CHAPTER - 1

INTRODUCTION

1.1 General

Most of the world's need for energy resources is supplied from petroleum, coal and natural gas, with the exception of nuclear power, hydroelectric and solar energy, and these resources are limited and due to the high intensity of energy consumption in the world, access to these resources increasingly reduced. Today the use of non-petroleum energy sources in many countries has been seriously investigated. Substituting biofuels instead of petroleum liquid fuels investigated in two groups. The first group is gasoline substituted fuels such as ethanol and other alternative fuel substituted of gas oil such as biodiesel, which are used in pure form or blended with diesel fuel in compression ignition engines (CI). Biodiesel, fatty acid alkyl esters (mainly methyl ester) is a result of trans-esterification reaction between triglycerides with an alcohol in the presence of a catalyst. Biodiesel as an alternative and renewable fuel source can be used in diesel engines to reduce air pollution and dependence on fossil fuels.

The expected scarcity of petroleum supplies and the negative environmental consequences of fossil fuels have spurred the search for renewable transportation biofuels. In view of this, vegetable oil is a promising alternative because it is renewable, environment friendly and produced easily in rural areas, where there is an acute need for modern form of energy. In recent year’s systematic effort have been made by several research workers to use vegetable oil as fuel for diesel engines. Diesel engine has become the engine of choice for power, reliability and high fuel economy, worldwide which was developed by inventor Rudolph Diesel in the 1890s.

For most of the twentieth century, an abundant supply for petroleum allowed for affordable petroleum diesel. However, in recent years the supply of petroleum has slowed, while the need for petroleum fuels has substantially increased.

It is said that energy consumption pattern is an indicator of the socio-economic development of a country. It is also a measure of the quality of life .Energy consumption is growing day by day along with technological development of the country. Although the industrialized and developed world consumes most of the energy resources, the demand of energy in the developing countries has also increased in recent decades due to their economic take off and sustainability.

Internal combustion (IC) engines are widely employed in many development activities using a greater portion worlds energy resources. From the very beginning, the IC engines are being fuelled mostly by petroleum products like petrol and diesel. IC engines use only a small fraction of distillation products of crude oils. These crude oils have limited reserves. Any shortfall of petroleum fuels in the world market will therefore, have a great impact on the economy of non-oil third world countries.

Renewable energy is the energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished). In 2008, about 19% of global final energy consumption came from renewables, with 13% coming from traditional biomass, which is mainly used for heating, and 3.2% from hydroelectricity. New renewables (small hydro, modern biomass, wind, solar, geothermal, and bio-fuels) accounted for another 2.7% and are growing very rapidly. The share of renewables in electricity generation is around 18%, with 15% of global electricity coming from hydroelectricity and 3% from new renewable [1]. Climate change concerns, coupled with high oil prices, peak oil, and increasing government support, are driving increasing renewable energy legislation, incentives and commercialization.

Vegetable oils from crops such as soyabean, peanut, sunflower, rape, coconut, karanja, neem, cotton, mustard jatropha, linseed and coster have been evaluated in many parts of the world in comparison with other non-edible oils. Different countries are looking for different vegetable oils depending on their climate and soil condition. As for example Soyabean oil in USA, rapeseed oil and sunflower in Europe, Olive oil in Spain, palm oil in south east Asia, mainly in Malaysia and Indonesia, coconut oil in Philippines are considered to substitute diesel fuel [2] . Different researchers results show that vegetables oils are promising alternative fuels for CI engine. In view of growing energy demand of our country, it is thus reasonable to examine the use of Biodiesel as a substitute fuel for IC engine.

1.2 Energy Scenario in Bangladesh

Bangladesh has one of the lowest rates of per capita energy consumption in the world. Bangladesh is not well endowed with conventional sources of energy. The country‘s energy sources are neither adequate nor varied. Non-commercial sources of energy include biomass fuels, agricultural residues, tree residues, and animal dung. The country receives 5.05 to 8.76 kWh (kilowatt hours) from solar radiation, but commercial photovoltaic generation is too expensive for Bangladesh. Conventional commercial sources of energy in the country include fossil fuels, such as coal, oil, natural gas and hydropower. A brief accounting of these commercial sources of energy in Bangladesh has been provided below:

Coal: The total reserves of coal in the country is estimated at about 1.75 billion tons [3], but at present underground mining has been initiated only at Barapukuria (one of the major coal deposits), with a production level of one million tons per year.

Peat: Bangladesh has approximately 173 million tons of peat deposits throughout the country. Production has yet to begin because it has not been considered as cost effective as other energy sources, given the country‘s existing technology.

Oil: A very insignificant reserve of oil was found in Bangladesh serendipitously, in 1986. The country possesses a small proven oil reserve of 56.9 million barrels [4].Between 1987–94, about 0.65 million barrels of crude oil was produced. But the production was suspended in 1994 and has remained inactive due to techno-economic considerations. So, Bangladesh is fully dependent on importing of oil. The import statistics of POL and crude oil of last few years is as follows:

Table 1.1: Imported quantity of pol products during 2009-2017 (M.Ton)

YEAR/PRODUCT	GAS OIL	JET A-1	MOGAS	SKO	HSFO	LUBE
2009	2243758	256576	98064	141103	0	7248
2010	2186597	339998	90197	107758	0	4745
2011	2955798	318202	95824	153598	665260	4980
2012	2618685	339699	95824	20380	670899	4852
2013	2608746	310884	97641	28376	1005104	-
2014	2903928	334079	35596	0	869124	-
2015	2974749	338315	33842	0	414451	-
2016	3130052	354430	150601	0	481673	-
2017	3716349	393918	32837	0	563856	-

Source: Bangladesh Petroleum Corporation

Table 1.2: Imported quantity of crude oil during 2009-2017 (M.Ton)

YEAR/PRODUCT	ALC	MURBAN	TOTAL
2009	612913	425614	1038527
2010	620238	654832	1275070
2011	627535	583960	1211495
2012	682039	583494	1265533
2013	592054	591091	1183145
2014	592865	714746	1307611
2015	697667	395006	1092673
2016	728307	579848	1308155
2017	497907	667861	1165768

Source: Bangladesh Petroleum Corporation

Hydropower: Being essentially a delta, Bangladesh has limited hydropower potential. According to assessments report in the Bangladesh Government‘s Power System Master Plan 1995, the country has the potential to produce 755 MW (megawatts) of hydropower per day. At present, its sole hydropower plant‘s production capacity is 230 MW per day.

Natural gas: In the overall energy picture, the country‘s natural gas endowment in comparison to other energy resources makes Bangladesh essentially a mono-energy country. It is estimated that Bangladesh‘s net recoverable reserves of natural gas (as of April 2002) lie in a range from 12.04 TCF (Trillion Cubic Feet) to 15.55 TCF. The national energy balance of Bangladesh clearly depicts that natural gas is Bangladesh‘s only significant indigenous source of commercial energy. It is the principal source of energy for country‘s power, industry, commercial, and domestic sectors. Natural gas provides over 90 percent of Bangladesh‘s electricity, and is also the feedstock and fuel of the urea and ammonia fertilizer plants. Urea has helped Bangladesh attain self-sufficiency in rice production—the major local food crop. Natural gas at present is undoubtedly an important driving force of its economy. The future development of Bangladesh‘s economy depends largely on the government‘s ability to sketch out a natural gas strategy that offers the best prospects of utilization of this unique asset of the country and to find other renewable sources of energy to reduce heavy dependence on the natural gas.[5]

1.3 What is Biodiesel?

Biodiesel is considered a renewable, clean burning and nontoxic fuel alternative for diesel engines. Figure 1.1 illustrates the cycle: how biodiesel is produced from vegetable oils from oil crops (such as soy or sun seed). The main reaction behind the biodiesel production is the transesterification reaction. The vegetable oils (consisting mainly of mono, di and triglycerides) are converted into Fatty Acid Methyl Esters (FAME) and the byproduct glycerol if using methanol. Other sources for raw material can be waste vegetable oil, but when cooking with vegetable oil the carbon chains of the glycerides could be broken and forming free fatty acids (FFA). FFA can be converted into biodiesel through a process, called esterification. The biodiesel can be used as a direct substitute for fossil diesel in public transportation. The emission (mostly CO_2) does not contain sulphur and represents a closed carbon cycle, is therefore called carbon neutral fuel, and is easily absorbed by the crops, producing oxygen, and more crops by photosynthesis [6].

Esters are organic compounds composed of an alcohol and an organic acid. Glycerol makes up ten percent of the total product and cannot be used as fuel, but it is used in many common products like cosmetics (moisturizing cream). Currently, methanol petroleum based product, is the most commonly used alcohol due to low cost and high availability.

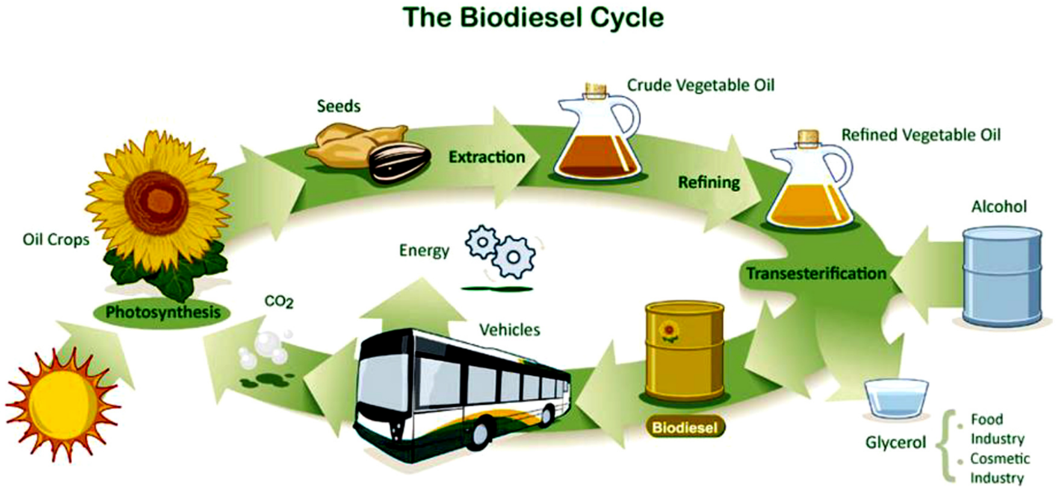


Figure 1.1: Illustration of the process from growing the crops to production and the use of biodiesel [7].

1.3.1 Historical developments of biodiesel

The idea of using vegetable oils as fuel appeared more than one hundred years ago. As Knothe [8] points out in a review on the historical development of biofuel production, Rudolf Diesel conducted engine tests using peanut oil at the show in Paris 1900. Such a demonstration was held under the auspices of the French government, which was interested in their African colonies becoming self-sufficient in fuel consumption. However, as petroleum-based fuels soon became available in large quantities at comparatively low cost, the interest in vegetable oils diminished.

However, some inherent chemical nature of the properties vegetable oils, mainly their low volatility and high viscosity, leaded to a number of technical drawbacks which limited the use of such oils directly in diesel engines, especially those with direct injection. The high viscosity of the oil (of the order of ten times, or more, higher than that of conventional diesel fuel) hinders the process of atomization of the jet. The high end point of the distillation curve, coupled with poor fuel atomization, leading to incomplete evaporation and mixing processes and poor combustion (formation of particles and carbonaceous deposits) [9, 10]. Due to the high temperatures reached in the combustion chamber, the oil can undergo thermal decomposition upon combustion, which also contributes to the formation of deposits on injectors, combustion chamber, pistons and valves. The extremely high flash point of vegetable oils and their tendency to thermal or oxidative polymerization aggravate the situation, leading to the formation of deposits on the injector nozzles, a gradual dilution and degradation of the lubricating oil, and the sticking of piston rings [11]. As a consequence, long-term operation on neat plant oils or on mixtures of plant oils and fossil diesel fuel inevitably results in engine breakdown. These problems can be solved by either adapting the engine to the fuel or by adapting the fuel to the engine. In addition, the crankcase oil can pass unburned diluting the lubricating oil and deteriorating. To overcome the above difficulties, alternative solutions have been proposed, i.e. preheating the oil, the use of oil mixed in very low proportions with petroleum diesel fuel [12], the introduction of modifications in conventional engines, building engines specifically designed to operate with vegetable oils and processing of the oil. Since the use of mixtures of vegetable oil and diesel fuel in modern engines can present similar difficulties as those reported for pure oils, the recommendation is based on the transformation of the oil, so a fuel with properties similar to conventional diesel fuel is obtained. Alternatives to transform the oil include thermal decomposition or pyrolysis oil [13] the preparation of microemulsions [14] and transformation of triglycerides in BD through transesterification reaction [15]. The oleochemical route proposed in the last alternative is the most expeditious for fuel and is now called BD pathway.

The term BD is restricted exclusively to mixtures of monoalkyl esters of fatty acids (FA) derived from renewable lipid as oils and fats of vegetable or animal origin [9]. The first report of the use of monoalkyl esters of FA as fuel appears in Belgium in 1937 [16]. In this patent, the collection and use of ethyl esters of palm oil was included. In 1980, two patents, a Brazilian and a German, contemplating the use of methyl esters as fuel were recorded. Despite the alcohol industry of bioethanol as fuel had its origins in the American continent (Brazil and USA), the BD industry was initially developed in Europe. Austria was the pioneer in BD production and the development of quality standards. The first plant for the industrial production of BD was built in 1991 in the city of Aschach van der Donau (Austria), using rapeseed oil as raw material and in that same year the Austrian Standards Institute published the first quality standard for fatty acid methyl esters (FAME).

With regard to new materials, the current trend is the search for renewable sources of different triglycerides to traditional vegetable oils, such as nonedible vegetable oils, waste cooking oil, animal fats and oil from microalgae [17]. Today, BD is commercialized in many countries, including Argentina, Austria, Brazil, Czech Republic, Germany, France, Italy, Slovakia, Spain and USA for up to 20 years[9]. BD is either used in pure form or as a blend with fossil diesel fuel, which is stable at any concentration.

1.4 Chemical Principles of Transesterification

1.4.1 Transesterification reaction

In a transesterification or alcoholysis reaction one mol of triglyceride reacts with three moles of alcohol to form one mol of glycerol and three moles of the respective FA alkyl esters [18]. The process is a sequence of three reversible reactions in which the triglyceride molecule is converted step by step into diglyceride, monoglycerides and glycerol [19]. In each step one mol of alcohol is consumed and one mole of ester is liberated, as can be seen in Figure 1.2 which depicts the scheme for transesterification.

In order to shift the equilibrium to the right, alcohol is added in an excess over the stoichiometric amount in most commercial BD production plants.

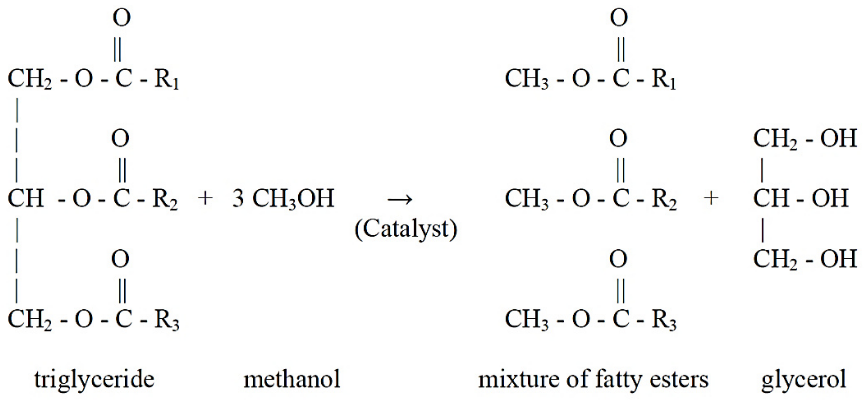
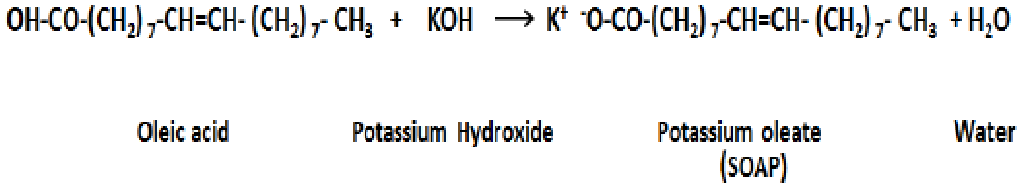


Figure 1.2: Transesterification reaction

1.4.2 Competitive reactions

It is common for oils and fats to contain small amounts of water and free fatty acids (FFA).When an alkali catalyst is present, the FFA reacts to form soap. Excessive soap in the productscan inhibits later processing of BD, including glycerol separation and water washing [20]. Figure 1.3 shows a common reaction between oleic acid and potassium hydroxid to produce soap.



$$OH\text{-}CO\text{-}(CH_2)_7\text{-}CH{=}CH\text{-}(CH_2)_7\text{-}CH_3 + KOH \rightarrow K^+\ {}^-O\text{-}CO\text{-}(CH_2)_7\text{-}CH{=}CH\text{-}(CH_2)_7\text{-}CH_3 + H_2O$$

Figure 1.3: Soap formation Reaction

Water in the oil or fat can also be a problem. When water is present, particularly at high temperatures, it can hydrolyze triglycerides to diglycerides and form FFA. Figure 1.4 shows a typical hydrolysis reaction [20].

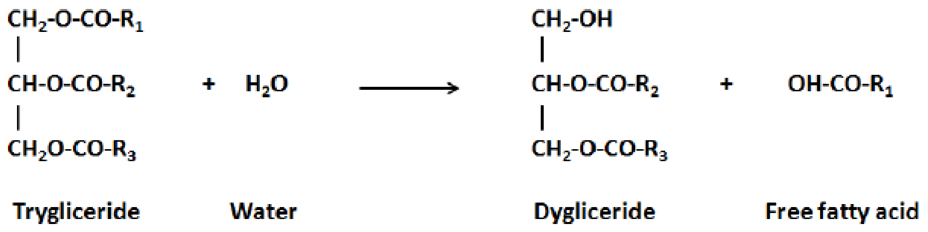


Figure 1.4: Hydrolysis reaction

1.4.3 Alcohols commonly used in biodiesel production

The most commonly primary alcohol used in BD production is methanol, although other alcohols, such as ethanol and isopropanol can be also used [20]. A key quality factor to choose the primary alcohol is the water content. Water interferes with transesterification reactions when using alkaline catalyst and can result in poor yields of BD, besides high levels of soap, FFA and triglycerides. Unfortunately, lower alcohols are hygroscopic and may absorb water from the air. Once transesterification is finished, methanol is considerably easier to recover than ethanol, as the latter forms an azeotrope with water so it is expensive to purify. If water is not removed it will interfere with transesterification reaction. Methanol can be recycled easier because it does not form an azeotrope. For this reason, as quality requirements, the alcohol needs to be undenatured and anhydrous. Since chemical grade ethanol is typically denatured with poisonous material to prevent its intake, to find undenatured ethanol is difficult [20]. Nevertheless, ethanol has positive characteristics for BD production as it can be considered a green reactant [20, 21]. In fact, bioethanol production through the fermentation of biomass or other renewable raw materials makes bioethanol a more sustainable reactant than methanol which is nowadays synthesized from fossil fuels [22].

Other advantage that brings methanolysis compared to transesterification with higher alcohols is the fact that the two main products, glycerol and FAME, are hardly miscible, thus producing separate phases (an upper ester phase and a lower glycerol phase). The former process makes easy to remove glycerol from the reaction mixture and enables high conversion. Ester yields can even be increased (minimizing the excess of methanol) carrying out the methanolysis in two or three steps. In this case, only a portion of the total alcohol volume required is added in each step and the glycerol phase produced is removed after each step is completed [20]. Reactivity of ethanol compared to methanol is a very controversial question and provided reactivity depends on many factors, generalities cannot be established. Some authors state that ethanol is less reactive than methanol, leading to lower yields [23]. In fact, ethoxide ions are more nucleophile than methoxide ions, but they have lower mobility due to their carbon chain length. However, the higher solvency of ethanol implies the formation of emulsions linked to the properties of ethanol that may complicate mass transfers.

1.4.4 Catalysts commonly used in biodiesel production

The catalyst may either be homogeneous or heterogeneous (including enzymes). Concerning homogeneous catalyst, the most commonly used catalysts to convert triglycerides into BD are alkaline sodium hydroxide and potassium hydroxide [20]. Basic catalysts are highly hygroscopic and form chemical water when dissolved in the reactant alcohol. They also absorb water from the air during storage. If excessive amount of water is absorbed by the catalyst, it will perform poorly and BD may not meet the European standard in terms of total glycerol. Alkaline catalysts give good performance when raw materials with high quality (FFA <1 % w/w and moisture <0.5 % w/w) are used [29]. Acid catalysts can also be used for transesterification, though they are generally considered too slow for industrial processing [20] and commonly used for the esterification of FFA, when the amount of FFA is high [20, 25]. The acid catalyst is mixed with methanol and then this mixture is added to the FFA or a feedstock that contains high levels of FFA; the acids will need neutralization when this process is completed, but this can be done as basic catalyst is added to convert any remaining triglycerides [20]. BD synthesis with heterogeneous catalysts involves the use of insoluble compounds in either methanol or ethanol reducing the problems arising from the employment of homogeneous catalysts, as contamination and washing steps. This could lead to a reduction of both environmental and economic costs [26]. These catalysts comprise a large number of compounds of different chemical nature such as alkaline earth oxides, alkali doped materials, transition metal oxides, hydrotalcites, mesoporous silicas, heteropolyacids, acidic polymers and resins, waste carbon-derived solid acids, miscellaneous solid acids, etc. [27].

The interest of lipases as enzymatic catalysts for the production of alkyl FA ester is growing in the last years. The advantages of using lipases to produce BD are, between others, the following:

i) Transesterification and esterification can be catalyzed by lipase simultaneously at low temperature (35-50 °C);
ii) During the transesterification reaction there is no risk of soap formation, simplifying the separation and purification of BD and glycerol; thus lipases are not corrosive to the production plant;
iii) The immobilized lipases may simply be separated and reused with a high catalytic activity [33]. The enzymes commercially used in the production of BD are extracted from different species as Pseudomonas fluorescens, Pseudomonas cepacia, Candida antarctica, Rhizomucor miehei, Thermomyces lanuginose.

1.5 Advantages of Biodiesel

1.5.1 Environmental benefits

The oil crisis has renewed an interest in alternative energy sources such as wind and solar power as well as alternative fuels. Biofuels include methanol, ethanol, biodiesel, and various diesel blends of the three. Biodiesel is environmentally superior to traditional diesel because it is renewable and emits lower emissions.

As populations expand, technology progresses, and cultures evolve humans create a setting where their relationship with their natural environment is incrementally complex. The continued existence of the species is dependent on the natural resources that sustain it. Hence the conservation and protection of our resource base must be a vital priority. In opposition to traditional fuels, finite resources extracted from the soil, biodiesel is renewable: it can be replenished at the same rate as it is being consumed. Biodiesel, when burned, releases less harmful emissions than diesel hybrid, B20 (20%biodiesel, 80% propane diesel), ethanol 85%, diesel or gasoline. In fact biodiesel has the following advantages when compared to traditional fuels:

Compared to gasoline:

- produces no SO_2;
- no net CO_2;
- up to 20 times less CO
- and more free oxygen

Compared to petroleum diesel fuel:

- Reduces net CO_2 emissions by 100%
- Produces no SO_2 emissions
- Reduces soot by 40-60%
- Reduces unburned hydrocarbon emissions by 10-50%
- Polycyclic Aromatic Hydrocarbons
- Slight increase of NO_X ,by 5-10%

The combustion of biodiesel is more complete and efficient than that of diesel or gasoline. Hence the process releases less carbon monoxide (CO), the most prevalent air pollutant whose main source happens to be non-ideal combustion. While most emissions are in the form of NO for the nitrous oxides (NO_X), NO has no adverse health effects. However, NO_2, the result of oxidation of NO, is related to respiratory diseases, acid rain, algal blooms and fish kills, and photochemical smog. Soot and polycyclic aromatic hydrocarbons (PAHs, of which many are carcinogenic) enter the human system in the form of particulate matter and are associated with respiratory diseases. Sulfur oxides (SO_X), with combustion being their main source, have adverse effects on health, a synergistic effect with particulate matter, and can result in acid rain. For human health as well as for environmental concerns, biodiesel is obviously a rational choice. It is a substantial step towards creation and diversification of energy sources therefore addressing the urgent and conflicting issues of rising energy demand and global warming.

1.5.2 Socio-economic benefits

Biodiesel, given an adequate access to used vegetable oil exists locally, can be produced locally. It can reinforce livelihoods through the creation of new jobs and business opportunities in the community. It can reduce dependence on fossil fuel imports and vulnerability to fluctuation of fuel prices on the world market; a tremendous economic and political advantage for any country especially an import-dependent country like Bangladesh.

1.5.3 Practical and technical advantages

Biodiesel is safe to handle because it is biodegradable and non-toxic. With a high flash point (or ignition temperature) of 300°F, compared to petroleum diesel fuel's flash point of 125°F, biodiesel is safer in transport and in storage. Engines running on biodiesel run normally and have similar fuel mileage to engines running on diesel fuel. Auto ignition, fuel consumption, power output, and engine torque are relatively unaffected by biodiesel. When burned in an engine, the exhaust fumes have the pleasant aroma of popcorn or French fries. Furthermore, Biodiesel has a higher lubricity, reducing wear and tear and enhancing lifetime of components. As it is also a mild solvent it cleans the engine as it runs.

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1.6 Disadvantages of Biodiesel

While many people consider the use of biodiesel is "carbon neutral", the machinery required to farm the plants for biodiesel does create carbon emissions, this machinery is also typically not powered by biodiesel. Research suggests despite this fact that biofuels help to reduce carbon emissions by 50-60%. One of the main detractors to the use of biofuels is that setting aside land for biofuel crops means less land for food production. Some of the countries have said that it is unethical to use crops for biofuel when global hunger is an ever present problem.

Despite the many positive characteristics of biodiesel, there are also many disadvantages to these energy sources which are mentioned below:

Energy output: Biofuels have a lower energy output than traditional fuels and therefore require greater quantities to be consumed in order to produce the same energy level. This has led some noted energy analysts to believe that biofuels are not worth the work.

Effects on Engine: The kinematic viscosity of biodiesel is higher than that of diesel fuel. This affects fuel atomization during injection and requires modified fuel injection systems. Its lower volumetric energy density means that more fuel needs to be transported for the same distance travelled when using biodiesel than when using diesel. It can also cause dilution of engine lubricant oil, requiring more frequent oil change than in standard diesel-fuelled engines. Moreover a modified refueling infrastructure is needed to handle biodiesel, which adds to its total cost.

Effects on food supply Chain: Agricultural feedstock is needed to produce biodiesel and at some times its availability might be constrained due to its necessity to produce food. This may impose limits on the production of biodiesel. There is concern that using valuable cropland to grow fuel crops could have an impact on the cost of food and could possibly lead to food shortages As demand for food crops such as corn grows for biofuel production, it could also raise prices for necessary staple food crops. Again, massive quantities of water are required for proper irrigation of biofuel crops as well as to manufacture the fuel, which could strain local and regional water resources

Effects on Environment: Biodiesel has high oxygen content, which, when combusted, produces higher NOx levels than the produced by mineral diesel. Oxidation of biodiesel happens more easily than oxidation of diesel, so, when it is stored for long periods some products that may be harmful to the vehicle components might be produced. Also Biodiesel is hygroscopic, it absorbs water easily. Water content of biodiesel is limited by the standards. Thus, contact of biodiesel with sources of humidity should be avoided.

Partly due to its local and home production, the biodiesel produced may not comply with European or US standards and it may cause corrosion, fuel system blockage, seal failures, filter clogging and deposits at injection pumps.

High Cost: To refine biofuels to more efficient energy outputs, and to build the necessary manufacturing plants to increase biofuel quantities, a high initial investment is often required.

