Biodiesel as an Alternative Fuel: A Review

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ABSTRACT

Biodiesel is an increased attended word as an alternative, in-noxious, ecological an sustainable, fuel. It is derived from oils and fats by transesterification with alcohols. The present situation of energy crises due to continuous depletion of frighten ancient fuels has resulted in rise of global prices of crude petroleum products which is bound to affect adversely on the overall economy of many countries like India. In a country like India, availability of edible oils are is partially dependent on import, it would be not be possible to use edible oil in CI engines. Therefore, the study on biodiesel as fuel for CI engine was undertaken. Biodiesel is defined as a trans-esterified methyl ester renewable fuel derived from vegetable oils or animal fats with properties similar or better than diesel fuel. The literature on extensive research demonstrates that it can be used pure or in blends with conventional diesel fuel in diesel engines without modification in design but still in actual practice, the use of biodiesel is limited. In this paper, the review with respect to the performance of diesel engine and emission analysis while using biodiesel has been presented.

Key words: Biodiesel fuel, performance and emission analysis, alternative fuels

1. INTRODUCTION

The world survey of the fossil fuel indicates that, the traditional fuels are likely to deplete within 130 to 150 years. Due to plodding depletion of world petroleum reserves and the influence of environmental pollution of increasing exhaust emissions, there is a crucial necessity for suitable alternative fuels for use in diesel engines. As per the environmental and economic concern, the biodiesel seems to be one of the best emerging alternative fuels for the diesel [1]. In view of this, vegetable oil is a promising alternative because it has several advantages. The problem of higher viscosity of vegetable oils based biodiesel has been tried to solve in several ways such as preheating the oils, blending or dilution with other fuels, transesterification and pyrolysis[2].

Biodiesel chemically called as 'mono methyl ester' can be extracted from a wide variety of plant oils, both edible and non-edible. Most of the developed countries produce biodiesel from sunflower, soya been, palm oil, peanut, and several other feed stocks which are principally edible in Indian context. Hence, in the developing countries such as India, it is desirable to produce biodiesel from the non-edible oils or nonpreferred edible oils such as Jatropha, cottonseed, which can be extensively grown in the waste lands of the country. The biodiesel serves the better performance characteristics in the sense of the fuel consumption, thermal efficiency, brake power, mean effective pressure, volumetric efficiency etc. Also the properties of the biodiesel such as cetane number, density, calorific value are closer to the petroleum diesel. The economic feasibility of biodiesel depends on the price and transportation of crude petroleum. It is a fact that day by day the cost of diesel will increase in future owing to increase in its utility, demand and limited supply [3].

This paper presents an exhaustive literature on the investigations carried out by different researchers on the use of various biodiesels along with their performance when used as alternate fuel.

2. PRODUCTION OF BIODIESEL

Biodiesel is produced by trans-esterification process of large, branched triglycerides in to smaller, straight chain molecules of methyl esters, using an alkali or acid or enzyme as catalyst. There are three stepwise reactions, as shown in fig. 1.1, with intermediate formation of di-glycerides and mono-glycerides resulting in the manufacture of three moles of methyl esters and one mole of glycerol from triglycerides.

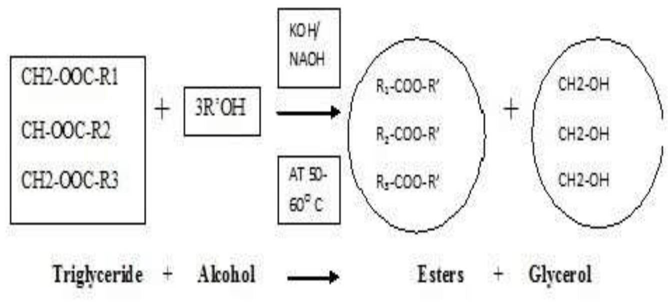

Figure 1.1 Transesterification process

Alcohols such as methanol, ethanol, propanol, butanol and amyl are used in the transesterification process. Methanol and ethanol are mostly preferred, especially methanol because of its low cost, and physical and chemical advantages. These can quickly react with triglycerides and sodium hydroxide is easily dissolvable in these alcohols. Stoichiometric molar ratio of alcohol to triglycerides necessary for transesterification reaction is 3:1. In practice, the ratio needs to be higher to drive the equilibrium to a maximum ester yield. The conversion of oil into its methyl ester can be accomplished by the transesterification process. Transesterification involves reaction of the triglycerides of edible or non-edible oil with methyl alcohol in the presence of a catalyst Potassium Hydroxide or Sodium Hydroxide (NaOH) to produce glycerol and fatty acid ester.

