Solid Waste Biofuel: An Overview

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Abstract Gradually mounting pollution and temperature levels that are associated with the widespread dependency on fossil fuels are of major concern. This can be avoided by increasing the renewable and bio-energy usage. Waste that is generated from different industrial sectors especially solid waste has the potential to compete in energy industry. This paper focuses on the available technologies for processing of solid waste into biofuels and utilisation of these in internal combustion engines. The processing techniques, nature of fuel, emission and efficiency characteristics are presented in this paper.

Keywords Solid waste · Biofuel production · Emissions · Brake thermal efficiency · Break-specific fuel consumption

1 Introduction

One of the most important reformation needed in current generation is the policies of climate change. Fossil fuel contributes to at least 75% of global energy needs currently. There are various potentially unwanted chemical compounds emitted from automobiles which are even after being treated with catalytic converters are still hazardous. Even depletion of resources like fossil fuels can show significant negative effects on future generations.

There are various alternate energy options available like the wind, hydro and solar energies but these cannot be made substantially available due to geographical limitations. Bio-energy derived from solid waste is promising as many of them readily produce liquid state fuels unlike renewable sources. These fuels are categorised into various generations that are first-, second- and third-generation fuels along with the

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types of raw materials such as agricultural wastes, domestic and urban wastes. This work summarises the recent efforts in producing energy from various wastes through novel and known technologies. This paper reviews the most recent work conducted on methods used for extraction, waste type and its performance analysis in internal combustion engines. Therefore, this manuscript is tailored to fit all the peer-reviewed work in the field of biofuel generation from solid waste.

2 Solid Waste

By-products that are in solid state which cannot be reused or recycled are considered to be solid wastes. Agricultural and municipal wastes contribute to most of the solid waste that can be used for biofuel generation. Carbon waste from industries also contributes to the solid waste but in smaller quantities. These wastes are discussed briefly in the following sections.

2.1 Agricultural Waste

Lignocellulosic fuels are derived from agricultural waste which is abundantly available in many nations across the globe. Fourteen percent of the global energy needs are met by lignocellulosic-based fuels, and if this lignocellulosic fuel usage is not regulated, then the demand for fuel cannot be satisfied by agricultural waste.

Biofuel production techniques from agro-waste need pre-treatment of lignocellulosic mass by physical methods such as mechanical reduction in size, pyrolysis and then followed by physiochemical treatment methods of steam explosion, liquid hot water method and ammonia fibre explosion. These methods require far lesser technological and investment needs but are far away from current biofuel exploration techniques. As a result, lignocellulosic base promises to be a better approach for future energy needs [1].

Transesterification of lipids from biological products such as food waste while the catalyst was lipase and methanol as base Karmee et al. 2015 produced 100% yield of biodiesel. They also found that changing the lipid-to-ethanol ratio from 1:3 to 1:10 significantly changed the yield. Reusability of lipase of needed as the reaction time is low as well as the prices of lipase has substantial impacts on the economic system. This would be damaging if much more efficient production techniques are met [2].

Apart from the conventional approaches such as the production and utilisation of bio-energy from biomass-related sectors, the land-intensive energy approach can be considered as one of the feasible ways to deal with non-heavy-duty transportation category and storage of harvested energy. Walter Reid et al. highlighted this kind of approach which is limited by the amount of land that is available. This is not only difficult to achieve but also it is more of a temporary solution for half a decade But, by taking into account the substantial carbon emissions, the policymakers restrict this approach to the local energy needs rather than considering global parameters which are quite difficult to manage. As a result, any concept of bio-energy alternatives should be able to significantly reduce the carbon emission impact on the environment with less investment on production scales [3].

Wai-Hong Leong et al. found that using oleaginous micro-organisms will help in the generation of high amount of biomass by yielding high lipid quantities. Even though most algae do better in cultivating the micro-organisms, when they are cultivated using the mixotrophic methodology it produces better yield quantities compared to the autotrophic and heterotrophic methods. Modification of nutrients by manipulating the carbon-to-nitrogen ratio also helped increasing the yield of biomass and composition of oleaginous micro-organisms [4].