1.7 World’s Biodiesel Production

Pioneering work in Europe and South Africa by researchers such as Martin Mittelbach in the early 1990s led to the development of the first BD industrial production plant in Austria in 1991. American industry was coming on more slowly due to lower prices for petroleum diesel fuel. "Pacific Biodiesel" became one of the first BD plants in the USA in 1996, establishing a BD production operation to recycle used cooking oil into BD on the island Maui in Hawaii. The BD industry became a household name in the USA after the terrorist attacks of 9 September, 2001, resulting in historically high oil prices and an increased awareness of energy security. In 2005, worldwide BD production reached around 1 million gallons, with most fuel being produced in the European Union (EU), although BD projects worldwide have been increasing due to rising crude oil prices and concerns over global warming [28].

The production of biodiesel has significantly increased in the mid- 2000s as can be observed in Figure 1.5 that is global BD production has always been increasing. It is important to mention that BD is becoming a significant fuel in the model of renewable energy production and consumption that each country is carrying out in order to be as independent as possible from fossil oil.

With regard to raw materials that have been mostly used in BD production, rapeseed, soybean and palm oils are the preferred ones. In this way, according to predictions of Oil World Information Service about increasing global production and consumption of BD in 2014, reports include that one-third of the nearly 30 million t of BD production comes from palm oil, thus becoming the main raw material used, followed by soybean and rapeseed oils [37]. The EU is the world top importer of palm oil for BD. Table 1.3 shows global BD production worldwide in the last seven years. In 2013, EU reached a record of 6.9 million ton of palm oil, of which 3.7 million were derived to energy production, including BD (2.5 million). The data provided by the Oil World Information Service report, confirmed that the main target of palm oil entering the EU is energy. Oil World Information Service estimated around 9.6 million ton of palm oil used for BD consumption in 2014 worldwide, offering the outstanding case of Indonesia, which can go from 1.2 to 3.8 million ton [29].

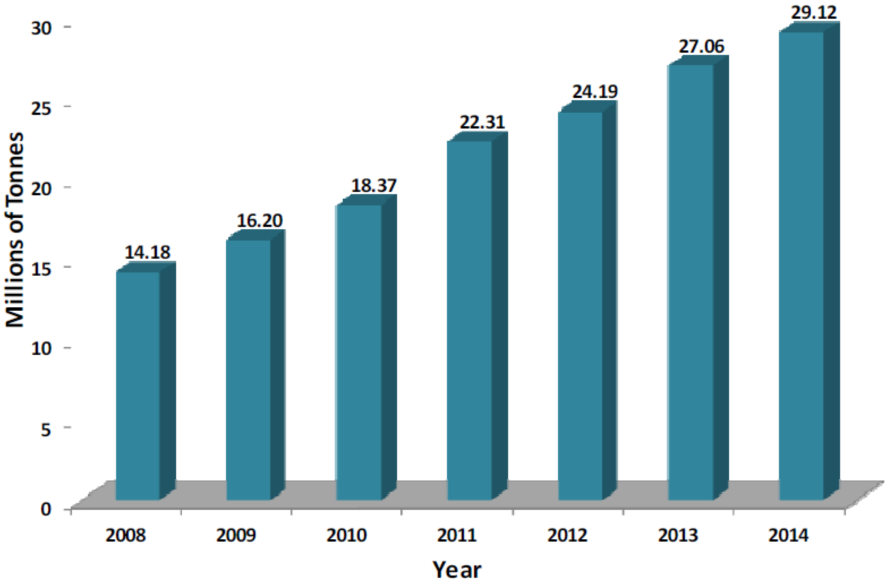


Figure 1.5: World biodiesel productions in recent years. [29]

According to Table 1.3, the second commodity most used for BD production, soybean oil, reaches 7.3 million t in 2014, USA being the leading manufacturer (2.3 million tons), followed by Brazil (2.2 million) and Argentina (2 million). Third preferred raw material is rapeseed oil, showing a production of 6.4 million t in 2014. World Oil Information Service considered that used cooking oils have also become an important raw material, with a projected 2.3 million tons of BD production. Oil World Information Service also quantified 30.85 million t of vegetable oils and fats consumption, of which 17.8 million were for food uses and 9 million to produce BD.

Table 1.3: World biodiesel production data by raw materials (Million Ton.) [29]

PRODUCER COUNTRIES		**YEAR**						
Ranking	Raw material	2014	2013	2012	2011	2010	2009	2008
WORLD BIODIESEL PRODUCTION		29.12	27.06	24.19	22.31	18.37	16.20	14.18
World soybean oil biodiesel Production		7.29	7.00	6.83	7.37	5.34	4.38	4.53
1	USA	2.27	2.50	1.83	1.88	0.52	0.96	1.62
2	BRAZIL	2.16	1.89	1.8	1.91	0.74	1.10	0.85
3	ARGENTINA	2.05	2.00	2.44	2.43	1.82	1.18	0.71
4	EU	0.40	0.27	0.44	0.84	0.97	0.85	0.14
World rapeseed oil biodiesel production		6.41	6.23	6.25	6.23	6.34	5.71	4.98
1	EU	5.76	5.64	5.64	5.64	6.07	5.42	4.70
2	USA	0.33	0.29	0.36	0.38	0.11	0.15	0.18
World palm oil biodiesel Production		9.56	8.59	6.82	5.12	3.99	3.37	2.28
1	INDONESIA	3.80	2.63	1.93	1.38	0.68	0.04	0.32
2	EU	2.28	2.51	1.93	1.42	1.45	1.51	0.94
3	THAILAND	1.00	0.95	0.92	0.79	0.65	0.57	0.40
4	MALAYSIA	0.63	0.47	0.25	0.17	0.19	0.24	0.20
5	COLOMBO	0.54	0.50	0.49	0.44	0.34	0.17	0.04
6	SINGAPORE	0.42	0.41	0.55	0.34	0.12	0.05	0.00
World sunflower oil biodiesel Production		0.18	0.19	0.18	0.15	0.14	0.20	0.13
World grease oil biodiesel Production		2.17	0.94	1.52	0.43	0.98	1.03	0.87
Other raw materials		3.52	3.16	2.61	2.03	1.55	1.51	1.33

1.8 International Biodiesel Regulation

The continued global growth of BD production made necessary the standardization in BD quality. The introduction of a new product in the market implies the identification and overcoming of technique, economic, social and legislative barriers. It is important to implement rules or standards to define the quality of the product according to its use. The development of quality rules must be the result of exchange of information, discussion and consensus between the actors involved in the production and distribution. Standards are of importance for producers, suppliers and consumers of BD. Authorities need approved standards for the evaluation of safety risks and environmental pollution. Standards are necessary for approvals of vehicles operated with BD and are; therefore, a prerequisite for the market introduction and commercialization of BD. BD quality forces the inclusion of its physical and chemical properties into the requirements of the adequate standard. Quality standards of BD are continuously updated, due to the evolution of compression ignition engines, ever stricter emission standards, reevaluation of the eligibility of feedstocks used for BD production, etc. The BD specifications can have a direct influence on the selection of raw materials and production technologies. Development of BD standards started in the 1990s, to support the increasing use of alkyl esters-based BD and its blends as automotive fuels.
Biodiesel standards in comparison to Diesel Fuel of USA and European Union is given in the Table A1 and A2 of Appendix - A.

1.8.1 American standards

In June 1994, a Task Force was formed within the American Society for Testing and Materials (ASTM) to begin the development of a standard for BD. The first step undertaken by the Task Force was the determination of the philosophy for the standard. Various options were considered, from adding a section to the existing ASTM petrodiesel standard (ASTM D975), to the development of a standard for a blend of BD with petrodiesel, or even a stand-alone standard. The following was agreed upon by *Biodiesel Task Force* and subsequently by the membership of ASTM in the mid-1990s:

1. To develop a stand-alone specification for straight BD, B100.
2. To work closely and cooperatively with petroleum, engine manufacturing and BD interests.
3. To base the development of the standard on the end-product physical and chemical attributes needed for satisfactory operation, not on the source of BD or the manufacturing process. This is the same philosophy used for the development of the USA petrodiesel specification, ASTM D 975.
4. To begin with existing D975 petrodiesel specifications, removing items not applicable to BD.
5. To extend it to new characteristics being considered for D975 updates.
6. To extend it to address BD specific properties needed for satisfactory engine operation.

Subsequent to the introduction of ASTM D 6751 in 2002, an additional change was approved in 2003 to account for the upcoming EPA regulation requiring 15 ppm maximum sulfur level. Finally, ASTM D6751-03 standard specification for BD fuel blend stock for distillate fuels was approved. This norm defines BD as "*mono-alkyl esters of long chain fatty acids derived from vegetable oils and animal fats"*. The type of alcohol used is not specified. Thus, mono-alkyl esters could be produced with any alcohol (methanol, ethanol, etc.) as long as it meets the detailed requirements outlined in the fuel specifications. By requiring that the fuel be monoalkyl esters of long chain FA, other components, with the exception of additives, would inherently be excluded. Since 2012, the ASTM D6751 standard defines two grades of BD: grade 2-B (identical to BD defined by earlier versions of the standard) and grade 1-B with tighter controls on monoglycerides and cold soak filterability. Two automotive standards for biodiesel/diesel fuel blends have also been published by ASTM:

- The ASTM standard specification for diesel oil, ASTM D975, modified in 2008 to allow up to 5% BD to be blended into the fuel.
- ASTM D7467 is a specification for BD blends from 6% BD (B6) to 20% (B20).

1.8.2 European standards

The European standard EN 14214 is adopted by all 31 member states involved in CEN: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom [10]. The European BD specification is even more restrictive and is applied only to *mono-alkyl esters made with methanol* (FAME) [30]. The addition of components that are not FAME (other than additives) is not allowed. In Europe, EN 14214 establishes specifications for FAME used as fuel for diesel engines. European standard could be used unblended in a diesel engine (if the engine has been adapted to operate on B100) or blended with diesel fuel to produce a blend in accordance with EN 590, the European diesel fuel specification. EN 14214:2012 introduced a number of changes including an expansion of the scope to cover heating oil applications and updates to cover blends up to B10. An additional set of climatic classes based on monoglycerides content was also established.

Biodiesel/diesel fuel blends are covered by EN 590. EN 590:2004 allowed blends up to 5% of FAME in diesel fuel, while EN 590:2009 increased the allowable FAME content to 7%. The actual EN 590:2013 standard does not limit the blending ratio of the paraffinic bio-component in diesel fuels. Consequently, these products obtained by the catalytic hydrogenation of vegetable oils can be blended into gasoil by up to 10 % or even more to meet the above EU requirements with respect to the utilization of renewable fuels.

1.9 Research Objectives

The ultimate goal of this project is to design, manufacture and test a continuous flow biodiesel processor. Therefore, this project is divided into two phases:

a) In the first phase, the design, manufacture and test an automated small scale biodiesel plant flow system that will limit the operator interaction to deposit waste vegetable oil into the processor. The system should automatically take care of moving fluids throughout the system, all chemical reactions, draining of waste glycerol byproduct, and upon completion of a full cycle the system should present the operator with finished biodiesel that meets ASTM standards. This system will make it easy to produce sufficient amounts of biodiesel which can be used to fuel more diesel engines.

b) In the second phase of this project, it is to characterize and determine physical and chemical properties and fatty acid compositions of the produced biodiesel. Also conducting engine performance and emissions analysis of biodiesel produced from some selected edible and non-edible biodiesel feedstocks.

1.10 Thesis Organization

Chapter 1 gives an overview of the research topic. It starts by giving an introduction to the importance of energy, GHG emissions, climate change, increasing prices and expected depletion of fossil fuels, importance of biofuels, and suggests biodiesel as a solution for the current world energy crisis. Here also the transesterification reaction is explained thoroughly, including reagents, catalysts, mechanism and conditions. Eventually, the advantages and disadvantages of biodiesel are displayed. This is followed by a background that shows the importance of biodiesel and gives some examples of biodiesel feedstocks around the world.

Biodiesel is whether keep a good aspect in worldwide use is discussed also. Some graphical surveys are given to make a specific idea and knowledge about it. The present and upcoming demands are shown with some recent calculated data tables. In third world country and developing country like Bangladesh how this renewable energy gives positive and effective impact over using conventional energy like natural gas, other petroleum oils used in vehicles are explored in this chapter.

Biodiesel standards and characterization, properties and qualities of biodiesel al around the world is also discussed in this chapter.

Chapter 2 deals with some of the research works done before in Bangladesh. Specially compares the fuel properties of various blends prepared by various researchers. This chapter also shows the prospect of different edible and non-edible oil source available in Bangladesh for the preparation of biodiesel. Also this chapter explored the conceptual design and fabrication of automated biodiesel production system by reviewing various works done by different researchers all around the world.

Chapter 3 explains in detail the research design and constructional details of the small scale biodiesel plant.

Chapter 4 describes the different experimental set-up and procedures both for measuring fuel properties and study of engine performance.

Chapter 5 is dedicated to show all the results that have been obtained from the experimental work and present the findings of the study followed by a detailed discussion and analysis of these findings besides comparing them with the existing results included in the literature.

The performance and optimization of various operating parameters of the automated Biodiesel Plant is analyzed in this section.

Again, the performance test of IC engine and performance parameters like torque, BMEP, thermal efficiency, Bsfc, volumetric efficiency, air fuel ratio, exhaust temperature etc. against speed are analyzed with the various blends of biodiesel.

Also, the engine's exhaust gas emissions such as carbon di oxides, carbon monoxide and oxygen, NO_X, SO_2 etc are measured. It is observed that various biodiesel blends (soybean oil, waste soybean oil palm oil and mustard oil) cause reduction of emissions remarkably. It is also observed that, there is a decrease of the noise of engine while performing with biodiesel blends.

The cost analysis of the biodiesel and comparative analysis of different biodiesel blends are also discussed on this chapter.

Chapter 6 provides a summary of the key findings in the light of the research and puts forward some recommendations for the future studies.

CHAPTER -2

LITERATURE REVIEW

2.1 Prospects of Biodiesel in Bangladesh

In Bangladesh, Biodiesel can be produced from both edible and non-edible sources of oil such as Soybean (Glycine max) [31, 32], Mustard (Brassica nigra) [33-35], Sesame (Sesamum indicum) [36], Mosna, Jatropha (Jatropha curcas) [37-39], Castor (Ricinus communis) [40-42], Bahera (T. bellirica) [43], Neem (Azadirachta indica), algae [44-46] etc. Soybean cultivation in Bangladesh is limited. Bangladesh can meet only 40% of its Soybean oil demand by producing locally. But 0.7 – 0.8 million hectares of land in char areas could be brought under Soybean cultivation. About 1.7 – 1.8 million metric ton of Soybean could be produced. It can be used for human consumption as well as Biodiesel production. Mustard plants grow widely all over the country. The production of Mustard seed exceeds the demand in every year. The surplus Mustard seed can be used as a source of Biodiesel. Sesame grows in almost all over the country. Sesame contains 42.5% - 46.2% oil [47]. Mosna is one of the edible oil plants that are mainly cultivated in the southern part of Bangladesh. The production of Mosna needs less fertile land. The cultivation of Mosna is cheaper than other vegetable oil plants. Jatropha is a non-edible plant. It grows in arable and arid lands. It contains 30% - 40% oil. Jatropha can be cultivated in the southern part of Bangladesh. Castor grows almost everywhere in Bangladesh. It can grow in stony, sandy and saline lands. Castor seeds contain 67.7% oil [47]. Castor plant can live for many years. It can produce huge amount of seeds every year. Bahera is found in large proportion in Bangladesh. It is commonly used as a medicinal plant. It can be cultivated almost all over the country though preferable in tropical and subtropical areas. Bahera fruits contain about 30% oil by mass of crushed Kernel. Neem is a non-edible plant. It grows everywhere in Bangladesh. Neem seeds contain 45% oil. The climate of Bangladesh is suitable for algae production. Algae can grow rapidly in fresh water, saline water, waste water and arid lands. The number of species of Algae varies from 30,000 to over 1 million. Some of them contain up to 80% oil of their dry weight. Algae possess fast growth rate and high productivity. The fuel properties of various Biodiesel feedstocks have been studied by the researchers of Bangladesh. Table 2.1 shows the fuel properties of some of the Biodiesel feedstock oil [31-46].

Table 2.1: Fuel properties of Biodiesel from different feedstock

Fuel	S.G. at 15°C	Kinematic viscosity (mm^2/s) at 40°C	Moist cont. (%)	Calorific value MJ/kg	Cetane No	Flash point (°C)	Fire point (°C)	Cloud point (°C)	Pour point (°C)
Diesel	0.85	2.98	0.05	43.4	47	72	210	-15 to 5	-35 to -15
Biodiesel standard	0.88	1.9 to 6.0	0.05 max	37.5	48 to 60	100 to 170	-	-3 to 12	-15 to 10
Soybean	0.928	5.4	0.05	38.2	37.9	135	342	-3	-6
Mustard	0.938	7.28	0.005	39.51	53	156	343	3.2	-4
Sesame	0.922	36.0	---	43.54	41.8	170	---	-6	---
Mosna	0.903	25.24	---	46.39	---	---	---	---	---
Jatropha	0.87	4.59	0.005	39.5	43	182	190	2.7	2
Castor	0.9628	15.98	---	36.25	55.9	183	335	3	2
Bahera	0.9077	5.936	0.07	---	53.4	162	---	5	1
Neem	0.968	50.3	0.005	39.81	31	76	---	9	2
Algae	0.864	4.519	0.005	41	48 to 65	75	81	-5.9 to 3.9	-12

Some Biodiesel feedstocks have the better calorific value and Cetane number. Mosna oil has the calorific value of 46.39 MJ/kg. The Cetane number of Mustard oil, Castor oil and Bahera oil is 53, 55.9 and 53.4 respectively. The properties of Algae Biodiesel are comparable to the properties of Diesel. Some other sources of Biodiesel are also available in Bangladesh such as Karanj (Pongamiapinnata) [48, 49], Cottonseed (Gossypiumhirsutum), Coconut (Cocosnucifera) [50], Rubber (Heveabarasiliensis) etc. The cultivation of Karanja plant in unused land of Bangladesh can reduce imported petroleum oil by 28%. Oil content of Karanja is 31.8% [51]. Cotton is mainly grown as rain fed crop in Bangladesh. It is generally cultivated in south western region, northern region, central region and hilly areas. An experiment showed 77% Biodiesel production from Cottonseed oil with 20% Methanol in presence of 0.5% Sodium hydroxide. Coconut is widely growing tree in Bangladesh. In the southern part of the country, coconut is considered as natural asset. Biodiesel can be produced from Coconut. Oil content of Coconut is comparatively higher than Soybean and Mustard. Coconut oil has better lubricant property. Rubber seed oil is a non-edible feedstock for Biodiesel production. Bangladesh has huge potentiality to grow Rubber seed. Rubber seeds contain 49% oil. Rice bran oil can be a potential Biodiesel feedstock in Bangladesh. Rice bran is a by-product of rice mill that contains 15-23% lipids [52].A local plant named Jamalgota (Corton Tiglium) can be the Biodiesel feedstock with oil content of 32-40% of the weight of dried seeds. Biodiesel also can be produced from mixed feedstock oil. In an experiment, mixed feedstock oil is prepared by random mixing of

Bakul oil, Waste Cooking oil, Nahor oil, Pitraj oil, Karanja oil and Castor oil [53]. Table 2.2 shows the properties of the mixed feedstock oil Biodiesel [53].

Table 2.2: Fuel properties of mixed feedstock oil Biodiesel

Fuel	Specific gravity	Kinematic viscosity (mm2/s) at 40°	Moisture content (%)	Flash point (°C)	Cloud point (°C)	Pour point (°C)
Mixed feedstock Biodiesel	0.82 at 25°C	3.96	0.05	155	3	0
Biodiesel standard	0.88 at 15.5°C	1.9 to 6.0	0.05 max.	100 to 170	-3 to 12	-15 to 10
Diesel	0.85 at 15°C	2.98	0.05	72	-15 to 5	-35 to -15

The oil composition is 33% Waste Cooking oil, 25% Pitraj oil, 25% Castor oil, 7% Bakul oil, 5% Nahor oil, 5% Karanja oil. Oils are collected from the local sources of Sylhet city in Bangladesh.

2.2 Potentiality of Biodiesel Feedstock in Bangladesh

Bangladesh is an agricultural country, where grows many kind of seeds either it is edible or non-edible. But the edible sources are not promising as they need arable lands for cultivation. The arable lands in Bangladesh are used for food production. About 47750 km of road and railway side arid lands can be used to produce non-edible Biodiesel feedstock. If those plants from whose seeds biodiesel is produced cultivated here it is possible to get huge amount of seeds.

2.2.1 Status of vegetable oils in Bangladesh

As Bangladesh is an agro-based country and suitably placed on the globe it has technological suitability and potential resources such as suitable soil, water and climate to grow more than one oilseed crops throughout the year [54], and as such a wide variety of vegetable oilseeds are produced each year mainly in the winter season. Common plant origin vegetable oils are mustard, sesame, soybean, sunflower, linseed, groundnut, cottonseed etc. Among the vegetable oilseeds produced, only a few are used for extraction of oils from them for multi-purpose uses.

The production of oilseeds in this country seems to suffer from unplanned input and management strategy. The existing policy is not enough to support a large scale production and processing towards attaining self-sufficiency [55, 56]. Production of some oilseeds can be increased in a planned way if the current extremely limited use of their oils is extended to non-edible purposes as substitute of petroleum products and mineral oils.

In Bangladesh only around 4.3% of the total cultivable land consisting an area of about 1.45 million acres goes into production [57] of mustard, sesame, groundnut and sunflower. An additional 1.2 million acres of lands in tea gardens, forest areas and the uncultivable lands in 'haor' and 'char' can be used for production of vegetable oilseeds. The total production can be estimated upto 1.0 to 1.2 million MT of oilseeds against the current production of 0.45 million MT.

Vegetable oils are mainly consumed as cooking oil which is estimated to be around 85% of the total available oils in Bangladesh [57]. Although several researches have been carried out on edible oilseeds but no consideration has been given to non-edible oils and their production potentialities. Main non-food uses in Bangladesh are in soap industry, surface coating (e.g. paints, varnishes etc.), printing inks, cosmetics and personal care products (especially coconut oil), textile processing, leather processing, shoe polish etc. Obviously the demand is not very high and there is no drive for increasing their production.

Table 2.3: Area and Production of Oil seeds in Bangladesh 2013-14 to 2015-16. (Area in acres and production in metric tons)

Name of Crops	**2013-14**		**2014-15**		**2015-16**	
	Area (acres)	**Production (M. Ton)**	**Area (acres)**	**Production (M. Ton)**	**Area (acres)**	**Production (M. Ton)**
Sesame(Till) (Rabi & Kharif)	8707	2997	8530	2970	99592	36921
Rape & Mustard (Local &HYV)	710562	280870	802882	359452	787025	361909
Groundnut (Rabi & Kharif)	72570	56039	78464	56713	88245	62264
Sub-Total	**791869**	**339906**	**889876**	**419135**	**974862**	**461094**
Linseed	22045	6172	17320	4865	16207	4475
Soya bean	150472	112024	118326	91496	124289	92181
Coconut	5822	347474	9152	383833	5878	374269
Other Oil Seed (Verendha, Sunflower etc)	2896	1724	3294	2148	4009	2229
Sub-Total	**181235**	**417269**	**148042**	**482342**	**150383**	**473154**
Grand-Total	**973104**	**757175**	**1037918**	**901477**	**1125245**	**934248**

(Yearbook of Agricultural Statistics-2016, 28th Series)

The production of mustard seed in every year is higher than any other oil seed. The environment also suitable for production of mustard. Every year the cultivating land is decreasing. To achieve the sufficient production of mustard as alternative fuel must be increased production per hector.

2.2.2 Potentiality of non-edible oils in Bangladesh

The area of Bangladesh is about 147,570 square kilometers having a population of 138.8 million [58]. Being over populated country it is not really possible to use edible oil sources for the biodiesel preparation purposes except the only choice is non-edible oil sources. The cultivable lands are can't be used for growing nonedible oil seeds because it is already using for growing edible oil seeds. So our only hope is the rail and road side areas as well as the lands which can't be used for Cultivation purposes [58]. Amounts of unused land are not too much to grow a huge number of non-edible oil seeds, thus rail and road attracts our consciousness. Considering the oil content of those forest seeds described in the above section we have done our assumption on biodiesel production. Table 2.4 shows the potential places for non-edible oil seeds production and Table 2.5 shows the potentiality calculation for biodiesel production in Bangladesh.

Table 2.4: Potential places for non-edible oil seeds production [58]

Total road line	= 21040 Km
Total rail line	= 2835 Km
Total amount of road side	= 42080000 m
Total amount of rail line side	= 5670000 m
Distance between two trees	= 2 m
Types of seeds	= 10
Total number of each kind of seeds planted both sides of road and rail line	= 2387,500

Table 2.5: Potentiality calculation for biodiesel production in Bangladesh [58]

Species	Oil content of kernel (%)	Yield (%)	Seed from each tree (assumed), Kg	Total amount of seed, Kg	Total amount of oil (ton)	Amount of biodiesel (ton)
Jaina	68.05	79	5	2387,500	162470	128351
Nageswar	65.26	82.45			155810	129322
Rubber	46	50			109825	54913
Pitraj	36.53	79			87215	68900
Bakul	45.31	68			108180	73562
Palm	60.22	79			143780	113586
Rata	43.88	77			104764	80668
Karanja	8.38	79			200073	158058
Chaulmoogra	46.38	79.5			110735	88590
Ponyal	58.38	76			139383	105931
Total					**1322,235**	**1001,881**

In Bangladesh, Algae can be the most effective source of Biodiesel. Algae possess high productivity and high lipid content. Producing 1kg of Algae Biodiesel can fix 1.83 kg of CO_2. Algae can be produced in non-arable lands, fresh water, salt water and waste water. In Bangladesh, about 4.418 million hectares of infertile land, 1.383 million hectares of water areas (lakes, rivers, costal saline water etc.) and 0.31 million hectares of ponds are available which can be used for Algae production. Flue gases and waste water of industries also can be incorporated with Algae cultivation which may reduce the production cost. To reduce the cost as lower as Diesel, more researches are needed to select the convenient species and production procedure. [59]

2.3 Automated Biodiesel Plant

The entire transesterification process requires a human operator to run and monitor the Transesterification system and interfere whenever needed. In order to make the process faster an advanced and smart system is required. The most common method for producing biodiesel is the one step or two-steps batch transesterification process on batch reactor which reacts at temperatures near the boiling point of alcohol. Batch processes have suffered several disadvantages compared to continuous processes because batch processes require larger reactor volume, resulting in higher capital investment [60]. Subsequently, continuous process in producing biodiesel from vegetable oils have been developed by some researchers to reduce a higher procurement cost and to enhance mixing of the reactants in order to improve the reaction rates [61-63].

The most common reactor for biodiesel production is the batch reactor which reacts at temperatures near the boiling point of alcohol. However, for large-scale industrial production of biodiesel using a continuous-flow reactor can lower production costs in compared to batch reactors. Highina,et.al [64] used batch reactor to produce biodiesel from Jatropha oil. The paper concluded that, 93% of triglycerides have been converted to the methyl esters as a result of using batch reactor.

In some literature, batch reactors are used for biodiesel production from vegetable oils and in some studies they compared both batch and continuous flow processes. Continues flow reactor replaced with the batch one, and it was indicated that both reactors performed similarly on an industrial scale.

Amir et al. produce biodiesel using a stirred batch reactor where waste cooking oil is used as feedstock and methanol as alcohol with molar ratio of 1:6 in the presence of potassium hydroxide as a catalyst with 1% by weight of waste cooking oil. In order to optimize the production process, two parameters of stirring velocity in 3 treatments (650, 550 and 450 rpm) and reaction time in 6 treatments (10, 20,30,40,50 and 60 min) was investigated. The results show that more than 95% of ester conversion occurred in the first 30 minutes. Biodiesel production increased in stirring velocity of 650 rpm and reached its maximum. Thus, reaction time of 30 min and stirring velocity of 650 rpm is optimal for biodiesel production from waste cooking oils in a batch stirring reactor. [65]

Leevijit et al. performed a simulation to optimize a mixing presentation of a permanent reactor for producing saleable Biodiesel from palm oil and to predict required residence times at the elected purities for transesterification of palm oil in optimized reactor [66]. Ghazi et al. discussed the concept of an incessant process in producing Biodiesel from Jatropha oil by using an oscillatory flow Biodiesel reactor [67].

