Production and Utilization of Useful Fuel from Waste Cooking Oil and Waste Lubrication Oil: Performance and Emission-Quality in a Naturally Aspirated Diesel Engine

Ghaleppa B, Suraj N Hiremath, Rana Pratapreddy

Abstract: ***Increase in the demand for the alternative fuel for diesel engine as led to quest for feasible fuel with competitive cost and environmental friendly compared to petrolium fuel. This article deals on waste energy recovery. The aim of this experimental work is to find an attractive alternative fuel for the diesel engine by harnessing fuel from waste disposed oils. Waste Cooking Oil (WCO) and Waste Lubrication Oil (WLO) energy sources are used for fuel production. Collected WCO stored in a container, mixed and cleansed by removing solidified fats and other food leftovers before the transesterification. The acid followed by base catalyst transesterification processes carried out for biodiesel production. The WLO oil cannot be used directly in diesel engine and hence it is processed to be used like DLF using pyrolitic vacuum distillation method. The characteristics test such as flash point, fire point, density; viscosity and calorific value of the produced biodiesel, DLF, B10, B20, B30 and B40 were determined & compared with standards. Performance and Emission characteristics conducted in a single cylinder, free aspirated, water- cooled computerized diesel engine setup and results discussed. Results outcome shows that B30 exhibits the similar performance as pure diesel. The results show an improvement in brake specific fuel consumption, thermal efficiency. The unburned hydrocarbons, carbon monoxide emissions less but increase in the NOx.***

Keywords: ***Waste Cooking Oil, Transesterification, Waste Cooking Methyl Esters, Waste Lubrication Oil, Pyrolitic vacuum distillation, Diesel like Fuel, Performance and Emission***

Nomenclature

WCO - Waste Cooking Oil
WCME - Waste Cooking Methyl Esters
WLO - Waste Lubrication Oil
WVO - Waste Vegetable Oil
WEO - Waste Engine Oil
DLF - Diesel like Fuel
BSFC - Brake Specific Fuel Consumptions
BTE - Brake Thermal Efficiency
NOx - Oxides of Nitrogen
HC - Hydrocarbons
CO - Carbon Monoxide

Revised Manuscript Received on July 30, 2020.
* Correspondence Author
Ghaleppa B*, Department of Mechanical Engineering, Global Academy of Technology, Bengaluru, India. Email: ghaleppa@gat.ac.in.
Suraj N Hiremath2, Department of Mechanical Engineering, Global Academy of Technology, Bengaluru, India. Email: nhsuraj@gmail.com.
Dr. RanaPratapreddy, Department of Mechanical Engineering, Global Academy of Technology, Bengaluru, India. Email: gbhvijay@gmail.com.

I. INTRODUCTION

In the upcoming years, because of the growth of population, growing of air pollution, decrease the source of conventional fossil fuels and increasing their cost also have encouraged researchers to improve performance of existing diesel engine or else investigate to find an alternative fuel for diesel engine. Hence, number of studies going related to developing renewable and alternative fuels to replace diesel fuel. It is quite feasible to make use of waste in a decent way to provide supplementary fuels for IC engines. With the ever increasing price of the conventional diesel fuel and depletion of fossil fuels in recent decade and their non-renewability, environmental impact with emission producing from the conventional diesel fuel has led researchers in search of alternative energy Resources. Moreover, global carbon dioxide (CO2) emissions from fossil-fuel combustion are increasing every year, higher air pollution and importance to curb the global warming problems Caused with release of carbon dioxide release. Significant increase in growth of automobiles and changes in lifestyle are resulting in ever increasing consumption of energy [1]. Waste cooking oil is the one of the feedstock available to use directly in the engine to reduce the fossil fuel consumption and enhance sustainability. WVO incorrect disposal causes serious damages to sewage systems and waste water treatment plants. However, biodiesel production requires complex physical– chemical treatments, while direct use of WVO just needs mechanical treatment. Moreover, as concerns the environmental impact, it should be considered that the direct use of WVO as fuel produces less polluting emissions when considering the whole life cycle: carbon dioxide produced during combustion, in fact, can be partially absorbed by crops used for oil production [2]. Singhabhandhu, T. Tezuka, explains the use of waste vegetable oil, since its energy content is high, heating value is approximately 90% of that of diesel fuel, and emissions are lower in sulfur and nitrogen. Because it not only combines the management of the disposal of two wastes, but also provides greater benefits from the production of pyrolytic oil that can be used as a diesel substitute, from an energy point of view [3]. Several studies on biodiesel synthesis from used cooking oil have been carried out. The study has synthesized biodiesel from used cooking oil with the trans-esterification process, namely the esterification process with ferry sulfate catalyst and potassium hydroxide base catalyst and requires double consumption of methanol.

