Plastic waste as a biofuel feedstock - A conceptual study

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Abstract. Current aim of energy scarcity and security is also concerned along with the environmental aspects and waste deposits on the earth. World is recording massive waste deposits every year amongst plastic became the irritating substance to the environment which is being left on the ground unprocessed. Almost 100 million plastics are deposited on the earth’s surface causing exhaustion of the ozone layer. Besides, the evolution of mankind is putting a huge demand on electricity generation. To compensate both the issues, researchers found the way to generate biofuel using plastic waste as a primary feed stock. Also, it is believed that bio-fuels will be vital enough to produce future energy. The transmutation of Waste Plastics to fuel oil is amongst one of the most propitious resources for fuel production being waste plastics are propounded in subsistence. We analyzed various Processes to proselytize Plastic waste into Diesel fuel. The present article throws a light on fuels from the waste feedstock, performance characteristics, emission characteristics and other parameters to generate efficient biofuel using plastic wastes.

Keywords: waste plastics, feedstock, degradable, four-stroke multi-cylinder diesel engine.

1. Introduction

Depending on the fossil fuels will no longer possible in terms of global climate change [1]–[3]. The evolution of mankind is putting a huge demand on electricity generation [4]–[9]. Researchers have shifted their focus in search of other renewable energies to decrease energy costs [10]–[15]. Solar energy, wind energy, solar-driven heat engines [16], and bio-fuels will be vital enough to produce future energy [17]–[19]. Biodiesel is a liquid fuel acquired from different chemical processes such as from vegetable oils, animal fats, and alcohol, etc. the biodiesel thus obtained be used in Diesel Engines alone itself or blended with diesel fuel. For example, B10 indicates 10% biodiesel and 90% biofuel. Biodiesel contains fatty acids and long chains. Depending on the production method, biodiesel ranges from golden to dark brown color. The main advantage of biodiesel is, it is easily available, the price cost remains constant for long period unlike traditional fuels, sustainability is safe to store, and can be handled safely during transportation. The metamorphosis of waste plastics into renewable plastics is one of the propitious conclusions for fuel paucity; plastic accretion can be
diminished. In general, plastics are classified into two types.

Thermoplastics and thermosets or thermosetting [20] Thermoplastics: too soft; on applying heat, it melts and mutates hard by chilling. Exemplary: Polyethylene, Polystyrene, and polyvinyl chloride. Thermosetting: These can be evanesced, structured only at once. Thermo sets are not competent for periodic cycles of heat treatment. Example: Phenol-Formaldehyde, Urea-formaldehyde. The annexure of sylvan and paper to waste plastics revenues quantity and dents production outgo of the total unit. The changeover of plastic into renewable plastic has not peeled middling outcome accompanying sequestration and cleansing of waste plastics is strenuous [21]. The incineration and gasification courses are not serviceable coincident with high dispersion and low productivity. Pyrolysis is regal in revamping waste plastics into fuel oil; no menace. In assimilation with other tactics pyrolysis is secured and not menaces able to human wellness and environment. The usage of waste plastic oil in automobiles is a surfacing technology. The waste plastic oil withholds altitudinous calorific value that assets consummated output and so imperative. The waste plastic oil descended through Pyrolysis process upshots Sulphur content; afflicts corrosion furthermore sled deposition [20]. Wherefore Sulphur content is disrated through desulphurization to downgrade ash contents and deposits in the combustion chamber. Eventually, the exercising renovating waste plastics to fuel oil complies with infund saline scintillating correspondingly accumulation of waste plastics on the earth’s surface get abated which obliquely degrades global warming.

Incipiently the pyrolysis reactor is heated up to 250ºC. The fuel oil undergoes valorization proceeded by pyrolysis with a similar boiling point 0-170ºC for light, 170-370ºC for distillate, exceeding 370ºC for heavy oils. Further, it can be upraised by a hydrotreatment to assuage the market ultimatum. In hydrotreatment, two-stage pyrolysis concerns investigation of hydrocarbon pyrolysis by catalysis process and second leads to gasoline hydrocarbons [22]. The hydrotreatment appertains to exclusion of hotrod atoms and saturated reactants. Hydro treatment collaborates in the upgrading of fuels such as bio-oils, Pyrolysis oils, etc [23]. The foremost advantage of pyrolysis and hydrotreatment is no kind of wastewater or perilous pollutants into the atmosphere. The capital advantage of pyrolysis; bare sulfur production, a pitfall pollutant. This treatment is consequential in revamping Pyrolysis oil to Diesel fuel being hydro-processed fuel retains excellent cetane number likewise density and viscosity declines down-and-out.

