Contemporary Review: Use of Mahua Oil and Waste Plastic Oil as Biofuels

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Abstract- In the automotive sector, price of petroleum products and its increasing demand needs a substitute to meet the energy requirements. Due to fuel lean operation, direct injection diesel engines are commonly used, when compared to spark ignition engine. For DI diesel engine, commercial fuel (diesel) is the major fuel source. However, the demand of petroleum based fuel increases one side and on other side there is rapid depletion of fossil fuels. Extensive research are being made to pursuit for an alternate fuel to avoid fossil fuel dependence. Biofuels are manufactured from both edible (sunflower, palm & peanut oil) and non-edible (jatropha oil, mahua oil, pongamia oil) feedstocks. The motivation of this work is to investigate the performance of biofuel from mahua seed oil and waste plastic oil on diesel engine. The advantage of non -edible biofuels compared to edible biofuels is that it doesn't compete with the foodstuff and freely available in forest. Energy recovery from waste plastics reduces the pollution and encouraging technique for waste management. The amount of hydrocarbon is rich in plastics which produce high calorific oil which can be used as a fuel with some additives. The literature study concludes that plastic oil derived from waste plastic as an alternate liquid fuel for diesel engine is probable.

Keywords Mahua seed, biofuels, plastic oil, transesterification, thermal decomposition, waste management, solid waste, waste to energy.

1. Introduction

Rapid industrialization, transportation and advanced agriculture are mainly considered petroleum fuels as their energy resource. The most appropriate power generation unit is diesel engine which are widely used in automobile and agricultural sector because of its thermal efficiency, reliability, robustness and its high fuel conversion capability. Due to the high utilization and population explosion leads to the depletion of fossil fuels and also increase the cost of fossil fuels. In addition to this, burning of fossil fuels causes environmental degradation by emitting smoke and oxides of nitrogen. Researchers analysed several fuel substitutes such as alcohol fuels, biofuels from biomass, dimethyl esters etc. to overcome the fossil fuel dependency and pollution [1].

Biodiesel is domestically manufactured biodegradable fuel from vegetable oils, animal fats, recycled cooking greases and waste plastics. It should meet the requirements of ASTM standards. It is obtained by transesterification and esterification chemical process which leaves glycerine and methyl esters as by products. For this process, 3:1 molar ratio of alcohol to triglycerides is required. Waste cooking oil is also used as the raw material for biodiesel production [2]. To achieve low viscosity and high conversion biodiesel, molecular weight of ester is one third of oil molecule [3]. Biofuels are classified as first generation and second generation bio fuels. First generation biofuels are produced from edible feedstocks which includes sunflower oil, palm oil, peanut raw oil and coconut raw oil. Second generation biofuels are produced from non-edible feedstocks which includes pongamia oil, jatropha oil, mahua oil, plastic oil and so on [4]. Microalgae also act as a biodiesel feedstock because of their lipid content [5]. Several researchers found that biodiesel from edible oil and non –edible oil produces lower performance when directly injected in diesel engine due to its high viscosity. Renewable energy sources like solar power, batteries and fuel cells, biogas and some other biomass finds an alternative to the petroleum fuels. Last 30 years, plastic usage has become essential in day to day life due to its flexible design and commodity demand. Millions of plastics are manufactured which is made of hydrocarbon. Moreover the usage of plastic increases, its non-biodegradable nature causes hazard to the environment. Large volume of plastic disposal adds the problem to waste management. In order to overcome the plastic waste management problem and fuel shortage problem, recycling of plastic waste into plastic oil is the possible solution [6].

2. Mahua Oil

The genus Madhuca (Mahua) belongs to the family sapotaceae. It grows upto 20 meters height in the dry environment. As a plantation species it plays a vital role in social- economic value. The parts of the tree such as bark, fruit, flowers and seeds are used as medicines, food, intoxicant and fuel oil respectively. Leaves of this tree produces a form of wild silk called tassar silk. It has a potential of enhancing the income generation. Depends on the growth of the tree, the yield of seed ranges from 20-200 kg per year. The seed kernel contains nearly 50% oil [7]. Nearly 0.12 million tons of seeds collected yearly in organized sectors for oil extraction. The seed contains 50-60% of fat which is not edible due to the presence of toxic elements like saponins, aflatoxin, aflatoxin B1 and tannins. The non-edible mahua oil has similar properties of diesel, so it is considered to be an alternative fuel for diesel [8].