The addition of catalyst can increase conversion percentage of biodiesel produced [4]. Higher viscosity of the waste cooking oil compared to that of other fossil fuel is one of the major limiting factors which restrict the direct use of waste cooking oil in internal combustion (IC) engines. The higher viscosity can be mainly attributed to the larger molecular mass and chemical structure of the oil [5]. The viscosity of biodiesel blends can be further reduced to acceptable level in the diesel engines by adding n-butanol. In n-butanol can be mixed with waste vegetable oils to produce stable and clean fuels at lower temperatures [6]. Use of waste cooking oil samples collected from several sources, mixed, and refined before transesterification. Results showed that acid number was reduced by 99% after refining. NOx has reduced by 33% while thermal efficiency increased by 7.5% when using waste vegetable oil biodiesel [7]. Feasibility of using WEOs as a WDLF was investigated experimentally. Diesel like fuel is produced from waste lubricating oil using pyrolytic distillation and can be used in diesel engines. Also the effect of Na2CO3 as an additive on thermal properties of oil and pyrolytic distillation yield was investigated [8].The gasoline like fuel gives a better improvement in performance brake power, BSFC, and brake thermal efficiency in performance and hydrocarbon emissions. The CO and exhaust temperature of gases rises [9].Recycling and co-processing of waste lubricant oil are cracking and pyrolysis. Properties of liquid products obtained from catalytic pyrolysis are similar to gasoline. Octane number of the waste oil gasoline is 96 higher than that of gasoline 89[10].Waste Engine Oil is converted to diesel like fuel by pyrolytic distillation method in presence of additives sodium carbonate, lime and Zeolite on mass basis. The results of 2% mass has the highest effect on decreasing of sulfur content of the engine oil and on acquiring the most suitable distillation temperatures close to values of a diesel fuel [11].Refining and processing of WCO, WLO to produce pyrolytic oil is a profitable and also not only solves disposal problems of the three wastes, but also provides energy recovery benefits as a diesel substitute fuel [12]. The possibility with WEOs as a diesel like fuel was obtained through by applying pyrolytic distillation process. In this process Na2CO3 additives with ratios of 2%, 4%, 6%, 8%, and 10% were added to filter WEO. The characteristics of the product fuel were examined and found to be close to diesel fuel used in the present study [13]. The waste oil was treated using pyrolytic distillation. The cause of sodium hydroxide, sodium carbonate additives, influence of number of distillations and thermal and physicochemical properties of the obtained fuel was studied. The most excellent results obtained with 2% of sodium carbonate and two successive distillations. The fuel can be used directly or blended with any vegetable fuel in diesel engine without any modifications [14].

II. MATERIALS AND METHODS

First, The WCO was collected from different hotels, restaurants and stored. Some researchers claimed problems associated with direct use of WCO in engine due to high viscosity & density, poor volatility characteristics, bad cold start problems lead to gumming, injector fouling, and wear of vital moving component, The properties of collected WCO are shown in Table [1] .Then, it is essential to improve properties of cooking oil as mentioned in to closer to that of diesel. So collected oil were mixed (to improve variability of oil properties), cleaned, filtered and heated to take out water content and solid food impurities present in the oil. The oil taken to refining process and it consists of degumming, neutralization, de-waxing and bleaching. The pre- heated oil subjected to de-gumming to separate gums, neutralization to separate higher amount of free fatty acids in presence of NaOH solution which converts FFA's to soaps. The soap solution will be drained it off. Further de-waxing done to remove wax content so that oil will not get cloud point at low temperature. The neutral oil with NaOH solution (5% of the oil and de-ionized water) was subjected to a 10°C temperature.

