced from kitchens of residential societies, restaurants, hostels, canteens and food and meat processing industries. Everyday gallons of food wastes generated from different sites are collected and thrown in an open area or dumped in landfill without proper disposal technique [4].

Food wastes adversely affect local water body, land and biodiversity. It causes serious environmental and social problems across the world. The national waste report of Australia in 2008 estimated that food waste make up approximately one-third of MSW and one-fifth of commercial and industrial waste streams. Food waste generated in Australia amount to 7.5 million tons in year 2008 [5]. According to the report released by Hong Kong environment bureau, among 9,000 tons of MSW that is thrown away everyday at landfills, 40% consists of putrescible. Approximately, 90% putrescible was food waste. Other developed countries like Taipei and Seoul produce 1,82,000 tons per year and 7,67,000 tons per year of food waste, respectively. In characterization of municipal solid waste, India comprises maximum of food waste (31.9%) as compared to other wastes such as plastic, textile, paper, glass, cardboard, ash, leather and metal waste [6]. The most common way of food waste disposal is landfill. Landfills by food waste are known to generate carbon dioxide, methane and other toxic gaseous substances [4]. Landfill spreads offensive odour and cause hazardous effects on animals, people and environment. It also generates harmful leachate when rain water falls. This leachate can contaminate soil and ground water [5].

Biodiesel can be produced by pyrolysis, thermal cracking, micro emulsions and transesterification. Transesterification is one of the most common methods for biodiesel production in which oil or fat is reacted with alcohol (methanol or ethanol) in presence of a catalyst to form alkyl ester and glycerol. Primary cost of biodiesel production is affected by cost of feedstock. In this paper an attempt has been made to reuse food waste for biodiesel production by identifying and characterizing the free fatty acids (FFA) present in lipid extracted from kitchen food waste. This innovative study will help to minimize disposal problem and overcome energy crisis. It will also reduce environmental pollution caused by fossil fuel.

2. Materials and Methods

2.1. Sampling site

Food waste is collected from girls hostel of National Institute of Technology, Rourkela, India. This sampling location site is chosen because of huge amount of food waste generation. Food waste after collection is brought to the laboratory for further analysis.

2.2. Food waste analysis

About 2 kg of food waste is collected and brought to the laboratory. Moisture content is removed and optimum temperature was determined. Different drying methods were performed i.e. oven drying (55 °C, 75 °C, 105 °C), freeze drying (-4 °C) and sun drying (25-30 °C) [7] to determine the optimum temperature. The main challenge to be faced for biodiesel production was efficient lipid extraction as it contains water along food particles. After drying the sample has been grinded to powdered form. The powdered sample has been used for lipid extraction.

2.3. Lipid extraction and analysis

Lipid extraction was performed in soxhlet apparatus using methanol as solvent. The extraction of lipid depends on octanol water partition coefficient (K_{OW}). It is defined as the chemical concentration in the octanol phase to its concentration in the aqueous phase of two phase octanol/water system. The organic compound that resides in water phase are hydrophilic and chemical that resides in octanol phase are hydrophobic. After extraction, sample was filtered to separate the liquid and solid particles using whatman 42 filter paper, 125mm (dia). Later, the solvent (methanol) was recovered using rotary evaporator by evaporating at 70 °C. The recovered methanol was stored and reused for next extraction. The extracted lipid was stored in a dessicator overnight and weighed to calculate the exact extraction of lipid yield. Lipid was further analysed in gas chromatograph mass spectrophotometer (GC-MS) to determine the presence of free fatty acids which will indicate the potential of food waste for biodiesel production. The residue left after lipid extraction can further be analysed and reuse in pharmaceutical to prepare medicine, drugs and plant nutrients.

2.4. Transesterification and FAME analysis

Transesterification of food waste was performed using acid catalyst. A known amount of lipid was taken in a round bottom flask. Solution of methanol (solvent) and sulphuric acid (catalyst) was added to lipid and kept closed. The solution kept in a heating plate maintaining a temperature of 65 °C and mixed properly for 2-2.5 h. Usually excess methanol is used for complete conversion of fat or oil to fatty acid methyl ester (FAME). After FAME production the sample was cooled and transferred to separatory funnel. The product was left undisturbed for 24 h for separation of biodiesel and glycerol. Methanol present in ester layer was recovered using rotary evaporator at 70 °C.