3. Biodiesel Characteristics of Mahua oil and its Blends

Researchers found that Mahua oil or its blends with additives used as a fuel for diesel engine. The red mud from aluminium industry waste recycled used as a catalyst with mahua oil possess lower fuel consumption and optimum engine performance compared to diesel. Among the different blends, B50 red mud diminishes the stress in the form of less emissions [9]. BTE increases due to the maximum availability of oxygen in the biodiesel causes good combustion and extensive ignition delay because of heat loss reduction and power raise with the rise in load condition. Along with the methanol solution acid and base catalyst converts mahua oil into biodiesel [10]. Roshan raman et al. [11] observed that 3% more BTE and minimum BSFC compared to diesel which improves combustion. DEE cooling effect reduces 7% NOx for AD20 blend. MOME/DEE enriches physiochemical characteristics by diminishing the smoke opacity and increased heat release rate. Engine Performance test using MOME biodiesel achieves the results relatively equal to diesel but it has slender power loss with increase in fuel consumption [12].

Experimental investigation on MPO in DI engine illustrates that direct use of MPO is not appropriate for diesel engine because of its low Cetane number and high viscosity. Instead, it can be used in its blended form without any engine modification. Also found that MPO30 has 7.4 % reduced smoke opacity, MPO40 has 27% of lower NOx emission and slower combustion compared to diesel [13].Farmaan et al. [14] determines NOx reduction due to ester decarboxylation, low burning temperature leads to higher unburnt hydrocarbon generation which indicates the mahua oil efficiency. Vibhansu et al. [15] reviewed that mahua oil has lower HRR and small quantity of blend considerably change the combustion process and provides better performance compared to commercial fuel. M.Arulprakasajothi et al.[16] analysed that adding 10% and 20% octanol with mahua reduces all emissions. Production of mahua oil involves two step esterification process in which first step involves acid catalyst with methanol at reaction temperature of 60ºC for 60 minutes. Second step includes alkali catalyst transesterification process which produces 98% mahua biodiesel [17].

Slight engine modifications also enhance the performance of mahua biodiesel. M.Kannan et al. [18] implemented two techniques such as low heat rejection and low temperature combustion. Low heat rejection technique modifies the engine by coating alumina in the cylinder head and piston head which improves engine efficiency and reduce heat loss.Low temperature combustion modifies the ratio of exhaust gas recirculation reduces the emission with the help of control valves . Santhoshkumar et al. [19] observed the optimal condition for the methyl ester conversion to biodiesel includes 9:1 molar ratio of alcohol to oil at the reaction temperature of 45ºC for 12 hours with 1.25 wt. % catalyst concentration. The authors concluded that the properties of mahua oil biodiesel except calorific value are within the ASTM specified limits and approximately equal to the diesel fuel properties. B100 blended with high speed diesel doesn't affect the engine performance [20].

4. Waste Plastic Oil

Plastics has its uses in daily life from household to industrial applications because of its low cost, light weight compared to other packaging material, corrosion resistant, poor conductor, durability and longevity. Large amount of plastic waste is due to the higher utilization of plastic and its non-biodegradable nature, it may take billion years to decay. Recycling of plastic into fuel solves plastic waste management and fuel scarcity problems [21].