Ghobadian et.al designed, fabricated and evaluated a novel biodiesel processor system with 70 liters capacity of batch type stirred tank reactor (STR). For efficient mixing both mechanical and hydraulic mixing has been incorporated. Also vacuum distillation method for methanol recovery, electrostatic coalescing method for glycerin separation and ion exchange dry wash is provided to increase the production capability and purity of biodiesel [68].

Stonestreet and Harvey [69] reported that oscillatory flow reactor is a novel type of continuous reactor, in which tubes fitted with orifice plate baffles have an oscillatory motion superimposed upon the net flow of the process fluid. The interaction between the fluid and the baffles creates the oscillatory motion of the fluid that generates excellent mixing and enhanced transport rates, whilst maintaining a close approach to plug flow. Oscillatory motion in the tube is provided by an electrically or pneumatically driven piston or diaphragm to oscillate the fluid or to displace series of baffles [70]

Hidayet et.al [71] developed an automated two stage biodiesel production system based on PLC (Programming Logic Control).

The relatively recent developments in heterogeneous-catalyst based supercritical biodiesel processing have enabled the construction of a simple, portable, efficient, automated and environmentally friendly biodiesel processing system. The processing of biodiesel in the supercritical state uses no water produces negligible waste and is insensitive to the free-fatty acid content in a lipid. McNeff et.al used a fixed-bed continuous-flow reactor containing a metal-oxide based catalyst and Operating temperature and pressure ranges were reported as 300 °C – 400°C and 17 – 28 MPa, respectively. [72]

Chen et.al designed a Tubular Reactor and reported extensively on the material properties of methanol in the supercritical state. However, the supercritical state properties of the lipid-plus-methanol system are still not well known or documented in the public domain. [73]

A work is carried out by Gajendra Kumar *et al.* to characterize a system for continuous transesterification of vegetable oil using five continuous stirring tank reactors (5CSTRs). Here the experimental conditions such as catalyst concentration, molar ratio (oil: methanol), reaction temperature, total flow rate, mixing intensity, and the residence time on biodiesel production from coconut oil were studies. The produced biodiesel is analyzed and characterized for their physical and fuel properties including density, viscosity, iodine volume, acid volume, cloud point, pure point, gross heat of combustion, and volatility. The purity and conversion of the biodiesel was analyzed by

HPLC. The authors have also noticed that a high stirring speed increased the reaction rate, but an excessive stir speed decreased the reaction rate and conversion to biodiesel. Furthermore, a higher catalyst percentage significantly increased the reaction rate and production capacity [74].

To make biodiesel an economically viable alternative fuel, the feedstock used for production must be relatively cheap. Waste cooking oils have the potential to reduce the raw material cost considerably. Many researchers have developed processes for converting waste oils into usable biodiesel fuel. For an effective reaction, the oil must be properly filtered to remove all contaminants. In the work of Zhang et al., an acid-catalyzed system was used to pre-treat the waste oil. Zhang et al. used pumps to provide the mixing in the reaction chamber and then used a water washing column to separate the mixture. [75]

This project is an attempt to build an automated system that will reduce operator interaction as well as to make the system affordable and completely portable. The system also have some options to change a few operating parameters such as time, rpm and temperature so that the final product can be studied for further optimization. Therefore the primary aim of the project is to explore for better and faster alternatives of biodiesel production and its commercialization.

2.4 Factors Affecting Biodiesel Production

Transesterification methods have been widely used to reduce the viscosity and improve the fuel property of vegetable oils. But the transesterification reaction is strongly influenced by several factors including molar ratio of alcohol, catalyst, presence of water, free fatty acid in oil samples, reaction temperature, reaction time and agitation speed. Many researchers have done research on optimization of these factors that will affect the transesterification reaction and a brief description is given below.

2.4.1 Effect of molar ratio of alcohol

Molar ratio of alcohol plays a vital role in biodiesel yield. Normally the transesterification reaction requires 3 mol of alcohol for one mol of triglycerides to three mol of fatty acid ester and one mol of glycerol. Excess amount of alcohol increases conversion of fats into esters within a short time. So the yield of biodiesel increases with increase in the concentration of alcohol up to certain concentration. [77, 78]

However further increase of alcohol content does not increase the yield of biodiesel but it also increase the cost of alcohol recovery [77, 78]. In addition to this the ratio of alcohol content may vary with catalyst used, i.e. when we use alkali catalyst the reaction requires 6:1ratio of alcohol to catalyze the transesterification of oils or fats [75, 76]. In case the oil samples contain high free fatty acid (FFA) such reaction does not respond to alkali catalyst. In that situation acid catalyst will be effective to catalyze the reaction and the reaction requires higher amount of alcohol than alkali catalyst. This is due to the fact that acid catalyst tolerates the FFA content and water content present in the oil samples. For example waste cooking oil requires higher ratio of alcohol i.e. 15:1 when subjected to acid catalyst reaction [75].

2.4.2 Effect of water and FFA contents

The water and Free Fatty Acid (FFA) contents are critical factors for transesterification reaction. Base-catalyzed transesterification reaction requires water free and low acid value (< 1) raw materials for biodiesel production. If the oil samples have high FFA content (more than 1%) then the reaction requires more alkali catalyst to neutralize the FFA. Presence of water gives greater negative effect than that of FFAs because Water can cause soap formation and frothing which can cause increase in viscosity. [79]

In addition formation of gels and foams hinders the separation of glycerol from biodiesel. Free fatty acid and water always produce negative result during transesterification and causes soap formation and consumes the catalyst which leads to reduction of catalyst effect. Water and FFA also leads to the reduction of methyl ester. To overcome this problem, supercritical methanol method (623 K, 43 MPa, 4 min of treatment with a methanol to oil molar ratio of 42:1) was proposed by Kusdiana and Saka which was compared to alkaline and acid-catalyzed method. It may be noted that water has less influence in supercritical methanol method. [80]

2.4.3 Reaction time

Freedman et al (1986) observed the increase in fatty acid esters conversion when there is an increase in reaction time. The reaction is slow at the beginning due to mixing and dispersion of alcohol and oil. After that the reaction proceeds very fast. However the maximum ester conversion was achieved within < 90 min. Further increase in reaction time does not increase the yield product i.e. biodiesel/mono alkyl ester [77, 78]. Besides, longer reaction time leads to the reduction of end product (biodiesel) due to the reversible reaction of transesterification resulting in loss of esters as well as soap formation [81].

2.4.4 Reaction temperature

Reaction temperature is another important factor that will affect the yield of biodiesel. For example higher reaction temperature increases the reaction rate and shortened the reaction time due to the reduction in viscosity of oils. However, many recherché found that increase in reaction temperature beyond the optimal level leads to decrease of biodiesel yield, because higher reaction temperature accelerates the saponification of triglycerides. [76, 77, 78]

Usually the transesterification reaction temperature should be below the boiling point of alcohol in order to prevent the alcohol evaporation. The range of optimal reaction temperature may vary from 50°c to 60°c depends upon the oils or fats used.

2.4.5 Catalyst concentration

Biodiesel formation is also affected by the concentration of catalyst. Most commonly used catalyst for biodiesel production is sodium hydroxide (NaOH) or Potassium hydroxide (KOH). However, Freedman et al found that the sodium methoxide would be more effective because mixing of sodium hydroxide with methanol produce little amount of water which inhibit the formation of end product (Biodiesel) due to the hydrolysis reaction. This is one of the reason for mixing of catalyst with methanol first and then added to the oil or fats. In addition to this when the concentration of catalyst is increases with oil samples; the conversion of triglycerides into biodiesel is also increases. On the other hand insufficient amount of catalyst leads to the incomplete conversion of triglycerides into fatty acid esters. However, optimal product yield (biodiesel) was achieved when the concentration of NaOH reaches 1.5 wt.% at the same time further increase of catalyst concentration proved to have negative impact on end product yield. Because addition of excess amount of alkali catalyst react with triglycerides to form more soap. [76, 77]

2.4.6 Agitation speed

Agitation speed plays an important role in the formation of end product (mono alkyl ester or biodiesel), because agitation of oil and catalyst mixture enhances the reaction. For example the mixing intensities chosen were 200 rpm, 400 rpm, 600 rpm and 800 rpm for 60 min while other parameters were kept constant. At 400 rpm higher conversion of end product were obtained. Because, lower stirring speed shows lower product formation. On the other hand higher stirring speed favors formation of soap. This is due to the reverse behavior of transesterification reaction. [81, 82]

CHAPTER-3

AUTOMATED BIODIESEL PLANT

3.1 General

Bangladesh produces huge grain and agricultural residues. Due to lack of economically viable technologies for their utilization, most agricultural residues are burnt in the field and village farmers and women use them for cooking purposes, which pollutes environment. But it may be the largest sources in terms of commercial and noncommercial sources in developing country like Bangladesh if proper scientific steps can be taken. Produce biofuel, bioenergy and bio-based chemicals through the lignocellulose biomass have been acknowledged world wide as an oil refinery science. It has also recently been highlighted because of high oil prices and global climate change by the over consumption of petroleum based products, particularly vehicle emission.

The thesis project aimed at constructing an inexpensive and automated biodiesel plant that would help mass produce biodiesel without manual observation. This is the first attempt ever undertaken in Bangladesh to produce biodiesel in an automated production system. The plant is about five feet high, completely portable and can fit into any corner. It's powered by 220V AC supply and can be used in both home and industries to produce biodiesel. The plant has different compartments for different raw material input. After all the inputs are given, it only requires to turn on the machine. A standard time and temperature for reaction is preset but it can be changed as per the requirements. Currently the plant in its miniature form has the capacity to produce 20 liters of biodiesel in 24 hours which includes the waiting time after trans-esterification reaction and water wash time for 4 hours. The complete final product can be extracted after 24 hours and the byproduct glycerin is also extracted out separately. It can be used again to recover methanol for further biodiesel production. The plant has simple construction geometry and can be built locally and it's very much on the budget. In Bangladesh biodiesel was conventionally produced in laboratory for research purpose, but this plant can be used to produce biodiesel for both research and commercial purpose conveniently. The specific goals for the design are:

- **Minimize manual labor**

With only one employee, the more automation in the system the better. Pumping systems were designed to eliminate the need for manual handling of products from one stage to another.

- **Minimize costs**

With a tight budget, cost was always the top concern. While there was a need to purchase essential tools, simplicity and cost-prevention measures remained a constant concern.

- **Flexibility**

The piping system was designed for one possible processing method, but several other methods were also identified. It is important that the system conserves the ability to experiment with different methods.

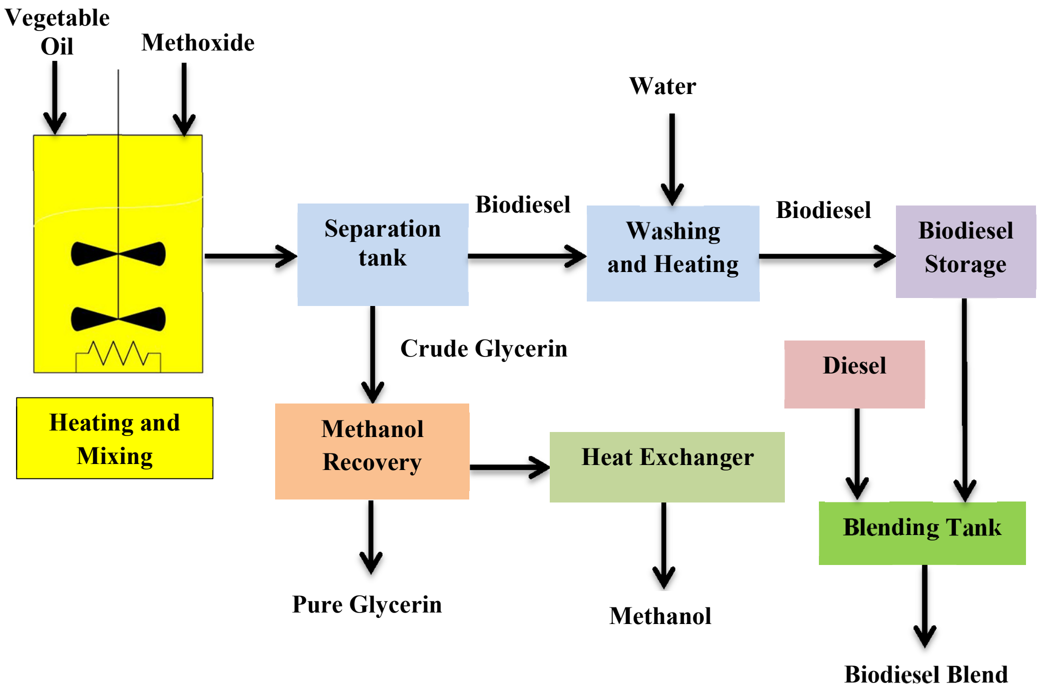


Figure 3.1: Process flow diagram of overall Biodiesel Production Process

3.2 The Process Design

Figure 3.2 shows the schematic diagram of the portable biodiesel processing plant which is divided in three separate sections. On top of the plant the two stainless steel tanks are situated for the storage of vegetable oil and methoxide. Middle section of the plant consists of the reactor, separator, washing tank, Control electronics and a blending tank. Bottom part of the plant contains a Diesel storage tank, Biodiesel storage tank, pressure pumps and methanol recovery unit. Figure 3.3 shows an illustration of the automated biodiesel plant which has been developed in this work. A functional description of different components is described below.

Table 3.1: Summary of the sections in the portable-biodiesel-processing-unit

Top Section	Middle Section	Bottom Section
Vegetable oil Storage tank MeOH storage tank	Reactor Control electronics Separation Washing and drying Heat exchanger Blending	Pressure pumps Diesel Storage Biodiesel Storage Methanol Recovery

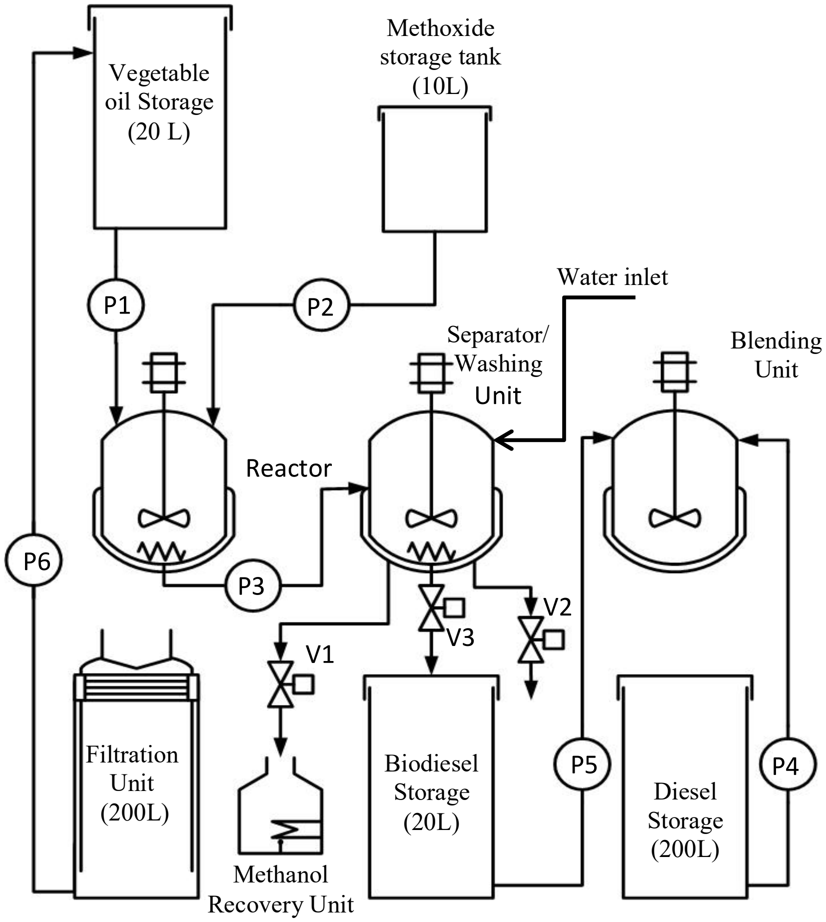


Figure 3.2: Schematic diagram of the portable-biodiesel-processing-unit

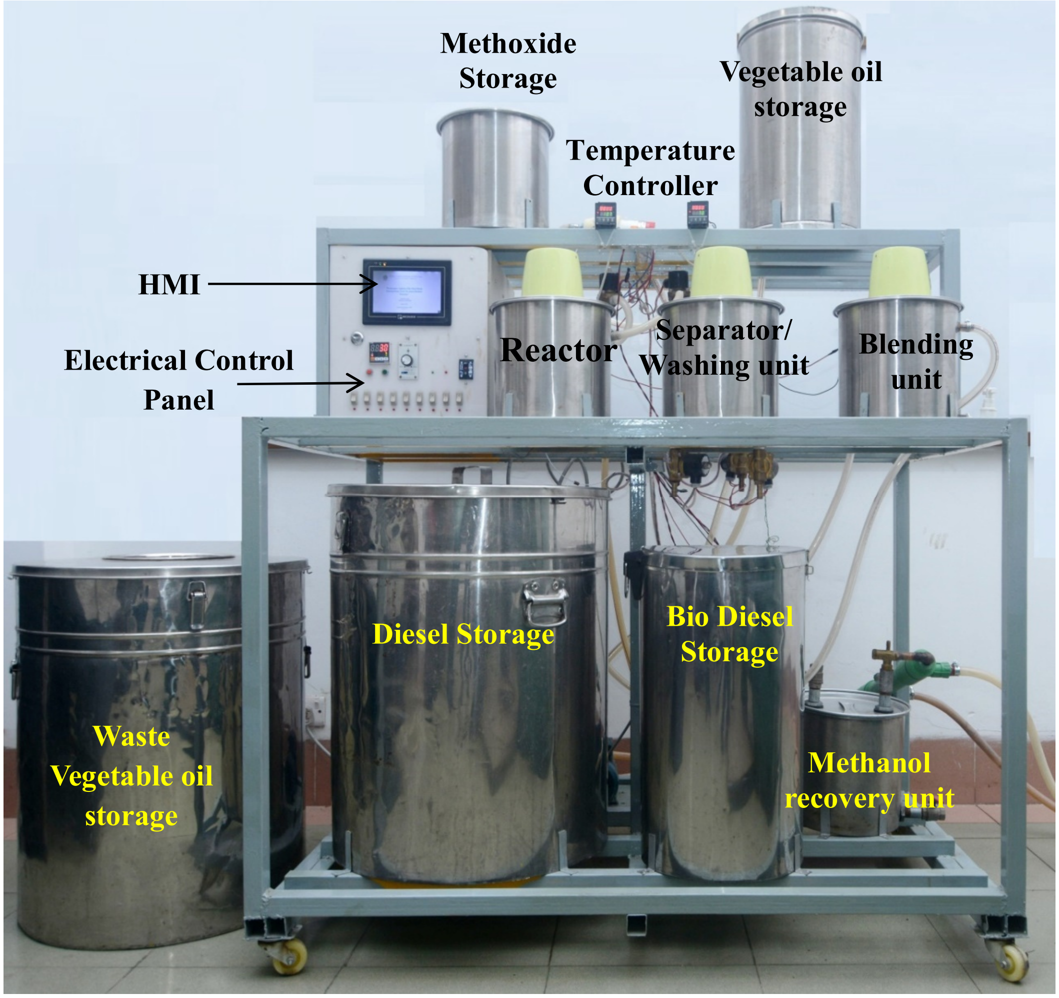


Figure 3.3: Illustration of the portable-biodiesel-processing-unit

3.2.1 Filtration of waste cooking oil

The waste cooking oil obtained from the cafeterias is pre-filtered to remove the extra-large particles from the grease. A better filtration system is required to produce pure products without particles floating inside. The filtration system will be coordinated with the input system to filter the waste cooking oil before it reaches the mixing chamber. A design challenge of creating a fully automated system is challenged by creating a filtration system that requires little to no changing of the filter. The goal is to ensure that filter maintenance does not become a nuisance. The filtration unit could include an automated cleaning system to reduce the amount of manual work or it could be a manual cleaning set of filters.

For separating impurities and suspended particles, at first the waste oil was passed through a fine strainer network manually. A wire screen that is placed at the top of the stainless steel container to collect large particles located inside the waste oil. The metal wire screen is woven to allow a pattern that only liquid and particles smaller than the holes are allowed to pass through. As the liquid passes through the strainer the particles are collected because they are not small enough to pass through the holes on the screen. Under the metal wire screen filter a fine mess cloth filter is there to collect fine debris of the WVO. This is a simple filtration system but if it becomes blocked by the particles buildup because they cannot pass through and then the liquid flow is stopped the system will not function. So a regular washing is required.

Water content removal is a great concern as water content in the oil may cause production of soap and reduce the efficiency of the reaction and make subsequent steps of biodiesel production difficult such as phase separation. Also have a significant impact on the percent of reactant conversion and the quality of products, in some cases, the water will not lead to reaction progress. Undesirable effect of water is more noticeable at higher temperatures. Water can causes triglycerides hydrolysis into diglycerides and produce free fatty acids, and alkaline catalyst can cause the free fatty acids conversion to the soap.

Two methods for removing water can be used, sedimentation and evaporation of water in oil. Here, we used sedimentation methods. In this method, the oil was heated to 60 ° C and kept at this temperature for 15 minutes. Then the oil is transferred to a settling tank and the water settled down at least in 24 hours. The advantage of this technique comparing with direct evaporation is reduction of free fatty acids production.

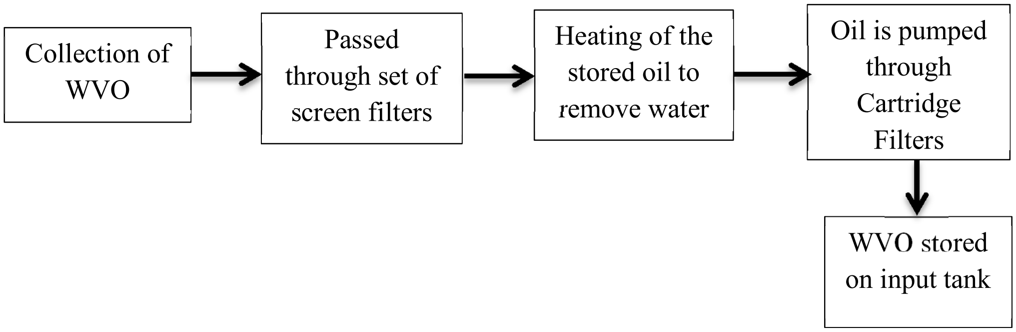


Figure 3.4: Process flow diagram of filtration of waste cooking oil

The system is also designed with an automated better filtration system to remove impurities from the WVO and moisture before future processing to biodiesel. It consists of taking the strained, heated oil and pumping it through two filters. The first filter is a 15-micron water block that is designed to remove water from the oil, while the second filter is a 10-micron filter that is designed to take out dirt and impurities in the oil (Figure 3.4). This process may be run twice so that will be able to produce a better overall biodiesel.

3.2.2 Reactor

Reactor is the sole part of the process in biodiesel production on which chemical reaction takes place. Batch and continuous reactors can be divided into two categories. Batch reactors simply made of a tank which equipped with stirrer. Tank is filled with the reactants (in this case waste cooking oil, alcohol, and catalyst), and then stirrer acts for a while. After the time required has elapsed, reactor contents drained and further processing is done. Beginning the process with the reactive substances and then leaving the processed materials is the main feature of batch reactors. In batch reactor we used the tank filled with reactive substances, then mix intensively and finally the mixed component has been left. In any moment, relative composition of objects inside the reactor is uniform.

The tank designed for reactor has capacity of 10 liters and the tank is built from 3 mm sheet of stainless steel.

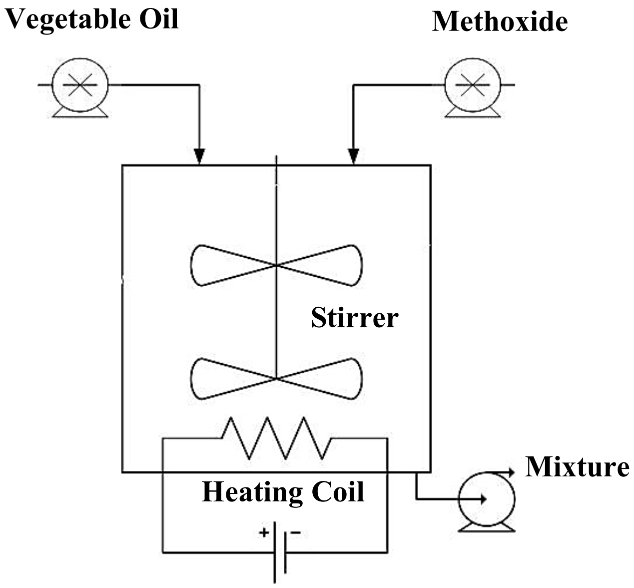


Figure 3.5: Schematic diagram of a reactor

Reaction tank and water washing tanks were built separately. Methanol is less soluble in oil, when liquids placed inside a container; they will be distributed to, two completely separate part of methanol in upper and the oil in lower part. Therefore, in order to increase the contact surface and mixing of these two materials, stirring with mechanical agitator is indispensable. It should be noted that the mixing time should not be too much, because in many chemical reactions, it leads to degradation of product and produce unwanted materials. Heating system was used for heating liquid and keeping it at a constant temperature.

The heating system for each tank is equipped with a 1000 watt heater element, a temperature sensor and a digital thermometer for monitoring and temperature adjustment. Electrical signals from sensor cause heater switched on or off. In the power transmission system, an AC synchronous motor (240V, 1 PH, 125 mA) was used to stir up the mixture. Two electro pump of 750GPH were used to transport raw materials (reactants) and products between tanks.

3.2.3 Separation, washing and drying unit

After the proper mixing the mixture is transferred to Separator/Wash tank by a 750GPH pressure pump. The Tank is similar to reactor tank having capacity of 10 liters fabricated with 3 mm sheet of stainless steel. It has a stirrer attachment on the top of the vessel and three different solenoid valves at the bottom for collecting pure biodiesel, glycerin and waste water. There is a 1000 watt heater element to heat the biodiesel to remove water from it.

Then the mixture is given time to react and settle into separating layers of Biodiesel and glycerin. The glycerin formed settles to the bottom of the mixing tank and is removed from the tank by a hose that leads to a glycerin/waste container by opening solenoid valves (valve-5) at the bottom of the Separating tank. Once the glycerin is completely removed, the valve (valve-6) that diverts the oil to the glycerin/waste container is closed.

3.2.4 FFA-separation and removal of glycerol:

After the reaction, the next phase is the separation of biodiesel and glycerin. Biodiesel is non-polar and less dense than water; glycerol is polar and denser than water meaning a separation can be performed. Much of the glycerol produced from the reaction can be mechanically removed (centrifuge) or via a two phase, liquid-liquid separator (settling tank) due to substantial differences in density compared to FAME.

A settling tank uses gravity to separate substances based on density. This is a low-cost, passive system requiring little to no added energy other than that already possessed by the effluent. It may be possible to perform glycerol separation co-currently with methanol recovery. Feasibility will likely depend on the reactor flow rate and rate of separation, which dictate the size of the settling tank needed for the glycerol to sufficiently separate from the FAME before leaving the settler

3.2.5 Washing and drying:

The final step in the biodiesel process is to remove any soap, water, methanol, and other contaminants from biodiesel that were inadvertently created during the processing.

The most widely used purification method of FAME is a wash cycle and involves the rigorous mixing of water with the biodiesel product and a following separation. The water wash helps to remove any remaining contaminants like salts from the FAME. The removal of the salts occurs during the wash cycle, while the FFA remains in the biodiesel. Neutralization of the mix before washing reduces the amount of water needed and minimizes the emulsions produced. But for simplification of system neutralization process is escaped for this system.