One of the important steps in biodiesel production is washing of biodiesel to remove catalyst and other impurities. Removal of glycerol and glycerides is a key step because quality of biodiesel is dependent on glycerol content. High concentration of glycerol in biodiesel can cause problem during storage and increase in aldehyde emissions [8]. Washing of biodiesel include wet washing and dry washing. Wet washing means adding distilled water to biodiesel and dry washing means adding adsorbent like magnesol, anhydrous sodium sulphate, resin etc. In this study, wet washing of biodiesel has been performed after transesterification also called water wash method. Wet wash method has been selected because this is the oldest and most common method of washing. Moreover, the waste water recovered after washing can be reused for irrigation purpose after minimal treatment. Other treatment methods generate hazardous wastes that are difficult to disposed off. The purpose of water wash method is to remove unreacted alcohol, catalyst or glycerine present in biodiesel. It will also remove if any soap is present. After glycerine settles in the bottom of the separatory funnel, biodiesel is separated and pH is measured. The pH of the unwashed biodiesel was found close to 9. Slowly warm distilled water was added in equal proportion to biodiesel. The solution was allowed to settle by transferring to separatory funnel to separate water and biodiesel. It will take around 24hrs to settle down. Once the mixture has settled down, biodiesel will float on top of water. After washing, the pH of biodiesel was found to be 7. Washing can be performed multiple times to purify the biodiesel.

The purified biodiesel was analysed in gas chromatograph flame ionization detector (GC-FID) to determine the concentration of fatty acid methyl ester. Further, biodiesel properties were compared with various standards.

3. Results and Discussion

3.1. Moisture content and lipid analysis

Removal of moisture content is a vital step in lipid yield and biodiesel production because water present in sample may inhibit the solvent to penetrate inside the sample by surrounding the food particles. The moisture of the sample is dependent on drying method and temperature.

Different drying methods have been selected to determine the optimized temperature for less moisture content and more lipid yield. In general, higher the drying temperature, lesser is the moisture content, more amount of lipid yield and hence biodiesel production [7]. Sun drying method gave moisture content of 4.6% in 240h at drying temperature of 25-30 °C with lipid yield of 16.5%. This method is dependent on weather condition and time consuming. Freeze drying method gave moisture content of 7.5% in 48 h. In oven drying 105 °C gave less moisture content of 0.1% compared to 55 °C (2.4%) and 75 °C (1.5%). When different drying methods are compared, it is observed that oven drying method at 105 °C gave less moisture content (0.1%) with lipid yield of 37.3%. Hence, the optimized temperature for drying is 105 °C. very high temperature in oven drying will burn the sample and break the fatty acid chain because for biodiesel production long chain fatty acids are required.

To study the effect of lipid yield due to variation in food waste composition, the food waste sample was collected weekly (7 days). The lipid yield due to food waste composition has been discussed in Table 1.

Food waste mainly consist of rice, pulses, vegetables along with paneer in vegetarian food whereas non vegetarian food consist of meat, fish, chicken along with oil and fats. Fat content in 100 g of chicken is 14 g, 100 g of mutton contains 21g fats, 100 g of fish contains 12 g fats, and 100 g of paneer contains 20.8 g fats. It is observed that lipid yield is more in case of vegetarian and non-vegetarian compared to vegetarian only because of more amount of oil and fats. According to

literature, more the amount of oil/fats, more is the lipid yield extraction and hence, more amount of biodiesel yield.