5. Fuel Characteristics of Waste Plastic Oil

Literature review proposed that test performed on diesel engine running on waste plastic oil with the influence of injection timing resulted in increased brake thermal efficiency, high carbon dioxide & smoke emissions, less emissions of carbon monoxide, unburned hydrocarbon and oxides of nitrogen [22,23]. Experimental investigation on DI diesel engine using waste plastic oil with optimised level of cooled exhaust gas circulation reduces the higher emissions of oxides of nitrogen and also achieve comparable brake thermal efficiency to diesel [24]. V.K.Kaimal et al. [25] perceived that efficiency of plastic oil with its blends at loading conditions is poorer than diesel. But at the full load condition, the plastic oil and its blend's efficiency of combustion characteristics such as heat release rate, cylinder peak pressure and ignition delay increases . Damodharan et al. [26] studied that the performance of plastic oil is improved by the process of combining influence of injection timing and exhaust gas recirculation which results in lower emissions and higher efficiency . To control the smoke emissions, waste plastic oil with oxygenated high carbon alcohols such as n-pentanol, n-hexanol and n-octanol are used. n- pentanol suits to minimize BSFC and also minimize the smoke and NOx emissions [27]. The experimentation on DI engine fuelled with WPPO in combination of DEE indicates that reduced smoke levels and better combustion process due to oxygenate addition and also shows the Cetane rating upturns equivalent to diesel [28]. Experimental results illustrates that PO-DEE blends proves better performance by having low BSEC, lower emissions, high BTE and delayed combustion with improved thermal efficiency and reduced peak pressure and heat release rate [29].

In steps of Pyrolysis and distillation of HDPE waste grocery bags ensued in a liquid hydrocarbon mixture comprises of saturated aliphatic paraffinic, aliphatic olefinic and aromatic hydrogen with the boiling range apposite to petro diesel fuel [30] .TPO obtained from pyrolysis of scrap tyre has the properties similar to conventional diesel but it has high sulphur content and lower Cetane number than diesel. Mostly, road vehicles prevent high sulphur oils whereas stationary and marine engines could use TPO [31]. A liquid fuel production by thermal degradation of rubber tyre with waste plastic increases the yield [32]. For all brake mean effective pressure, the engine efficiency is analogous to diesel, but smoke emissions is slightly higher but for lower BMEP, no significant variation found [33]. Addition of diesel with the pyrolysed polypropylene oil blends improves the performance with longer combustion and ignition delay periods and lower the emission of pollutants [34]. Without EGR operations, Nox emissions increases due to high adiabatic flame temperature and heat release rate. WPO blend with optimised EGR reduces 36.3% of NOx emission [35].

6. Transesterification Process

Generally biodiesel from edible and non-edible seed is produced by the transesterification process of triglyceride with alcohol in the presence of catalyst. The author investigate the physiccochemical properties of biodiesel and reported the effects of different alcohol to molar ratio on biodiesel production [41]. Experimentation results shows that some of the factors affects the transesterification process. It includes catalyst used, alcohol to oil molar ratio, fatty acids present in fats and oils and reaction time,temperature and pressure [42]. Intensive study on biodiesel production develops a supercritical technology which outcomes catalyst free biodiesel using methyl acetate [43]. High quality biodiesel is obtained from the continuous esterification process and purification process [44]. In transesterification, increase the alocohol to oil molar ratio increases the biodiesel yield. Free fatty acid non- edible oils requires two step transesterification for biodiesel production [45] . Due to steric hindrace effect, higher chain molecular alcohols are not used in transesterification reaction [46]. Quitain et al [47] discussed that without transesterification process, biodiesel was synthesed by using microwave irradiaton. Viscosity and calories measurements of biofuel using catalyst and time variations for stirring in transesterification process was observed [48].

7. Pyrolysis Process

Decomposition of plastic waste through the combustion process reduces the plastic waste and at the same time it causes health problem by the toxic gases generated from the emission of plastic combustion. To reduce this environmental pollution, pyrolysis process of plastic decomposition is an alternative solution [49]. Pyrolysis process limits the dioxin formation and also produce high valued product includes fuel and chemicals [50]. The quality of pyrolysis process mainly depends on the temperature and time[51,52]. Mixed plastic decrease the amount of waxy compound. To recover plastic waste and convert it into fuel, pyrolysis is an effective technique[53]. The observations on pyrolysis process shows that at perfect conditions, the oil and gas produced without any residue left. High quality of oil product was obtained from the mixed waste pyrolysis at 500°C for 60 minc in a fixed bed reactor [54]. Hosokai et al. [55] estimated the thermodynamic properties of liquid fuel from pyrolysis.