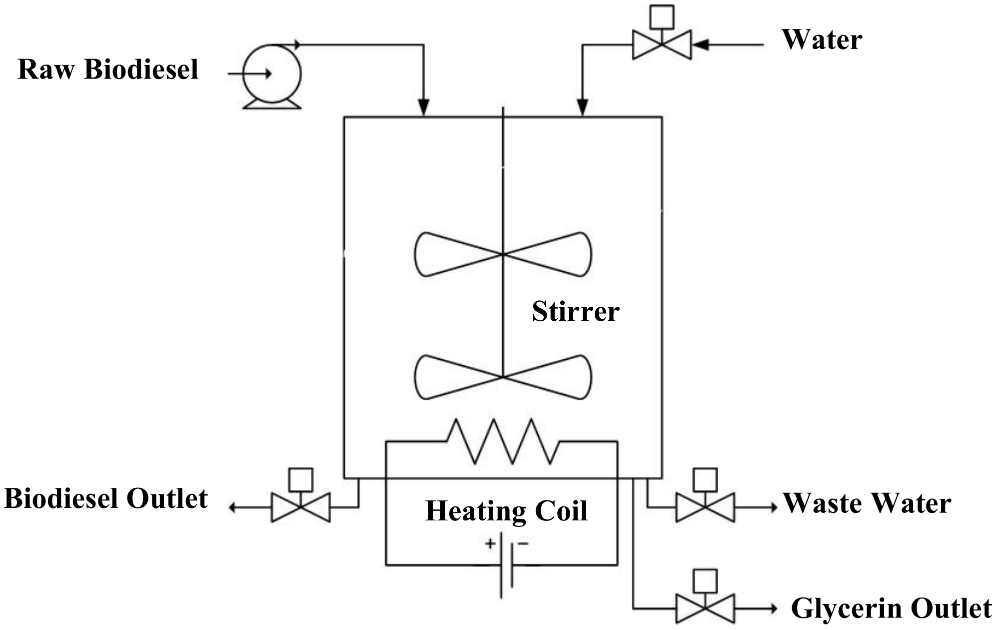


Figure 3.6: Schematic diagram of separation, washing and drying Unit

Here, a wet wash system is used for this process. It requires several wash cycles with water, and each cycle requires 4+ hours of settling/separation time. Then, it is also common practice to test the pH of the resulting biodiesel, and add an acid, such as vinegar, as necessary to balance the biodiesel's pH level. Then the contaminated water must be properly disposed of, adding cost and time to the process. But here in this automated system PH testing is also eliminated by analyzing different test result.

Disadvantages include the difficulty of converting the process into a continuous method. This is caused by slow cycle times due to the need for multiple wash cycles, non-polar contaminants can be left behind in the biodiesel, high operating costs associated with removal of all traces of water in order to meet the required specifications, and the cost associated with treatment of the wastewater.

3.2.6 Storage tank for vegetable oil and methoxide:

Vegetable oil and methoxide storage tank is situated on the topmost section of the processor having capacity of 20L and 10L. Both of the tanks are connected with 24v and 750GPH pump to pump out desired amount of oil and methoxide to the reactor.

3.2.7 Storage tank for diesel and biodiesel:

Diesel and Biodiesel storage tank is situated on the bottom section. Both the tank is made with 3mm stainless steel having capacity of 30L and 15 L respectively.

3.2.8 Blending unit:

Biodiesel can be blended and used in many different concentrations. They include B100 (pure biodiesel), B20 (20% biodiesel, 80% petroleum diesel), B5 (5% biodiesel, 95% petroleum diesel), and B2 (2% biodiesel, 98% petroleum diesel). The most common biodiesel blend is B20, which qualifies for fleet compliance under the Energy Policy Act (EPAct) of 1992. Blends of 20% biodiesel and lower can be used in diesel equipment with no, or only minor modifications. [6] The B6 to B20 blends are covered by the ASTM D7467 specification. [7] Biodiesel can also be used in its pure form (B100), but may require certain engine modifications to avoid maintenance and performance problems. [8]

3.2.9 Methanol recovery unit:

Methanol is the most expensive input for the biodiesel process. The price is of Methanol is tied to the price of oil, and as such is at risk of instability as crude prices rise.

In order to ensure that the reaction consumes all of the vegetable oil, methanol is added in excess to force the equilibrium to the right. This excess methanol ends up in the glycerin by-product and represents a significant loss. Methanol in the glycerin also limits the potential for marketing it as a product, as the combination is deemed unsafe and flammable.

Given the relatively low boiling point of methanol, it is possible to recapture the methanol via a simple still. The mix of glycerin and methanol, still liquid following the reaction stage, can be heated to vaporize the methanol. These vapors can then be condensed and recycled, maximizing use, reducing waste, and lowering overall processing cost.

The glycerin by-product is poured in to a stainless steel container through a flexible pipe attached with the lid. The container must be sturdy and air-tight. An electric heater heats the glycerin to the methanol boiling point of 66 °F. The vapors rise through the bucket and into a length of copper tubing. The copper tubing then coils as it enters a condenser. Cold tap water passes through the condenser, cooling the methanol vapors to a liquid. The liquid falls through the copper tubing where it is collected at the bottom. Once the liquid methanol stops flowing, the process is completed and the glycerin is drained from a tap. Characteristics of fabricated methanol recovery system are given in table 3.2. Figure 3.7 shows the designed and fabricated methanol recovery system.

Table 3.2: Characteristics of designed heat exchanger.

Type	Shell and tube
Flow management	Single pass-countercurrent
Mechanism of heat transfer	Conduction Single phase (water)-dual phase (methanol)
Number of fluid	2 (water and methanol)

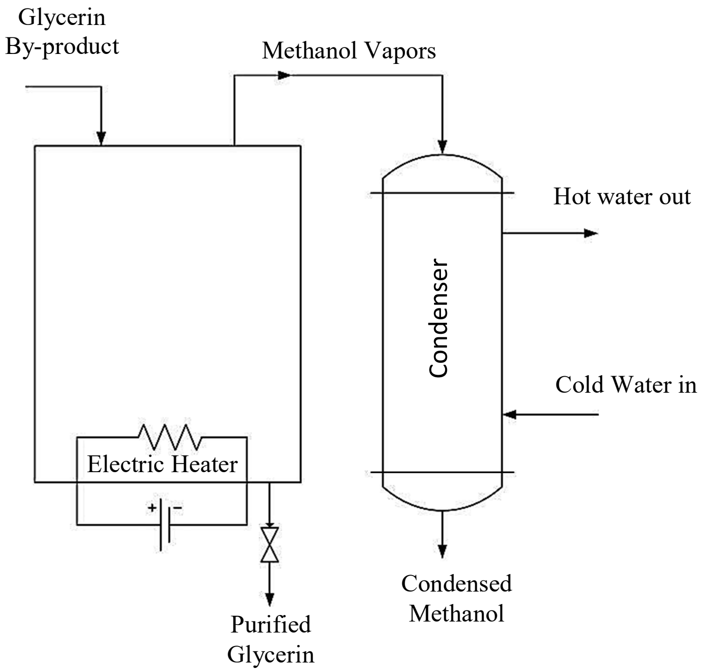


Figure 3.7: Schematic diagram of methanol recapture unit

3.4 Different system

To be economically viable the small-scale production plant must be efficient, able to producing high quality biodiesel and by-products as part of a biodiesel system. Different systems involved in the automated biodiesel plant are summarized in the following table.

Table 3.3: Summary of the subsystems in the portable unit

Subsystem	Components
Fluid	Pumps, tubing, fittings, connectors
Thermal	Heat exchanger, preheater, insulation
Reaction	Reactor, catalyst
Electrical/Control	PLC, HMI, magnetic contactor, relay sensors, communication links
Power	AC/DC Distribution
Structure and storage Tanks	Metal frame, input, output weir

3.4.1 Mixer (motor-powered shaft with mixing vanes)

Once the reactants have entered a common tank, they must then be mixed thoroughly to ensure the best possible reaction efficiency. Our concepts for mixing are described and evaluated in the following section.

The design consists of rotating shaft powered by a motor. Mixing vanes are rigidly attached to the central shaft and physically mix the reactants. We had various concepts on the manufacturing of the shaft/vane assembly and the vane geometry. The most feasible solution we discussed was to mill slots into the shaft and to insert strips of sheet metal to serve as vanes. We would then just bolt the vanes to the shaft with two bolts. One drawback to this design is that some fluid at the bottom of the tank and in the outlet tube would not be mixed. We could place the outlet valve as close as possible to the bottom of the tank, but there will always be some unmixed fluid that enters the separation tank.

3.4.2 Heating elements

The application of heat is required to speed up the chemical reaction and reducing the oil viscosity as well as remove the remaining water content from the oil. For this system, a submerged heating element was used to supply the required heat. The chosen heating element is standard submersible water heating element with 1000 Watts of power and an AC voltage requirement of 220 Volts. This will fit perfectly with the designed power scheme.

Figure 3.8: Heater

3.4.3 Piping and hoses:

The recommended flow rate in a process plant is between 1 and 5 m/s for liquids. The average temperature is 60 ℃ and 1 bar, but some of the pipes must have a requirement of withstanding a pressure of 7 bars and max 150 ℃.

For transport of fluids in the plant, a Merlett Armorvin, Polyurethane Lined Clear PVC hose, with Steel Spiral can be applied as seen in Figure 3.9. This hose has all the transparency advantages of clear PVC, but with the additional advantages of a Polyurethane (PU) lining, which is more resistant to vegetable oil based products.

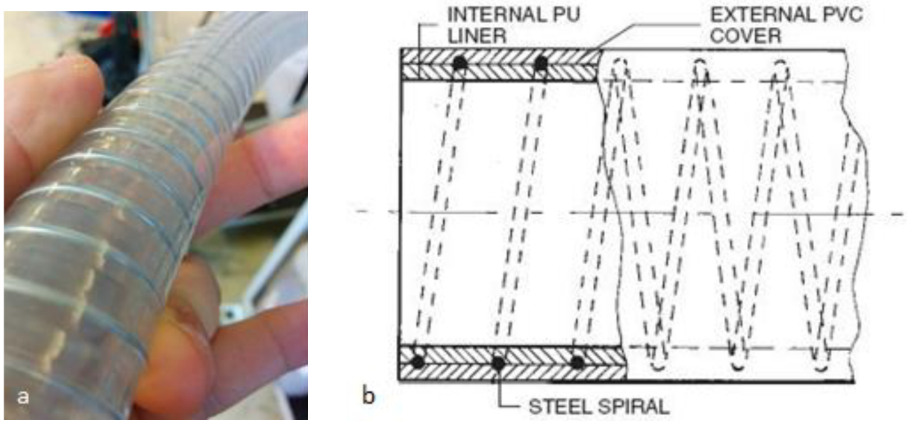


Figure 3.9: Polyurethane Lined Clear PVC Hose with Steel Spiral (a) and its schematic (b)

The hose also has a very high working pressure of 20 Bar and temperature range of -20 to +90°C. In the reactor system, specialty hoses seen in figure 3.9 will be purchased to insure extra safety in the harsh conditions such as in the separation of water, where the temperature exceeds 100°C.

3.4.4 Transport of fluids (pump):

Six 750 GPH pumps are used for the transportation of the different fluids and mixtures in between different tanks.

Specifications:

Model: MIS-00130 (Made in China)
Voltage rating: 24V
Current Rating: 2.5A
Flow Rate: 750GPH/2839 LPH
Head: 3 m

Figure 3.10 : 750 GPH Pump

3.4.5 Solenoid Valves

Electrically-actuated valves were seen as the most economical, feasible, and accurate method for controlling liquid movement. Their simple design easily incorporates them into the automation plan of this project. As shown in the figure 3.11, six 0.5 inch diameter of electrically-actuated valves will be used though using smaller valves in the system will slow down the process. It is estimated that the process time of start to finish of this plant will still fall below that of competitive products.

Specifications:

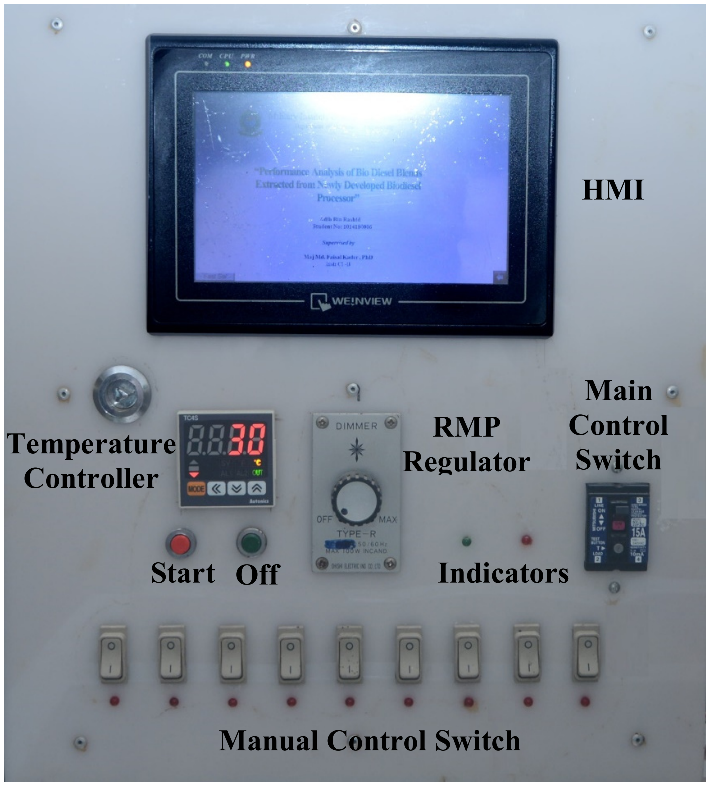
Model: 2W-160-15
Voltage rating: 220V
Orifice: 16mm
Pipe size: ½”
Operating Temperature: -5 °C - 100 °C
Operating Pressure: 0 kg/cm^2 - 10 kg/cm^2

Figure 3.11: Solenoid Valves

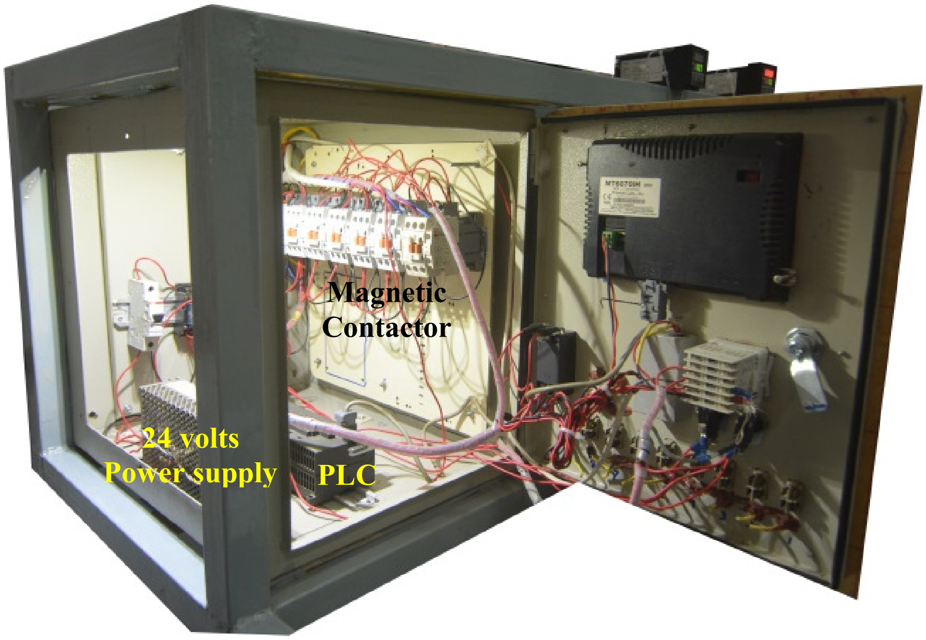
3.4.6 Automation and control system of the biodiesel plant

In order to accomplish the objective of the study, it is necessary that the automated plant of biodiesel has sensors, actuators, and controllers. These instruments together constitute what is known as an automated process. The automation in a productive environment aims to facilitate the processes, using basic components such as sensors, controllers, and actuators. The automated system aims at the optimization of the process, increasing the production rate, precision and quality, including the reduction in costs.

The automation process consists in the interaction of electrical, electronic, mechanical, and information technology areas. The mechanic area, through the use of machines, can separate raw material into “final” products. The electrical engineering provides the engines and its operations, and the electronic is essential for the control and automation of the production network. The information technology allows the distribution of information to all levels of the industry, through its data bases and communication networks. The control theory refers to a behavior analysis of the dynamic systems, through which the real behavior. Figure 3.12 shows the electrical controll panel of the Automated Biodiesel Plant.



(a) Out side view



(b) Inside view

Figure 3.12: Electrical controll panel , (a) Out side view, (b) Inside view

3.4.6.1 Programmable logic controller

A programmable logic controller (PLC) or programmable controller is an industrial digital computer which has been ruggedized and adapted for the control of manufacturing processes, such as assembly lines, or robotic devices, or any activity that requires high reliability control and ease of programming and process fault diagnosis. These controllers are specially designed to survive in harsh situations and shielded from heat, cold, dust, and moisture etc. PLC consists of a microprocessor which is programmed using the computer language.

The program is written on a computer and is downloaded to the PLC via cable. These loaded programs are stored in non – volatile memory of the PLC. During the transition of relay control panels to PLC, the hard wired relay logic was exchanged for the program fed by the user. A visual programming language known as the Ladder Logic was created to program the PLC.

They were first developed in the automobile industry to provide flexible, ruggedized and easily programmable controllers to replace hard-wired relays, timers and sequencers. Since then they have been widely adopted as high-reliability automation controllers suitable for harsh environments. A PLC is an example of a "hard" real-time system since output results must be produced in response to input conditions within a limited time, otherwise unintended operation will result.

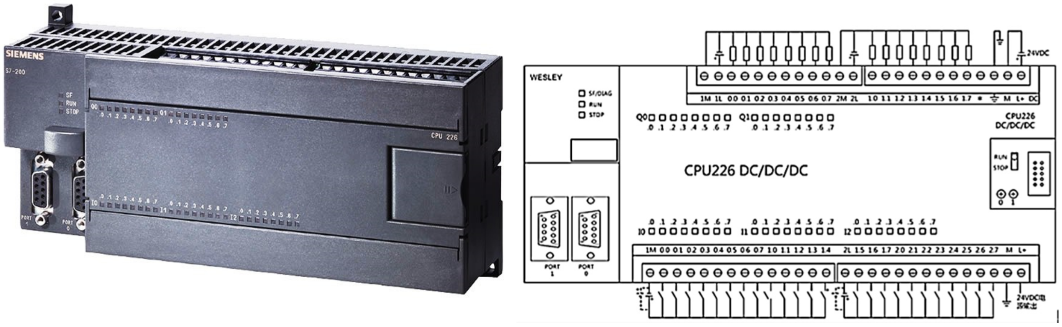


Figure 3.13: Programmable logic controller

3.4.6.2 PLC hardware

The hardware components of a PLC system are CPU, Memory, Input/Output, Power supply unit, and programming device. Below is a diagram of the system overview of PLC.

- **CPU** – Keeps checking the PLC controller to avoid errors. They perform functions including logic operations, arithmetic operations, computer interface and many more.

- **Memory** – Fixed data is used by the CPU. System (ROM) stores the data permanently for the operating system. RAM stores the information of the status of input and output devices, and the values of timers, counters and other internal devices.

- **I/O section** – Input keeps a track on field devices which includes sensors, switches.

- **O/P Section -** Output has a control over the other devices which includes motors, pumps, lights and solenoids. The I/O ports are based on Reduced Instruction Set Computer (RISC).

- **Power supply** – Certain PLCs have an isolated power supply. But, most of the PLCs work at 220VAC or 24VDC.

- **Programming device** – This device is used to feed the program into the memory of the processor. The program is first fed to the programming device and later it is transmitted to the PLC's memory.

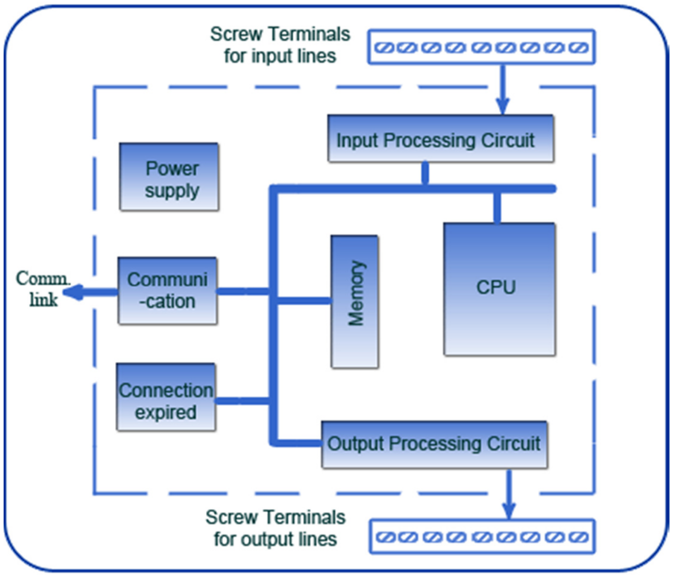


Figure 3.14: PLC hardware

System Buses – Buses are the paths through which the digital signal flows internally of the PLC. The four system buses are:

- Data bus is used by the CPU to transfer data among different elements.
- Control bus transfers signals related to the action that are controlled internally.
- Address bus sends the location's addresses to access the data.
- System bus helps the I/O port and I/O unit to communicate with each other

3.4.6.3 HMI (Human-Machine Interface)

An HMI, or Human Machine Interface, is a device or software that lets users communicate with a machine or automation system. Besides translating complex data into useable information, an HMI relays the user's commands. By providing information, alerts, commands and others tools, an HMI connects the users with process being controlled. So the more adapted the tools are to the user, the more appropriately he or she can react. An intuitive, user-friendly HMI can make the difference between an inefficient system and a cost-effective one.

In this project **MI (Model MT6070iH)** is used MT6000 series is the new HMI generation of **Weintek**. With the design concept of meeting customers' satisfaction while easy-to-Use attribute as before, a MT6000 not only performs as a Human Machine interface but also plays as a role of data exchange center. MT6000 series is the best choice for your requirement tomorrow. The MT6070iH is equipped with a USB 1.1 host, and a USB 2.0 high speed device. Features and specifications the HMI is shown in the Table B1 of Appendix – B.

Figure 3.15: HMI (Model MT6070iH)

3.5 Programmable Logic Controller Programming

The last step involved is writing a PLC program to control different process. The biodiesel processor uses **Siemens S7-200 CPU 222** PLC controller. The **Siemens S7-200 CPU 222** PLC controller was selected because it is currently widely used in industry. Features and specifications of the PLC (**Siemens S7-200 CPU 222)** are shown in the Table B1 of Appendix – B.

It has multiple inputs and output capabilities and is easy to program. In addition, the PLC will allow the operator to add a vast array of items to the process, such as flow meters, temperature gauges, timers, solenoid valves, and pumps quite easily. The processor works on an input/output basis for each action to occur. Once an input signal/signals are received (a given temperature, elapsed time, etc.) the controller sends an output signal (begin mixing, turn heater on, etc.).

There are two buttons on the PLC panel; a green start button and a red stop button. The red stop button can be pressed at any time to stop the processor. There could be a reset button to stop the program, and it must be pressed after the stop button is pressed in order to reset the counters in the program. Ladder programming language is used to program the PLC for this biodiesel production.

The operator has to press the Start button on the PLC panel and this will start the pump #1 for 5 min to fill the reactor with 5L of oil. After that heater #1 and stirrer motor #1 should be switched on for 15 minute to ensure all of the oil is thoroughly heated.

Once the temperature of the oil in the reactor reaches at 50° C (via a thermometer attached to the tank) and also 15 minutes are up, pump #2 will start and begin pumping the sodium methoxide from the tank into the 10L reactor. It takes 1 min to deliver 200 ml sodium methoxide to the reactor.

The mixture is maintained at 50° C temperature and mixed for one hour using a stirrer. Then the mixture is transferred to settling/Wash tank by switching on pump #3. On the settling tank the mixture is kept for 12 hours and the glycerin was separated and settled into the bottom of the settling tank and is drained off to methanol recovery unit by opening valve #1.

Then for wet wash of the biodiesel Valve #2 will open for 2 min and continue to stir the biodiesel and water at a very low RPM and about 2 min. After 4 hours passes, valve #3 will automatically open to drain waste water from the wash tank. Then the heater#2 of the wash tank will be switched on and heated to remove water of the oil. After words valve #4 will open to drain biodiesel to storage tank.

In the different storage tank four fluid level sensors are there for the indication of empty tank. Once Fluid Level Sensor #1 (located in the bottom of the sodium methoxide small tank), Fluid Level Sensor #2 (located in the bottom of the vegetable oil storage tank), Fluid Level Sensor #3 (located in the bottom of the Diesel storage tank), Fluid Level Sensor #4 (located in the bottom of the Biodiesel storage tank) reads empty, a red indictor will be lit to inform the operator.

CHAPTER-4

EXPERIMENTAL SET-UP AND PROCEDURE

4.1 General

This chapter describes the different experimental set-up and procedures both for measuring fuel properties and study of engine performance.

4.2 Determination of Fuel Properties

This section describes experimental set-up and procedures of measuring some relevant fuel properties - density, viscosity, volatility, carbon residue, ash content, heating value and flash point. Individual set-up for each parameter is outlined below:

4.2.1 Density

Density of fuel at different temperatures (30, 40, 50, 60ºC) were measured by a standard 25 ml marked flask. Weight of the fixed volume of fuel (25 ml) was measured at different temperatures by an electronic balance which measures up to 0.0001 gm. The density values are reported in kg/m^3.

4.2.2 Viscosity

The measure of a fluid's resistance to flow under gravity is called the kinematic viscosity. This is one of the most important parameters of biodiesel in terms of engine operation because it affects both the combustion process and the injector pumps. Incorrect viscosity can cause mechanical damage to the injector pump, poor fuel atomization when injected into the cylinder and will eventually lead to the coking of the injector tips. This coking may eventually cause the engine to lose power or component failure.

Figure 4.1: Viscosity tester

Viscosities of fuels were measured as per ASTM standard D88-56 [19] using saybolt viscometer and accessories. Time of falling of 60 ml sample under controlled conditions through a standard oil tube was measured. This time is reported as Saybolt Universal Second (SUS). Corresponding kinematic viscosity was obtained from ASTM standard conversion chart ASTM D2161-79 [18] and the value was checked by computing the same as per empirical formula over a wide range of SUS. Measured values of kinematic viscosities are presented on ASTM standard D341-87 Viscosity- Temperature charts.

4.2.3 Carbon residue

ASTM standard D189-81 [20] method was followed to determine carbon residue of the test fuels. A weighed quantity of sample was placed in the apparatus subjected to destructive distillation. At the end of specified heating period, the final weight of remaining material in the crucible was taken. The weight of the residue was calculated as the percentage of original sample and the result is reported as Conradson carbon residue at 700-800 °C for 10 minutes. Crucible was then cooled and weighed. The residue at this stage was the ash content of the test fuel and it was reported as percentage weight of original sample.

Figure 4.2: Carbon residue tester

4.2.4 Heating value

Heating values of fuels used in this research were measured experimentally following ASTM standard D240-87 [16] using an oxygen bomb calorimeter [Figure: 4.3]. One gram of previously weighed sample was burnt at constant volume. Heat of combustion was computed from temperature observations using a digital thermometer before, during and after combustion with necessary temperature corrections.

Figure 4.3: Bomb calorimeter

4.2.5 Flash point

Flash point is the lowest temperature of a liquid at which its vapours will form a combustible mixture with air. Flash point is a key property for petroleum products and chemicals and is included in many specifications.

Closed cup tests simulate an enclosed environment for example storage in a tank or sealed container, whilst open cup tests simulate an uncontained condition, for example a spillage. Closed cup tests are usually specified due to improved precision.

Setaflash methods cover flash point tests within the range -30 to 300 °C using a small scale closed cup tester. The procedures can determine whether a product will or not (flash/no flash Method A) at a specified temperature, or the flash point of a sample (Method B).

Small scale tests are typically used to assist the rapid classification of potentially hazardous substances where storage, transport and disposal charges are based on flammability and where correct classification is vitally important and has significant cost and safety implications.

Flash point of test fuels was measured as per ASTM standard D93-85 [17] using Pensky-Martens closed tester. The sample taken into the closed-cup tester was heated slowly with continuous stirring. A flame was inserted into the oil cup at every 2°C temperature rise of the oil. Flash point of the fuel was noted as the lowest temperature at which application of the test flame causes the fuel vapor to give flash of fire and then disappear.