Most of the bio-energy-related fuels come from these vital sources such as agricultural crops, industrial biowastes, energy crops, forest residues and animal manure. Many model assumptions were made which helped us to see the possible biofuel transformation. The land availability and biomass energy production are predicted to be 18,833 and 24,901 Peta Joules in two decades after 2030 [5].

Most of the renewable energy sources in Turkey are derived from the fuelwood and animal waste biomass which are mostly used for domestic energy needs. Munzir Ozturk et al. have highlighted that the production of 1.5 million tonnes of biodiesel, 4 billion tonnes of biogas that is produced per year. The authors had shown that much more can be achieved with other waste resource but there needs to be proper policy which can alter the numbers in production [6].

Second-generation biofuels will have positive effects compared to first-generation fuels as the first generation would require 85% of harvest around the globe to serve as the need for replacing fossil fuels. The cellulose biomass which is second generation is naturally available and consists of more than 60% of terrestrial biomass [7].

Second-generation biofuels that are derived from lignocellulosic waste that is derived from agricultural base prove to be one of the best possible alternative to petroleum-based fuels. The metabolic engineering, production of enzymes, pre-treatment and yeast development from the waste will show potential that is available in biofuels [8].

Lack of porous nature in synthetic mixture for biofuel production did not facilitate the volatile release of cellulose for the chemical reaction unlike the lignocellulosic biomass which hindered the pyrolysis distribution in mixture. This behaviour led to the production of unwanted gas and char by repolymerisation at temperature between 350 and 400 °C [9].

2.2 Municipal Waste

Production of an alternative fuel source from biodiesel is possible through utilising solid waste collected by municipal department, and this has major benefits from manufactures of paper production waste particularly from major cities across the globe [10].

Most of the current biodiesel approaches include the usage of second-generation methods which are actually a by-product of first-generation usage like vegetable oils which are extracted from the plants and the used for cooking. Waste biomass to cellulose ethanol efficiencies was calculated where the lowest to the scale of ligno-cellulosic MSW to ethanol. The total production accounted for 92% of mainly paper-based waste. The global production of 83 billion litres of cardboard and papers waste is accounted for ethanol production, with increase in ethanol-based technology the ability for the biodiesel production will be increased when compared with vegetable oil and agro-based waste recovery techniques.

Allen Zihao S H I et al. concluded that it is possible to replace about 5.36% of the gasoline consumption worldwide with the available of up to 82.9 billion litres of ethanol derived from waste-paper products. This would not only reduce the consumption of petroleum products but as well as greenhouse emissions around 29% worldwide. The technology available to convert the paper-waste products into usable fuel needs to take new approaches, thus increasing the conversion efficiencies and making the cellulose-based products a better possible alternative for future in place of fossil fuels [11].

Anaerobic digestion of floral waste is hugely limited by the literature on biogas production. Higher quantities of biogas production are achieved by implementing new techniques like alkaline pre-treatment, solar heating and co-digestion with food. An output increment of 106% was observed along with a savings of 96% over chemical treatment methods [12].

By employing the dark fermentation and anaerobic technologies, food waste can be used for generation of much more biogas than other approaches. This will not only reduce the waste disposal issues but also will reduce the greenhouse gases (GHG) emissions with immediate effect. Biorefineries need to be developed with some new technologies [13].

Smart food waste recycle bin can be an effective method to deal with surplus food waste which is being generated. This method also helps in dealing with moisture content and lower heating value (LHV) of the waste. The food waste can be converted into an energy source using wooden biochips which contain naturally occurring fermentation micro-organisms using smart food waste recycling system (S-FRB) [14].