8. Closure

The comprehensive review on the performance of nonedible mahua oil and waste plastic oil as substitute fuel for Diesel engine. Table 1 summarises the preparation materials of Mahua oil and waste plastic oil, test conditions and type of engine used. Table 2 describes the properties of Mahua oil, waste plastic oil and its blends with the properties of commercial fuel. Table 3 précises the emission characteristics of Mahua oil, waste plastic oil and its blends. It comprises the details about emission level of carbon monoxide, unburnt hydrocarbon, oxides of nitrogen and smoke in comparison with diesel. Table 4 condenses the performance characteristics such as brake thermal efficiency, exhaust gas temperature, brake specific fuel consumption are compared. BTE calculates how engine converts heat to mechanical energy from fuel. BSFC reflects the fuel efficiency of combustion engine which burns and produces rotational power at the shaft. EGT measures the temperature of exhaust gas which varies fuel to air ratio thereby regulate the mixture of fuel/air entering the engine. Table 5 review the combustion characteristics of a fuel in diesel engine which specifies the engine performance and affects engine resilience. The major combustion characteristics includes the cylinder pressure, heat release rate and ignition delay. For the prediction of accurate engine performance and measurement of cylinder pressure is necessary. Ignition delay is the period between fuel injection and fuel combustion. Heat release rate provides information about the rate at which fire releases heat energy.

NOMENCLATURE

DI- Direct Injection
WC- Water Cooled
MOME- Mahua oil methyl ester
MOEE- Mahua oil ethyl ester
MOB-Mahua oil biodiesel
MME- Mahua methyl ester
DEE- Di-ethyl ester
WPPO- Waste plastic pyrolysis oil
HDPE-High density polyethylene
BTE- Brake Thermal Efficiency
EGT- Exhaust Gas Temperature
BSFC-Brake specific fuel consumption
HSD – High speed Diesel
MPO- Mahua Pyrolysis oil
WPO- Waste plastic oil
WTPO- Waste tyre pyrolysis oil
TPO-Tyre Pyrolysis oil

Table 1 Summary of Mahua oil and waste plastic oil Preparation

MAHUA OIL						
Engine Type	**Testing condition**	**Catalyst**	**Alcohol/ Mixture**	**Reaction Temperature**	**Duration**	**References**
4 Stroke DI diesel engine	Constant speed-1500 rpm	Sulphuric acid (H_2SO_4)	Methanol Ethanol	60-65°C 72-75°C	5 hours	Sukumar Puhan et al .[36]
Unmodified Diesel engine	Constant Speed-1500 rpm	Sulphuric acid(H_2SO_4) Potassium Hydroxide (KOH)	Methanol	60°C	1 hour	Vijay Kumar et al. [37]
1cylinder, 4 stroke water cooled C.I engine	Constant speed 1400 rpm, 3.6 KW brake power	Sulphuric acid (H_2SO_4)	Methanol	60°C	1.5 hours	Ramasubramanian et al. [10]
AVL5402, 1 cylinder, air cooed diesel engine	Varying loads, constant speed 1500rpm	Potassium Hydroxide (KOH)	Methanol	65°C	1 hour	Arulprakasajothi et al. [16]
WASTE PLASTIC OIL						
1cylinder, 4 stroke, air cooled D.I engine	Constant speed 1500 rpm at 4.4 KW rated power	-	1% (weight) catalyst, 10% coal, 75% liquid hydrocarbon, 5 - 10% residual coke, rest LPG	300 °C- 400 °C	3-4 hours	Mani et al. [22,24,39]
1 cylinder, DI disel engine	Constant speed 1500 rpm , 3.7 KW rated power	Silica	1% catalyst, 10% coal, 80% plastic oil, 15% solid coke, 5% gas	300 °C- 400 °C	4 hours	V.K.Kaimal et al. [29]
1 cylinder, DI, WC disel engine	Constant speed 1500 rpm , 3.7 KW rated power	Silica	1% catalyst, 10% coal, 80% plastic oil, 15% solid coke, 5% gas	350 °C- 400 °C	4 hours	V.K.Kaimal et al.[25]

