Design of Biodiesel Plant using Transesterification of Non-edible oil seeds

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Abstract- *Self reliance of fossil fuels are increasing at faster rates, nearly 70% of nations economy depends upon transportation thereby depleting fossil fuels at faster rates. Additionally subsequent increase in greenhouse gases emissions and stringent emissions norms, has forced to think of renewable fuel resources. Biodiesel is one of the alternative that can be used as fuels in any conventional engine. Many technologies are designed to reduce emissions of harmful gases but if fuel itself is not clean, all of this design is not sustainable and unaffordable. So the main aim of this research is to design biodiesel plant from transesterification of non-edible oil seeds like Jatropha, Undi and Thumba for increasing oil recovery and good quality of fuel. Also validation of synthesized biodiesel as per ASTM D-6751 standards. Results showed that designed biodiesel plant has significant oil recovery and properties of synthesized biodiesel are also validated*

Keywords- Biodiesel plant design, transesterification, oil recovery, ASTM D-6751 standards

I. INTRODUCTION

Diesel fuel is largely utilized in the transport, agriculture, commercial, domestic, and industrial sector for generation of power and substitution of even a small fraction of total consumption by indigenous alternative fuels particularly of bio origin will have significant impact on economy, the environment, the development of agro based industries in the region of the alternative fuels. Biodiesel obtained from non-edible oils is considered to be promising alternative fuel resulting in numerous environmental, economic and social benefits.

II. LITERATURE REVIEW

Biodiesel benefits include bio-degradable, non-toxic, free from Sulphur (< 0.001%) and 60% less net carbon dioxide emissions [1] and can be synthesized using vegetable oils and fats [2]. In addition it has high flash point (greater than 160°C) which helps biodiesel for transportation and storage safe. The important quality that biodiesel possess is that it decomposes more easily when they expose to environment and most importantly they can be produced easily compared to petrol and diesel. The lubrication property of biodiesel dominates more when compared to diesel fuel and increases the engine life. Biodiesel causes less emission of carbon dioxide, hydrocarbon and particulate matter, which are dominating factors while compared to diesel. The only drawback is that NOx emission is to be increased upto 15-20% [3]. Most of the researchers studied performance and emission parameters of methyl ester on various engines, speeds, loads and biodiesel blend ratios. These results proved that the engine performance is affected by percent biodiesel in diesel fuel, while they agreed with decrease in CO and HC emissions but increase in NOx and CO2emissions. The CO and HC emissions depends upon aromatic content of fuel while increase in NOx and CO2 indicates more oxygen atom in biodiesel fuel [4-12]. In India, Ministry of New and Renewable Energy (MNRE) prepared National Biofuel Policy in 2008. As per MNRE report, about 20% blend with diesel fuel of biofuels (like bioethanol and biodiesel) will be used commercially by 2017. [13]. So it becomes most important to search/ identify for new and potential feedstocks for biodiesel preparation. Indian Government focused on non-edible oil (NEO) seeds plants like Jatropha Curcus [14] and Pongamia pinnata (Karanja) [15]. Government has been planted these plants on road side, along railway tracks and in forests. These two plants has potential to grow in bare lands with minimum inputs of irrigation and fertilization. Along with that researchers has been concentrating on Madhuca indica [16], Calophyllum inophyllum [17],[18],Castor [19], Citrullus colocynthis [20] and more NEO's for biodiesel synthesis.

It was investigated that synthesized thumba ethyl ester and calophyllum (undi) methyl ester by using 0.75wt%, 1.2wt% of potassium hydroxide (KOH), 1:8 molar ration of oil to alcohol at 65° C reaction temperature and 650rpm stirring speed. [17-20].