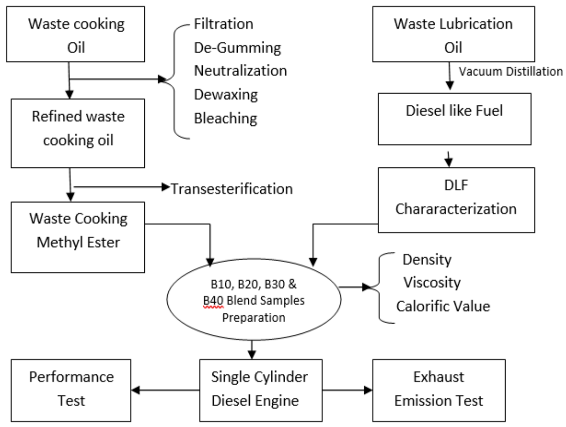


Fig.1. Flow diagram of the study

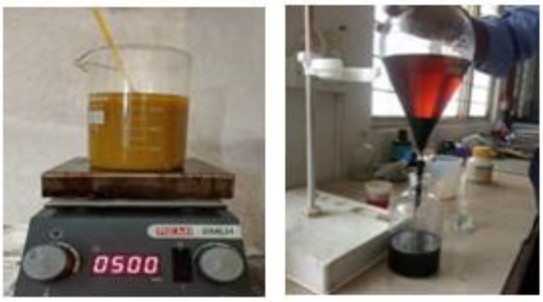
The wax dispatched after several hours of time. Bleaching was carried by subjecting the de-waxed oil to 100°C . The FFA value of refined waste cooking oil is 18% which needs to be reduced 1% by two-step of transesterification method. Another source of energy is waste lubrication oil. Waste Lubrication Oil (WLO) collected from different sources like industrial, automobile service centre's and stored in a tank. Collected oil has high viscosity value as represented in Table [1] and contains a lot of debasements, like sulfur, little metal particles; gum like material therefore directly cannot be used as a fuel in engine without purification and processed. Collected oil was filtered and converted to Diesel like

Fuel DLF using pyrolitic vacuum distillation method. The 100mL filtered waste oil placed into a boiling flask of 250ml. The flask introduced in a heating mantle undergoes pyrolysis process by reaching maximum surface temperature of 450oC and treated for 1 hr at this temperature. To reduce the Sulphur content in oil NaOH and Na2CO3 additives are added. The oil vapor condensed to liquid oil in water cooled condenser. Properties of obtained DLF were determined and listed in table [2].

A. Transesterification Process

The % of catalyst H2SO4 in first step and KOH in second step was determined based on percentage of acid value in a given sample of oil by titration method. The first step was done by mixing 175 ml of methanol, 5ml of concentrated H2SO4 with 500 ml of refined waste cooking oil in a 1 lit beaker and heated to 60°C in magnetic stirrer heater for 60 mins at 500 RPM Fig 2[a].

After the reaction, mixture was allowed for separation for 12hrs. The low-density acid esterified oil (top layer) taken to base transesterification and bottom layer glycerin residue removed. In base transesterification, product of acid esterification is mixed with 125 ml of methanol and 3.5 gm KOH. The solution container placed again on a magnetic stirrer heater, continuously stirred at 500 rpm for 1hr at 60°C. Biodiesel mixture allowed settling for at least 12 hr in a separating funnel. Two major products are Glycerin and main biodiesel separation shown in Fig 2[b]



(a) (b)

Fig.2 (a). Electro Magentic stirring & Fig.2(b). Glycerin separation

B. Biodiesel washing and cleaning

The proportional quantity of warm distilled water at 50°C added to the biodiesel and the mixture was shaken vigorously Fig 3. The biodiesel gently washed with distilled water 2 to 3 times to remove glycerin residual Fig 4[a]. Two spatulae of anhydrous sodium sulfate were mixed to biodiesel to remove water residual from waste cooking biodiesel. Waste cooking biodiesel (WCME) collected in beaker Fig 4[b]. WCME properties were determined, and the results were tabulated in table 2. Hence biodiesel produced from WCO can be used as an alternative fuel directly or it can be blended with any suitable oil, which meets the standards of diesel.The desired WCME-DLF blends were prepared, tested its thermal properties. CI engine performance with blends and exhaust emission tests are conducted.