The biodiesel produced by transesterification process of the oil is generally occurs using the following steps:

1. Preheating of crude oil: Oil is preheated at 50-55^{o} C.
2. Mixing up of Alcohol, KOH or NaOH and crude preheated oil: biodiesel is produced by using methanol having optimum molar ratio (4:1) and KOH of about 1.5% of the content of the respective oil.
3. Reaction: The mixture is kept on magnetic stirrer at 50-60^{o} C for 1 hour 15 minutes.
4. Glycerol and biodiesel after reaction, gets separated in separating funnel.
5. Washing of biodiesel: The biodiesel in separating funnel is washed with the heated three times to remove remaining extracts of the KOH/NaOH and Methanol [4].

Flow chart in fig. 1.2 shows the procedure to prepare Methyl ester of oil.

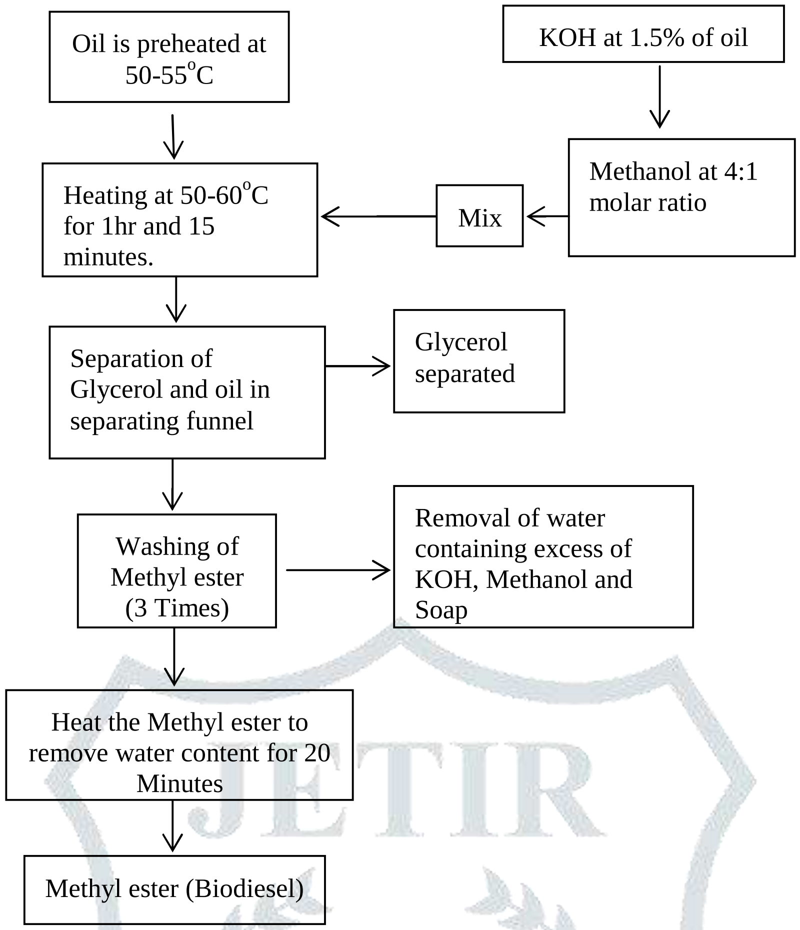

Figure.1.2 Flow Chart for Preparation of biodiesel

The literature indicates that researchers have been working on alternative fuels since long for standardization of biodiesel preparation and optimization of performance parameters for better emission characteristics through experimentation and analytical modeling. The information available on biodiesel is widely scattered and hence for better understanding it has been presented in two sections as below:

1. Experimental investigation
2. Modeling and optimization

3. EXPERIMENTAL INVESTIGATION

The usefulness of any biodiesel as a fuel is obsessed on the basis of three different aspects. The combustion is an important process useful for testing the feasibility of the fuel as well as performance efficiency. The performance is mainly related to the engine performance in terms of thermal efficiency, specific fuel consumption, torque etc. Environmental clearance is also key aspect for selection of fuel so as to fulfill environmental regulatory norms which are measured for exhaust gases. The ‘Experimental Investigation’ is divided under three subsections;

1. Performance
2. Emission and 3. Combustion

3.1. Performance

The performance of the biodiesel is referred to engine parameters as brake thermal efficiency, brake specific fuel consumption, mechanical efficiency, torque etc. The summary of literature indicates that investigators used three types of engines for experimentation,

1. Single cylinder engine
2. Multi cylinder engine

The literature reveals that, the different investigators have conducted experiments on different engines using different biodiesel with variety of blend ratio. Thus it becomes quite difficult to compare the performance. Therefore, the literature on engine performance is presented in tabular format for each of the engine separately for easy understanding. Tables 3.1 to 3.2 depict the experimental investigations on the performance of three different engines. The tables indicate the author name, engine parameters, fuel variables and observations along with the remarks.