The deployment of plastics is aggrandized as a concomitant to colossal applications in variegated fields consequential to blue-chi peculiarities suchlike weight, design flexibility, the formation of rust and low corrosion, ease of manufacture. Nevertheless, remonstrance affiliate with the redeployment of plastics in daily life. Non-decadence is hulking in alliance with the plastics [24]. Even though the production and deployment of plastics have not been demoted, coincident to its humongous applications bare declension of plastics trails added fortunes for waste plastic feedstock. Consequent to proliferation in plastics, the waste feedstock from plastics is mammoth augmenting from the past 4 to 5 decades. Tons of plastic non-degenerates is the major radical antecedent for depleting the Ozone layer. Multitudinous recycling manners are progressive felicitous to downsize the accumulation of waste plastics on the earth [24].

Innumeros facets accounted for the permutation of prescriptive fuels. Forsooth technical, Socio-economic demurs to answer the fuel importunity. When the orthodox fuels are superseded by the third generation fuels in the same engine, the performance, efficiency, and other traits may not be the same. Consequently, few alterations of engine specifications or variations in the combustion chamber or distinctive type of melds can be deployable to the apt the same performance as that of customary fuels [25]. Global warming is alarming thought the world. The cardinal cause towards the usage of third-generation fuels development is to baffle pollutants into the atmosphere. Fuel scarcity is more in countries with more population especially population growing countries which are developing countries like India. Due to the increase in population, traditional fuels such as petrol and its by-products are not sufficient for fuel demand. Therefore, there is a need for alternative fuels.
2. Waste feedstock production for biodiesel production

After a wider analysis of the literature survey in thrust areas of fuel from the waste feedstock, it is noticed that there is not much literature review on fuels from the waste feedstock. This motivated a review article. The present article throws light on fuels from the waste feedstock, its characteristics, properties, performance, and other parameters. Complete literature analysis is shown in Table 1.

Table 1 Waste feedstock production for biodiesel production

| I Generation fuels (Edible oils) | II Generation fuels (Non Edible oils) | III Generation fuels |
|----------------------------------|--------------------------------------|---------------------|
| Soybean oil linseed oil          | Calophyllum inophyllum seed oil      | Waste plastics      |
| Crumbed seed oil Cottonseed oil  | Yogurt                               | Fish and chicken bones |
| oil Papaya seed oil Corn oil     | production Lignocellulosic biomass   | Microalgae          |
| Rice bran blend Coconut oil      | Safflower                            | Animal fat oil      |
| Soybean oil Sand apple oil       | Yellow Oleander oil. Canola          | Waste cooking oil   |
| Custard apple Cashew nutshell    | Jatropha curcas                      | Waste heat recovery from diesel engine |
| Hazelnut                         |                                      |                     |

2.1 First generation fuels

The first-generation fuels are comprised of all edible oils. Cropping of these kinds of fuels is easy. The conversion process (converting these raw crops into fuels) is easy. However, it leads to scarcity of food which leads to ecological, financial income of the countries under development. D Leite et.al, used soya bean, linseed, and crumbed seed oils in varied proportions of 10,20,30,40,50,60,70 and found declination in specific fuel consumption [26]. H Venkatesan et.al, done an energy analysis of cottonseed oil using in single-cylinder diesel engine and noticed a downfall in brake thermal efficiency [27] G Sudalaimuthu et.al, used two fuel (94% corn oil + 4% water + 2% Span80 and 90% corn oil + 8% water + 2% Span80) were used to evaluate the performance and emission characteristics [28]. Sharma et.al worked with soya and soya ethanol in a diesel engine by using the RMS method and showed that there is a reduction in carbon monoxide by 0.715% [29]. A Parlak used Canola oil Methyl ester is used in single-cylinder diesel engine and performed various tests showing that the torque and power for B10 2.5% for 10% at 1200 rpm, for B20, 2.8% for 20% at 2200 rpm [30]. O Ogunkunle et.al, extracted oil from sand apple by transesterification method using catalyst KOH that is also blended with diesel and found a torque improvement in the engine [31] Energy analysis was made by Yesilurt et.al, with cottonseed oil along with diesel in a single-cylinder engine to evaluate the performance and emission characteristics [32]. Energy, exergy, and economic analysis of some literature are tabulated in Table 2.
Table 2 Analysis of first-generation fuels