Lipids are extracted by using Soxhlet extraction method from micro-cystis bloom samples collected from Biesa Lake, Sri Lanka. The properties of lipids are similar to grade 02 auto-diesel at 15 °C with respect to ASTM standard [15].

2.3 Algae and Micro-organisms Use

Algae can be used as a biofuel as it possesses a property of storing biogas, which can be extracted through various temperature facilities that help algae to survive. But the process of extraction clearly shows that it is economically and ecologically difficult to deal with. Much more research is needed to understand the effect because this concept lacks literature [16].

Bio-hydrogen generation is a new and actively prototyped method along with carbon-based biofuels. Kuan-Yeowshowa et al. conducted experiments by performing photosynthesis on the algae. They found that smaller chlorophyll antenna shape can provide high intensity of light which resulted in threefold hydrogen production improvement [17].

Aerobic process is where the solar energy and the interaction of photosynthesis organisms generate biogas upon some exposure time. This can be used for various purposes that need the availability of conventional fuels. Micro-algae have better yield percentage than the terrestrial plants. The aerobic process is hindered by the biomass composition, digestion and the methods of pre-treatment. The production efficiency increased when biohydrogen and biogas process were coupled together [18].

Pre-treatment of microalgae by ohmic heating process helped in lipid secretion from the cells. The extraction fluid is suspended on water which then resulted in the separation of various unwanted chemicals. Taguchi method was used for modification which increased the biomass yield. Transesterification at 40 °C for 24 h increased the transesterification by two times with an incubation time of 120 s [19].

2.4 Current Technological Trends

Along with the production of biofuel-related energies, process followed to extract the biofuel from solid waste is also an important factor. The biochemical strategies employed are much more effective than the thermochemical strategies. Thermal processes use heat as the primary reaction mechanism which is not sensitive to biomass-related waste generation. Processing of biomass material to extract energy requires much more study on the material handling, conversion efficiencies, transportation and not but not the least economics of production [20].

The work conducted by Pursiheimo et al. shows that the drastic usage of biomass for fuel generation by 2050 is needed. This can be achieved by making the industries run primarily on bioenergy. Global coverage of solar energy is primarily up to 39–44% and the rest is in electric generation sectors. This will help in the generation of synthetic fuels through usage of photovoltaic technology which can be used for the industries and the transportation sectors. They found that such a transition rather than the usage of biofuels for transportation purposes directly will reduce carbon emissions by 90% by the year 2050 [21].

Mustafa reviewed that biomass is a fuel source which can produce all three types of fuel energy matter by various thermochemical processes. Biodiesel and charcoal that were produced were analysed for their performance characteristics. This proved that there is still more room for the development of the machinery to consume less energy and at the same time be economical [22].

Many materials are serving in the energy storage applications like porous carbon, graphene, carbon nanotubes, etc., but there is a scope for the development of biomass-derived materials. Lili Jiang et al. observed that even the biomass materials contain the microstructures similar to the above-mentioned materials like oculus dexter (0D) spherical, 1D fibrous structure. These materials also exhibit porous nature that can work as supercapacitors [23].

The substitute material that is obtained from the conversion of activated carbon- and carbon-based materials is biochar. If this material is treated thermochemically and hydro-thermally, then it has the potential to be used as catalyst in pyrolysis which can be used to remove the pollutants and heavy metals. Then it can be used as an energy storage material for electric transportation issues [24].

Algae use in biofuel generation is a very effective substitute compared to other methods due to their evolving nature with respect to the atmosphere around them. However, it is still difficult to produce the amount of fuel needed for global use and the pricing of the methods and fuels need to be improved for a better reach [25].

Swati et al. showed that mild reaction conditions and optimum molar ratio of alcohol are required for economical production of biodiesel. Nano-porous material is effective in this process as it increases the feedstock reaction area of the catalyst for absorbing the oil and methanol. Solid-based catalysts possess a challenge in reusing them for the following process but the carbon-based nanoporous material mitigated that [26].