3.1.1 Single Cylinder Engine

The single cylinder diesel engine is generally used either for generator sets or for agricultural implements. But still primary research is always carried out on single cylinder diesel engine from cost point of view.

Table 3.1 Experimental performance on single cylinder engine

Sr no.	Author and year	Engine variables	Fuel variables	Observations and findings	Remarks
1	K. Pramanik [5] 2003	CR:- 15:1 RPM:- 1500**Engine Variable**:- 1) Brake horse power:- from 0 to 3.74 (By changing load)	Jatropha oil **Variable:** Blend Ratio:- B0 - B100 In five steps.	1) With the increase in load, SFC decreases &EGT and Break Thermal efficiency increases. 2) With the increase in blend ratio SFC and EGT increases and BTE decreases.	Jatropha oil is directly used without transesterification, which is not recommended as engine may face problems like gumming exhaust.
2	Md. NurunNabi[6] 2005	CR:- 20:1 RPM:- 2000, **EngineVariable**:- 1)EGR	Neem oil biodiesel **Variable:** B5, B10, B15	With increase in EGR rate, BTE decreases.	The availability of Neem Oil is a problem as it is used in medical application.
3	G. LakshamiNarayanrao et. Al. [7] 2008	CR:- 17.5:1 RPM:- 1500 **Engine Variable**:- 1) Brake power:- 0 to 4.4 kw in four steps.	Used cooking oil biodiesel Variable:- B20-100 with four steps.	1) With increase in brake power BSFC decreases while BTE and EGT increases. 2) With increase in blend ratio, BSFC and EGT increase while BTE decreases.	
4	D. Ramesh et.Al. [8] 2008	RPM:- 1500 **Engine Variable:-** 1) brake power:- 2 to 3.5 kw in three steps	Jatropha biodiesel Variable:- B0 to B 100 in 5 steps	1)With increase in power, SFC decreases while EGT increases 2)With increase in blend ratio, SFC increases while EGT is nearly constant for lower loads and slight increases at higher load	
5	B. B. Ghosh, et.al. [9] 2008	RPM:- 1200. **Engine Variable** 1) Brake power:- from 0 to 2.7 (By changing load).	Putranjiva, karanja and Jatropha biodiesel **Variable**:- Fuel and blend ratio B10,30,50,70	a) With increase in brake power, BSFC decreases while BTE and EGT increases. b) Karanja shows better BTE and low EGT thanPutranjiva and Jatropha whereas Jatropha has low BSFC. c) With increase in blend ratio, BTE for putranjiva and Jatropha is decreased and for karanja is almost same.	Though the engine used is variable compression engine, compression ratio and load are fixed for experimentation.

6	Xiaohu Fan et. Al. [10] 2008		Cottonseed and Soyabeen biodiesel **Variable:-** COME , SOB, PBSY (Dark color)	BSFC is higher for Biodiesels as compared to diesel.	Soya been oil is edible oil, not recommended.
7	Siva kumar et. Al. [11] 2009	CR:- 17.5:1 RPM:- 1500 **Engine Variable**:- 1) Torque:- from 4 to 22 N.m	Cottonseed oil biodiesel **Variable**:Blend Ratio:- B10, B20, B30	1) BSFC decreases for the torque from 4 N-m to 17 N-m and then increases up to 22 Nm. Increase in torque increases BTE. 2) With increase in blend ratio BSFC increases while BTE decreases.	The observation is in contradiction to normal trend of increase in BTE with increase in blend ratio.
8	Samir J. Deshmukh et. Al. [12] 2009	**Engine Variable**:- 1) Load :- from 0 to 4.0 kw.	biodiesel of 1)Cottonseed, 2) Jatropha, 3) Hingan oil 4) soyabeen oil	With increase in load BSFC decreases while BTE and EGT increases for all fuels.	Soya been oil is not recommended. Availability of Hingan oil is also an issue. More research on cottonseed and jatropha is required.

The literature indicates that, the list of biodiesels used include different vegetable and non-vegetable oils Like Karanja, Neem, Soya Been, Jatropha, Palm Oil, Cottonseed, ,Mahua, Fish Oil, Hingan, Waste Cooking Fried Oil, etc. The country like India where population and density of population is high, nonedible or non-preferred edible oils which are easily available should be preferred as an alternative fuel.