Figure 4.4: Flash point tester

4.3 Engines Performance Test Procedure

The Engine Test Set is a versatile engine test set with instrumentation for testing the small single cylinder engines, normally used to power lawn mowers, generators, cultivators, pumps and generators. Engine Test Set helps students to understand of the most important features of an engine, including the thermodynamic cycle and performance.

The apparatus consists of two main parts:

a. The Test Bed with Dynamometer
b. A bench-mounted Instrument Frame

4.3.1 Test bed with dynamometer

4.3.1.1 Test bed

This is a low level movable trolley fitted as standard with locking wheels, the Hydraulic Dynamometer (with half-coupling) and an Air box with orifice plate. A k-type thermocouple and pressure tapping are fitted near to the orifice plate. The orifice is used with the pressure tapping to calculate engine inlet airflow. The thermocouple is to measure ambient air temperature. The Air box helps to dampen inlet air pulses and includes a pressure sensitive ‘blast panel’ underneath. This panel is a protection device that will puncture in the very unlikely event of an inlet pressure problem, such as unburnt fuel combustion. The Test Engine fits to the bed, in-line with the Dynamometer and coupled to its shaft by means of a semi-flexible coupling, enclosed in a safety guard. Technical specifications of Dynamometer Test Bed and instrument units is given in the Table C1 of Appendix – C.

4.3.1.2 The hydraulic dynamometer

The Hydraulic Dynamometer is a simple but effective means to apply a load to a test engine. It consists of two casings with internal radial ribs. A rotor with radial ribs on both sides is attached to a shaft that runs through the Dynamometer. The Dynamometer is mounted in self-aligning bearings to allow the casing to react against a strain gauged load cell. Water enters the top of the Dynamometer by means of an adjustable needle valve, and leaves via a drain at the bottom of the casing. A vent allows air and excess water to escape.

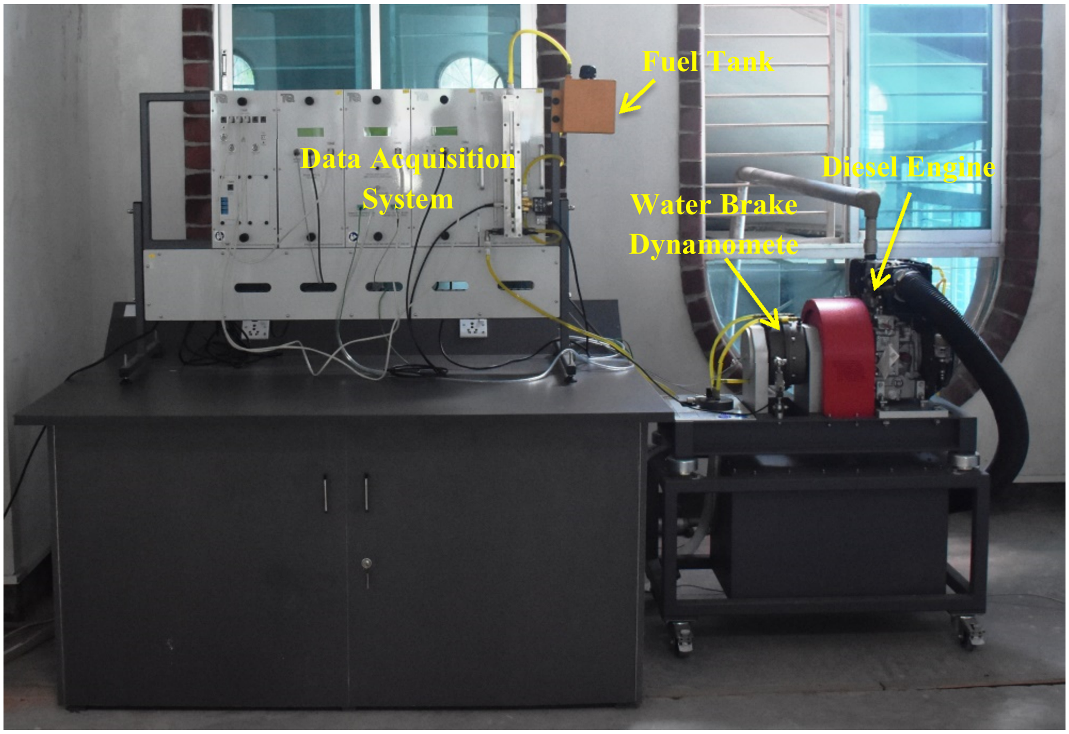


Figure 4.5: The single cylinder CI engine with water brake dynamometer and data acquisition system

4.3.1.3 Instrument frame

The Instrument Modules for the Small Engine Test Set mount onto the Instrument Frame. The frame has a single IEC type power inlet and several IEC type outlets to power the Instrument Modules (some modules are supplied as standard and others are optional extras).

The Instruments and Test Bed are kept separate to prevent transmission of vibration from the engine to the measuring devices. Two separate cable trunking conduits are fitted to the back of the Instrument Frame, one for the power (mains voltage) cables and the other for the signal cables. Slots are provided to help bring the cables out from the trucking. To the right of the Instrument Frame are mounting holes for the fuel tanks supplied with each Test Engine.

4.3.1.4 Instrument Modules

- ***Torque and Speed Display - DTS***

This module displays the torque measured at the Dynamometer and the speed calculated from the optical sensor pulses (with time). Power is calculated from the product of the speed and torque.

- ***Engine Inlet Air and Exhaust Display - DPT***

This module displays the ambient (barometric) pressure and temperature, and the pressure inside the Airbox. The engine inlet airflow is calculated from the Airbox orifice dimensions, and the pressure difference between ambient and inside the airbox (Δp).

4.4 Four-Stroke Diesel Engine

The Four-stroke Diesel Engines are both made from a modern small engine, specially adapted for use with Small Engine Test Set. This type of engine is normally used on portable generators and small gardening and agricultural machines. It is reliable, easy to use and has a manual recoil type starter. The engine is mounted on a Base Plate and assembled with:

- Color-coded fuel tank (caramel/light brown for diesel)
- Fuel pipes
- Exhaust Thermocouple
- Air Inlet adaptor

The diesel engine is made from a small air-cooled single cylinder diesel engine with:

- Overhead valves - one for inlet, one for exhaust
- Direct fuel injection
- Pressurized oil lubrication
- Recoil starter

The engine includes a governor that prevents the engine exceeding its optimum speed. The governor is a device inside the engine, linked to the fuel injection system. When the engine speed increases to a certain level, the governor forces the fuel injection system to reduce the amount of fuel that enters the cylinder. This regulates the maximum speed and engine power.

The engine is lubricated by ordinary engine oil, stored in a small sump at the base of the engine body. The oil is pressurized and forced around the engine, to lubricate its moving parts and bearings. The oil passes through a fine mesh oil filter that helps to clean the oil.

The engine is based on the standard cross-flow design, so that the fuel/air mixture enters from one side of the cylinder head and is forced out as exhaust to the opposite side of the cylinder head. Forced air-cooling is provided by the fins around the engine flywheel. As the flywheel turns, the fins force air around the cylinder by means of simple ducting. The engine is started by a starter handle and cord, wrapped around a pulley on the flywheel. The pulley includes a clutch to disengage the cord and pulley when the engine starts. This arrangement is called a 'recoil starter'.

The engine includes a speed control (often called a 'rack'). The rack directly adjusts the amount of fuel that can enter the cylinder. If the rack is moved to the minimum position, no fuel is injected to the cylinder and the engine stops. Alternatively, an engine stop button is provided. This button stops the fuel injection system. Technical specifications of Four-Stroke Diesel Engine are given in the Table C2 of Appendix – C.

4.5 Governing Equations

Mass and Volume Flow

Many of the calculations need the mass flow of a liquid, but the instruments read volume flow. This is because the mass flow depends on the density of the liquid, which can vary with temperature. The relationship between mass and volume of a liquid is:

$$\text{Mass} = \text{Density} \times \text{Volume}$$

So:

$$\text{Mass Flow (in kg.s}^{-1}\text{)} = \text{Density (in kg.m}^{-3}\text{)} \times (\text{Volume Flow (in L.s}^{-1}\text{)}/1000)$$

Air Consumption

The Airbox includes an orifice at its inlet. The DPT1 Instrument Module shows the ambient air pressure (before the orifice) and the air pressure in the Airbox (after the orifice). The difference in the pressures (Δp) and the air density (ρ) will give you the basic air flow velocity (U):

$$\mathrm{U} = \sqrt{\frac{2\,\Delta\mathrm{p}}{\rho}}$$

To find the mass flow ($\dot{m}_a$) the air flow velocity equation is modified to separate out the factors of density and to include the coefficient of discharge (Cd) for the orifice and the orifice diameter:

$$\dot{m}_a = \mathrm{C_d}\ \frac{\pi \mathrm{d}^2}{4}\ \sqrt{\frac{2\ \mathrm{p_A}\ \Delta \mathrm{p}}{\mathrm{R\ T_A}}}$$

Where,

$\dot{m}_a$= Mass flow rate of Air, Kg/s
$\mathrm{C_d}$ = Co-efficient of discharge = 0.6
d = Orifice diameter = 0.0185m
$\mathrm{p_A}$ =Ambient pressure, N/m^2
Δp = Air box differential pressure
$\mathrm{T_A}$= Ambient Temperature, °C
R = Gas constant value= 287 J/Kg-k

Fuel Consumption

To find the mass fuel consumption you need the volumetric fuel flow and the fuel density:

Mass Fuel Flow (in kg.s^{-1}) = Fuel Density (kg.m^{-3}) × (Fuel Volume Flow (L.s^{-1})/1000)

To find the specific fuel consumption (work from the fuel) you need the mass fuel consumption and the mechanical power developed (measured by the Dynamometer):

$$Specific\ Fuel\ consumption\ = \frac{Mass\ Fuel\ Consumption\ \times\ 3600}{Mechanical\ Power/1000}$$

Where:

Specific Fuel Consumption = kg kW.h^{-1}
Mass Fuel Consumption = kg.s^{-1}
Mechanical Power = Watts

Air/Fuel Ratio

This is simply the ratio of the air mass flow against the fuel mass flow:

$$Air/Fuel\ Ratio\ = \frac{\dot{m}_a}{\dot{m}_f}$$

Where,

$\dot{m}_f$ = Mass flow rate of fuel, Kg/s

Mechanical Power (Watt)

Power in mechanical systems is the combination of forces and movement. In particular, power is the product of a force on an object and the object's velocity, or the product of a torque on a shaft and the shaft's angular velocity. Mechanical power is also described as the time derivative of work.

$$P = \frac{2\pi NT}{60}$$

Where,

N = Speed, m/ s^2
T = Torque, N-m

Specific Fuel Consumption (Bsfc)

Brake specific fuel consumption (Bsfc) is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational, or shaft, power. It is typically used for comparing the efficiency of internal combustion engines with a shaft output. It is the rate of fuel consumption divided by the power produced. It may also be thought of as power-specific fuel consumption, for this reason. BSFC allows the fuel efficiency of different engines to be directly compared.

$$Bsfc = \frac{\dot{m_f}\ 3600}{p}$$

Thermal Efficiency (η_{th}%)

In thermodynamics, the thermal efficiency is a dimensionless performance measure of a device that uses thermal energy, such as an internal combustion engine. , thermal efficiency indicates the extent to which the energy added by work is converted to net heat output.

$$\eta_{th} = \frac{P}{m_f\ C_l} \times 100\%$$

Where,

C_l= Calorific value of diesel, MJ/Kg

Break mean effective pressure (BMEP) in bar

The mean effective pressure is a quantity relating to the operation of a reciprocating engine and is a valuable measure of an engine's capacity to do work that is independent of engine displacement. (P.V.Ramana1) when quoted as an indicated mean effective pressure or IMEP (defined below), it may be thought of as the average pressure acting on a piston during the different portions of its cycle.

Where,

Engine capacity = 232 c
Stroke number = 4

Volumetric Efficiency

The four stroke engine piston moves down to draw air/fuel mixture in, then moves up to compress and combust the mixture. It is then forced down again by the combustion and moves up to push out the exhaust gases. The four strokes are:

- Fresh Air/Fuel Mixture Drawn In
- Mixture Compressed
- Mixture Ignited
- Exhaust Pushed Out

The volumetric efficiency is the ratio of the measured volume of air or gas that enters the engine against the calculated volume of air that the engine should use. For this, you need to know the engine capacity, the amount of engine strokes and its speed:

Calculated volume

Calculated volume is known as Actual volume of air sucked in to the cylinder (V_a)

$$V_a = \frac{Engine\ Capacity(m^3)\ N}{\frac{Strokes}{2}\ 60}$$

Note: Engine capacity is normally given in cc (cubic centimetres) or Litres. You must convert this into cubic metres for the volume calculations.

$$100\ cc = 0.0001\ m^3$$

Measured Volume

Measured volume also known as Swept volume (V_s).

$$V_s = \frac{\dot{m}_a\ R\ T_A}{p_A}$$

$$Volumetric\ Efficiency = \frac{Measured\ Volume}{Calculated\ Volume} \times 100$$

Heat Energy and Enthalpy

The heat energy of combustion from the fuel (in Watts) is found by the fuel consumption and its calorific value:

$$H_F = \dot{m}_f C_L$$

The inlet air enthalpy (in Watts) is found from the air mass flow rate and the ambient temperature:

$$H_A = \dot{m}_A C_P\ T_A$$

Thermal Efficiency

This is the ratio of the heat energy of combustion from the fuel against the useful mechanical power developed by the engine:

$$\eta_T = \frac{Mechanical\ Power}{H_F} \times 100$$

Brake Mean Effective Pressure (BMEP)

This is the average mean pressure in the cylinder that would produce the measured brake output. This pressure is calculated as the uniform pressure in the cylinder as the piston rises from top to bottom of each power stroke. The BMEP is a useful calculation to compare engines of any size.

$$BMEP = \frac{60 \times Power \times (\frac{Strokes}{2})}{0.1 \times Speed\ Engine \times Capacity}$$

Where:

BMEP is in bar
Power = Watts
Speed = Rev.min^{-1}
Engine Capacity = Cubic Centimeters (cm^3) or cc

4.6 Engine Emission Testing Methodology

Biodiesel is a captivating renewable resource providing the potential to reduce particulate emissions in compression–ignition engines. A comparative study is conducted to evaluate the effects of using biodiesel on exhaust emissions. Exhaust smokiness, noise and exhaust regulated gas emissions such as carbon dioxides, carbon monoxide and oxygen are measured.

The three most common methods for measuring vehicular emissions are – dynamometer testing, on-road remote sensing (RS), and using a portable emission measurement system (PEMS). [18] On-road testing is a real-time data collection methodology which involves measurements. On the vehicle operating on an actual route, unlike dynamometer testing which assumes a speed profile in a laboratory setting. In the present study, on-road testing was performed using a portable emissions measurement system. In this case, emissions were directly sampled from the tail pipe of an operating vehicle into a system which analyses the exhaust and records the concentrations of the various emissions. Everything from the data analyzer to storage is integrated into a PEMS unit.

Figure 4.6: MAHA- MGT 5 with integrated MDO 2 LON diesel engine emission analyzer

MAHA- MGT 5 with integrated **MDO 2 LON** Diesel Engine Emission Tester is used in this experiment. Networking and connection of the MGT 5 to the PC is flexibly designed. Various interface modules can be integrated at any time without damaging calibration or warranty seals. It has Easy, comfortable operation with clearly structured screen display. Intelligent software provides adequate operation and all necessary information. Extremely short warm-up phase at unit switch-on due to the very compact measurement chamber equipped with active temperature recognition. The temperature sensor registers the actual measurement chamber temperature erasing the need for the obligatory 10 min. warm- up phase. Practically speaking, an average of 1-2 minutes is needed for the warm-up phase. The emission probe made of high quality steel (400 mm length) with flexible, steel braided sampling hose including clamp and cap plug. Activated carbon filter, electro-chemical sensors. This Meter can efficiently measure and analyze HC, CO, CO_2, O_2, NO_X, SO_2 emissions with calculation of Lambda. Technical specifications of the emission analyzer (MAHA- MGT 5 with integrated MDO 2 LON) is given in the Table C3 of Appendix- C.

CHAPTER-5

RESULTS AND DISCUSSIONS

5.1 General

This chapter deals with the performance analysis of the Automated Biodiesel Processor. Also the analysis of experimental results obtained both in fuel testing and in engine performance study has done in this chapter.

5.2 Performance Analysis of the Automated Plant

To perform the test, the optimal 4:1 molar ratio of oil to alcohol and in presence of KOH as catalyst with amount of 1% oil weight. The experiments based on three levels of the variable factor, stirrer velocity (450, 500, 550, 600 and 650 rpm) and reaction time (20, 30, 40, 50 and 60 min) with temperature of 50 ° C was performed. Performance analysis results of the Automated Biodiesel Plant are presented in Appendix – D.

5.2.1 Effect of mixing time on the yield of biodiesel production at the reactor

Figure 5.1, 5.2, 5.3 and 5.4 shows that conversion of 90% ester happened in first 30 minutes. Solution is stirred for 20,30,40,50 and 60 minutes. The results show that with increasing time after 30 minutes, little change in the conversion rate has been observed. After 30 minutes after process begin, increasing rate of production dropped down and reaction rate reaches equilibrium. Transesterification process begins by mixing between methanol and vegetable oil in the presence of potassium hydroxide (KOH). The rate of reaction initially due to the low solubility of alcohol to oil and in the second stage increases finally, the consumption of reactants decreases and reaches equilibrium.

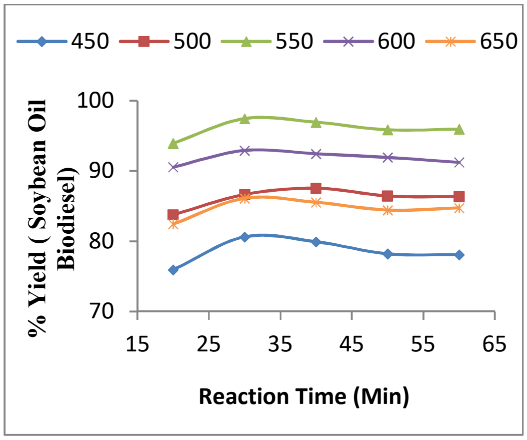


Figure 5.1: Effect of mixing time on biodiesel conversion rate for Soybean Oil

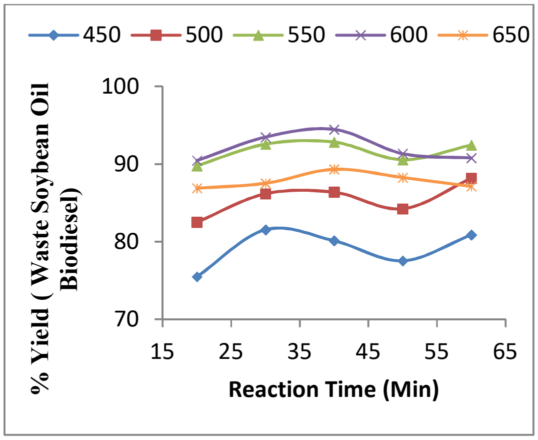
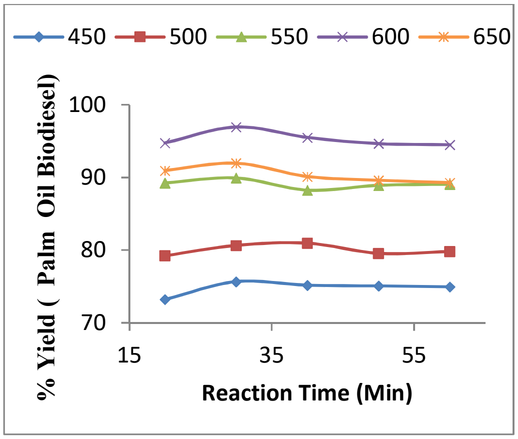


Figure 5.2: Effect of mixing time on biodiesel conversion rate for Waste Soybean Oil



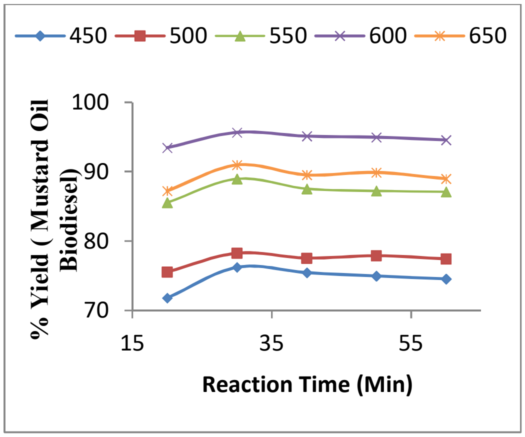
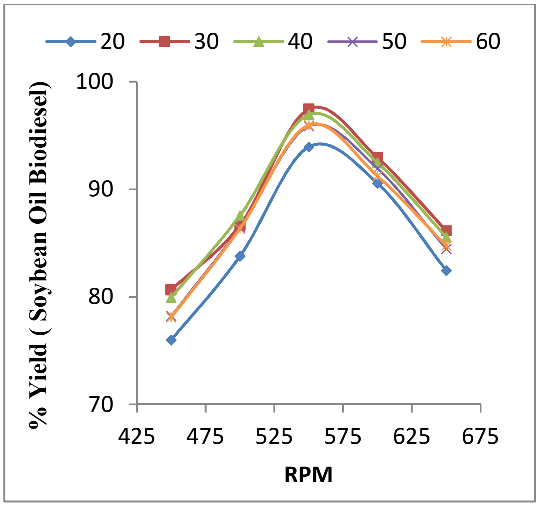


Figure 5.3: Effect of mixing time on biodiesel conversion rate for Palm Oil

Figure 5.4: Effect of mixing time on biodiesel conversion rate for Mustard Oil

5.2.2 Effect of stirring velocity on the yield of biodiesel production at the reactor:

Figure 5.5, 5.6, 5.7 and 5.8 shows that with the increase of stirring velocity, biodiesel production rate increases and reaches its maximum at around 600 rpm. With increasing stirrer speed, collisions between molecules that are insoluble in alcohol and oils and form a homogeneous phase, increased and more mass transfer takes place. Higher stirring velocity, cause higher conversion rate in a lower time. However, excessive stirring rate may reduce the reaction rate.



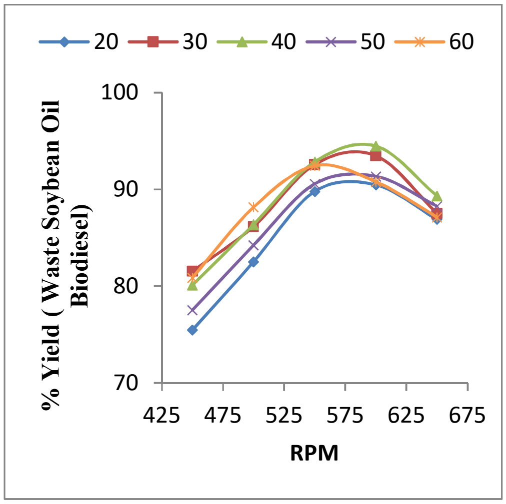


Figure 5.5: Effect of stirring velocity on biodiesel production from Soybean Oil

Figure 5.6: Effect of stirring velocity on biodiesel production from Waste Soybean Oil

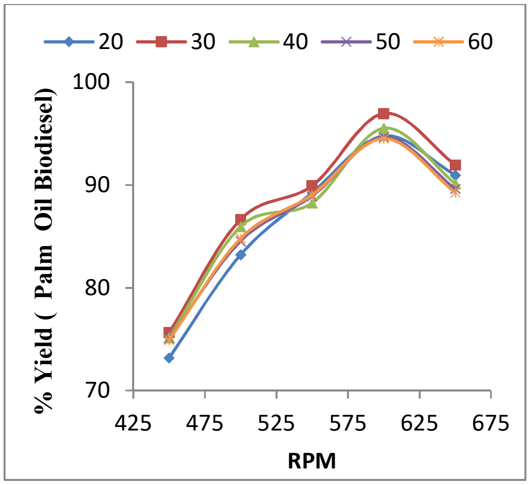


Figure 5.7: Effect of stirring velocity on biodiesel production from Palm Oil

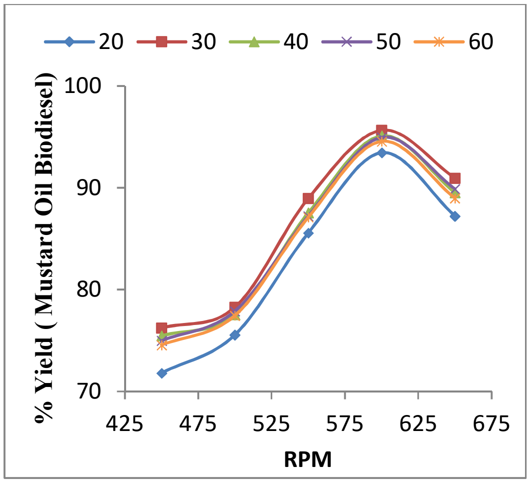
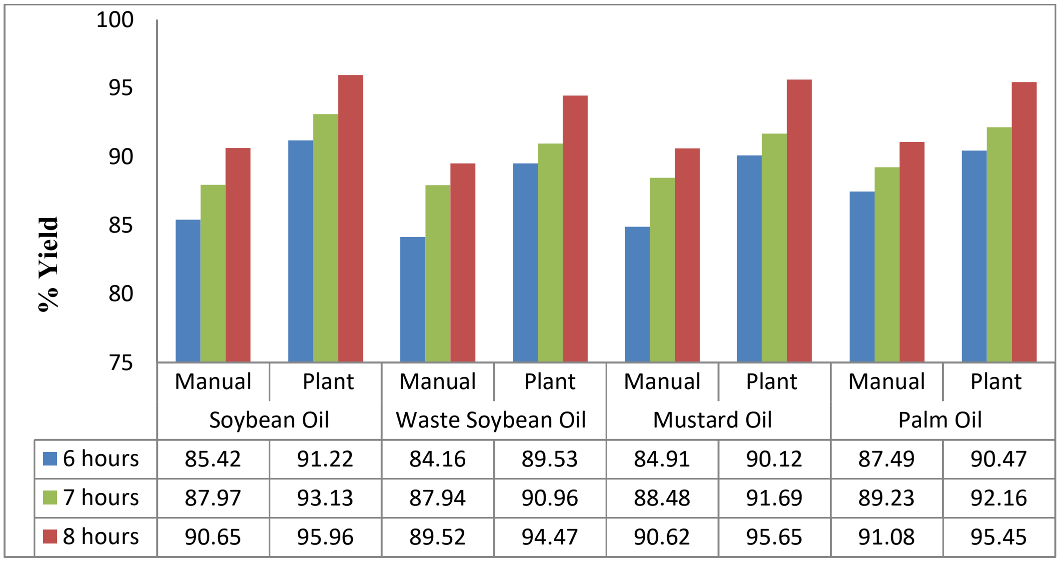


Figure 5.8: Effect of stirring velocity on biodiesel production from Mustard Oil

5.2.3 Effect of separation time on the yield of biodiesel production at the reactor

For the preparation of biodiesel the reactor is run with the optimized heating temperature of 50°C, stirring velocity 550 - 600 rpm and stirring time of 30-35 minutes for different feedstock. After reaction ended, the next step is the phase separation. Biodiesel and glycerin are products of the reaction. Time required for the separation of more than 90%, is about 7 to 8 hours for both manual and automated method.

But figure 5.9 show that biodiesel yield increased almost 5% at 8 hours of separation time when it is generated by the automated plant.



	Soybean Oil		Waste Soybean Oil		Mustard Oil		Palm Oil	
	Manual	Plant	Manual	Plant	Manual	Plant	Manual	Plant
🟦 6 hours	85.42	91.22	84.16	89.53	84.91	90.12	87.49	90.47
🟩 7 hours	87.97	93.13	87.94	90.96	88.48	91.69	89.23	92.16
🟥 8 hours	90.65	95.96	89.52	94.47	90.62	95.65	91.08	95.45

Figure 5.9: Effect of separation time on yield of biodiesel

5.2.4 Efficiency of methanol recovery unit

Most of the biodiesel production methods require an excess of methanol over the stoichiometric ratio required for the reaction. Typically an excess of twice the required amount is used. Because of the nature of the equilibrium and reversible reaction for biodiesel production, the excess methanol is employed to favor a more complete reaction to achieve a higher quality product. In order to improve efficiencies and conserve resources, it behooves producers to recover and reuse the excess or residual methanol.