Undi biodiesel for VCR engine, has proved that engine performance improved with slightly reduction in emissions like HC, CO and NOx. It was reported that blending of diesel with 20% Pongamia pinnata oil methyl ester can be used safely in a conventional CI engine without modifications in engine.[20-21]Engine performance using jatropha biodiesel and its blends on IC engine was analyzed and it was reported that better performance (of BSFC and BTE) using JB10, B20, JB30, JB50 than diesel fuel. The CO emissions decreased consequently with increase in engine speed up to 1700 rpm while NOx emissions increased for all blends. [23]

The Jatropha curcas Linnaeus plant belongs to the family euphorbiaceae. It is a hardy shrub that can grow on poor soils and areas of low rainfall. The oil content of Jatropha seed ranges from 25% to 30% by weight. Fresh Jatropha oil is slow-drying, odorless and color less oil, but it turns yellow after aging. Non-edible oil generally contains about 3-4 %wax and gum. De-waxing and degumming of plant oils is required not only for smooth running of the CI engine but also to prevent engine failure even if plant oils are blended with diesel. It is therefore necessary to remove wax and gum from the fresh oil before it could be used in CI engine. [24-27].

Undi is a species of family Guttifereae (Clusiaceae), native to India, East Africa, South east Asia, Australia and South Pacific. Commonly it is called as Indian laurel, Alexandrian Laurel, Beach calophyllum. The oil content of undi seed ranges from 55% to 60% by weight. The greenish yellow oil with disagreeable odour contains 28.08 mg of KOH/gm FFA. The undi oil obtained from the calophyllum seeds was used as alternative to candlenut oil in lamps [17], [18].

Thumba is planted/ grown naturally in rainy season and its fruits / seeds are available in winter. Commonly it is called as 'Bitter apple' (in English), Thumba (in Marathi), Indrayan (in Hindi), It is a creeper, short period cropgrown naturally wild in Indian arid zone (Western Rajasthan). Thumba is planted/ grown naturally in rainy season and its fruits / seeds are available in winter. It has annular and rough stem, rough leaves that are 3-7 lobed, 5-10cm long in middle, flowers are monoleceios and have yellow rounded fruit.The average seed yield is about 2500-3500 kg of seeds/ ha. Seeds contains 12% to 20% of golden yellow- brown oil. Currently all extracted oil is consumed by saponification industries [20].

So non-edible oil seeds like Jatropha, Undi and Thumba which are favorable for Indian climatic conditions are selected as feedstock for oil extraction and biodiesel production. The main objective of this research is to design biodiesel plant for biodiesel production from transesterification of non-edible oil seeds like Jatropha, Undi and Thumba. Also to design biodiesel plant to increase oil recovery and validation of synthesized biodiesel as per ASTM standards.

III. METHODOLOGY

A. Design of Biodiesel Plant

Biodiesel plant is designed at Indian Biodiesel Corporation Baramati (IBDC) taking into account most influencing parameters of Biodiesel production process i.e transesterification process. Biodiesel plant equipment has designed at IBDC taking into consideration design, chemical, thermal aspects of fuels and chemicals involved during transesterification process. Also biodiesel plant was designed considering safety and fuel hazards aspects. Process flow diagram for design of biodiesel plant is shown in Fig. 1