The investigation indicates that the researchers have tried to compare engine performance by using different biodiesels and their blending with that of pure biodiesel Such combinations include studies on comparison between diesel and individual biodiesels [10, 12, 18, 20, 21, 24, 26], comparison between diesel and blended biodiesels [5, 6, 7, 8, 9, 11, 13, 16, 17, 19, 28, 29, 31,], diesel and mix biodiesels [15], diesel and mixed blended biodiesel [15, 23, 27], diesel and biodiesel with additives [14, 22, 25, 30]. However, it is very difficult to understand as to which combination results performance owing to different working conditions.

Though biodiesel made from Jatropha with Cottonseed is required to be focused being non edible, availability and performance wise the series of experimentation on different combinations of fuels based on availability and performance as explained above may throw light on this issue.

The different engine parameters investigated in Table 3.1include load, injection pressure, injection timing, engine coating while fuel parameters include blend ratio, addition of additives or another fuels, mixture of different biodiesels, additional process on biodiesels.

It is now well established that the existing single cylinder diesel engine can be used for biodiesels without change in engine design. However, it does not allow changing compression ratio, which is the most important engine parameter affecting engine performance.

In view of varying properties like calorific value and viscosity for different biodiesels, the variation of compression ratio is inevitable for optimum performance. The only study available on variable compression ratio engine [32] is on four stroke single cylinder modified VCR engine having rated power 3.7 kW at 1500 rpm with variable compression ratio varying from 5:1- 20:1. The study indicates that change in CR affects the engine performance and emission. For B5, BSFC increases with increase in CR.

For B10, BSFC decreases with increase in CR. For B15, BSFC decreases with increase in CR up to designed CR (17.5:1) and then increases marginally. For B20, BSFC increases for CR 17:1 only. BTE increases with increase in CR.

3.1.2 Multi-cylinder Engine

The multi-cylinder engines are operated at fixed compression ratio. These engines are used in automotive. Table 3.2 shows the findings on experimentation carried out to assess performance of multi-cylinder engine.

Table 3.2 Experimental performance on Multi cylinder engine

Sr. no	Author And Year	Engine Variables	Fuel Variables	Observations and findings	Remarks
1	D. Laforgia et. Al.[33]1994	Cylinders:- 4 CR:- 22:1 RPM:- 4200 **Engine Variable:-** 1) Speed:- 20004000 in six steps.	Rapeseed biodiesel **Variable:-** B0, D100 and biodiesel with methanol (B+M)	1) With increase in speed, BP and BSFC increases while torque and global efficiency decreases. 2) The brake torque for diesel is higher than both the fuels. BSFC is higher for biodiesel. Torque is nearly same to diesel, and the global efficiency is higher for B+M.	The attempt was good one but the study is limited with use of methanol with biodiesel. The effect on blending percentage on performance was not studied.
2	Abdul Monyem, Jon H. Van Gerpen [34] 2001	CR:-16.8:1	Soyabeen Oil **Variable:-** **B20 un oxidized and oxidized biodiesel**	Marginal BSFC and BTE increase with oxidization.	**Oxidation increases BSFC, hence not recommended.**
3	Mustafa Canakci et. Al. [35] 2005	No. of Cylinders:- 4 CR:-16.8:1 RPM:-2100	Soyabeen oil and yellow grease (BSO and BYG) **Variable:-** Fuel:-Soyabeen oil and yellow grease (BSO and BYG) and B20	1) With increase in blend ratio, BSFC and EGT increases.	
4	Gholamhassan Najafi et.al. [36] 2007	No. of Cylinders:- 2 CR:-18:1 RPM:-3000 **Engine Variable:-** 1) RPM:- Speed 1200 to 3600 in 6 steps	Waste cooking oil **Variable:-** B0-B50 In five steps	1)With increase in RPM, Power increases up to 3200 rpm then decreases, whereas torque increases up to 2400rpm and then decreases and SFC decreases up to 2400 rpm, then increases. 2) With increase in blend ratio, the trend for torque, power and SFC is random.	
5	A.A. Pawar and R. R. Kulkarni [37] 2008	No. of Cylinders:- 4 CR:- 19:1 **Engine Variable:-** 1) RPM:- from 04000 in four steps 2) Equivalence ratio:- 1.0-1.7	Not mentioned	1) With increase in RPM, EGT increases. 2) With increase in equivalence ratio, EGT decreases.	Equivalence ratio is studied first time.
6	Sergio C. Capareda, st.al. [38] 2008	No. of Cylinders:-3 **Engine Variable:-** 1) RPM:- from 2800-3150 in 7 steps	Cottonseed biodiesel with marine diesel. **Variable:-** B0 , B5 , B20 and B100	1) With increase in RPM, power is increased till 2875 RPM then reduces for B100. 2) With increase in blend ratio BSFC increases specially for B80 and B100.	