Fig.3. water washing

4 (a) 4(b)

Fig.4(a). Biodiesel cleaning and 4.(b).Clean biodiesel

III. EXPERIMENTAL TEST METHOD

A. Test fuels characteristics

Thermal and physical properties of the DLF and WCME were determined and also compared with diesel fuel and numbers are within the standard limits. The test values were listed in table 2.

B. Engine set-up

The engine experimental set-up consists of computerized single cylinder, 4 stroke, free aspirated,
and water-cooled stationary compression ignition engine to test the performance and emission characteristics of blended fuels. The technical specifications of the test engine elaborated in Table [3].In addition, the engine set-up has an air metering, fuel measuring equipment, exhaust gas analyzer and exhaust gas temperature measuring system shown in fig [5]. The engine shaft connected to electrical dynamometer & it is connected to a control panel with computerized system. The load on engine varied from 0 kg to 12 kg (0- 100%) in each interval load increased by 2 kg. Initially the engine runs with conventional diesel fuel to prevent it from cold start problem for 30 to 40 minutes. The warm up period ends when the cooling fluid water temperature reached steady state condition. The computerized engine set-up system was used to measure performance parameters like brake power, brake specific fuel consumption and brake thermal efficiency. It will also give the air- fuel ratio; different exhaust gas emissions like NOx, HC, and CO measured in a gas analyzer. All readings were recorded at a 1500 rpm which is a constant rated speed.

IV. RESULTS AND DISCUSSIONS

A. Fuel sample properties Test

The thermal and physical numbers of B10, B20, B30, B40 blends almost similar to that of diesel which is represented in Table 4.

Fig.5. Computerized Diesel Engine Test Rig

B. Engine performance

The performance parameters, BSFC and Brake thermal efficiency tested in a given naturally aspirated test engine for all the samples. The results discussed below.

C. Brake specific fuel consumption

The fig 6 shows the variation of BSFC with respect to load with diesel and blended samples. The value of BSFC should be less for better performance. It is clear that value of BSFC for B30 sample less compared to other samples due to the low density and amount of oxygen in the fuels. The bsfc of B30 is near to that of diesel and henceforth B30 blend can be used as fuel in diesel engine.

D. Brake thermal efficiency

The fig7 illustrates the comparison of BTE with respect to load with diesel and DLF blend samples.

BTE states that how efficiently the heat is converted to mechanical work. From the experimental test is very clear that the thermal efficiency of the diesel is 30% and that of B30 fuel is 26.7%. The small variation may be due to the chemical composition of vegetable oil. For all the loads the brake thermal efficiency for diesel is same as B30 same.

Table- III: Engine Specification

Particulars	Description/values
Type of Engine	Single Cylinder, 4 stroke, air-cooled, direct injection
Manufacturer and Model	Kirloskar, AV1 Make
Fuel	Diesel
Rated power	3.5 KW
Speed	1500 rpm
Bore	87.5 mm
stroke	110 mm
connecting rod length	234 mm
Loading	Eddy current dynamometer
starting	Cranking
compression ratio	12 to 18:1
Engine Position	vertical
Cylinder capacity	553 cc