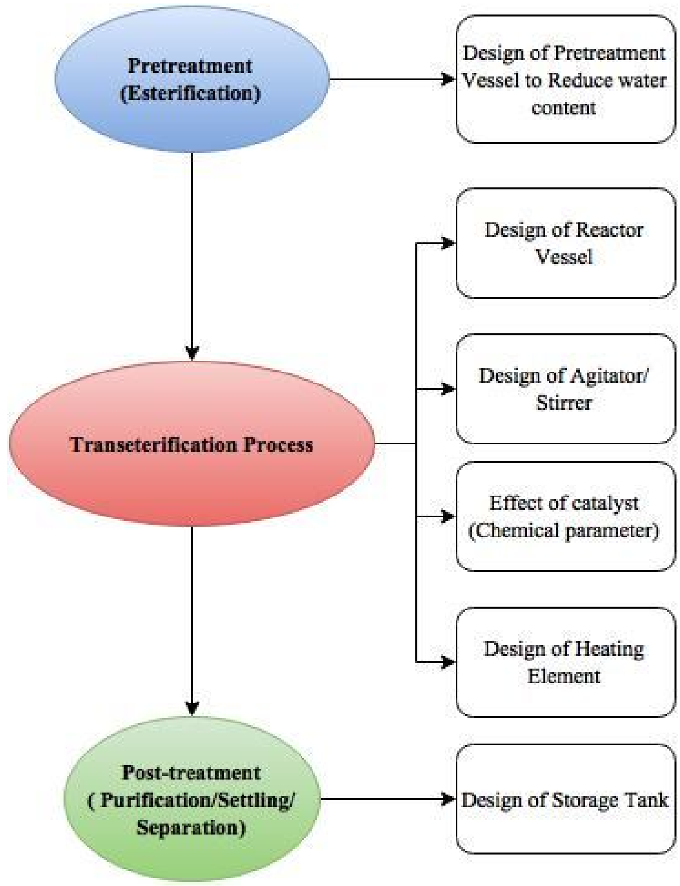

Fig. 1-Process flow diagram for design parameters of Biodiesel Plant

1. Design of Pre-treatment Vessel.

Pre-treatment Vessel is designed to carry out esterification process. Lowering the water content of selected non-edible oils is primary step to handle high Free Fatty Acid (FFA) content of non-edible oils. According to ASTM standards FFA should be less than 1 wt%. So if water content in feedstock is high it should be lowered to approximately 0.3 wt%.

Pre-treatment vessel of capacity of 12 litres is designed with heating element to preliminary heat the oil in order to reduce water content. Table 1 shows variations of FFA content with water content (wt%).

2. Design of Reactor Vessel.

Reactor Vessel is of the main component of biodiesel production process because transesterification process is carried out in this vessel. Reactor vessel volume is designed taking into consideration reactor vessel volume, temperature (60-120°C), pressure developed during process, stirring speed (500-1200rpm).

Reactor vessel volume has significant impact FFA content of oil so the capacity of reactor volume suitable for 12000ml is designed.

3. Design of agitator/stirrer.

Stirring or agitation design during reaction process is one of the important parameter as it is responsible for speeding up reaction and oil recovery of non-edible oil. Mechanical stirrer suitable for range of speeds of 200-1400 rpm is employed for designed plant. Mechanical stirrer has shown significant oil recovery for transesterification of non-edible oil seeds. [9]

4. Selection of Catalyst for biodiesel production Process.

Biodiesel produced via transesterification process using homogeneous catalyst required about 90 minutes of reaction time and catalyst need to be change after every batch of biodiesel production which was not economical. Also oxidation stability was found to be low using homogeneous catalyst. So homogeneous catalyst is replaced with heterogeneous catalyst aluminium trioxide for designed plant.

5. Design of Heating Element

Generally a temperature range of 55-120°C is desired to carry out transesterification process and temperature has significant effect on total reaction time needed to complete the process. Also it is ensured that properties of synthesizes biodiesel should meet norms while selecting appropriate temperature range.

Two main heating mechanism were available including in tank heating and external tank heater. Screw plug immersion was selected for designed plant since it allows for heating variety of fluids and it is easily inserted in reactor vessel without any leakages.

6. Design storage tank.

Storage tank in design of biodiesel plant has two main functions to perform as follows.

i. Allow for settling of biodiesel methyl ester at temperature of approximately 60°C.
ii. It should have provision for separation of Biodiesel methyl ester and glycerine (by-product). Storage tank suitable for volume of approximately 12000ml biodiesel was designed and care it taken for oxidation of biodiesel since it is major concern in bio-fuels.

B. Biodiesel Production using Transesteification Process

The two stage process was used to transfer triglyceride to its respective ester, first step was esterification and transesterification carried out afterwards. The principal role of esterification is to reduce free fatty acid (FFA) value of oil [14].

12000 ml capacity of reactor vessel suitable for temperature range 10°C to 110°C. Jatropha oil is first heated to 50°C then 1.7% (by wt. of oil) sulfuric acid was to be added to heated oil and methyl alcohol about 1:8 molar ratio (by wt of oil) added afterwards. The reaction started with stirring speed about 950 rpm and temperature was controlled at 55-60°C for 60 min with regular analysis of FFA every after 25-30 min. Finally the FFA was reduced upto 1.5% then the excess methyl alcohol was removed by distillation and esterified oil was transferred into settling tank. The trace quantity of moisture was formed in this step, which was removed. The major obstacle to acid catalyzed esterification for FFA is the water formation. Water can prevent the conversion reaction of FFA to esters from going to completion [28]. Afterwards the esterified oil were fed to the transesterification process [29]