Ralph et al. compared the GHG emission characteristics of first and second stage biofuels where they found that second stage has very less emissions than first stage fuels. Moreover, the second stage fuels are more sustainable as they have the better land-use opportunities and these produce much more liquid-based fuels readily than the first stage fuels [27].

Municipal Solid Waste (MSW) wastes were subject to pyrolysis gasification at temperature between 700 and 900 °C, the increase in yield and the LCV gas of synthesis gas was observed whenever the reaction temperatures were increased. The quality of the gas improved after optimum amounts of water vapour was introduced into the system which resulted in tar cracking [28].

The process of producing second-generation fuel using lignocellulosic biomass is a short-term solution. More research needs to be carried in optimising the pace of pyrolysis and sync gas gasification. Hydrogen generation process and bio-oil generation can be clubbed to increase the quality of oil produced [29].

According to Zabed et al., the lignocellulosic base (LCB) has greater potential for ethanol production as they consist of third category waste and cannot be recycled further. The availability along with low pricing of LCB makes it favourable to deal with them. The fermentation and sugars such as pentose and hexose have major knowledge gap technically. But without the help of micro-organisms and carrying the process synthetically is a challenge [30].

3 Vegetable Oils

3.1 Seed Oil Extraction Technique

The techniques available in the world oil extraction are compared with each other. Out of the four available options that are chemical, distillation through steam, mechanical and supercritical extraction, mechanical extraction process is found to be the most pocket-friendly to the operator, since it ensures high quality of the oil delivered for the mechanical screw-based fits. However, when compared to the method of solvent extraction, some disadvantages are associated like the higher residual oil quantity from the cake and others [31].

Cottonseed oil provides an opportunity to explore the alternative fuel segment. Purification of the oil with activated charcoal followed by transesterification proved to be beneficial. The purification and analysis methods include purification of the crude cottonseed oil, determination of free fatty acids concentration, molecular weight through gas chromatography, biodiesel synthesis of transesterification determines the biodiesel yield. The purification revealed that the charcoal removes the unnecessary plant-related pigments and the coloured bodies absorption is proportional to temperature increase and mass of absorbents. Intensity of free fatty acids present in the oil depends on the concentration of charcoal and charcoal exposed time. The hot neutralisation technique proved beneficial as the oil colour and quality with respect to the ASTM standards were respectful compared to cold neutralisation technique. The energy evaluation test showed that the oil contains 38 MJ/kg of energy which is closer to 42 MJ/kg when compared to gasoline [32].

3.2 Vegetable Waste

Hoffmann et al. conducted a compatibility test for various oils that emerged from both vegetables and solid wastes. The deterioration rate of oil was measured. These oils were found to be holding well under 300 °C but after which the chemical transformation occurs with the ageing of oil. This proved a bit unstable for internal combustion engine operations [33].

Bio-ethanol has been a viable alternate as a transportation fuel. The presence of starch is vital for the fermentation stage. Kumar et al. considered this product of kitchen waste that can be renewed by exposing the potato peel waste to microwave radiations. With an exposure time of 15 min, they were able to extract 60 wt. % of glucose-based material [34].

Methods involved in the conversion of raw and untreated disposal into ethanol for energy conversion were studied by Dhiman et al. using the anaerobic bacteria called thermophilic. They concluded that around 94% of carbon recovery was achieved particularly when the bacteria were grown at 65 °C. These results proved that commercial production of ethanol can be supported by this method [35].

This study conducted focuses on the zero-waste generation from potato processing industries. The waste is mostly comprised of starch-based products. The process involves the usage of Aspergillus Niger and Saccharomyces with different incubation times of 12–24 h in place of enzymes. The material that was leftover as a by-product after the process can be later used for the ethanol production through fermentation [36].