After the biodiesel has been produced, about 70% of the methanol left over will be found in the glycerin by-product. Boiling the methanol out of the glycerin within a closed container and funneling it into a condenser can recover this portion. Approximately 30% of the remnant methanol is in the un-washed biodiesel. It is generally agreed upon that it takes too much energy and time to be worth reclaiming this portion.

Methanol (CH_3OH) used in this system is 99.8% pure, Density is 793 kg/m^3 and Molar ratio is 32.04 g/mol. Methanol is a colorless liquid that is highly volatile (boiling point of 64.7°C) and flammable (flash point of 8ºC), and burns with an invisible flame. It is very toxic and quickly absorbed into the body through the skin and lungs. So, appropriate safety precautions must be taken to avoid accidents.

Among the various types of heat exchangers that are used in industries, tubular heat exchanger is selected. Advantage of the tubular heat exchanger are capability of design for all pressure, temperature and flow, possibility of selecting various design pipe diameter, length and arrangement of core and economical aspects. The selected operating temperature and pressure of the methanol recovery unit was 70 ℃ and, 1 atm respectively. Table 5.1 shows the amount of methanol recovered during the heating of 1 liter of glycerin. After recovering methanol, it is good to test the purity of it before using it. Hence, the density of the recovered methanol is measured and found similar with the initial one.

Table 5.1: Amount of methanol recovered

Sample	Sample Volume (Glycerin)	Volume of Methanol recovered	Density
Sample 1	1000 ml	695 ml	790
Sample 2		712 ml	787
Sample 3		705 ml	791

5.3 Fuel Property Analysis

In this experimental investigation biodiesel made from soybean oil, mustard oil and palm oil blended with diesel at various ratio. The blend of Soybean Oil Biodiesel with diesel is denoted S20, S40, S60, S80 and S100. The blend of Waste Soybean Oil Biodiesel with diesel is denoted B20, B40, B60, B80 and B100. Again the blend of Mustard Oil Biodiesel with diesel is denoted M20, M40, M60, M80 and M100. And the blend of diesel with Palm Oil Biodiesel is denoted P20, P40, P60, P80 and P100.The blends were tested for density, kinematic viscosity, heating value and flash point. Fuel testing results are presented in Appendix - D.

5.3.1 Comparison of fuel properties of biodiesel blends

5.3.1.1 Density:

Density is an important property of CI engine fuel. Figure (5.10, 5.11, 5.12 and 5.13) shows density for diesel, biodiesel and their blends made from soybean oil, waste soybean oil, palm oil and mustard oil respectively. It is found that density of fuel increases with the increase in their blending number.

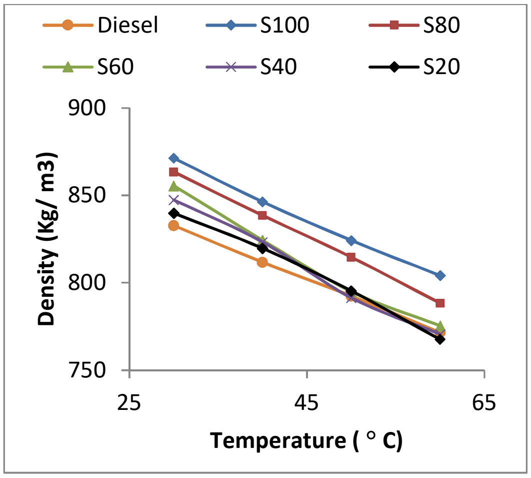


Figure 5.10: Temperature vs. density curve for diesel and biodiesel blends made from Soybean oil

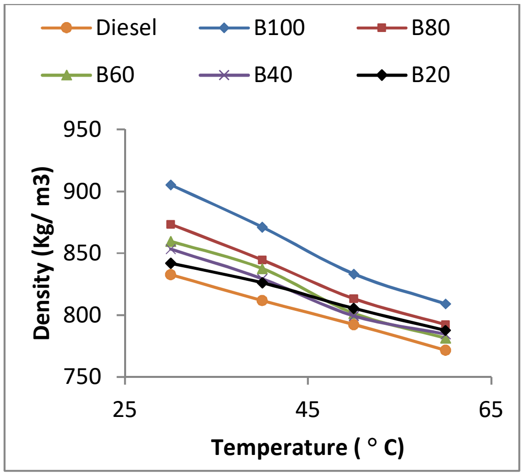


Figure 5.11: Temperature vs. density curve for diesel and biodiesel made blends made from Waste Soybean oil

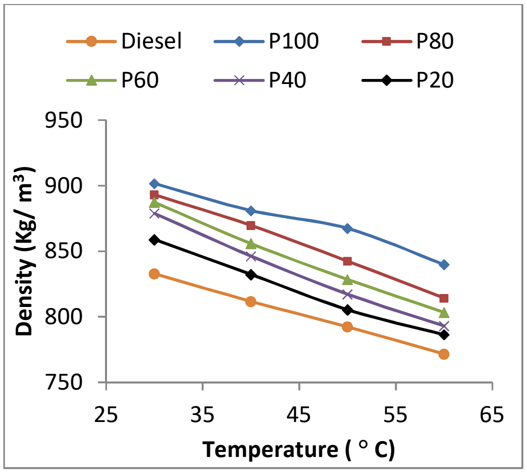


Figure 5.12: Temperature vs. density curve for diesel and biodiesel blends made from Palm oil

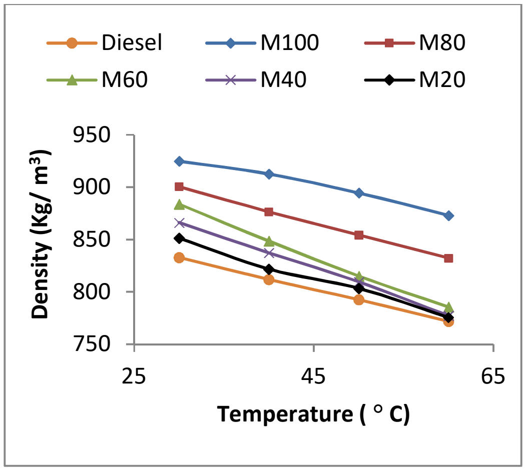


Figure 5.13: Temperature vs. density curve for different biodiesel blends made from Mustard oil

5.3.1.2 Viscosity

Viscosity of the fuel exerts a strong influence on the shape of the fuel spray; high viscosity for example, causes low atomization (large-droplet size) and high penetration of the spray jet. A cold engine, with higher viscous oil, discharge wills almost a solid stream of fuel into the combustion chamber and starting may be difficult while a smoky exhaust will almost invariably appear. On the other hand, very low viscous fuel would cause to pass through the leakage of piston and piston wall especially after wear has occurred, which subsequently prevents accurate metering of the fuel.

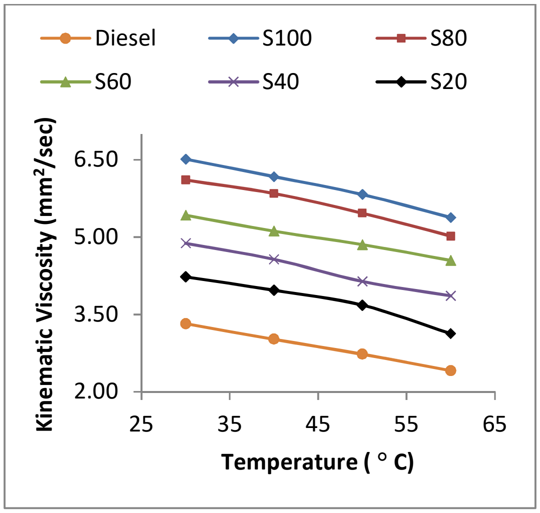


Figure 5.14: Temp vs. Kinematic viscosity curve for diesel and biodiesel blends made by Soybean oil

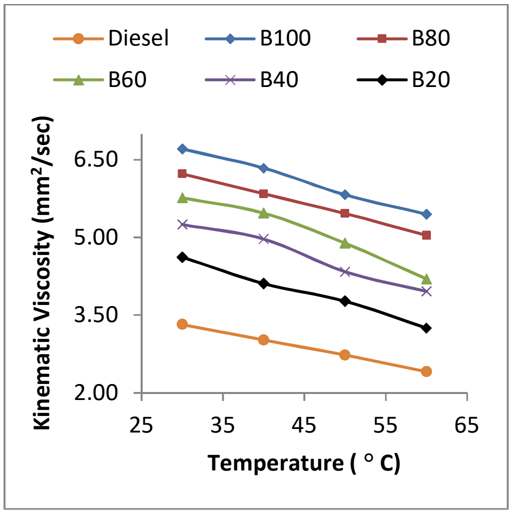


Figure 5.15: Temp vs. Kinematic viscosity curve for diesel and biodiesel blends made by Waste Soybean oil

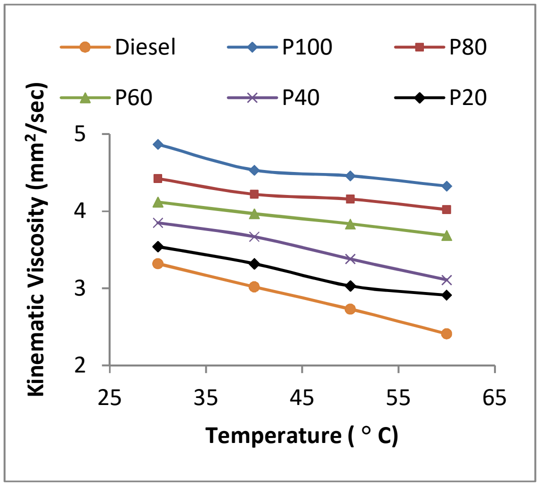


Figure 5.16: Temp vs. Kinematic viscosity curve for diesel and biodiesel blends made by palm oil

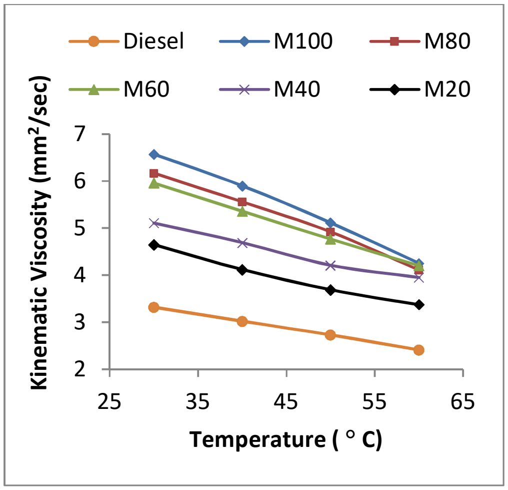


Figure 5.17: Temp vs. Kinematic viscosity curve for diesel and biodiesel blends made by Mustard oil

From figure 5.14 -5.17 it is found that, the viscosity of fuels decreases with the increase of the temperature. Apparently the viscosity of the various blends is increasing with the mixing percentage of biodiesel with the diesel.

5.3.1.3 Heating value and flash point

Heating value indicates the energy density of the fuel. From Table 5.2 it is observed that, diesel fuel has heating value about 46.8 MJ/kg. And heating value of the biodiesel blends decreases with higher blending of biodiesel. This is because, biodiesel has lower energy density than diesel fuel, so higher amount of biodiesel is required for producing same amount of energy as compared to diesel fuel.

Flash point is an important property of CI engine fuel. From Table 5.2 it is observed that, diesel fuel has a flash point of 65℃. The flash point of the bio fuel is higher with higher blending of biodiesel. This is also because of biodiesel; has lower energy density than diesel fuel. So, higher amount of compression ratio is required for producing same amount of energy as compared to diesel fuel. Table 5.1 shows the heating value of diesel, neat biodiesel and their blends in MJ/kg and flash point in degree Celsius.

Table 5.2: Comparison of heating value and flash point of different fuels

Fuel type	Blends	Heating value MJ / Kg	Flash point (°C)
Diesel	D100	46.8	65
Soybean oil	S 100	39.93	92
	S 80	41.09	82
	S 60	42.24	81
	S 40	43.2	78
	S 20	44.5	73
Waste Soybean oil	B 100	39.43	113
	B 80	40.27	101
	B 60	41.36	95
	B 40	42.89	84
	B 20	43.56	77
Mustard oil	M 100	33.53	122
	M 80	35.4	113
	M 60	37.5	105
	M 40	39.3	92
	M 20	41.2	85
Palm oil	P 100	39.81	262
	P 80	40.23	213
	P 60	41.59	183
	P 40	42.05	162
	P 20	43.46	123

5.4 Engine Performance Analysis

Engine performance data are shown in Appendix - D from Table D3 to D17 in experimental Data Result. From those tables various graphs are drawn to show the engine performance.

5.4.1 Engine speed vs. bsfc for different blends originated from same bio fuels

BSFC refers to consumption of fuel per unit power and in a unit time. Generally using bio fuel results in higher BSFC than that of OD fuel [83]. As biofuels have higher density and lower calorific value than OD fuel, increase of BSFC is obvious. Injection pressure and atomization rate also have some effects on BSFC. Most of the papers reviewed here reported increase or closely similar BSFC of bio fuels compared to OD fuel. But there were also some exceptions.

Here, figure 5.18 – figure 5.21 also show that biodiesel has higher BSFC than that of OD fuel.

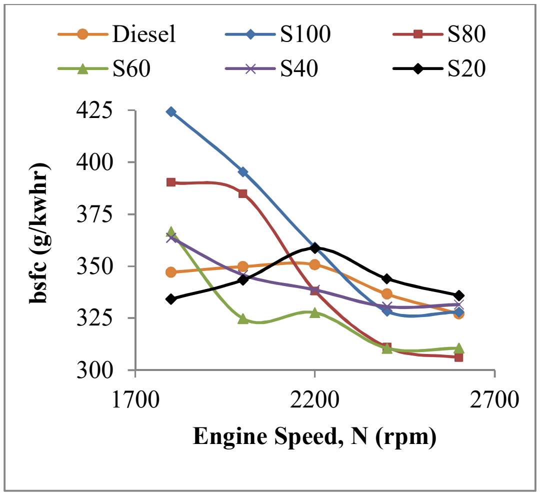


Figure 5.18: Comparison of Engine Speed vs. bsfc curve for diesel and biodiesel blends made from Soybean

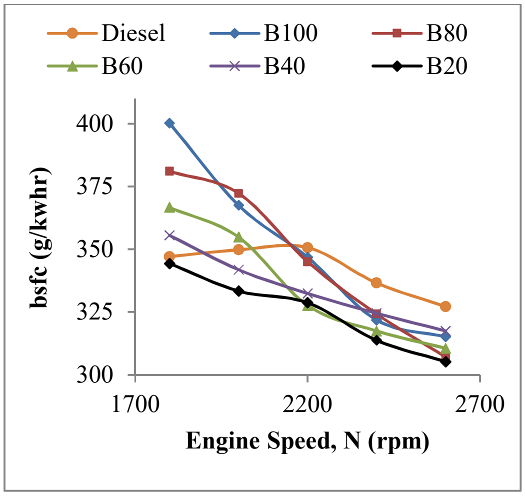


Figure 5.19: Comparison of Engine Speed vs. bsfc curve for diesel and biodiesel blends made from Waste Soybean oil

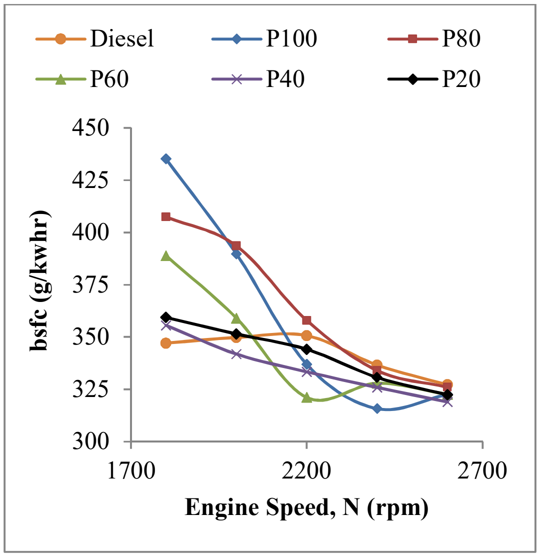


Figure 5.20: Comparison of Engine Speed vs. bsfc curve for diesel and biodiesel blends made from Palm oil

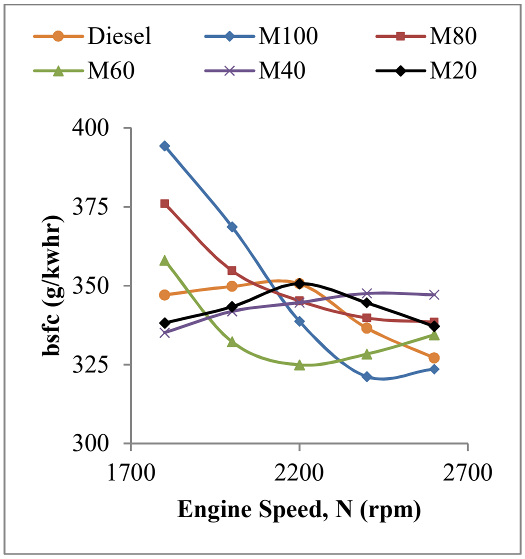


Figure 5.21: Comparison of Engine Speed vs. bsfc curve for diesel and biodiesel blends made from Mustard

5.4.2 Engine speed vs. bhp for different blends originated from same bio fuels

Figure 5.22, 5.23, 5.24 and 5.25 reported slight brake power reduction compared to OD fuel, with the increase of biofuel percentage in the blends of Biodiesel made from Soybean oil, Waste soybean oil, Palm oil and Mustard oil respectively. Many authors mentioned lower heating values of bio fuels and their blends are responsible for this phenomenon [84]. However, other physicochemical properties of bio- fuel like higher density, viscosity etc. result poor atomization and problems in fuel flow. These are also some justified causes of low power output. To maintain the same power as obtained by OD fuel BSFC will be higher for the biofuels.

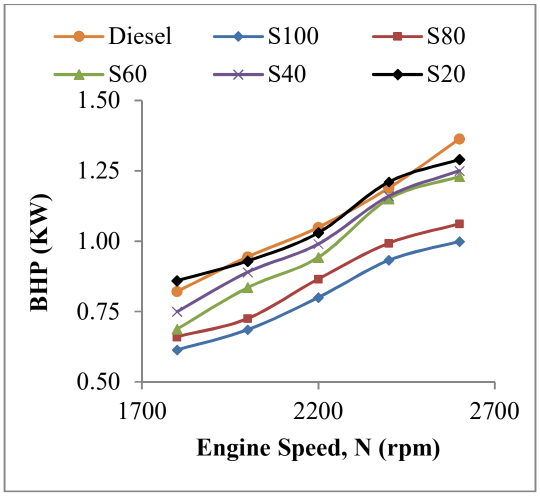


Figure 5.22: Comparison of Engine Speed vs. BHP curve for diesel and biodiesel blends made from Soybean

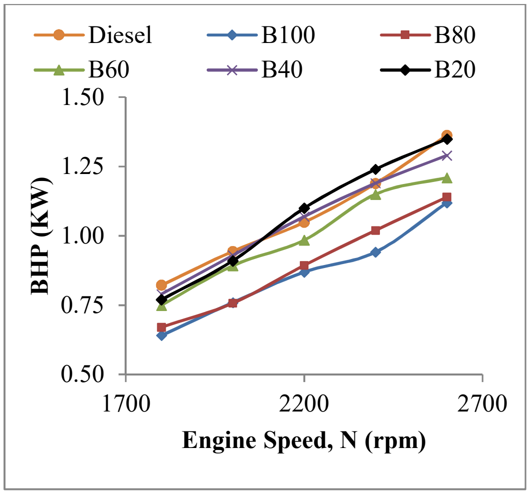


Figure 5.23: Comparison of Engine Speed vs. BHP curve for diesel and biodiesel blends made from Waste Soybean oil

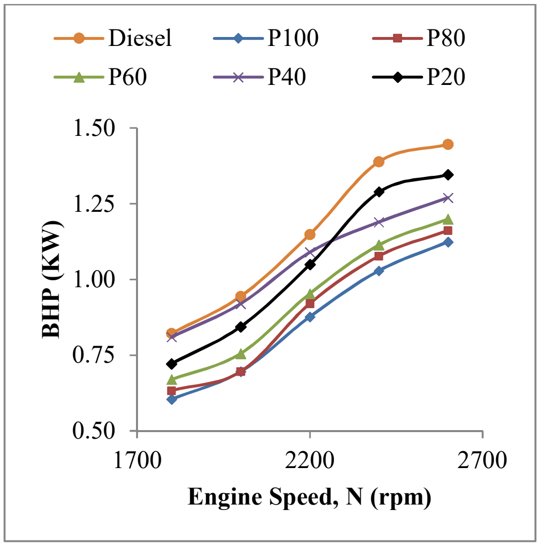


Figure 5.24: Comparison of Engine Speed vs. BHP curve for diesel and biodiesel blends made from Palm oil

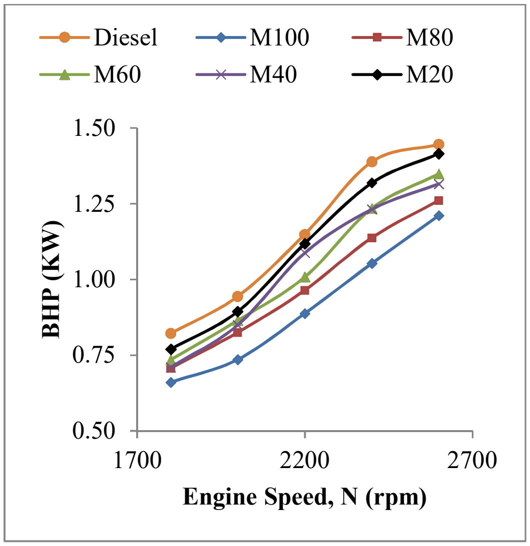
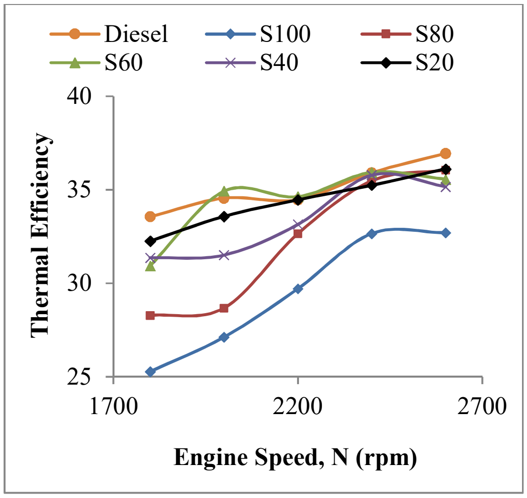


Figure 5.25: Comparison of Engine Speed vs. BHP curve for diesel and biodiesel blends made from Mustard

5.4.3 Engine Speed vs. brake thermal efficiency (BTE) for different blends originated from same bio fuels

As biodiesels have lower calorific value than OD fuel and different biofuels have different calorific values and densities, comparing them in the basis of BSFC could be misleading. For this reason BTE can be considered instead of BSFC.



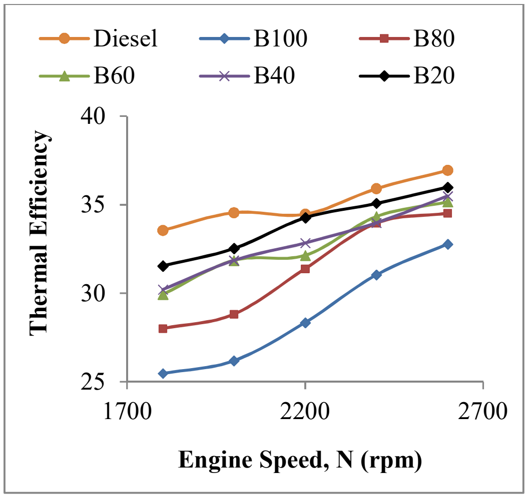
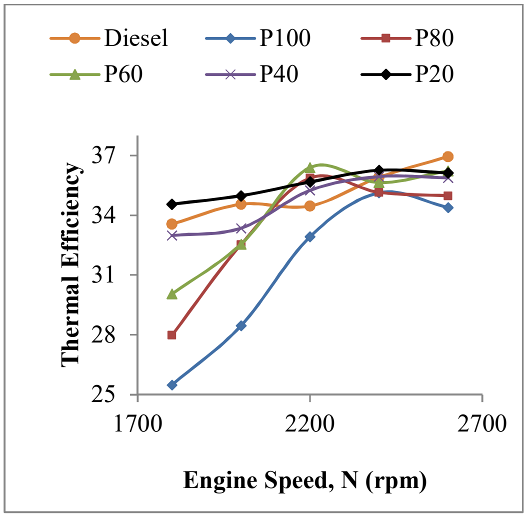


Figure 5.26: Comparison of Engine Speed vs. Thermal Efficiency curve for diesel and biodiesel blends made from Soybean oil

Figure 5.27: Comparison of Engine Speed vs. Thermal Efficiency curve for diesel and biodiesel blends made from Waste Soybean oil



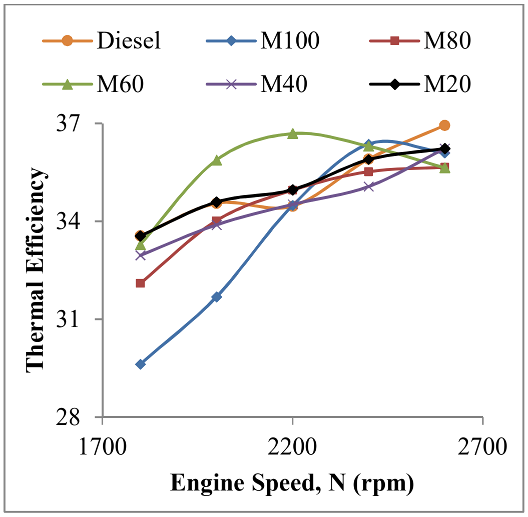


Figure 5.28: Comparison of Engine Speed vs. Thermal Efficiency curve for diesel and biodiesel blends made from Palm oil

Figure 5.29: Comparison of Engine Speed vs. Thermal Efficiency curve for diesel and biodiesel blends made from Mustard oil

Figure 5.26, 5.27, 5.28 and 5.29 reported both increasing and decreasing phenomena regarding BTE of the blends of Biodiesel made from Soybean oil, Waste soybean oil, Palm oil and Mustard oil respectively. However, for 20% blending very similar BTE of biodiesels compared to OD fuel is observed. In other cases BTE deteriorated due to higher viscosity and lower cetane index. Also, time taken for complete combustion is decreased, oxygen molecules get small time to change its state to atomic oxygen, hence BTE drops slightly.

5.4.4 Engine speed vs. exhaust gas temperature (EGT) for different blends originated from same bio fuels

Effective use of heat energy contained in the fuel is indicated by EGT. Emission characteristics of biodiesels generally show a wide range of reports regarding EGT. Lower value of EGT is an indication of good burning of fuel inside the engine cylinder. As EGT for biofuel remains lower than that of OD fuel, it indicates that the engine is not thermally overloaded though BSFC was higher. Heating value, cetane number, density and kinematic viscosity these four physicochemical properties also have potential impact on EGT. As all discussed biofuels have higher cetane number and lower heating value than OD fuel, ignition delay occurred which results lower EGT. Higher density and kinematic viscosity of biodiesel causes poor fuel atomization and leads to EGT reduction. In most of the experimental results, EGT increased and causes behind this phenomenon perhaps, high oxygen content and more fuel burning at higher load condition resulted in improved combustion, hence increased EGT. Due to longer physical delay of biofuels some fuel particles do not get enough time to be burnt completely initially after injection and get burnt at latter part of expansion. As a result, afterburning occurs which leads to high EGT.