6000ml of esterified jatropha oil was measured and poured into a 12000ml reactor vessel & it was heated up to 400c. In the separate 1500 ml beaker 1.2wt % of aluminium trioxide dissolved with methyl alcohol (8 mol of that oil) at 400C, then this mixture was slowly added to heated oil & reaction started for 90 min with stirring speed about 650 rpm and at 55-60oC temperature. After reaction completion i.e. when FFA reduced up to 0.7% the transesterified oil was again transferred for distillation and separation to storage tank. The three distinct layer of methyl ester, glycerol and unreacted oil were formed. The glycerol settled at bottom of storage tank due to gravity and jatropha methyl ester were settled at the top of storage tank. The unreacted oil settled in between glycerol and methyl ester layer. The glycerol was separated manually. Then the product i.e. jatropha methyl ester was washed with the help of hot distilled water to remove dissolved sulphric acid, sodium, methyl alcohol and glycerol. The wasted biodiesel were dried over anhydrous sodium sulphate. The purified methyl ester were proceeded for quality testing. The undi methyl ester and thumba methyl ester were synthesized as per protocol using aluminium trioxide as a strong base catalyst and methyl alcohol [17], [20]

Same process carried out to synthesize biodiesel from undi and thumba oil.

C. Experimental Set-up at IBDC

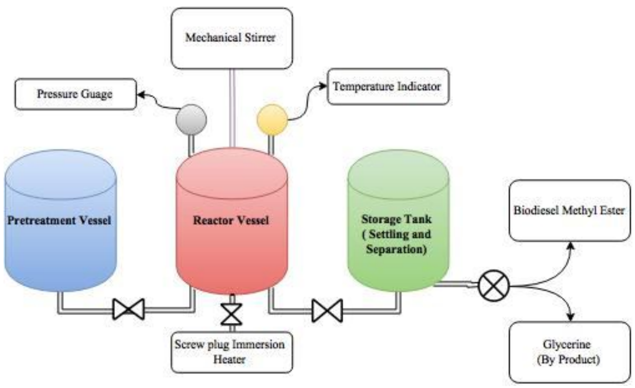

Fig. 2- Designed Biodiesel plant at IBDC.

IV. RESULTS AND DISCUSSIONS

Optimized results obtained from design of biodiesel plant and effect of various designed parameters and finally results obtained from experimentation are discussed in this section.

A. Effect various designed parameters of biodiesel plant

a. Effect of Water Content on FFA (in Pre-treatment Vessel)

Results had shown that water content (wt%) in pre-treatment vessel has significant effect on FFA content. According to ASTM standards FFA content should be less than 1% is acceptable. So pre-treatment vessel is designed to keep water content approximately 0.3 wt% which will finally lead keep FFA content below 1%. Table 1 shows variation of FFA content with water content in oil seeds.

Table 1- Variations of FFA content with water content in non-edible oil seeds

Free Fatty Acid (FFA) Content %	Water Content (wt%)
1	0.28
2	0.38
3	0.42
4	0.58
5	0.65
6	0.68

b. Effect of Reactor Vessel Volume

Results have shown that reactor vessel volume has significant effect on triglyceride conversion i.e (to convert into methyl ester) as shown in fig 3. Results have shown that reactor vessel volume of 12litres has good conversion ability and thereby increasing oil recovery and quality of synthesized biodiesel.

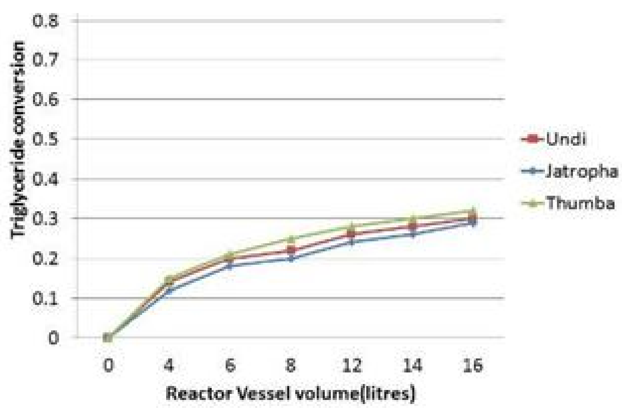

Fig. 3- Effect of reactor volume (litres) with Triglyceride Conversion (wt%)

c. Effect of stirring.