| S.No | Fuel Used/Blend | Energy Analysis | Exergy Analysis | Economic Analysis | Engine Used/Remarks | References |
|------|----------------|----------------|----------------|-------------------|---------------------|------------|
| 1    | Papaya seed oil | Yes            | Yes            | Yes               | The seeds are crammed in conventionally; oil is extracted from the seeds and supervened by the metamorphosis of oil into biodiesel | [33]       |
| 2    | Rice bran blend | Yes            | Yes            | Yes               | The results showed that there is no decrease in performance of the engine though there are no modifications in the engine set up. | [34]       |
| 3    | Coconut oil     | Yes            | Yes            | Yes               | Five different fuels are used at various proportions in a six-cylinder diesel engine. Results showed that there is only a 10% variation from experimental results to simulation. | [35]       |
| 4    | Soya bean oil   | No             | No             | No                | Proposed a technique to generate jet fuel and green diesel by converting lipids into biodiesel using a catalyst and yielded 70-90%. | [36]       |
| 5    | Soya bean oil   | Yes            | Yes            | No                | Nano additives- Alumina is used to reduce the emission and greenhouse gases by using Soybean oil and compared to that of traditional diesel. The results showed that there is a decrease in NOx. | [37]       |

2.2 Second generation fuels

Second-generation fuels are not from edible oils. Only a marginal portion of the land is required for cultivation. Though there is no scarcity of food because of second-generation fuels. However, marginal land cultivation leads to force the farmers for land cultivation instead of food production leading to food scarcity or an increase in the cost of the available food. A Tamilvanan et.al, worked on Calophyllum inophyllum seed oil in a diesel engine to distrait the emissions with nanoparticles and found serious diminishing of specific fuel consumption of the engine apart from emissions [38]. Ramesh et.al, used non-edible Calophyllum inophyllum seed oil with nano copper additives showing that the specific fuel consumption is reduced and also release of emissions are also less [39]. Energy, exergy and economic analysis of some literature is tabulated in Table 3

Table 3 Analysis of second-generation fuels

| S.No | Fuel Used/Blend | Energy Analysis | Exergy Analysis | Economic Analysis | Engine Used/Remarks | References |
|------|----------------|----------------|----------------|-------------------|---------------------|------------|
| 1    | Yogurt production | Yes            | Yes            | Yes               | Three dissimilar types of food production mechanisms were used and strawberry flavored yogurt is produced. | [40]       |
Lignocellulosic biomass

Yes

Yes

Yes

Study of exergy analysis of chemical and biochemical stages in liquid biofuel production is investigated [41]

Lignocellulosic biomass

Yes

Yes

No

By using sugar cane bagasse, pretreatment reaching 79, that of acid diluted pretreatment. Dehydration evinced the lowest exergy [42]

Safflower

No

No

No

Diesel and safflower biodiesel are used at SB0, SB50, and SB100 proportions showing that 36% of blend diesel and 64% of diesel fuel are found to be the best proportion. [43]

2.3 Third generation fuels

Due to advancements in science and technology, there are various fuels such as waste cooking oil, waste plastics oil, fish and chicken bones, microalgae, animal fat oil. These fuels overcome the problems of first and second-generation fuels. These are inexhaustible fuels since the source is waste feedstock. Nabi M.N et.al, performed an experiment on waste cooking oil and macadamia oil on a four-stroke diesel engine and showed that there is no abatement in performance of the engine notwithstanding; the combustion efficiency is addend [44]. D. Damodharan et.al, proposed a single-cylinder diesel engine running at 1500 rpm and the consequence is the maximum changeover of microalgae to biodiesel [45]. Erdogan S et.al, validated vegetable oil is the optimal fuel even in hybrid ways [46]. Rachmat D et.al, performed on waste cooking oil to curtain free fatty acids, cocoa pod husk from cocoa beans are expressed as an additive annex with a catalyst called K2CO 3 [47]. Deshmukh S et.al, explained different methods used for converting microalgae into biodiesel using microwave [48]. Energy, exergy, and economic analysis of some literature is tabulated in Table 4.