Table 1. Effect of lipid yield due to food waste composition

S.N.	Days	Food waste composition	Lipid yield (%)
1.	Monday	Vegetarian	32.5
2.	Tuesday	Vegetarian and non-vegetarian	37.3
3.	Wednesday	Vegetarian and non-vegetarian	36.8
4.	Thursday	Vegetarian	30.2
5.	Friday	Vegetarian and non-vegetarian	36.4
6.	Saturday	Vegetarian and non-vegetarian	37.3
7.	Sunday	Vegetarian and non-vegetarian	37.2

3.2. Lipid analysis

Lipid extraction was performed in soxhlet apparatus using methanol as solvent. Lipids are of two types i.e., neutral lipid and polar lipid. Neutral lipids are insoluble in water but soluble in organic solvents such as methanol, chloroform, hexane, etc. Solvent extraction of lipid is performed to separate the components dissolved in mixture. The separation of specific compound is possible because solvent dissolve the targeted compounds. Targeted compounds such as triglyceride can be separated by mixing the solution to a temperature near to boiling of solvent which will evaporate solvent but targeted compounds will not [9]. The role of methanol is to extract triglyceride, phospholipids, cholesterol, etc [10]. The extracted lipid was analysed in gas chromatograph mass spectrophotometer (GC-MS) to determine the presence of free fatty acids. Table 2 discuss about the free fatty acids identified in lipid analysis. These identified free fatty acids indicate the potential of food waste for biodiesel production.

Table 2. Free fatty acids identified in lipid analysis

S.N.	Retention time	Organic compounds
1.	4.070	Caproic acid (C6:0)
2.	9.191	Lauric acid (C12:0)
3.	11.181	Mystric acid (C14:0)
4.	12.595	Palmitic acid (C16:0)
5.	13.741	Stearic acid (C17:0)
6.	13.853	Oleic acid (C18:0)

3.3. Transesterification and FAME analysis

Transesterification of lipid was performed using methanol as solvent and sulphuric acid as catalyst. The reaction was performed in the ratio 11:1 (methanol: lipid molar ratio) at 60°C for 2-3 h and catalyst of 2.5 wt % was added. It is always advisable to perform the reaction close to the boiling point of methanol because of proper miscibility of methanol with lipid. Reaction rate increases with increasing temperature resulting in increase in solubility of methanol in oil-rich phase. Higher reaction temperature results in shorter reaction time in mass transfer controlled reaction because transesterification reaction is more preferred at higher temperature [11]. Usually the transesterification should be performed below the boiling point in order to prevent evaporation of methanol. It is recommended to perform reaction below boiling point by various literatures. Kusdiana and Saka (2004) also reported that in supercritical state, methanol acts as an acid catalyst in transesterification reaction [12]. Temperature increases the energy of the reacting molecule and also improves the miscibility of alcoholic polar media into a non-polar oily phase resulting in much faster reaction [13]. Due to proper mixing of solvent and lipid in presence of catalyst for time i.e. 2-3 h result in faster reaction rate and complete conversion of biodiesel. The biodiesel yield of 32.3% was obtained in the ratio 11:1 at 60°C for 2-3h and catalyst of 2.5 wt%. The produced biodiesel was washed properly using

distilled water to remove impurities and obtained pure biodiesel. The pure biodiesel was further analysed in gas chromatograph flame ionization detector (GC-FID) to determine the concentration of fatty acid methyl ester (FAME). The organic compound was identified by comparing the peaks of obtained FAME of food waste with that of standard FAME. Figure 1 shows the peak of the identified fatty acid methyl ester. Table 3 discuss about the wt% of fatty acid methyl ester identified in GC analysis.