Table 2 Properties of Mahua oil and waste plastic oil in Diesel engine

MAHUA OIL									
References	**Fuel**	**Kinematic Viscosity °C**	**Specific Gravity/ Density °C/ (Kg/m³)**	**Flash Point °C**	**Fire Point °C**	**Cloud Point °C**	**Pour Point °C**	**Cetane Number**	**Gross Heating Value (MJ/Kg)**
Sukumar Puhan, G.Nagarajan, N.Vedaraman, B.V. Ramabramham[36]	MOME MOEE Diesel	5.2 6.2 2.6	0.865 °C 0.865 °C 0.82 °C	162 164 65	169 173 70	3 5 -15	1 2 -17	52 55 45	39.91 41.6 45.6
N.Kapilan, T.P.Ashok Babu, R.P.Reddy[38]	MO MOB Diesel	27.63 4.85 2.68	-	212 129 56	-	-	14 5 -20	- 51 48	35.6 36.9 42.9
M.Vijay Kumar, A.Veeresh Babu, P.Ravi Kumar[37]	Raw MO MME Diesel	37.18 4.86 2.89	899 Kg/m³ 867 Kg/m³ 819 Kg/m³	238 108 48	243 140 52	14 14.5 -10	15 10.2 -5	- 52 49	36.37 38.51 44.29
Debalaxmi Pradhan, Harisankar Bendu, R.K.Singh, S.Murugan [13]	MPO Diesel	23.19 2.58	921 Kg/m³ 833 Kg/m³	84 50	118 56		11 -6	37.7 50..	41.8 43.8
Sukumar Puhan, N.Vedaraman, G.Sankaranarayanan, Boppana V.Bharat. Ram [40]	MOEE Diesel	6.2 2.6	0.865 °C 0.82 °C	164 65	173 70	3 -15	1 -17	47 51	41.6 45.6
Shashikant Vilas Ghadge, Hifjur Raheman [17]	Mahua Diesel	3.98 2.60	880 Kg/m³ 850 Kg/m³	208 680	-	-	6 -20		37 42
H.Raheman, S.V.Ghadge [19]	Mahua Diesel	5.11 2.39	854 Kg/m³ 824 Kg/m³	224 54	231 62	-9 0	-21 -14		40.11 42
WASTE PLASTIC OIL									
M.Mani, G.Nagarajan [22,23,24,39]	WPO WTPO Diesel	2.52 3.2 2	0.8355g/cc 0.935 g/cc 0.840 g/cc	42 43 50	45 50 56			51 - 55	44.34 42.83 46.5
J.Devaraj, Y.Robinson, P.Ganapathi [28]	DEE WPPO Diesel	-	0.713 0.798 0.840	45 42 50	55 45 56			126 51 40-45	33.9 45.21 46.5
Viswanath K.Kaimal, P.Vijayabalan [29]	DEE PO Diesel	0.22 2.64 2.15	0.714 0.83 0.84	-45 40 45				~125 40 45	33.87 44.2 43.5
Viswanath K. Kaimal, P.Vijayabalan [25]	Diesel PO	2.15 2.64	0.84g/cc 0.83/cc	45 40	48 44			54 50	43.5 44.2
Archit S. Ayodhya, Venkatesh T.lamani, Parashuram Bedar and G.N Kumar [35]	Diesel WPO	2.3 3.52	832 Kg/m³ 915 Kg/m³	50 42	56 44			54 50	41.6 37.8

Table 3 Effect on Emission of Mahua oil and waste plastic oil in Diesel engine

MAHUA OIL					
References	**Biofuel**	**CO**	**HC**	**NO_X**	**SMOKE**
Sukumar Puhan, G.Nagarajan,	MOME MOEE	↓ 79% ↓ 67%	↓ 60% ↓ 49%	↓ 9% ↓ 27%	↓ 53% ↓ 37%