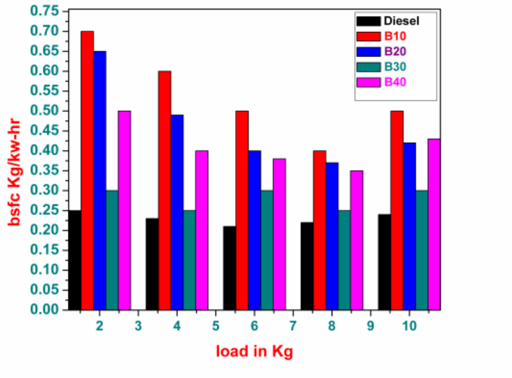


Fig.6. BSFC Vs load

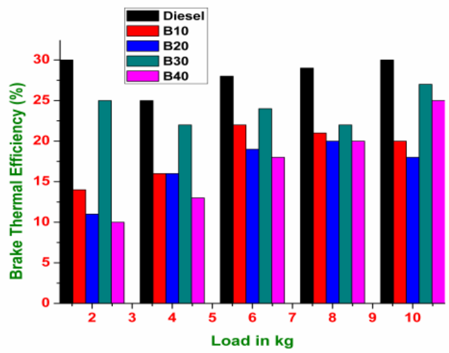


Fig.7. Brake thermal efficiency Vs load

Table- I: Properties of Waste Cooking Oil and Waste Lubrication Oil

Properties	Units	Test Standard	Limits	Diesel	WCO	WLO
Color				Light Brown	Black	Brown
Density @15°C	(kg/m^3)	D 6822	-	830	920-946	940
Kinematic Viscosity @40°C	mm^2/s	D 445	1.9-6.0	2.89	31	35.99
Flash Point	°C	D 93	130 max	48	>250	230
Acid value content	mg KOH/g	D664	0.5max	-	18	-
Calorific value	MJ/kg	D 4809	-	44	32-40	41

Table- II: Properties of Diesel, DLF, Waste Cooking Methyl Ester (WCME)

Properties	Units	Test Method	Limits	Diesel	DLF	WCME
Color	-	-	-	light brown		Brown Yellow
Density @15°C	(kg/m^3)	D 6822	-	830	818	850
Kinematic Viscosity @40°C	mm^2/s	D 445	1.9-6.0	2.89	3.48	4.5
Flash Point	°C	D 93	130 m	48	56	150
Fire Point	°C	-	-	52	150	162
Pour Point	°C	D 2500	-	-5	3	2
Cloud Point	°C	D 2500	-	-10	13	11
Boiling Point	°C	-	-	282-338	500	ND
Cetane number	-	-	-	40-55	-	-
Acid value content	mg KOH/g	D664	0.5max	ND	18	0.231
Calorific value	MJ/kg	D 4809	-	44	42.5	38-42

NOTE: ND= Not determined, m=minimum

Table-IV: Properties of various sample blends

Properties	Test method	Units	Diesel	B10	B20	B30	B40
Density @15°C	IS: 1448	kg/m^3	830	850	849	842	839
Viscosity @40°C	IS: 1448	mm^2/s	2.89	3.05	3.19	3.85	8.4
Flash Point	IS: 1448	°C	48	70	75	76	81
Fire Point	IS: 1448	°C	52	73	76	76	84
Calorific Value	IS: 1448	MJ/kg	44	37	37	41	39

E. Unburnt Hydrocarbon emission

Unburnt Hydrocarbon is an appropriately organic emission and it is consequences of the incomplete combustion of hydrocarbon fuel. The level of UBHC in the exhaust gases generally the measure of combustion inefficiency. Fig8 represents the discrepancy of UBHC of Diesel and blends. B10, B20, B30, shows 7%, 18% & 29% reduction in UBHC emission than the conventional diesel fuel at the constant load, which might be because of the higher concentration of oxygen content in the biodiesel.