An integrated approach to generate biofuels and manures thus reducing the usage of conventional fuels and fertilisers in agriculture by using simultaneous saccharification and fermentation technique (SSF) was used to produce bio-ethanol from pineapple leaves. The by-products of the process were mixed with blue-green algae which resulted in increase in nitrogen, phosphorus and potassium element that can act as manure. So, two stages of pollution are reduced simultaneously [37].

3.3 Current Technological Trends

The study conducted by Spyridon et al. shows that there are many current trends followed by various industries in production of biochemical ethanol, moreover much more promising methodologies are currently under development phase. Government funding was even approved in countries like USA and Europe to develop the yeast and bacteria responsible for the fermentation of ethanol [38].

There are several technologies like anaerobic digestion (AD), anaerobic co-digestion (AcoD) process which are a promising and effective current day methods to extract biogas. The research review conducted by Hagos et al., the AcoD technology is problematic when the demand increases as the production stages increase exponentially. These methods need a tool like ADM1 and biochemical methane potential testing which calculates the biodegradability of the organic materials used. Further, inclusion of nanomaterials can improve the production pace of the standard systems [39].

Gonzalez et al., 2018 have described the current scenarios of biomass liquefaction for transport fuel needs. Thermochemical process that converts lignocellulosic biomass conversion to liquid substances. To achieve better conversion efficiencies, finally, many systematic methodologies and process system engineering which will help the main synthesis process [40].

The production of biofuel or other fuels related to internal combustion engine use does have synergic effects on both positive and negative sides. Merdun et al., 2018 conducted an analysis on the generation of biofuels from vegetable feedstock waste. Greenhouse vegetable waste (GVW) and lignite coal were taken for the experiments with different particle sizes and pyrolysis temperatures along with some naturally occurring catalysts. They found out that a positive synergic effect was noticed for biochar yield while an opposite effect was observed for the bio-oil and fuel yield [41].

Ethanol and butanol compounds provide the chemical energy required for biofuels that can be used as an alternative fuel for transportation needs. Shao et al., 2015 increased the fermentation process of carbohydrates by using amorphophallus konjac waste with the help of ATCC 824. They found that the ABE yielding increased as the fermentation time reduced because of the alkaloid effect. This proved that using amorphophallus in the fermentation produced low-cost high yield strategy [42].

Experiments were conducted to increase the yield of quality biodiesel according to the ASTM standards. They used palm oil and waste cooking oil following transesterification methods. The ratio of methanol to palm and cooking oil is 4:1 and 11:1 with contact time varying from 2 to 4 h. Biodiesel production yield from 90 to 70% was obtained from the above-mentioned ratios at reaction temperature of 60 °C [43].

Hydrogen production from biomass has been a long-term research due to the complexity in hydrogen interaction at molecular levels as well as its metabolic network. The metabolic flux of hydrogen will have substantial impact on enzymatic metabolism and synthesis of hydrogen gas [44].

4 Engine Testing

4.1 Waste Oil Usage

Muddineni et al. worked towards the usage of natural-based oils that are capable of generating combustion-related pressures. A single cylinder four-stroke engine was used for the experiments to analyse the smoke emissions of oil from coconut, cottonseed and rice bran against the convectional fuels. The fuel consumption analysis proved that the rice bran is better performing than the other compounds of natural occurrence, as well as the rice bran products, are similar in properties of diesel like brake-specific fuel consumption (BSFC), total fuel consumption, fewer emission levels of carbon monoxide, carbon dioxide and nitrogen dioxides [45].

The recycled engine oil can be a potential fuel for blending the standard diesel fuel for use in compression ignition engines. Prabakaran et al. conducted various experiments by blending the standard diesel fuel with recycled engine oil which resulted in reduced brake-specific fuel consumption (BSFC), NO_x (oxides of nitrogen) and hydrocarbons (HC) emissions. The brake thermal efficiency (BTE) of fuel for blends such as D95R5 (blend containing 95% diesel and 5% recycled oil), D85R15 (blend containing 85% diesel and 15% recycled oil) and D80R20 (blend containing 80% diesel and 20% recycled oil) proved effective by 2, 4 and 5% of the total energy output compared to diesel fuel [46].