N.Vedaraman., B.V. Ramabramham [36]					
M.Vijay Kumar, A.Veeresh Babu, P.Ravi Kumar [37]	MME and its blends	↓	↓	↑	↓
Roshan Raman, Naveen Kumar [11]	MOME with DEE	↓ 47% for AD20		↓ 7% for AD20	↓ 55% for AD20
H.Raheman, S.V.Ghadge [20]	Mahua and its blends	↓		↑ 6%	↑
Debalaxmi Pradhan, Harisankar Bendu, R.K.Singh, S.Murugan [13]	MPO	↓	↑	↑	↓
Arulprakashjothi Mahalingam, Yuvarajan Devarajan, Santhanakrishnan, Suresh Velliyan and Beemkumar Nagappan [16]	M90O10 M80O20	↓ 6.8% ↓ 7.4	↓5.1% ↓5.7%	↓ 4.8% ↓ 5.4%	↓ 2.1% ↓ 2.7%
A.SanthoshKumar, T.Vinoth and R.Anand [19]	Mahua	↓		↑	↓
WASTE PLASTIC OIL					
M.Mani, C.Subash, G.Nagarajan [39]	WPO	↑	↑	↑	↓
M.Mani, G.Nagarajan and S.Sampath [23]	Diesel WPO	14.1 →5.5g/kWh 18.5→6.1g/kWh	0.33→0.12g/kWh 0.34 →0.14g.kWh	12.15 →7.61g/kW h 14.68 → 8.23/kW h	0.2 → 3.78 0.6→5.6
J.Devaraj, Y.Robinson, P.Ganapathi [28]	Diesel WPPO	.07%→.08%ppm 0.06%→0.14%	32→57ppm 53→91ppm	129→855ppm 150→904ppm	1.7→53.5% 2→55.1%
Viswanath K.Kaimal, P.Vijayabalan [29]	Diesel PO	0.74 g/kWh 1.17 g/kWh	0.06 g/kW h 0.1g/kW h	4.29g/kWh 6.18 g/kWh	0.5→3.8BSU 1.02→5.7 BSU
Archit S. Ayodhya, Venkatesh T.lamani, Parashuram Bedar and G.N Kumar [35]	Diesel P30	0.16%→.02% 0.3%→.04%	24→44ppm 26→7ppm	58→855ppm 59→1265ppm	0.4 →15.54% 0.6→16.2%

↑- increases / higher than diesel, ↓- decreases/lower than diesel, → varies from no/low load to rated power/full load

Table 4 Effect on Performance of Mahua oil and waste plastic oil in Diesel engine

MAHUA OIL			
References	**BSFC**	**BTE**	**EGT**
Sukumar Puhan, G.Nagarajan, N.Vedaraman., B.V. Ramabramham [36]	↑ 6% for MOME ↑14% For MOEE	Diesel- 26.36% MOME- 28.307% MOEE- 26.42%	Diesel- 294°C MOME- 392°C MOEE-439°C
M.Vijay Kumar, A.Veeresh Babu, P.Ravi Kumar [37]	↓ for MME (B20 &B40) ↑ for MME (B60,B80 &B100)	↓ for MME (B60,B80 &B100) ↑for MME(B20 &B40)	-
Roshan Raman, Naveen Kumar [11]	↓ 10.63% for AD-10 ↓ 12.16% for AD-20	HSD-27% AD-10-28% AD-20-29.8%	HSD-293 °C AD-10-288 °C AD-20 -280 °C
H.Raheman, S.V.Ghadge [20]	↑ 4% in case of B100	↓ 10.63% at full load conditions for B100 and ↑ 17.1% t lower loads	16% ↑ in B100

A.SanthoshKumar, T.Vinoth and R.Anand [19]	Diesel- 12.5 MJ/kWh B10-16.04 MJ/kWh B20- 16.24 MJ/kWh B40-16.51 MJ/kWh B100-16.99 MJ/kWh	Diesel- 24.8% B10-22.4% B20-22.17% B40-21.79% B100-21.37%	Diesel – 56.8740 J/°CA B100- 42.530J/°CA
WASTE PLASTIC OIL			
M.Mani, C.Subash, G.Nagarajan [39]	-	Diesel- 28.2% WPO- 27.4%	Diesel- 221°C → 417 °C WPO- 240 °C → 450 °C
D.Damodharan, A.P.Sathiyagnanam, D.Rana, B .Rajesh Kumar, S .Saravanan [26]	Earlier injection timing improves BSFC from 314g/kWh to 296g/kWh	Earlier injection timing increases BTE from 30.6% to 32.8%	Decreases
Archit S. Ayodhya, Venkatesh T.lamani, Parashuram Bedar and G.N Kumar [35]		DF- 21.01% → 39.2% P30- 21.34%→ 40.14%	DF-129.94 °C→353 °C P30-131.87°C→368.82 °C