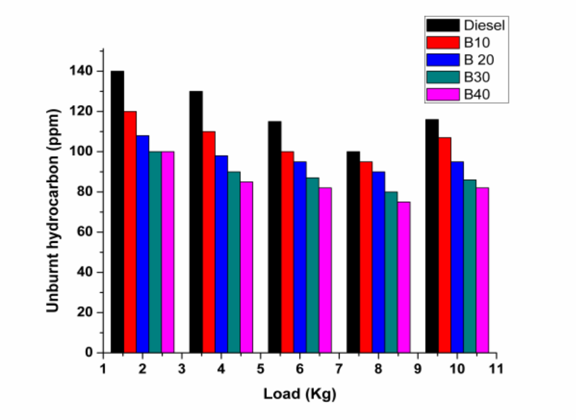


Fig.8. UBHC vs load

F. Oxides of Nitrogen emission

The quantity of NOx varies from a few hundred to over thousand ppm conventional diesel engine exhaust. NOx emission is common term of nitric oxide (NO) & Nitrogen dioxide (NO2), which is formed during the combustion process from the reaction of Nitrogen & oxygen gases in the air. The conditions that cause highest local peak temperature have sufficient oxygen & time period of reaction are critical parameters for NOx formation. Fig, [9] shows comparative No emission of diesel & fuel blends B10, B20, B30 & B40 at various loads. B40 biodiesel blend shows the highest NO all through the engine test compared to conventional Diesel as it has the highest level of oxygen & B30 biodiesel shows lowest of among B10, B20 & B40.

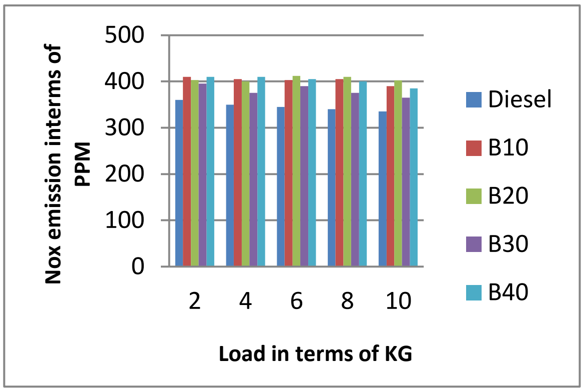


Fig.9. NO_x vs load

G. Carbon monoxide emission (CO)

Carbon monoxide is a poisonous colorless & odorless gas. It is generated in the engine when it is operated with fuel rich equivalence ratio. Fig [10] shows the variation in carbon monoxide of all the tested fuels i.e B10, B20, B30 & B40 Biodiesel blends against the diesel fuel. It is identified that percentage variation for all biodiesel and diesel fuel is minimal. CO emission of B10 & B30 fuel is 20% & 43% lower than diesel fuel at the given load. Lower CO emission is because of rich level of O2 content in the Biodiesel blends.

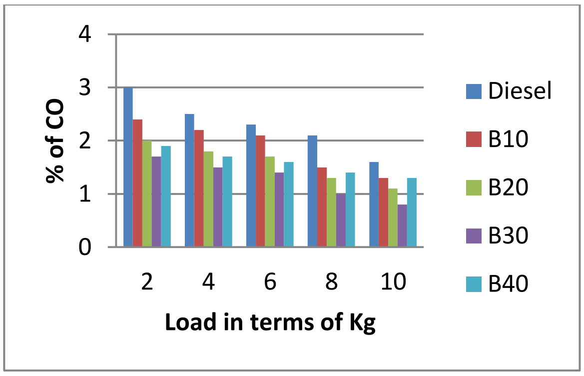


Fig.10. CO vs load

H. Exhaust Gas temperature

Fig [11] shows exhaust gas temperature with load in the range of 0 to 12 kg for diesel and other blends. The results intimate that the exhaust gas temperature increased for with load.

The maximum temperature is of 285oC seen for B30 at full load condition, whereas diesel it was 163oC only. The reason may be of higher heating value, higher oxygen content and better combustion.

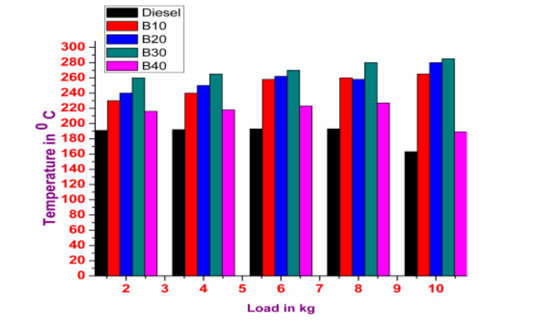


Fig.11.Exhaust Temperature vs load

V. CONCLUSION

In this experimental work, the used lubrication engine oil improved into diesel like fuel through pyrolytic refining was explored. The methyl ester was derived from waste cooking oil using transesterification. The performance and emission of different volume bases prepared samples were tested in single cylinder diesel engine. The results from the graph showed that blend sample gives the better result in bsfc, exhaust temperature and brake thermal efficiency compared to conventional diesel fuel. Among the blends B30 sample shows exceptional results and could be used as a fuel in diesel engine without any alteration to diesel engine.