There are many alternatives for producing unconventional fuels not only from used engine oils but also from cooking oils and plastics that can also be worked out. Concentration of carbon emissions is higher when compared to the standard diesel; the recycled oils have 18.51 g/kWh at 25% of rated power to 14.14 g/kWh. Even the No_x emissions even increased by the use of recycled oils compared to diesel fuel [47].

The process of pyrolysis has the ability to guide the recycled fuels without any modification. Properties of the fuels produced by pyrolysis were observed to be similar to that of standard diesel and gasoline [48].

4.2 Micro-organisms and Algae-Based Fuels

The experiments conducted by Karmakar et al. used biodiesel that was generated by unused algae that are produced by two-step esterification of bio-acids and then followed by the transesterification process which reduced the emissions from petrol- or diesel-based internal combustion engines. Particularly, the No_x, CO and CO_2 were drastically reduced. The production methodology of biodiesel was altered by using the Taguchi's method with the help of L25 array. The oil molar ratio of 6:1 to ethanol, reaction time of ninety minutes, reaction temperature of fifty degrees Celsius and potassium hydroxide concentration of 2.5 wt. % were the altered conditions of the transesterification process, thus generating biodiesel of 89.7% with free fatty acid of 0.25% only [49].

The reduction in peak pressure within the cylinder of 3.28% and with an 8.21% reduction in BTE was noticed by Kamarulzaman et al., when black soldier fly larvae oil (BSFL) oil was investigated. The shorter (ignition delay) ID period of BSFL oils improved when blended with diesel fuels by 30% along with higher oxygen content. They concluded that BSFL oil is a good substitute for biodiesel blending with standard fuel with respect to emissions and power variation [50].

4.3 Other Category Fuels and Technical Advancements

Apart from extraction and using of solely, the biofuels mixing of some naturally generated oils with standard diesel are a better approach as it mitigates the process of production. When the blending ratios were of 6:1, then the maximum thermal efficiency was achieved. This blend produced fewer quantities of carbon emissions as well as hydrocarbons. The toxicity of the pollutants was significantly low compared to standard diesel [51].

Testing an internal combustion engine with three biofuels (chocolate waste, methyl ester and algae) for the performance and emission analysis, they found out that methyl ester reduced the emissions significantly while the chocolate waste emissions increased rapidly with increments in ignition timing. However, NO_x emissions remained of a concern even with all three fuels which were of minimum 20% increase compared to standard diesel [52].

Lemon oil was used in a four-stroke diesel engine with the help of steam distillation for extraction. It was observed that lemon oil performance was good compared to diesel in terms of slight improved BTE and reduced fuel consumption. When tested with in cylinder coating then the thermal efficiency improved which better in cylinder temperatures [53].

Thermally coated engines when used with biofuels are 11% higher in temperatures which resulted in faster combustion speeds. Masera et al. also noticed improved torque and power output along with increase in 10.17 percent in BTE, 13.4% reduction in BSFC reduced CO and HC emissions when compared to standard diesel [54].

Combustion delay is a major concern when it comes to internal combustion engine efficiency. Mateusz et al. conducted experiments with liquid biofuel in a standard diesel engine without any modifications. They found that there is a delay of more than 5° at tested speeds from idling to cruising. This showed that there is a need for the modification of engines in order to retain more heat from the combustion cycle [55].

The mixed and premixed conditions of the biofuels were investigated by Asadi et al. where they concluded that increased premixing of biodiesel led to reduction in flame propagation speeds which is opposite to diesel fuel. With B10 and B20 blends of biodiesel, the soot emission reduction was noticed as these fuels contained higher oxygen molecules. Even the chamber temperature increased with these fuels but it did not trigger the NO_x emissions rapidly to rise [56].