Table 4 Analysis of Third generation fuels

| S.No | Fuel Used/Blend | Energy Analysis | Exergy Analysis | Economic Analysis | Engine Used/Remarks | Reference |
|------|-----------------|----------------|----------------|------------------|---------------------|-----------|
| 1    | Waste Plastic   | Yes            | Yes            | Yes              | Pyrolysis Method is used and Hydro treatment of the waste plastics is discussed | [20]      |
| 2    | Waste Plastic   | Yes            | Yes            | Yes              | Pyrolysis synthesized is not exactly competent for CI engines. Thereupon hydrotreatment is needed for upgrading the fuel quality. | [21]      |
| 3    | Waste Plastic   | Yes            | Yes            | Yes              | Reconstruction of waste plastics to renewable plastic befalls into the picture. Hydro treatment proceeds for valorizing the fuel | [22]      |
|   | Waste Plastic | Yes | Yes | Yes | Alternative fuel vantages over conventional fuels are demystified and transfiguration of waste plastics to biodiesel is expounded [23] |
|---|----------------|-----|-----|-----|----------------------------------------------------------------------------------------------------------------------------------|
|   | Waste Plastic | Yes | Yes | Yes | Extrusion machine is antecedent to pyrolysis reactor aspired for segregation consequently to catalytic reactor wherein reaction betides and features of the bio-fuel are ameliorated [24] |
|   | Waste Plastic | Yes | Yes | Yes | The metamorphosis of waste plastic to useful plastic is fulfilled by incineration and by gasification [25] |
|   | Fish and Chicken bones | Yes | Yes | Yes | Transfiguration of these fish and chicken bones is through Brunauer–Emmett– Teller, Thermal Gravimetric Analysis, Scanning Electron Microscopy, x-Ray Diffraction. The catalytic reaction comes about at 65°C in 1.5 hours. The alcohol to oil ratio is 10:1. [49] |
|   | Waste cooking oil | Yes | Yes | No | The outcome is diminished Brake specific Fuel consumption and progressive Brake thermal efficiency when intermixture with Nano-fluids. [50] |
|   | Waste Plastic | Yes | Yes | No | The output showed that there is a slight boost in brake thermal efficiency; downsized emissions [51] |
|   | Waste heat recovery from diesel engine | Yes | Yes | No | The corollary is that the exergy efficiency of the diesel engine is less than that of the energy Efficiency for the same output [48] |
|   | Waste plastic Methyl Esters | Yes | No | No | The specific fuel consumption is reduced and brake thermal efficiency is improved. [31] |

3. Production and properties of WPO biodiesel

Predominantly the waste plastic is recycled in countless methods

**Primary Recycling Process:**

Waste plastic is provisioned to grosses basic material production. The output product assimilates the original fed waste plastic. Nevertheless, the waste plastic materials requisite to be disencumbered from waste contaminations. Here the segregation of waste plastics is distinguished by their color. This process is noted as mechanical reprocessing.

**Secondary Recycling Process:**

Fillers, recyclates aid in recycling. In contrast to the primary recycling process, the waste plastics need not be free from contamination that fetches the fiscal vantage.
Tertiary Recycling process:
It is a big-named cracking process. It supervenes to thermal degradation (heating to a high temperature) wherewithal cracking at low temperature in the company of a catalyst noted as catalyst degradation.

Quaternary Recycling:
Assimilate to all non-identical recycling proceedings; it altogether epicenters on energy content. Even so, the solid waste problem is not riddled out in this recycling process and so inclines to air pollution

3.1 Processes to proselytize Plastic waste into Diesel fuel

Pretreatment Process:
Waste Plastics are sent through the pre-treatment process, wherein nonnative particles are shrugged off. The cleaned waste particles endure through shredder. Ahead of the pre-treatment process, waste plastics get to sort out by four different processes recycled through the commented primary recycling process, secondary recycling process, tertiary recycling process, and quaternary recycling process.

Shredder:
Shredding machine comported to the vigorous capacity of 20-30kg, archetypal of shredder has an inlet, shredder (blades), filter, mover, and outlet. Shredding machine runs on Diesel engine/gasoline engine wherein the output of the engine is transmitted to pulleys. At the inlet waste, plastic material is squashed and postdates through the filter and then to the outlet. The filter ensures meliorated fast-forwarding the pyrolysis reaction green-lighting the dwarfish pieces of crushed plastic.

Pyrolysis Process:
In the early 1990s, the Pyrolysis Process is espoused for waste plastics for producing crude oil and Paraffin. ‘Pyro’ signifies heat and ‘lysis’ denotes fragmenting. The Pyrolysis acclimated for breaking large chemical compound to decompose by applying heat. Crude oil and paraffin are extracted from plastics by Pyrolysis. Fast Pyrolysis is adopted for achieving good output.

Condensation:
In the pyrolysis reactor, waste plastics are converted to achieve proper output. The waste plastic which is heated to a high temperature slowly melts and converted into a gaseous state; this gas is sent into the condenser, where the condensation takes place. The liquid is sent to the oil refinery chamber.

Refining:
After the condensation process, the liquid is refined in the refining section. The plastic is refined to 80% oil, 15% gas, 5% carbon, and this oil is used as a heating material, which is utilized in glass and ceramic factories and generators for electric production

3.2 Properties and Characteristics

Density: Density defines the quantity of the fuel which is sent through the injection system for proper combustion. The factors which affect the density are the conversion method of fuel feedstock etc. The density ranges from 860kg/m$^3$ to 900 kg/m$^3$ for third-generation fuels.