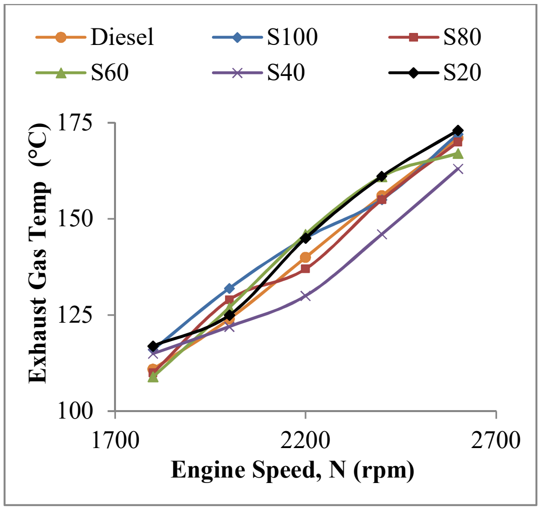


Figure 5.30: Comparison of Engine Speed vs. Exhaust gas Temp curve for diesel and biodiesel blends made from Soybean oil

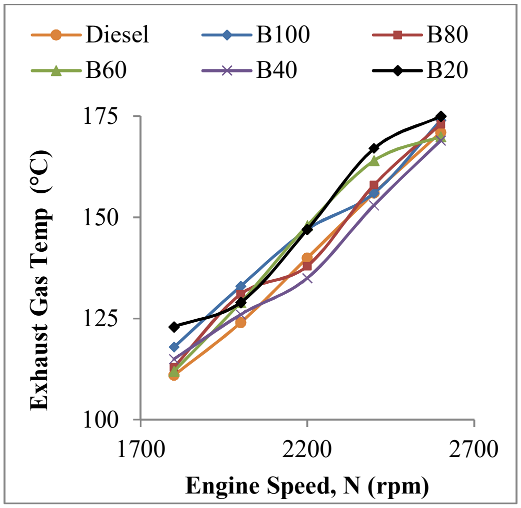


Figure 5.31: Comparison of Engine Speed vs. Exhaust gas Temp curve for diesel and biodiesel blends made from Waste Soybean oil

Figure 5.30, 5.31, 5.32 and 5.33 reported that exhaust gas temperature increases with increase in speed for diesel as well for all combination of blends of Biodiesel made from Soybean oil, Waste soybean oil, Palm oil and Mustard oil respectively. As the load increase fuel air ratio increases and hence the operating temperature increases which results in higher exhaust gas temperature. In Biodiesel operation the combustion is delayed due to higher fire point. As the combustion is delayed, injected Biodiesel fuel particles may not get enough time to burn completely during before top dead center, hence some fuel mixtures tends to burn during the early part of expansion, consequently after burning occurs and hence increase in the exhaust temperature. Here exhaust temperature is increasing with increasing of engine speed 1800 rpm to 2600 rpm for diesel,

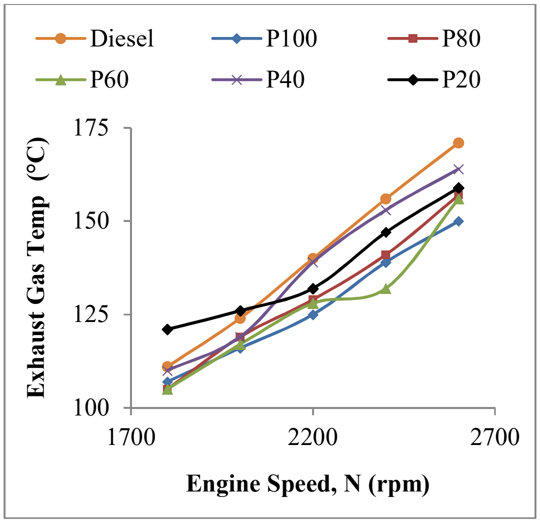


Figure 5.32: Comparison of Engine Speed vs. Exhaust gas Temp curve for diesel and biodiesel blends made from Palm oil

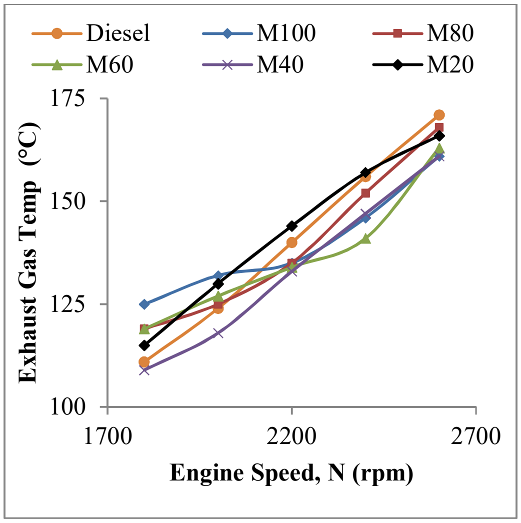


Figure 5.33: Comparison of Engine Speed vs. Exhaust gas Temp curve for diesel and biodiesel blends made from Mustard oil

5.5 Emission Analysis

Adequate quantities of air and fuel, combined with a complete combustion would result in carbon dioxide (CO_2), nitrogen (N_2) and water (H_2O). However, complete combustion is generally impracticable to achieve unless the reaction take place under controlled situations, such as in a laboratory. Therefore, it is necessary to provide the correct air/fuel ratio to reduce CO_2 emissions. Because, even though CO_2 is not directly damaging to humans, it is harmful to environment and also contributes to global warming. Engine Emission Analysis of different biodiesel Blends are presented in Appendix – D.

5.5.1 Carbon monoxide (CO) emission at different speed conditions:

CO is very harmful for nature and toxic to human health. It combines with hemoglobin to produce carboxy-hemoglobin, which is ineffective for delivering oxygen to bodily tissues. Concentrations as low as 667 ppm may cause up to 50% of the body's hemoglobin to convert to carboxyhemoglobin. A level of 50% carboxyhemoglobin may result in seizure, coma, and fatality. [10]

CO is mainly produced due to incomplete combustion of the fuel. Incomplete combustion occurs when flame temperature cools down and progression to CO_2 remains incomplete. When flame front approaches to relatively cool cylinder liner and in crevice volume, combustion process is slowed down and flame front is extinguished. If the air fuel mixture is too rich amount of oxygen becomes insufficient for complete combustion.

Figure 5.34 – 3.37 showed a decrease in CO emission while diesel fuel is replaced by different biofuels. Pure biodiesel produces less CO than the blended one which indicates complete combustion of biofuel than OD fuel. Explanation of this finding is additional oxygen content of biodiesel which ensures complete combustion of the fuel. Higher cetane number and lower compressibility of biodiesel compared to diesel fuel reduce the probability of advanced injection and forming fuel rich zone. As a result ignition delay becomes shorter, duration of combustion process increases and combustion gets completed properly, hence reduces CO.

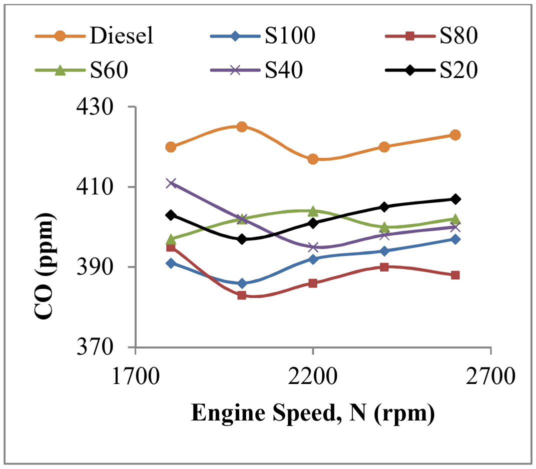


Figure 5.34: Variation of Engine speed with Carbon-monoxide for different Biodiesel blends made from

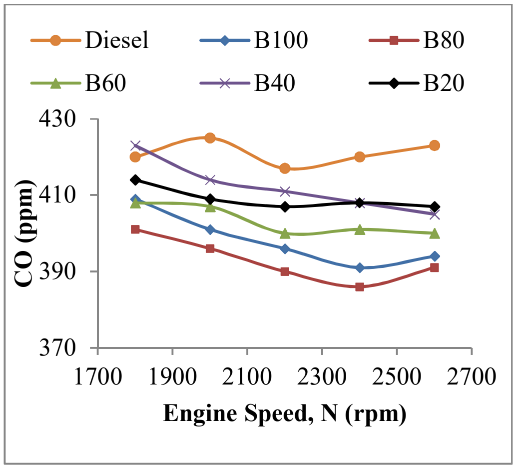


Figure 5.35: Variation of Engine speed with Carbon-monoxide for different Biodiesel blends made from Waste Soybean Oil

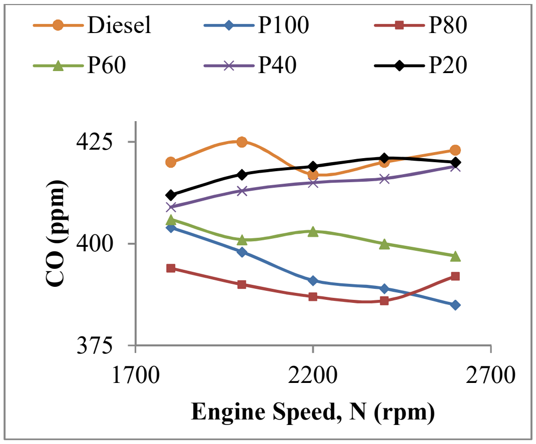


Figure 5.36: Variation of Carbon-monoxide with speed for different blends of Palm Biodiesel

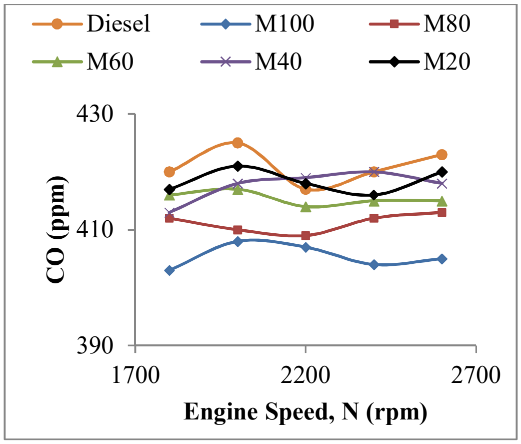


Figure 5.37: Variation of Engine speed with Carbon-monoxide for different blends made from

It is observed that CO emissions from biodiesel blends made from different blends of biodiesel made from soybean oil, waste soybean oil, palm oil and mustard oil are much lesser than diesel fuel at different speed.CO emission from biodiesel varies from 391 to 421 (ppm) which is lesser than commercial diesel (around 420 to 425).

5.5.2 Carbon dioxide (CO_2) emission at different speed conditions:

Figure 5.38, 5.39 and 5.41 shows that commercial diesel fuel gives less CO_2 than 100% and 80% Biodiesel blends of soybean oil, waste soybean oil and mustard oil respectively. This happens due to incomplete combustion of the higher blends of biodiesel. For other lower percentage blends CO_2 emission is less or equal of commercial diesel fuel. But from figure 5.40 it is reported that for all the blends of Palm oil Biodiesel CO_2 emission is equal or less than the emission of commercial diesel fuel.

It is also seen that with the increase of speed the rate of percentage of CO_2 emissions for biodiesel blends varied between 4.71 to 6.16 % while commercial diesel fuel varied 4.94 to 5.83%.

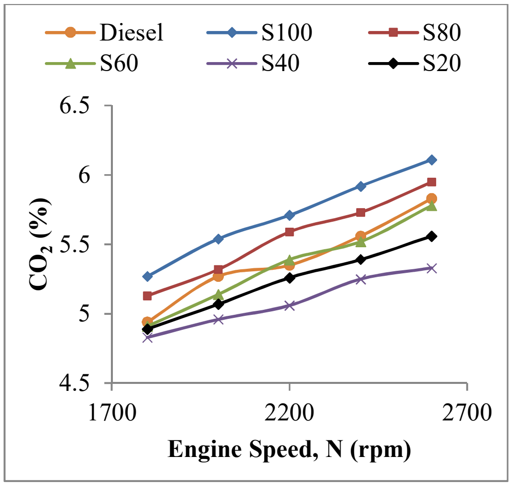


Figure 5.38: Variation of Carbon-dioxide with speed for different blends of Soybean Biodiesel

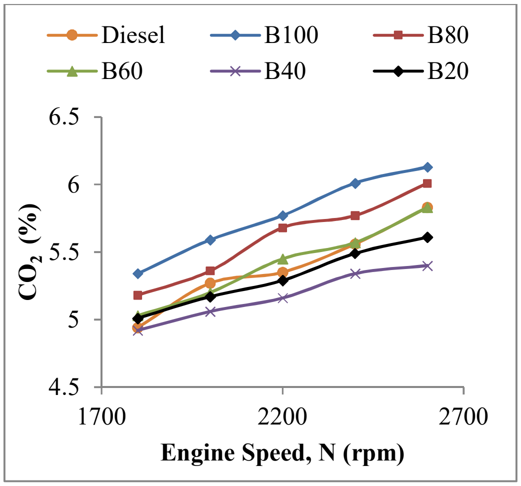


Figure 5.39: Variation of Carbon-dioxide with speed for different blends of Waste Soybean Oil

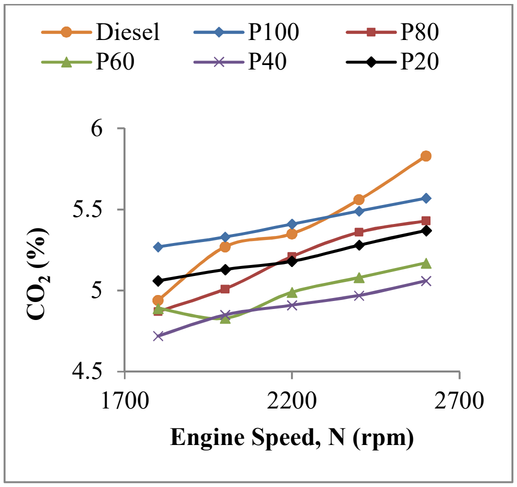


Figure 5.40: Variation of Carbon-dioxide with speed for different blends of Palm Biodiesel

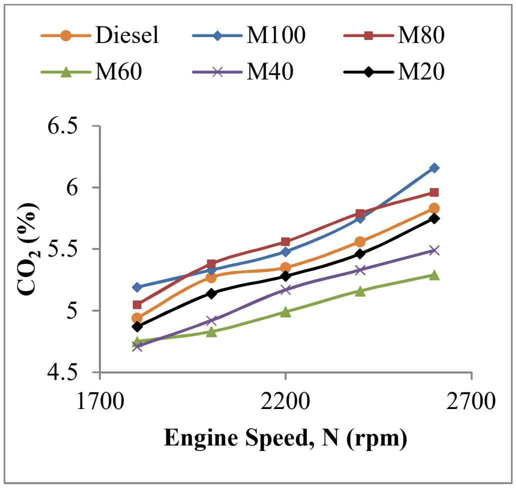


Figure 5.41: Variation of Carbon-dioxide with speed for different blends of Mustard Biodiesel

5.5.3 Oxygen (O_2) emission at different speed conditions:

In CI diesel engine operating with diesel fuel, approximately 5 to 15 % of exhaust emissions of the engine is composed of oxygen.

Figure 5.42-5.45 shows the percentage of oxygen emitted from diesel and bio diesel blends made from soybean oil, waste soybean oil, palm oil and mustard oil respectively. Biodiesel and its blends emit much higher O_2 around (18.08-25.64%) than commercial diesel (18.21-21.58%).

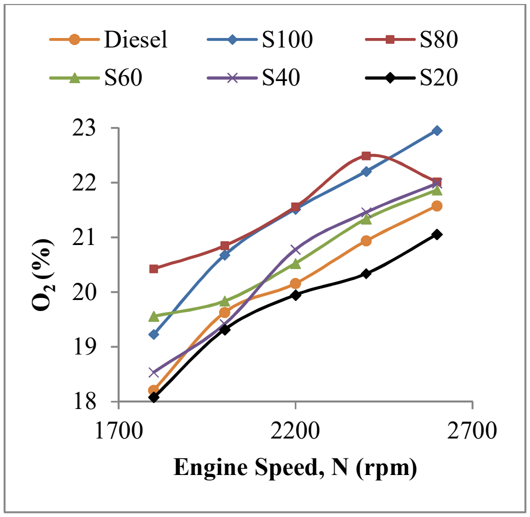


Figure 5.42: Variation of Oxygen with speed for different blends of Soybean Biodiesel

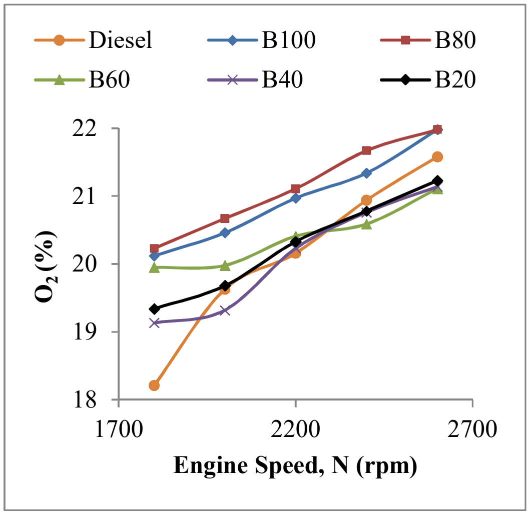


Figure 5.43: Variation of Oxygen with speed for different blends of Soybean Biodiesel

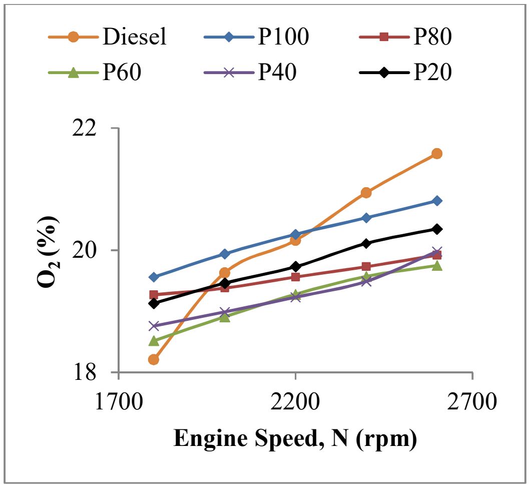


Figure 5.44: Variation of Oxygen with Engine speed for different blends of Palm Biodiesel

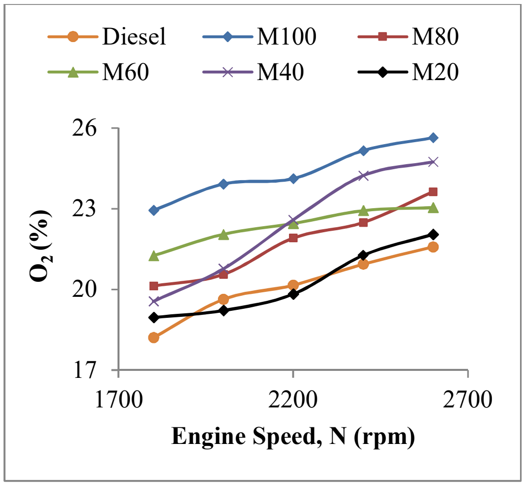


Figure 5.45: Variation of Oxygen with Engine speed for different blends of Mustard Biodiesel

5.5.4 Hydrocarbon (HC) emission at different speed conditions:

Hydrocarbons present in the emission are either partially burned or completely unburned. Generally a sharp decrease in the trend of HC emission is observed while running the engine with biofuel. Similar to CO emission, HC emission is also resulted from incomplete combustion due to flame quenching at cylinder lining and creviceregion. Engines operating conditions, fuel spray formation, fuel properties etc. are some other important HC emission influencing conditions. As the blending percentage, cetane number and oxygen content of the biodiesel increases, hence leads to more complete combustion and combustion efficiency increases. Higher combustion efficiency reduces unburned HC emission. At higher engine speed, as injection pressure is higher and atomization ratio is also increased, HC emission shows similar trend regardless of the fuel type. Enhanced air flow inside engine cylinder at high speed range helps to create more homogeneous mixture and reduces HC emission. On the whole, there was a decrease in the HC with increase in the speed.

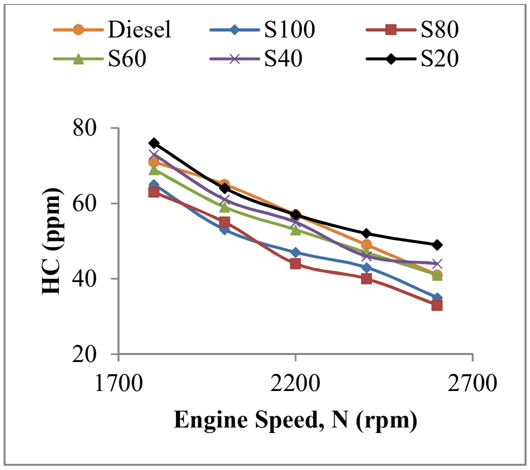


Figure 5.46: Variation of Hydrocarbon with Engine speed for different blends of Soybean Oil

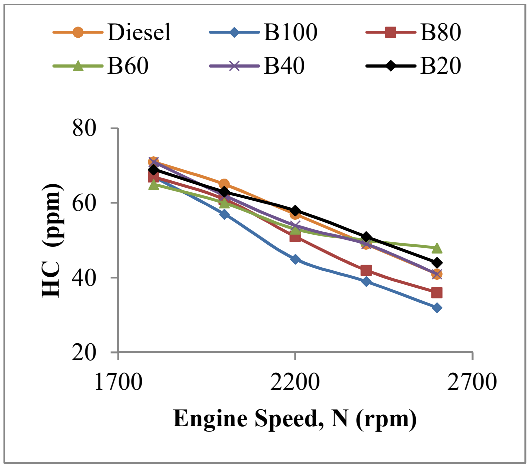


Figure 5.47: Variation of Hydrocarbon with Engine speed for different blends of Waste Soybean

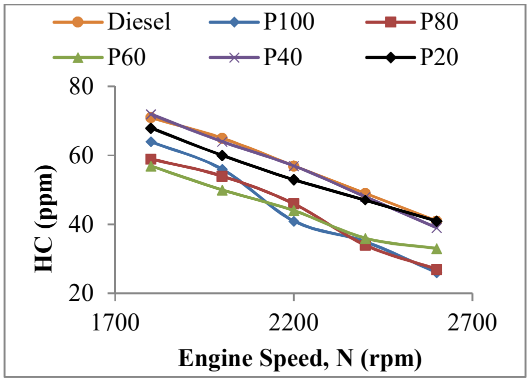


Figure 5.48: Variation of Hydrocarbon with Engine speed for different blends of Palm Oil Biodiesel

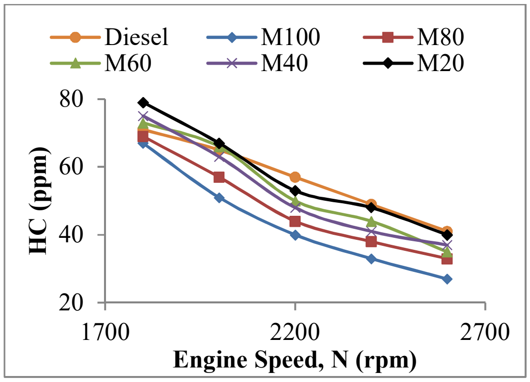


Figure 5.49: Variation of Hydrocarbon with Engine speed for different blends of Mustard Oil

5.5.5 Oxides of nitrogen (NO_X) emission at different speed conditions:

NO_X emissions depend on the oxygen concentration and the combustion time. Most of the literature states that at all speeds conditions, NO_X emission of the blends is always higher than that of standard diesel due to the oxygen concentration and combustion timing.

NO_x emissions are generated when nitrogen is burned or oxidized. As the air is composed of 78% of N_2 any engine regardless of fuel type or, the characteristics of engine, will produced some level of NO_x. Favored by the temperature levels and the local supply oxygen, most of the NO_x found in exhaust gas of diesel engines is produced in the lean flame region, where either micro volume combustion occurs or independent flames propagate.

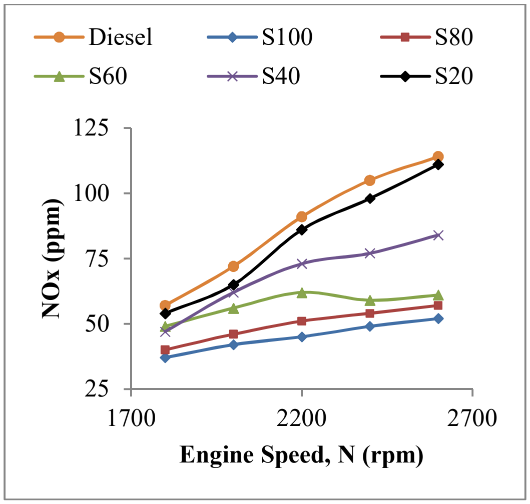


Figure 5.50: Variation of NO_X with Engine speed for different blends of Soybean Oil Biodiesel

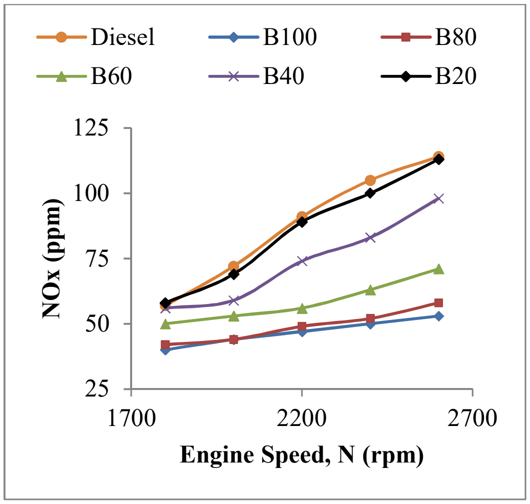


Figure 5.51: Variation of NO_X with Engine speed for different blends of Waste Soybean Oil Biodiesel

From figure 5.50, 5.51, 5.52 and 5.53 it was seen that NO_x level decreases with increase of biodiesel percentage in the blends of Biodiesel made from Soybean oil, Waste soybean oil, Palm oil and Mustard oil respectively.

Also from the graph it is reported that NO_x level increases with increase in speed for diesel as well for all combination of blends of Biodiesel.

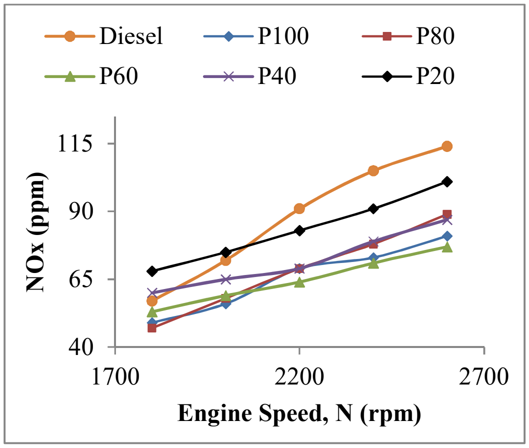


Figure 5.52: Variation of NOx with Engine speed for different blends of Palm Oil Biodiesel

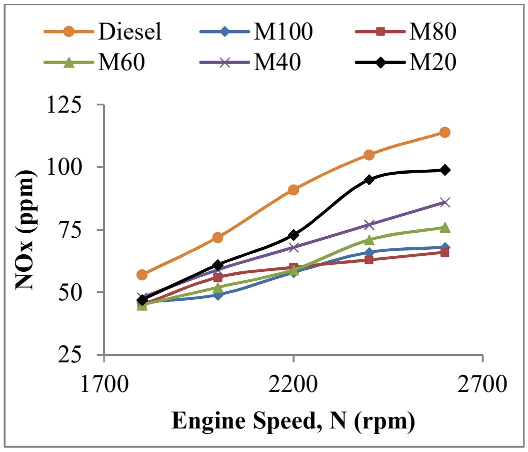


Figure 5.53: Variation of NOx with Engine speed for different blends of Mustard Oil Biodiesel

5.5.6 Oxides of sulfur (SOx) emission at different speed conditions:

SO_2 which contributes to the formation of acid rain depends upon the sulphur content of fuel. It has been seen that the amount of SO_2 is very less in biodiesel and its blends. As the amount of sulphur content much lesser in vegetable oil, very small amount of SO_2 is emitted from the exhaust.