Transesterification process was carried out for stirring speeds of 200, 400 , 600, 800, 1000rpm and oil recovery of jatropha, undi and thumba oil were investigated as shown in Table 2

Table-2 Effect of stirring speed on oil recovery.

Stirring Speed rpm	Oil recovery %		
	Jatropha	Undi	Thumba
200	72.5	70	68
400	75	72	70
600	83.5	90	87
800	83	87	87.3
1000	83.8	86.5	84.5

d. Effect of Catalyst used.

Heterogeneous catalyst used in designed biodiesel plant for transesterification process has shown significant effect on various parameters shown in Table 3.

Table-3 Effect of Catalyst used on various parameters

Catalyst	Parameters	Jatropha	Undi	Thumba
Heterogeneous Catalyst (Aluminium Trioxide)	Reaction Time (minutes)	90	75	87
	Temperature (°C)	55-60	55-60	55-60
	Oil Recovery (%)	84	90	83

e. Design for safety at Biodiesel plant.

Safety precautions are important concern in biodiesel production process as many chemicals need to be handled. Specially methanol potassium or sodium hydroxide etc. It was recommended that material safety data sheets (MSDS) should be available all the time for all chenicals and mixtures involved in the process. Also use of safety goggles, lab coats and gloves need to worn all the time

B. Oil Recovery of designed Plant

Results for oil recovery are shown in Table 4 which indicates that designed plant has ability to synthesize biodiesel (methyl ester) about 90% for selected non-edible oil seeds.

Table 4- Oil Recovery of designed Plant

Sr. No	Non-edible oil seeds	Oil Recovery (%)
1	Jatropha	85
2	Undi	90
3	Thumba	90

C. Validation of properties of synthesized biodiesel from designed plant according to ASTM standards.

Synthesized Biodiesel (Methly Ester) from Jatropha, Undi and Thumba oil should meet ASTM standards which is the important parameter in concern with quality of fuel. Results have shown that selected Jatropha, Undi and Thumba methyl ester has validated ASTM standards as shown in Table 5 and also it has potential to use as fuel for conventional gasoline/diesel engine without any modification. Also the cetane number of Undi and Thumba has meet the norms which indicates good ignition quality of fuel.

Table. 5- Properties of synthesized biodiesel as per ASTM standards

Properties	ASTM Standards	Properties of synthesized biodiesel Methyl Ester		
		Jatropha	Undi	Thumba
Density (g/cm3)	0.860-0.900	0.872	0.892	0.87
Viscosity (cst)	3.5-5	3.82	3.87	3.8
Calorific Value (MJ/kg)	35-45	38	37.18	37
Flash point (°C)	160-190	164	176	164
Fire point (°C)	160-190	171	182	172
Cetane Number	51	48	51	51

V. CONCLUSION

Biodiesel plant designed at IBDC has shown significant oil recovery for selected non-edible oil seeds like Jatropha (85%), Undi (90%)and Thumba (90%) using transesterification process. Generally Undi and Thumba oil has shown recovery upto 90%. Also heterogeneous catalyst (Aluminium trioxide) used for designed plant is reusable and eco-friendly, which is one of the additional benefits in economical concern.

Effect of design parameters like reactor vessel volume,agitation/stirring, pre-treatment volume on FFA content, with reaction time, water content in oil has contributed towards good quality of fuel. Also properties of synthesized biodiesel (Methyl ester) from Jatropha, undi and thumba oil are validated with ASTM standards which shows that synthesized biodiesel can be used as fuel in conventional engine.

VI. FUTURE WORK

Characterization of synthesized biodiesel (methyl ester) produced from designed plant using single cylinder engine. Performance and emission characteristics of different blends of Jatropha, Undi and Thumba methyl ester will be investigated.

ACKNOWLEDGMENT

The authors thanks to Indian Biodiesel Corporation, Baramati, Pune for their valuable suggestions and provide facility for experimentation and testing.

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