7	Mustafa Canakci et. Al. [39] 2009	No. of Cylinders:- 4 CR:- 21.47:1 **Engine Variable:-** 2) RPM:- 10003000 in five steps.	Waste frying palm oil **Variable:-** B0-B100 in seven steps.	1) With increase in RPM, BSFC decreases while BTE and brake torque increases till 2000 RPM then decreases. 2) With increase in blend ratio, BSFC increases and BTE and torque decreases.	The observations contradict with earlier investigations.
8	A.A. Pawar and R. R. Kulkarni [40] 2009	No. of Cylinders:- 4 CR:- 21:1 RPM:-2300 **Engine Variable:-** 1) BMEP :- from 1-5 bar in five steps (in terms of load), where, Load is 0-100% in five steps 2) RPM:- 1200-1600	Jatropha oil **Variable:** Blend ratio: B20, B30 and B50.	1) With increase in load, BSFC decreases. 2) With increase in RPM, BSFC increases (except for B20 at 40% load). 3) With increase in blend ratio, BSFC increases.	
9	P. K. Sahoo et. Al. [41] 2009	No. of Cylinders:-3 **Engine Variable:-** 1) Throttle position:- full and part throttled 2) Engine speed 1200-200 RPM in seven steps.	Jatropha, Karanja and Polanga oil **Variable:-** **Blend ratio:- B20, B50, B100**	**For full throttle:-** 1) As speed increases, BSFC decreases. While, power is reduced for KB20, KB100, JB100, PB20, PB100 and is increased for JB20 and JB50 while no change for JB20 and JB50. 2) Increase in blend ratio results increase in BSFC.	

The literature on experimentation presented in Table 3.2 indicates that, the multi-cylinder engine has been used generally for investigating effect of engine speed (rpm) on the performance with an exception where variation in equivalence ratio has been tried [37]. However, the change in speed is also possible with single cylinder engine [23]. Therefore, use of Multi cylinder engine for experimentation appears to be not necessary as the purpose can be solved by use of single cylinder engine and can reduce the cost of experimentation.

3.2. Emission

Apart from engine performance, emission is also an important parameter for study as it is related to lives (human, animal and trees) on the planet. The main components of exhaust gases from biodiesel are NOx,CO,CO2,HC and smoke. All the exhaust parameters are harmful for human being as well as for animals.

The emission norms are decided worldwide for environmental protection. Every country has regulatory authority for environmental control which decides the allowable range of different emission parameters. Therefore, it becomes vital to perform emission analysis of exhaust gases. The investigations, reported in literature, on emission analysis for single cylinder and multi-cylinders engines are presented in section 3.2.1 and 3.2.2 respectively.

3.2.1 Single cylinder engine

Table 3.3presents the findings on effect of different engine parameters and fuel parameters on emission of single cylinder engine.