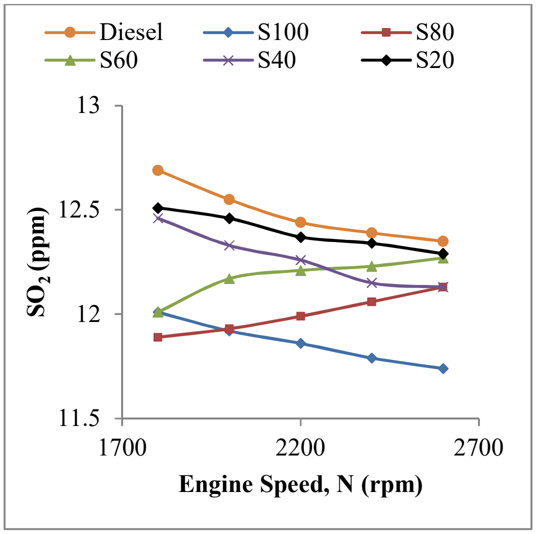


Figure 5.54: Variation of SOx with Engine speed for different blends of Soybean Oil Biodiesel

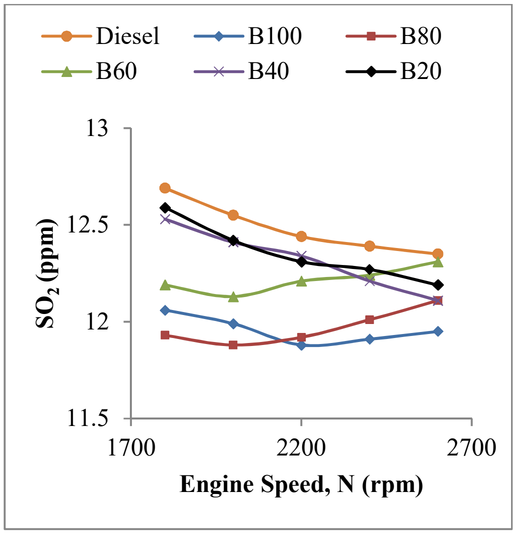


Figure 5.55: Variation of SOx with Engine speed for different blends of Waste Soybean Oil Biodiesel

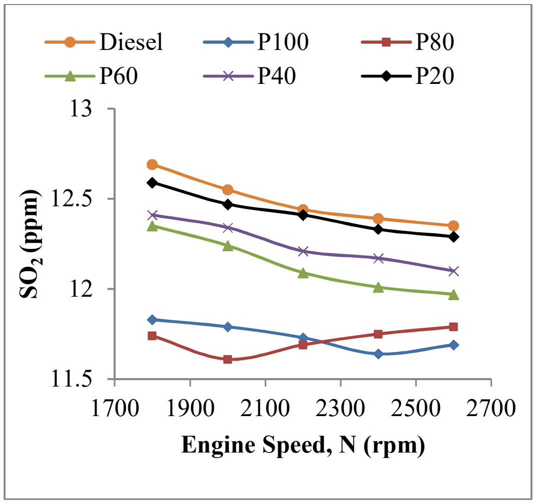


Figure 5.56: Variation of SOx with Engine speed for different blends of Palm Oil Biodiesel

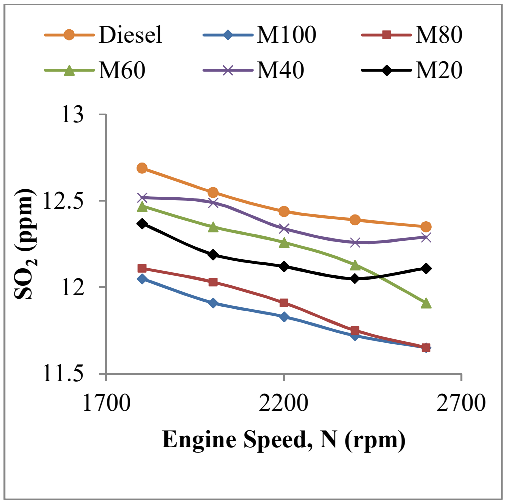


Figure 5.57: Variation of SOx with Engine speed for different blends of Mustard Oil Biodiesel

From figure 5.54, 5.55, 5.56 and 5.57 it is observed that the amount of sulphur dioxide emission for diesel, biodiesel and its blends is decreasing with increase of engine speed. SO_2 emission from biodiesel varies from 11.61 to 12.59 ppm which is lesser than commercial diesel (around 12.35 to 12.69 ppm).

5.6 Cost Analysis

The prices for products and feedstock will vary as the supply and demand in addition to global economy is continually changing.

The prices of feedstock's and production cost per liter biodiesel produced is presented in the table 5.3. From the table it is clear the cost of running a diesel engine with bio-diesel made from soybean and mustard oil is more expensive than pure diesel. This is the biggest hurdle in the way of popularity of biodiesel among consumers. However cost can be drastically reduced if methanol can be recycled after transesterification reaction. Moreover using food grade soybean oil or mustard oil as feed stock is not economically viable. But, using raw oil would cause to decrease of the production cost. Again production cost of biodiesel made from waste vegetable oil is also less. It costs only 67 taka and 27 taka to produce biodiesel from pam oil and WVO respectively. Hence WVO and palm oil would be good biodiesel feedstock.

Table 5.3 Cost Analysis of Various Biodiesel

Ingredients	Price (Taka)	Total Cost	Total Cost (With Methanol recovery)
Soybean oil (1Litter)	100	190 Taka	107 Taka
250 ml Methanol	83		
2g KOH	7		
Waste Soybean oil (1Litter)	20	110 Taka	27 Taka
250 ml Methanol	83		
2g KOH	7		
Palm oil (1Litter)	60	150 Taka	67 Taka
250 ml Methanol	83		
2g KOH	7		
Mustard oil (1Litter)	200	290 Taka	207 Taka
250 ml Methanol	83		
2g KOH	7		

Assumptions regarding the production cost is that the catalyst used is very inexpensive (NaOH/CaO) or it can be reused several times, both resulting in minimal catalyst cost per kg biodiesel produced. Also the fabrication cost of the automated biodiesel plant and the labor cost are not included when calculated the cost of biodiesel.

CHAPTER - 6

CONCLUSION & RECOMMENDATION

6.1 Conclusion

This work is focused on the design of an automated small scale biodiesel production plant and analysis of fuel properties of the product obtained. The procedure has been tested by varying different parameters (reaction time and stirring velocity) and satisfactory results of biodiesel yield were found in all cases. The manual control of the production process is very limited and it can even be used in home to produce homemade biodiesel. The system could be redesigned on a bigger scale to produce biodiesel in large quantities.

The research work also involved with the study of the performance of a diesel engine using the various biodiesel blends generated by the automated biodiesel processor. From this research some conclusions can be drawn which are listed below:

- It has been observed that Biodiesel yield increased almost 5% at 8 hours of separation time when it is generated by the automated plant.
- Higher stirring velocity causes higher conversion rate in a lower time. With the increase of stirring velocity, biodiesel production rate increases and reaches its maximum at around 600 rpm.
- 90% ester happened in first 30 minutes. The results show that with increasing time after 30 minutes, little change in the conversion rate.
- Properties (Density, Viscosity, Heating value) of 10-20% Blends of all the Biodiesel feedstock shows pretty similarity with the Diesel fuel. So it is recommended to use 10-20% blends of Biodiesel in the Diesel engine.
- Due to lower heating value of biodiesel, increasing percentage of biodiesel in the blend increases BSFC and decreases brake power.
- Discussed four particular biodiesel reduce smoke opacity, PM, HC, CO and CO_2 emissions.
- All biofuels contain higher amount of oxygen than OD fuel which ensures complete combustion, hence reduce above mentioned pollutants. Amount of oxygen remains almost invariable in all feedstock.
- Cost of running a diesel engine with bio-diesel made from soybean and mustard oil is more expensive than pure diesel. However, as the production cost of biodiesel made from waste vegetable oil and palm oil is low, so WVO and palm oil would be good biodiesel feedstock

6.2 Recommendations

Biodiesel has superior combustion characteristics and a lower emission rating when compared to other petrochemical diesel. This is why design, construction and performance analysis of a small scale biodiesel plant with minimum human effort and better efficiency is done in this project. The short-term goal is to create a simple purification set-up for WCO and use the end product as fuel for a different vehicle. The long-term goal is to integrate this system into a commercial small-scale biodiesel plant with modified and better purification system for WCO.

It has been observed that biodiesel yield increased almost 5% at 8 hours of separation time when it is generated by the automated plant.

This project is fully operational and due to financial constraints, the focus shifted to the main processing stage. In order to development of the plant, more funding is needed as well as kinetic data and modeling through experimental research using the different feedstock will be analyzed. Even though we were unable to obtain all of our objectives, we believe the efforts have been very helpful and further work should be done on the following areas:

- The performance of the automated plant is determined with some vegetable oil (soybean oil, Mustard Oil and Palm Oil) by varying three parameters- RPM, Time and Temperature. Studies should be done with other edible and nonedible oils too.
- Animal fat and oil extracted from algae could be good source of biodiesel feedstock
- Different heterogeneous and enzymatic catalyst could be analyzed for the reduction of different reaction parameters.
- Ultrasonication of the reactor could reduce the processing time by introducing cavitation to the reaction process.
- Solar thermo siphon system could be added for the heating of the reactants.
- Electrostatic Coalescing method in separation of glycerin could be incorporated in which the high voltage / low current is used.
- More washing methods could be studied and integrated as per requirement. Ion exchange dry wash by using magnesol powder as filter aid on the absorbing column.
- Methanol recovery process could be done by using vacuum distillation method.

REFERENCE

[1] REN21 (2010). Renewables 2010 Global Status Report, pp 15-16.

[2] Srivasata, A. and Prasad, R. Triglyceride based diesel Fuels, Renewable and sustainable Energy Reviews 4: 111-11, 2000.

[3] Shakti-Energy and Environment Related Information Source of Bangladesh, Coal reserves of Bangladesh

[4] United States Department of Energy, Energy Information Administration (EIA), Country Analysis Brief on Bangladesh, May 2003, http://www.eia.doe.gov/emeu/cabs/bangla.html.

[5] https://www.petrobangla.org.bd

[6] Environmental Protection Agency (EPA), A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions, EPA, 2001.

[7] GreenerPro, [Online]. Available: http://www.greenerpro.com/Products.html.

[8] G. Knothe. Historical perspectives in vegetable oils-based diesel fuels. Inform 12, 11 (2001)1103-1107.

[9] M. Mittelbach, C. Remschmidt. Biodiesel: The comprehensive handbook. Boersedruck Ges. M.B.H.; Vienna (2004).

[10] S. PinzI, P. Rounce, J.M. Herreros, A. Tsolakis, M.P. Dorado. The effect of biodiesel fatty acid composition on combustion and diesel engine exhaust emissions. Fuel, 104 (2013)170-182.

[11] D. Srinivas, Satyarthi, Jitendra Kumar. Challenges and opportunities in biofuels production. NISCAIR-CSIR, 51A (2012) 174-185.

[12] M.P. Dorado, J.M. Arnal, J. Gomez, A. GIL, F.J. Lopez. The effect of a waste vegetable oil blend with diesel fuel on engine performance. Transactions of the Asae, 45 (2002) 519-523.

[13] A.W. Schwab, G.J. Dykstra, E. Selke, S.C. Sorenson, E.H. Pryde. Diesel fuel from thermal-decomposition of soybean oil. *Journal of the American Oil Chemists Society*, 65 (1988) 1781-1786.

[14] M. Ziejewski, K.R. Kaufman, A.W. Schwab, E.H. Pryde. Diesel-engine evaluation of a nonionic sunflower oil aqueous-ethanol micro emulsion . *Journal of the American Oil Chemists Society*, 61 (1984) 1620-1626.

[15] A.W. Schwab, M.O. Bagby, B. Freedman. Preparation and properties of diesel fuels from vegetable-oils Fuel, 66 (1987) 1372-1378.

[16] G. Chavanne. Procede de Transformation d' Huiles Vagetales en Vue de leur Utilization comme Carburants. Patent number: 422877.University of Brussels, Brussels (1937)

[17] L. Brennan, P. Owende. Biofuels from microalgae. A review of technologies for production, processing, and extractions of biofuels and co-products. Renewable and Sustainable Energy Reviews, 14 (2010) 557-577.

[18] M.P. Dorado, E. Ballesteros, J.A. DE Almeida, C. Schellert, H.P. Lohrlein, R.Krause. An alkali-catalyzed transesterification process for high free fatty acid waste oils. Transactions of the Asae, 45 (2002) 525-529.

[19] S. Pinzi, D. Leiva, G. Arzamendi, L.M. Gandía, M.P. Dorado. Multiple esponse optimization of vegetable oils fatty acid composition to improve biodiesel physical properties. Bioresource Technology, 102 (2011) 7280-7288.

[20] J. VAN GERPEN, B. SHANKS, R. PRUZSKO, D. CLEMENTS, G. KNOTHE. Biodiesel production technology. National Renewable Laboratory, (2004).

[21] C. Brunschwig, W. Moussavou, J. Blin. Use of bioethanol for biodiesel production Progress in Energy and Combustion Science, 38 (2012) 283-301.

[22] M. Balat, H. Balat, C. OZ. Progress in bioethanol processing. Progress in Energy and Combustion Science, 34 (2008) 551-573.

[23] M.G. Kulkarni, A.K. Dalai, N.N. Bakhshi. Transesterification of canola oil in mixed methanol/ethanol system and use of esters as lubricity additive. Bioresource Technology, 98 (2007) 2027-2033.

[24] T. Le Tu, K. Okitsu, B. Luu Van, Y. Maeda. Catalytic Technologies for Biodiesel Fuel Production and Utilization of Glycerol: A Review. Catalysts, 2 (2012) 191-222.

[25] M. Farooq, A. Ramli. Biodiesel production from low FFA waste cooking oil using heterogeneous catalyst derived from chicken bones. Renewable Energy, 76 (2015) 362-368.

[26] S.M. Coman, V.I. Parvulescu. Chapter 4-Heterogeneous Catalysis for Biodiesel Production. *The Role of Catalysis for the Sustainable Production of Bio-fuels and Bio-chemicals*. Elsevier; Amsterdam (2013)

[27] A.F. Lee, J.A. Bennett, J.C. Manayil, K. Wilson. Heterogeneous catalysis for sustainable biodiesel production via esterification and transesterification. Chemical Society Reviews, 43 (2014) 7887-7916.

[28] T. Serra, J.M. Gil. Biodiesel as a motor fuel price stabilization mechanism. Energy Policy, 50 (2012) 689-698

[29] http://www.oilworld.biz/app.php?ista=0a0e7303d37d176cd9ccb2b2050af918.

[30] G. Knothe. Analyzing biodiesel: Standards and other methods. *Journal of the American Oil Chemists Society*, 83 (2006) 823-833.

[31] Kaniz Ferdous, M. Rakib Uddin, Maksudur R. Khan, M. A. Islam, Preparation of Biodiesel from soybean oil by using heterogeneous catalyst, *International Journal of Energy and Environment, 4(2),* 2013, 243-252

[32] Md. Abdullah Al Bari, Hasan Ali, Mizanur Rahman, Rakibul Hossain, Prospect of Bio-diesel Production from soybean oil and sesame oil: An Alternative and Renewable Fuel for Diesel Engines, *International Journal of Mechanical Engineering, 2(2),*2012

[33] A. K. Azad, S. M. Ameer Uddin, and M. M. Alam, Mustard oil, an alternative Fuel: An experimental investigation of Bio-diesel properties with and without Trans-esterification reaction. *Global Advanced Research Journal of Engineering, Technology and Innovation Vol. 1(3) pp. 075-084, June, 2012*

[34] Investigation of Bio-diesel properties with and without Trans-esterification reaction, *Global Advanced Research Journal of Engineering, Technology and Innovation, 1(3)*, 2012, 75-84

[35] Z.M. Hasib, K.A. Rahman, Performance Characteristics Analysis of Small Diesel Engines Fueled with Different Blends of Mustard Oil Bio-diesel, *Int. J. of Thermal &Environmental Engineering, 6(1),* 2013, 43-48

[36] A S M Monjurul Hasan 1, A S M Muhaiminul Hasan, Experiment for Producing a Renewable Alternative Fuel for Bangladesh from Mustard Oil, *International Journal of Open Scientific Research IJOSR, 1(5),*2013, 11-17

[37] Kaniz Ferdous, M. Rakib Uddin, Maksudur R. Khan, M. A. Islam, Biodiesel from Sesame Oil: Base Catalyzed Transesterification, *International Journal of Engineering and Technology, 1(4),* 2012, 420-431

[38] Mohammad Mashud, M. Hasan Ali, Md. Roknuzzaman and Asadullah Al Galib, Biodiesel from Jatropha Oil as an Alternative Fuel for Diesel Engine, *Proceedings of the International Conference on Mechanical Engineering 2009 (ICME2009) 26- 28 December 2009*, Dhaka, Bangladesh

[39] Kazi Mostafijur Rahman, Mohammad Mashud, Md. Roknuzzaman, Asadullah Al Galib, Biodiesel from Jatropha Oil as an Alternative Fuel for Diesel Engine, *International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, 10(3)*, 2010

[40] Md. Nurun Nabi, Md. Shamim Akhter and K.M. Farzadul Islam, Prospect of Biodiesel Production from Jatropha Curcas, A Promising Non Edible Oil Seed in Bangladesh, *Proceedings of the International Conference on Mechanical Engineering 2007 (ICME2007) 29- 31 December 2007,* Dhaka, Bangladesh.

[41] Dr. Kamrun Nahar, Castor Bean (Ricinuscommunis L.) - A Biofuel Plant: Morphological and Physiological Parameters Propagated from Seeds in Bangladesh, *Asian Business Review, 2(4),* 2013

[42] Kaniz Ferdous, Anjan Deb, Jannatul Ferdous, Rakib Uddin, Maksudur R. Khan, M.A. Islam, Preparation of Biodiesel from Higher FFA Containing Castor Oil, *International Journal of Scientific& Engineering Research, 4(12),*2013

[43] Md. Saiful Islam, Abu Saleh Ahmed, Aminul Islam, Sidek Abdul Aziz, Low Chyi Xian, Moniruzzaman Mridha, Study on Emission and Performance of Diesel Engine Using Castor Biodiesel, *Hindawi Publishing Corporation Journal of Chemistry,* 2014

[44] Md. Shamim Akhter, Abul Hasanat, Md. Eyasin Arafat, Bahera (T. Bellirica) Biodiesel Production in Bangladesh, Characterization of Bahera Biodiesel and its Performance on a Diesel Engine, *Global Journal of Researches in Engineering Mechanical and Mechanics Engineering, 13(11),* 2013

[45] Md. Imran Kais, Farsad Imtiaz Chowdhury, Kazy Fayeen Shahriar, Biodiesel from Microalgae as a solution of third world energy crisis, *World Renewable Energy Congress, 2011-Sweden*

[46] Mohammad Farzid Hasan, Syeda Zohra Halim, Choudhury Mohammad Shahariar, Noor Quddus, Mitigation of Agricultural Energy Requirement in Bangladesh Using Microalgae Production, *International Conference on Mechanical Engineering Research (ICMER2013)*, 1-3 July 2013

[47] I. B. Muhit, D. Baidya, Nurangir Nahid, Prospect of Algal Biodiesel Production in Bangladesh: Overview from Developed Countries, *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 11(1- III),* 2014, 49-54

[48] Md. Abdul Wakil, Z.U. Ahmed, Md. Hasibur Rahman, Md. Arifuzzaman, Study on Fuel Properties of Various Vegetable Oil Available in Bangladesh and Biodiesel Production, *International Journal of Mechanical Engineering, 2(5),* 2012, 10-17

[49] Sukanta Kumar Mondal, Kaniz Ferdous, M. Rakib Uddin, Maksudur R. Khan, M. A. Islam, A. K. Azad, Preparation and Characterization of Biodiesel from Karanja Oil by Using Silica Gel Reactor, *1st International e-Conference of Energies*, 14-31 March, 2014

[50] Hossain Mohammad Imran1, Arafat H.Khan , M. Shahinul Islam , Niher R. S., Asaduzzaman Sujan, A.M. Sarwaruddin Chowdhury, Utilization of Karanja (Pongamiapinnata) as a Major Raw Material for the Production of Biodiesel, *Dhaka Univ. J. Sci. 60(2)*, 2012, 203-207

[51] Md A. Hossain, Shabab M. Chowdhury, Yamin Rekhu, Khandakar S. Faraz, Monzur Ul Islam, Biodiesel from Coconut Oil: A Renewable Alternative Fuel for Diesel Engine, *World Academy of Science, Engineering and Technology, 6,* 2012

[52] M.A. Haque, M. P. Islam, M.D. Hussain, F. Khan, Physical, Mechanical Properties and Oil Content of Selected Indigenous Seeds Available for Biodiesel Production in Bangladesh, *Agricultural Engineering International: the CIGR Ejournal. Manuscript 1419, Vol. XI,* 2009

[53] Yi-Hsu Ju, Shaik RamjanVali, Rice bran oil as a potential resource for Biodiesel: A review, *Journal of Scientific & Industrial Research, 64,* 2005, 866-882

[54] Ahmed, H. The Role of Crop Research in the production of Edible oilseed crops in Bangladesh, Paper presented at the workshop on Achieving Edible oil Self-Sufficiency in Bangladesh, BARC, Dhaka, Bangladesh, 30-31 May, 1995.

[55] Hoque, M.A., Present Status, Problems and future prospects of Edible oil Mills in Bangladesh, Paper presented at the workshop on Achieving Edible oil Self-sufficiency in Bangladesh, BARC, Dhaka, Bangladesh, 30-31 May, 1995.

[56] Siddique, A.K.M.T., Present Status, Problems and Future Production Projects of Edible Oil Crops in Bangladesh, Paper Presented at the workshop on Achieving Edible Oil Self Sufficiency in Bangladesh, BARC, Dhaka, Bangladesh, 30-31 May, 1995.

[57] Haris, M., Prseent Status of Edible Oil in Bangladesh : Household and Industrial Needs, Domestic Availability , By-Product Utilization and Importation Situation, Paper Presented at the workshop on Achieving Edible Oil Self-sufficiency in Bangladesh , BARC, Dhaka, Bangladesh, 30-31 May, 1995.

[58] Kaniz Ferdous, M. Rakib Uddin, Rehnuma Islam, Maksudur R. Khan, M. A. Islam, Potentiality of Biodiesel Production From Non-Edible Oil: Bangladesh Perspective, Journal of Chemical Engineering, IEB Vol. ChE 27,No. 2, December, 2012

[59] I. B. Muhit, D. Baidya, Nurangir Nahid, Prospect of Algal Biodiesel Production in Bangladesh: Overview from Developed Countries, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 1 Ver. III (Jan. 2014), PP 49-54

[60] Darnoko, D. and Cheryan, M. (2000). Continuous production of palm methyl esters. J. Am. Oil Chem. Soc., 77, 1269-1272.

[61] Krisnangkura, K. and Simamahamnop, R. (1992). Continuous transesterification of palm oil in an organic solvent. J. Am. Oil Chem. Soc., 69, 166-169.

[62] Kusy, P. F. (1982). Transesterification of vegetable oils for fuels. In proceedings of the International conference on vegetable oil as fuels. American Society of Agricultural Engineers, St. Joseph, Michigan, 127-137.

[63] Noureddini, H. Harkey, D., and Medikonduru, V. (1998). Continuous process for the conversion of vegetable oils into methyl esters of fatty acids. J. Am. Oil Chem. Soc., 73, 1775-1783.

[64] Highina BK, Bugaje IM and Umar B. 2011 Biodiesel production from Jatropha caucus oil in a batch reactor using zinc oxide as catalyst, *Journal of Petroleum Technology and Alternative Fuel,* Vol. 2(9), pp. 146-149, September 2011

[65] Amir hashemi nezhad, Seyed jafar hashemi, Seyed Reza Tabatabaie, Biodiesel production from waste cooking oil using a stirred batch reactor, JNAS Journal-2014-3-10/1125-1130, ISSN 2322-5149, 2014

[66] Leevijit, T., Wisutmethangoon, W., Prateepchaikul, G., Tongurai, C., Allen, M. Design and test of a continuous reactor for palm oil transesterification Songklanakarin J. Sci. Technol., 2006, 28(4) : 791-802

[67] Azhari t. I. Mohd. Ghazi, m. F. M. Gunam resul, r. Yunus, t. C. Shean yaw, preliminary design of oscillatory flow biodiesel Reactor for continuous biodiesel production From jatropha triglycerides, *Journal of Engineering Science and Technology,* Vol. 3, No. 2 (2008) 138 - 145 ,School of Engineering, Taylor's University College

[68] Ahmad Abbaszaadeh, Barat Ghobadian, Gholamhassan Najafi , Ali Motevali, Design, Fabrication and Evaluation of a Novel Biodiesel Processor System, *International Journal of Renewable Energy Technology Research*, Vol. 2, No. 12, December 2013, PP:249-255, ISSN: 2325-3924

[69] Stonestreet, P., and Harvey, A. P. (2002). A mixing-based design methodology for continuous oscillatory flow reactors. Institution of Chemical Engineers, 80(A), 31-44.

[70] Mackley, M. R. (1991). Process innovation using oscillatory flow within baffled tubes. Trans IchemE, 69(A), 197-199.

[71] Hidayet OĞUZ, Muciz ÖZCAN, Mustafa YAĞCI, Ali Osman ÖZKAN, *International Journal of Automotive Engineering and Technologies*, Vol. 4, Issue 4, pp. 254–260, 2015, ISSN 2146-9067

[72] McNeff et.al. "A continuous catalytic system for biodiesel production" , Applied Catalysis A: General Volume 343 (2008), Issue 1-2, Pages 39-48.

[73] Chen et.al, "Continuous Production of Biodiesel via Supercritical Methanol Transesterification in a Tubular Reactor. Part 1: Thermophysical and Transitive Properties of Supercritical Methanol", Energy & Fuels, 23 (2009) 526-532.

[74] Gajendra Kumar, D. Kumar, Shailandra Singh, S. Kothari, Sumit Bhatt, Chandra P. Singh, "Continuous low cost transesterification process for the production of coconut biodiesel," Energies 2010, ISSN 1996-1073, Volume 3, pp. 43-56,doi:10.3390/en3010043

[75] Zhang, Y, M A. Dube, D D. McLean, and M Kates. ″Biodiesel Production From Waste Cooking Oil: 1. Process Design and Technological Assessment.″ Bio resource Technology 89 (2003): 1-16.

[76] Freedman B, Pryde EH, Mounts TL. 1984. Variables affecting the yields of fatty esters from transesterified vegetable oils. J Am Oil Chem Soc; 61: 1638–43.

[77] Guo Y. 2005. Alkaline-catalyzed production of biodiesel fuel from virgin canola oil and recycled waste oils. PhD dissertation, Department of Mechanical Engineering, the University of Hong Kong, Hong Kong; p. 184.

[78] Leung DYC, Guo Y. 2006. Transesterification of neat and used frying oil: optimization for biodiesel production. Fuel Process Technol; 87:883–90.

[79] Demirbas A. 2009. Progress and recent trends in biodiesel fuels.

[80] Kusdiana D, Saka S. 2004. Effects of water on biodiesel fuel production by supercritical methanol treatment. Bioresour Technol; 91:289–95.

[81] Knothe, G., Van Gerpen, J.H., Krahl, J. 2005. The biodiesel handbook. Champaign (IL): AOCS Press; CRC Press].

[82] Eevera T, Rajendran K, Saradha S. Biodiesel production process optimization and characterization to assess the suitability of the product for varied environmental conditions. Renew Energy 2009; 34:762– 5.

[83] Sidibé SS, Blin J, Vaitilingom G, Azoumah Y. Use of crude filtered vegetable oil as a fuel in diesel engines state of the art: literature review. Renewable and Sustainable Energy Reviews 2010; 14:2748–59

[84] [77] Uzun BB, Kılıç M, Özbay N, Pütün AE, Pütün E. Biodiesel production from waste frying oils: optimization of reaction parameters and determination of fuel properties.Energy2012; 44:347–51.