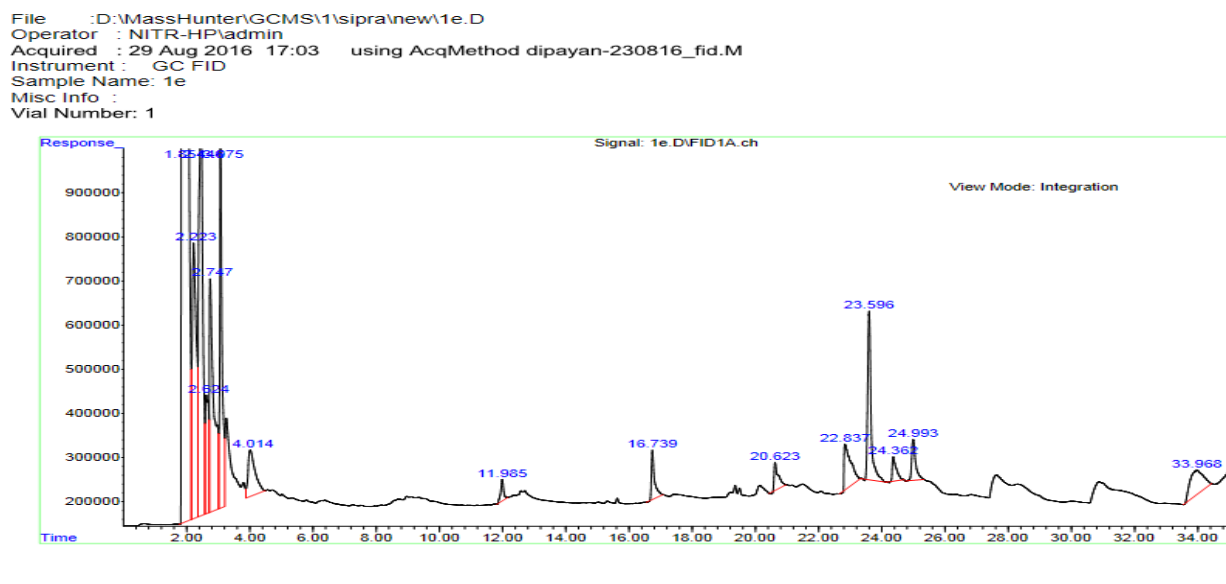


Figure 1. GC-FID FAME analysis of food waste

Table 3. Wt% of fatty acid methyl ester identified in GC analysis.

Fatty acid	Retention time	FAME	Wt %
1.	4.014	Caproic acid methyl ester (C6:0)	17.64
2.	11.985	Lauric acid methyl ester (C12:0)	4.04
3.	16.739	Mystric acid methyl ester (C14:0)	9.23
4.	22.837	Palmitic acid methyl ester (C16:0)	21.23
5.	23.596	Palmitoleic acid methyl ester	11.06
6.	24.362	Stearic acid methyl ester (C18:0)	19.19
7.	24.993	Oleic acid methyl ester (C18:1)	15.67

Fatty acids identified may be both saturated and unsaturated. Fatty acids mostly have carbon atoms between C12- C22. Saturated fatty acids identified in biodiesel include caproic acid (6:0), lauric acid (12:0), mystric acid (14:0), palmitic acid (16:0) and stearic acid (17:0). Unsaturated fatty acids have one carbon-carbon double bond which can be present in different positions. The most common unsaturated fatty acids contain chain length of 16-22 and a double bond with cis configuration. Unsaturated fatty acid identified in biodiesel is oleic acid (18:0). It was found that saturated fatty acids dominate in FAME analysis of lipid. Due to saturated components, biodiesel produced from food waste will undergo cold flow problem. Several studies were conducted by various researchers to improve cold flow properties of biodiesel such as use of additives to reduce intermolecular bond, decrease the crystalline temperature and combining biodiesel with petro diesel, as well as the use of thermal cracking process, ozonation technique and winterization technique to reduce the concentration of saturated fatty acid esters. However, specific method or additive that can improve cold flow behaviour of all types of biodiesel is not available. Cold flow enhancers are used to improve the cold

flow properties of biodiesel [14]. According to Refaat (2009), length of fatty acids chains as well as its composition plays a substantial role in cold flow properties of biodiesel [15]. National biodiesel board (2013) also stated that properties of biodiesel depends on the raw material (type of grease, fat or oil) from which they are produced [16].

3.4. Biodiesel properties

The obtained biodiesel was further analysed to determine its physical and chemical properties and then compared with various standards as summarized in Table 4.