Table 3.3 Experimental investigation of emission for single cylinder engine

Sr. no	Author and year	Engine variables	Biodiesel and variables	Observations and findings	Remarks
1	Md. NurunNabi[6] 2005	CR:- 20:1 RPM:- 2000 **Engine Variables:-** 1) BMEP:- 0.130.31 M Pa. 2)EGR	Neem oil **Variable:** Blend ratio:- B5, B10, B15	1) With increase in BMEP, NOx, smoke increases while CO decreases. 2) With increase in EGR rate NOx emission decreases while CO, smoke increases. 3) With increase in blend ratio, NOx increase while CO and smoke decreases.	**Neem oil is used in medicine, not recommended.**
2	James P. Szybist, et.al. [42] 2005	RPM:- 3600, **Engine Variables:-** 1) Injection timing	Soya been biodiesel, Variable: 1) Methyl oleate and 2) Cetane improver as an additives	With advance injection timing, NOx is increasing and with addition of additives, NOx is reduced.	**Soyabeen oil is edible not recommended.**
3	G. Lakshami Narayanrao et. Al. [7] 2008	CR:- 17.5:1 RPM:- 1500 **Engine Variable:-** 1) Brake power:- 0 to 4.4 kw in four steps.	Used cooking oil biodiesel **Variable:-** B20-100 with four steps.	1) With increase in brake power smoke, NOx, CO and HC increase. 2) With increase in blend ratio, NOx and EGT increase while Co, HC and smoke decreases.	
4	D. Ramesh et.Al [8] 2008	RPM:- 1500 **Engine Variable:-** 1) brake power:- 2 to 3.5 kw in three steps	Jatropha biodiesel Variable:- B0 to B 100 in 5 steps	1) With increase in brake power, CO2 and CO (Except at middle load) decreases, while NOx is lower at higher and lower loads and increasing at middle load 2)With increase in blend ratio, CO2 and NOx increase while CO decreases.	**For middle load, the NOx formation contradicts with earlier investigations.**
5	B. B. Ghosh, et.al. [9] 2008	CR:- 4.5:1 to 20:1 RPM:- 1200 **Engine Variable** 1) Brake power:- from 0 to 2.7 (By changing load)	Putranjiva, karanja and Jatropha biodiesel **Variable**:- Fuel	1) With increase in brake power NOx, HC, CO, particulates, smoke increases. 2) Minimum NOx, particulates and CO is obtained for putranjiva oil, minimum HC and smoke is obtained for Jatropha oil.	Though the engine used is variable compression engine, compression ratio and load are fixed for experimentation.
6	Xiaohu Fan et. Al. [10] 2008		Cottonseed oil, Soyabeen oil **Variable:-** COME , SOB, PBSY (Dark color)	1) Biodiesel has less CO, CO2, NOx emission.	**1) Soyabeen oil is edible oil , not recommended** **2)Reduction in NOx and CO2 contradict with previous investigations [6, 7, 9].**

7	Siva Kumar et. Al. [11] 2009	CR:- 17.5:1 RPM:- 1500 **Engine Variables:-** 1)Torque:- from 4 to 22 N.m	Cottonseed oil **Variable:-** Blend Ratio:- B10-B30	1)Increase in torque rises NOx, CO, PM and smoke. 2) Increase in blend ratio decreases CO, PM and smoke and increases NOx	
8	Samir J. Deshmukh et. Al. [12] 2009	**Engine Variables:-** 1) Load:- from 0 to 4.0 kW.	biodiesel 1)Cottonseed, 2) Jatropha, 3) Hingan oil 4) soyabeen oil	1) With increase in load, Smoke, CO, HC, NOx (except at full load) increases.	
9	Praveen K. S. Yadav, Onkar Singh and R. P. Singh [16] 2010	CR:- 16.5:1 RPM:- 1500 **Engine Variables:-** 1) Brake power:-O to 3.7kw	Palm Oil biodiesel: Variable:- Blend ratio:- B20- B100 in five steps.	1) With increase in Brake power NOx, increases and CO and HC are changing alternatively up-to 2.22 kW and then rising beyond it. 2) With increase in blend ratio, CO, HC decreases while NOx increases.	**Palm oil is edible oil, not recommended. CO and HC emission are not significant w. r. t. brake power.**
10	T. Hari Prasad et. Al. [17] 2010	CR:- 16.5:1 RPM:- 1500 **Engine Variable:-** Load:- 0 to 8 in four steps	Fish oil biodiesel **Variable:-** Blend ratio:- B0-B100 in five steps	1) With increase in blend ratio CO, CO2 and HC decreases while NOx increases.	**Fish oil is edible, not recommended. Reduction of CO2 contradicts with previous investigations.**

The Investigation presented in table 3.3 is on fixed compression ratio engine. The only study available on variable compression ratio engine [32] indicates that change in CR affects the engine emission. At design value NOx is higher. Smoke and CO decrease with decrease in CR. Marginal change is found for HC.

Table 3.3 indicates that very few investigators focused on all main combustion parameters. Many contradictions have been noticed in emission parameters for same engine with same variables. For example, somewhere CO increases with increase in load, while it decreases in others. Similarly, somewhere NOx increases with blend ratio, while it decreases in other investigations. The similar situation appears for CO_2, HC and Smoke. These contradictions can be clarified by investigating all emission parameters together with same variables. The study on effect of injection timing and injection pressure on emission analysis [26] is likely to be very useful for further investigation on biodiesel.

3.2.3Multi Cylinder Engine

The Table 3.4 provides information regarding emission analysis for multi- cylinder engines.