Kurczynski et al. used a 1.3 L Fiat diesel engine and tested blends of diesel with (fatty acid methyl ester) FAME acids known as B20 and B30. They concluded that by the addition of 7% biodiesel by volume, the effective power was reduced by 4KW at 1750 RPM. As the feed ratio was increased the power and torque figures distinctly fell. The B20 fuel is helped in reducing the ignition characteristics when compared with B30 [57].

Sugarcane diesel and sugarcane biodiesel –LS-9 were tested for emissions on a four-stroke diesel engine. Soto et al. found that the LS-9 variant produced the least THC which is basically due to the rich oxygen and absence of aromatic compounds in the fuel. The NO_X emissions of LS-9 are, however, higher than the sugarcane diesel—farnesane but with fewer margins. Even the BSFC increased for the LS-9 fuel with higher HC ratio [58].

The boosting characteristics of prenol biofuel with gasoline blends were discovered and the rated octane number (RON) of the prenol was found to be exceeding the blending agent and the stock due to the low water solubility and high density of energy close to petrol [59].

Patel et al. investigated the combustion and emission variable of an engine using the rapeseed and soyabean biodiesels where they observed lower cylinder pressures than the standard diesel. The effective combustion noise was reduced by a range of 0.25–8 Db and the duration increased. However, the CO emissions were high which is mostly due to the trouble associated with atomising the fuels [60].

5 Discussion

Agricultural wastes show potential in the generation of the required liquid or gaseous fuels. In order to meet the demands of local or global transportation energy needs pre-treatment of this waste to achieve a better yield, many such techniques were tested but most of them need more development in terms of efficiency, the energy needed for the pre-treatment and the quality analysis of the fuels after extraction.

- Generation of biofuel by using micro-organisms produced different results as they were treated with different approaches like anaerobic, consideration of shorter antennas and ohmic heating produced appreciable results but there is a need for combing all these approaches here the maximum possible quality and quantity of the fuel can be obtained.
- Mechanical extraction techniques of seed oils were generating low qualities of biofuels, and these methods need to be clubbed with chemical treatments where the char is removed from the waste and not transferred to the oils as mentioned by Djomdi et al.

6 Conclusion

The solid waste is of better option as they are the most aggressively generated wastes across the globe. Wastes that are starch-based can be a viable option due to their readiness in fermentation process with efficiency of over 70% than other conversion techniques. Fuel quality is dependent on the reaction time and exposed temperatures but as the temperature rises the fermentation bacteria is killed resulting in reduced quantities of fuel that is generated with optimum time and temperature being 12 h and 60 °C, respectively. The testing of biofuels in internal combustion engines is mostly resulted in delay ignition, increased combustion duration which resulted in increase of emissions by 4.37 g/kWh carbon emissions even at lower loading conditions according to Naima et al., When the micro-organism-based fuels were tested, there was a noticeable reduction in BTE of 8.27% and cylinder pressure by 3.28 and increased BSFC except for lemon oil extract which showed percent 0.423 kg/kWh, 0.392 kg/kWh, 0.357 kg/kWh, 0.321 kg/kWh and 0.295 kg/kWh as per Karthickeyan et al., which improved with the addition of lemon oil composition and thermal insulation coating of the surfaces exposed to combustion. Thus, it can be said that biofuels have the potential to significantly reduce the dependency on fossil fuels and result in reduced emission but this result can be achieved with further research and improvement in biofuel generation, waste tackling systems and the fuel consuming technologies.

7 Future work

- More work needs to be carried out regarding the reduction of biofuel generation time by improving the efficiencies of waste to fuel conversion systems which will help in meeting the fuel demand.
- Biofuel quality can be improved to meet the fuel rating and the molecular blending ratios if needed.
- Focus on designing new engine heads according to the biofuel characteristics can help in dealing with the combustion-related issues of biofuels.

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