Table 4. Comparison of biodiesel properties with ASTM, EN and IS standard

S.N.	Properties	ASTM D6751	EN14214	IS 15607 (2005)	Obtained value
1.	Densitv at 15°C (kg/m ³)	875-900	860-900	860-900	872
2.	Kinematic viscosity (mm ² /s)	1.9-6.0	3.5-5.0	2.5-6.0	2.2
3.	Acid value (mg of KOH/g), Max	0.5	0.5	0.5	0.63
4.	Pour point (°C)	-3 to 12	-	-	7
5.	Calorific value (MJ/kg)	-	35	-	31.38
6.	Metals (Na+K) (mg/kg)	5	5	-	1.5
7.	Metals (Ca+Mg) (mg/kg)	5	5	-	1.25
8.	Ash content, percent by mass, Max	0.02	0.02	0.02	0.0072
9.	Cloud point (°C)	-	-	-	12
10.	Flash point (°C), Min	130	101	120	164

Density of biodiesel produced from food waste is found to be 872 kg/m³ which is within the limit according to ASTM, EN and IS standard. The values depend on their fatty acid composition as well as on their purity. One of the most important properties of biodiesel is kinematic viscosity. The kinematic viscosity of biodiesel is found to be 2.2 mm²/s which in the range of 1.9-6.0 according to ASTM D 6751 according to test method D445. This implies that biodiesel enhanced fluidity of fuel for diesel engine and good spray pattern that would generate across the combustion chamber, allowing proper mixing with air [17]. The acid value for biodiesel is 0.63mg KOH/g and it exceeds the EN 14214 and ASTM D6751 standard according to which acid value should not exceed the value 0.5mg KOH/g. as triglycerides present in oil and fats converted to fatty acids causing an increase in acid number. Pour point is the lowest temperature at which oil starts to melt or pour. It is the measure of ability of a fuel to operate under cold weather conditions. The pour point of biodiesel is found to be 7°C which is within the range of ASTM D6751 (-3 to 12 °C). During cold weather biodiesel causes fuel starvation and operational problem which cease the fuel flow in engine. Calorific value is the measurement of heat or energy produced and is measured either as gross calorific value or net calorific value. The gross calorific value of biodiesel measured by bomb calorimeter is found to be 31.38MJ/kg which is less than the standard i.e., 35 MJ/kg according to EN 14214 standard. Calorific value of diesel fuel is 45.5MJ/kg. Less calorific value means more fuel consumption.

If metal contamination can occur, metal deactivators can be used to chelate transition and inhibit catalytic oxidation and polymerization effect. Alkali metals could also form soap and cause insoluble of diesel blends. Alkali metals of (Na+K) were found to 1.5 mg/kg and (Ca+Mg) were found to be 1.25mg/kg which is within the range of 5mg/kg according to standard EN 14538. Flash point is the minimum temperature at which vapour given off by a fuel when heated will flash with a test flame held above the surface without catching fire and plays a vital role in fire hazard of fuel. It gives the idea about the boiling point of liquid fuel, volatility and explosive hazards. Flash point (164 °C) of biodiesel obtained from food waste is within the limit according to ASTM, EN and IS standard. As the biodiesel starts to freeze, it will form crystals that start clumping together. Cloud point of obtained

biodiesel is 12 °C i.e., below this temperature biodiesel will form a cloudy appearance. Ash point describes the amount of inorganic contaminants such as abrasive solids, catalyst residue, soluble metals contained in fuel. Ash content of biodiesel is found to be 0.0072 which is within the standard value (0.02).

4. Conclusion

To overcome fossil fuel crisis problem, environmental pollution and meet the energy demand one of the best way is to replace non-renewable resource with renewable resource. Various researches have been performed to identify the best alternative way of reusing renewable resources, most importantly waste product for biodiesel production. Waste products like sewage sludge, industrial waste, waste cooking oil etc., are zero cost raw materials that can be used for biodiesel production which will help to minimize waste generation, handling and disposal problem. In this study an innovative approach to utilize kitchen food waste for biodiesel production has been initiated. Food waste was dewatered and lipid was extracted using methanol as solvent with yield of 37.3%. Lipid analysis was performed in GC-MS to identify the fatty acids. Lipids were further transesterified using methanol as solvent and sulphuric acid as catalyst producing FAME yield of 33.2%. The extracted biodiesel was analysed in GC-FID to determine the concentration of free fatty acid methyl ester. Physical and chemical properties of biodiesel were performed and found satisfied by comparing with different standards.

5. References

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