Table 3.4 Experimental investigation of emission for Multi cylinder engine

Sr. no	Author And Year	Engine Variables	Fuel variables	Observations and findings	Remarks
1	D. Laforgia et. Al.[33]1994	Cylinders:- 4 (IDI) CR:- 22:1 RPM:- 4200 .	Rapeseed biodiesel Variable:- B0, D100 and biodiesel with methanol (B+M)	1) The CO, CO2, HC are lower for biodiesel compared with diesel while opacity is higher. 2) With increase in advance injection timing, all the emission parameters are decreased.	
	Abdul Monyem, Jon H. Van Gerpen [34] 2001	CR:-16.8:1 Engine Variable:- 1) injection timing (only for NOx and smoke):- 3°advance, standard 3° retard	Soyabeen Oil Variable:- B20 un oxidized and oxidized biodiesel	1) NOx decreases while smoke increases with increase in retardation. 2) Oxidization reduces CO and HC emission while NOx emission found insignificant.	CO, CO2 and HC analysis is carried out without retardation.
2	Mustafa Canakci et. Al. [35] 2005	No. of Cylinders:- 4 CR:-16.8:1 RPM:-2100	Soyabeen oil and yellow grease (BSO and BYG) Variable: Fuel: Soyabeen oil and yellow grease (BSO and BYG) and B20	With increase in blend CO, HC decreases, while CO2 and NOx, smoke number increases.	Experimentation is carried out at fixed load and speed.
3	GholamhassanNajafi et.al. [36] 2007	No. of Cylinders:- 2 CR:-18:1 RPM:-3000	Waste cooking oil Variable:- Blend ratio:- B0- B50 In five steps	1) With increase in blend ratio, CO and HC decrease except HC (Up to B30 then increases).	
5	Sergio C. Capareda, st.al. [38] 2008	No. of Cylinders:-3 RPM:-3200 Engine Variable:- 1) RPM:- from 2800-3200 in 7 steps	Cottonseed biodiesel Variable:- Blend ratio:-B0 , B5 , B20 and B100	1) With increase in RPM, NOx increases, while SO2 decreases in sinusoidal form. 2) With increase in blend ratio NOx, CO (except B100), HC and SO2 decreases, While CO increase for B100.	With increase in blend ratio, NOx decreases which contradicts with previous investigations [34, 36, 37, 38].
6	Mustafa Canakci et. Al. [39] 2009	No. of Cylinders:- 4 CR:- 21.47:1 RPM:-4250 Engine Variable:- 2) RPM:- 1000-3000 in five steps.	Waste frying palm oil Variable:- B0-B100 in seven steps.	1)With increase in RPM, a) CO increases for 1000-1500 RPM then decreases up to 2500 RPM and again increases. b) HC increases from 1000 RPM to 1500 RPM and then decreases. c) CO2 increases from 1000-1500 rpm then decreases to 2000 rpm and beyond it remains nearly constant. d) Decrease with engine speed, NOx is nearly constant till 1500 rpm, decreases up to 2000 rpm and beyond it, it increases. 2) With increase in blend ratio, CO, CO2, HC, smoke decreases, while NOx increases.	The data appears to be unreliable as variation in speed is shown insignificant and the findings contradict for certain speeds with previous investigations[33, 34, 35, 36, 38].

7	A.A. Pawar and R. R. Kulkarni [40] 2009	No. of Cylinders:- 4 CR:- 21:1 RPM:-2300 Engine Variables:- 1) BMEP :- from 1-5 bar in five steps (in terms of load), 2) RPM:- 1200-1600	Jatropha oil Variable: Blend ratio: B20, B30 and B50.	1) With increase in load, NOx is decreases. 2) With increase in RPM, NOx increases. 3) With increase blend ratio, NOx increases.	
8	P. K. Sahoo et. Al. [41] 2009	No. of Cylinders:-3 RPM:-2200 Engine Variables:- 1) Throttle position:- full and half throttled 2) Engine speed 1200-200 in seven steps.	Jatropha, Karanja and Polanga oil Variable:- Blend ratio:- B20, B50, B100	1) With increase in speed, smoke emission reduces. 2) With increase in blend ratio, smoke emission, PM and HC (except PB20) reduces while CO (except PB100) and NOx increases.	Behavior of CO emission is insignificant and contradicts with previous investigations[33-41].
9	Wenqiao Yuan and A. C. Hansen [44] 2009	No. of Cylinders:- 4 CR:- 17:1 RPM:-2200 Engine Variables:- 1) Spray cone angle-31.5, 41, and 47.5. 2) Injection timing- (-7,-6.7, -6.4 crank angle).	Biodiesel of 1)Soyabeen 2) Yellow grease, 3) Genetically modified soyabeen, 4) diesel	1) With increase in spray cone angle, NOx decreases. 2) With advancement of injection, NOx increases.	
10	B. Ghobadian et. al. [45] 2009	No. of Cylinders:-2 CR:-18:1 RPM:-3000	waste cooking oil Variable:- Blend ratio: B10- B50 in five steps.	With increase in blend ratio, CO and HC decrease.	
11	Breda Kegl [46] 2010	CR:- 17.5:1 RPM:- 12200 Engine Variable:- 1) engine speed:- 1000-2200 in seven steps 2) Injection pressure:- 75-375 bar -	Rapeseed oil Variable:- B0 and B100	1) With increase in RPM, HC, CO, smoke and NOx decreases till 1700 RPM and increases slightly. Smoke reduces gradually. 2) With increase in injection pressure, NOx and HC increases while CO and smoke decreases.	NOx formation is linked with combustion process.