↑- increases / higher than diesel, ↓- decreases/lower than diesel→ range from no/low load to rated power/full load

Table 5 Effect on Combustion of mahua oil and waste plastic oil in Diesel engine

MAHUA OIL				
References	**In- Cylinder Pressure**	**Maximum In-Cylinder Pressure**	**In- Cylinder gas temperature**	**Heat Release rate**
M.Vijay Kumar, A.Veeresh Babu, P.Ravi Kumar [37]	↑for MME(B20 &B40)	↓ for MME (B60,B80 &B100)	↑ for MME	↓ for MME
Roshan Raman, Naveen Kumar [11]	HSD- 71bar AD-10- 72.7 bar AD-20- 73.8 bar	-	-	↓
Debalaxmi Pradhan, Harisankar Bendu, R.K.Singh, S.Murugan [13]	↓	↑	↑	↓
A.SanthoshKumar, T.Vinoth and R.Anand [19]	Diesel- 64.85 bar B10-64.13 bar B20- 63.757 bar B40-62.116 bar B100- 60.08 bar		Diesel- 131.89°C B10-133.91 °C B20- 149.35 °C B40- 155.45 °C B100- 156.09 °C	
WASTE PLASTIC OIL				
References	**Cylinder Pressure**	**Cylinder Pressure-Crack angle diagram**	**Ignition delay**	**Heat Release rate**
M.Mani, C.Subash, G.Nagarajan [39]	Diesel- 57 bar → 67bar WPO- 54 bar →71 bar	Diesel 67 bar WPO 71 bar	»» 2° CA to 2.5° CA	Diesel- 65 J/°CA WPO- 85 J/°CA
M.Mani, G.Nagarajan and S.Sampath [23]	Diesel 56 bar → 66 bar WPO 57 bar→ 67 bar	Diesel 67 bar WPO 72 bar	»» 2° CA to 2.5° CA	Diesel- 80 J/°CA WPO- 119 J/°CA
References	**Cylinder Pressure**	**Cylinder Pressure-Crack angle diagram**	**Ignition delay**	**Heat Release rate**
Viswanath K. Kaimal, P.Vijayabalan [25]	Diesel 56 bar → 67bar PO 58 bar →71 bar	Diesel- 67 bar PO- 71 bar	↑ 11 ° CA	Diesel- 85 J/°CA WPO- 147 J/°CA
D.Damodharan, A.P.Sathiyagnanam, D.Rana, B .Rajesh Kumar, S .Saravanan [26]			»»	Diesel- 39 J/°CA WPPO-43.28 J/°CA
Viswanath K.Kaimal, P.Vijayabalan [29]	Diesel 56 bar → 67bar PO 58 bar →71 bar	↑ 5.8%	»»	Diesel- 85.44 J/°CA PO- 147 J/°CA

»» delay longer than diesel, → range from no/low load to rated power/full load

9. Conclusion

The explored research on performance, emission and combustion characteristics of diesel engine fuelled with mahua oil & its blends and waste plastic oil& its blends surrogates for fossil fuels were reviewed. Based on the survey, the following conclusions are drawn.

1. Mahua oil possess good heat release rate but it is low compared to diesel.
2. Due to high calorific value, waste plastic oil retains high heat release rate.
3. Depends on the added oxygenated compound with mahua oil, NOx emission level increases or decreases.
4. Oxygenated additives with WPO has less emissions compared to mahua oil and also improves high oxygen content, octane rating and low viscosity.
5. Increasing the compression ratio and injection pressure for WPO and its blends leads to improve brake thermal efficiency and reduce the emissions of HC, CO and smoke.
6. Higher combustion is achieved by increasing the fuel particles velocity within ignition period and also by keeping high compression temperature.

At the outset, even though diesel engine is able to run mahua oil with its blends, waste plastic oil had superior properties comparable to diesel. Waste plastic oil with its blends forms an alternate fuel without any modifications on the diesel engine. It is also recommended as a solution for energy conservation and environment management.

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