Flash Point: It is the minimum temperature where fuel ignites. The flashpoint of petrol and diesel ranges from 50-60°C, whereas biodiesels have a flashpoint of 150°C. This indicates that biodiesel is safe compared to conventional fuels.
Kinematic Viscosity: Viscosity resists the flow of fuel. The third-generation fuels have higher viscosity compared to conventional fuels. The viscosity of the third generation fuels is 10-15 times higher than that of conventional fuels. For reducing the viscosity of methyl esters, the transesterification process is used.

Cold filter plugging: It is the minimum temperature, which defines the cold flow operability. The cold filter plugging point is always less than that of the cloud point.

Pour Point: It signifies the loss of flow characteristics of the fuel when compared to conventional fuels; biodiesel has a low pour point.

Calorific Value: It is defined as the amount of heat/energy dissipated by the combustion of fuels. Biodiesel has less calorific value compared to conventional fuels.

Cloud Point: It is named as so because the wax in fuel appears to be in crystallization form, which appears to be cloudy. Therefore, it is named the cloud point.

Cetane Number: It indirectly defines the quantity of fuel. Cetane number affects the delay period of ignition is defined as the time delay between the periods of injecting fuel to the ignition time. Higher is the cetane number lower will be the ignition delay. Lower the cetane number results in problems such as higher exhaust emissions, knocking detonation, etc. The increase of Cetane number depends upon the increase in fatty acids degree of saturation, chemical structure, and chain length. The microalgae have a good cetane number of 75 and the least value of 41 for waste cooking oil.

4. Effect of WPO biodiesel on performance characteristics

Brake thermal efficiency: Testing of the engine has been done for various first, second, and third-generation fuels. Maximum reduction on microalgae is observed. Compared to urban areas, the rural area's test conditions resulted in better performance. Brake thermal efficiency from B5-B20 for pure Diesel highest Brake thermal efficiency is observed.

Brake specific fuel consumption: Brake specific fuel consumption is high for microalgae compared to Diesel. An increase in Brake specific fuel consumption leads to a decrease in heating value. It is noticed that Brake specific fuel consumption is shown highest for waste cooking oil. Very few researchers have noticed that brake specific fuel consumption decreased while adding blends of biodiesel.

5. Effect of WPO biodiesel on emission characteristics

Carbon dioxide: The release of carbon dioxide always indicates there is complete combustion takes place. It was observed that because of the addition of butanol, there is complete combustion, indirectly reducing the carbon monoxide contents.

Un-burnt hydrocarbons: Due to incomplete combustion, emissions, un-burnt gases, and hydrocarbons are released. There are factors such as combustion chamber design; engine operating conditions that influence the release of hydrocarbons. It was observed that hydrocarbons are released less by using rice bran. It is released due to insufficient oxidants, ineffective mixing of fuel and air. Reduction in carbon monoxide is observed for algal and methyl esters. Good cetane number of biodiesel results in reduced carbon monoxide.

NOx: Due to the high temperature in the engine and also the presence of more amount of oxygen, nitrogen oxides are released. These cause acid rain and smog.

5.1 Traits, purity of fuel oil, and Quality of fuel oil
Accentuated pour point along with specific gravity being the traits of pyrolysis extracted oil likewise rids of Nitrogen, Sulphur, and lead. In equivalency to orthodox fuels and superior calorific value, flash point, and specific gravity. The oil obtained from pyrolysis not only par with the calorific value however it is good in terms of quality.

5.2 Additives and catalyst

It is the additives annexed for the amelioration of the traits. To uptick, the rate of reaction, the catalyst is assured with it. Silica, Alumina, Y Zealot, Barium Carbonate, HZSM-5, HY, Hβ, and HUSY are the most handled catalysts in the pyrolysis process.

6 Conclusion

The employment of plastic is accrued commonplace accompanying with its availability, low weight, and frugality despite the waste plastic has become the major problem for earth’s ozone layer as most of the plastic usage is non-developable, and hereby accumulation of waste plastic on the earth’s surface is more. The metamorphosis of waste plastic to fuel oil redeems the triple solution for the subsisting problems: Fuel inadequacy, degradability, and extravagance. Various techniques used so far to convert waste plastics into biodiesel are critically analyzed. Apart from the waste plastics, all of the three-generation fuels are well-reviewed according to their energy, exergy, and economic analysis. However, most of the blends are successful enough in increasing the performance or decreasing the pollution; whilst some of the blends gave an adverse report of the used engines. Whereas, the properties and characteristics of the fuel blends affected the performance of the experiment as well as the emission characteristics of the engines to a greater extent.

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