Table 3.4 shows the emission analysis for multi-cylinder engines by varying load and speed. It also indicates that very few investigators focused on all components of emission analysis and also contradictions in emission behavior for same speed and load are visible. It has also been reported that the combustion process may affect the formation of emission components, particularly NOx[46], and hence needs attention.

3.3. Combustion

Combustion is a phenomenon which affects performance as well as emission of engines. Non-availability of sufficient literature indicates that the combustion phenomena with respect to biodiesel is largely ignored. It may be attributed to consideration of combustion parameters while designing biodiesel fuelled engine. The available investigations on combustion are presented in Table 3.5.

Table 3.5 Experimental investigation of Combustion

Sr. no	Author And Year	Engine Variables	Fuel variables	Observations and findings	Remark
1	D. Laforgia et. Al.[33]1994	Cylinders:- 4 CR:- 22:1 RPM:- 4200 Engine Variable:- 1) Injection timing 2) Speed:- 2000-4000 in six steps.	Rapeseed biodiesel Variable:- B0, D100 and biodiesel with methanol (B+M)	The combustion is worst with biodiesel and B+M fuel compared with diesel. The ignition delay time is longer for biodiesel and B+M.	
2	G. Lakshami Narayanrao et. Al. [7] 2008	CR:- 17.5:1 RPM:- 1500 Engine Variable:- 1) Brake power:- 0 to 4.4 kw in four steps.	Used cooking oil biodiesel Variable:- B20-100 with four steps.	1) With increase in brake power ignition delay decreases. 2) With increase in blend ratio, ignition delay decreases while maximum heat release rate decreases and the crank angle at which it takes place advances.	
3	B. Rajendra Prasath et. Al. [18] 2010	CR:- 17.5:1 RPM:- 1500 Engine Variable:- 1) Coating of engine with LHR	Jatropha oil Variable:- B0 and B100	1) Coating shows highest peak pressure fuelled with diesel, shows highest cylinder temperature for biodiesel, peak heat release with diesel is higher and lowest heat rejection to outside.	High cylinder temperature rises NOx formation, hence coating is not recommended.
4	Breda Kegl [46] 2010	CR:- 17.5:1 RPM:- 12200 Engine Variable:- 1) engine speed:- 1000-2200 in seven steps 2) Injection pressure:- 75-375 bar	Rapeseed oil Variable:- B0 and B100	1) With increase in engine speed, the heat release rate and start of combustion increases while ignition delay and start of injection decreases up to 1200 RPM beyond it increases. The shorter ignition delay for B100 is lower than diesel. 2) Increase in injection pressure causes early start of combustion.	The findings contradict that rise in NOx formation depends on inside cylinder temperature. It depends on combustion.

The literature indicates that the increase in NOx formation due to inside cylinder temperature is only at the start of combustion, later on other parameters like speed and injection pressure effect persists [46].

4. CONCLUSION

Even though the performance of engine is found to depend on many parameters, the literature indicates consideration of few of them for analysis. Different researchers have dealt with different parameters and hence the differences in the reported findings are not unnatural. The disparities in the findings are also obvious due to different test conditions they have used. Although bio diesels can be directly used in diesel engines, there are many issues related to optimum performance and emission, which need to be addressed. The parameters considered for study in literature are different for different engines with different bio fuels and at different environmental conditions. Hence, there is no clear cut consensus on the use of bio diesel and therefore concept could not commercialize yet to the expected extent.

Fuel properties and engine parameters influence combustion, performance and emission characteristics. The performance of single cylinder engine with varying compression ratio and varying speed at different loads for different biodiesels blends and combinations is required to be studied with respect to performance and emission. It is found that there is wide scope to have models (empirical, semi-empirical, mathematical or simulated) for prediction on the basis of fuel properties, engine parameters individually and at the same time together. Appropriate optimization of fuel parameters and engine parameters is also required for getting better performance with minimum emission levels. It may be possible through exhaustive using scientific approach so as to cover appropriate number of variables and to widest possible working range. A comprehensive data dependent systems modeling approach may be used.

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