VI. SCOPE OF FUTURE WORK

The DLF and biodiesel blends with different ratio can be tested for performance and emission. NOx level can be reduced by using the Nano additives and also the other additives like diethyl ether, n-butanol etc. Performance results can also be validated using different injection pressure.

VII. ACKNOWLEDGEMENT

The authors sincerely acknowledge finance supported by Karnataka State Council for Science and Technology (KSCST), Karnataka, India for successful completion of this research work.

REFERENCES

1. Endang Sri Rahadianti, Yerizam and Martha, "Biodiesel Production from Waste Cooking Oil". Indonesian Journal of Fundamental and Applied Chemistry, DOI: 10.24845/ijfac.v3.i3.77.
2. Billaud F, Gornay J, Coniglio L. "Pyrolysis of secondary raw material from used frying oils". In: Recents Progres EN GENIE DES Procedes, Number 94 - 2007 ISBN 2-910239-68-3.
3. Ampaitepin Singhabhandhu, Tetsuo Tezuka "Prospective framework for collection and exploitation of waste cooking oil as feedstock for energy conversion". Energy 35 (2010) 1839–1847.
4. Y.Wang, Qou., S.,Liu., P., Zhang, Z., "Preparation of Biodiesel from Waste Cooking Oil via Two-Step Catalyzed Process, Energy Conversion & Management", Vol.48, Issue 1, pp. 184-188, 2007.
5. Kalam M, et al. "Emission and performance characteristics of an indirect ignition diesel engine fueled with waste cooking oil". Energy 2011;36(1):397–402.
6. Dimitrios C. Rakopoulos, "Butanol or DEE blends with either straight vegetable oil or biodiesel excluding fossil fuel: Comparative effects on diesel engine combustion attributes, cyclic variability and regulated emissions trade-off". Energy 115 (2016) 314e325.
7. Greg M. Cubio, Sergio C. Capareda, "Real-Time Analysis of Engine Power, Thermal Efficiency, and Emission Characteristics Using Refined and Transesterified Waste Vegetable Oil" Journal of Energy Resources Technology, Vol. 136 / 032201-1.
8. A. Demirbas, M. A. Baluabaid, M. Kabli, and W. Ahmad, "Diesel Fuel from Waste lubricating Oil by Pyrolytic Distillation", Petroleum Science and Technology, 33:129–138, 2015.
9. Orhan Arpa, Recep Yumrutas, "Experimental investigation of gasoline like fuel obtained from waste lubrication oil on engine performance and exhaust emission", Fuel process technology 91(2010)197-204.
10. A. Demirbas. "Gasoline-like Fuel from Waste Engine Oil via Catalytic Pyrolysis Energy Sources", Part A: Recovery, Utilization, and Environmental Effects, Part A(16):1433-1441.
11. Orhan Arpa , Recep Yumrutas , Ayhan Demirbas , "Production of diesel-like fuel from waste engine oil by pyrolitic distillation" , Applied Energy 87 (2010) 122–127.
12. Ampaitepin Singhabhandhu, Tetsuo Tezuka. "The waste-to-energy framework for integrated multi-waste utilization: Waste cooking oil, waste lubricating oil, and waste plastics", Energy 35 (2010) 2544e2551.
13. A. Demirbas, M. A. Baluabaid, M. Kabli & W. Ahmad. "Diesel Fuel From Waste Lubricating Oil by Pyrolitic Distillation", Petroleum Science and Technology. 33:129–138, 2015.
14. R. Maceiras a , V. Alfonsín , F.J. Morales : "Recycling of waste engine oil for diesel production". Waste Management, 0956-053X/2016.

AUTHORS PROFILE

Ghaleppa B: Working as Assistant professor in department of Mechanical Engineering, Global academy of Technology since 7 years with proficient expertise in teaching basic and applied Thermal engineering courses.. Received Grants from KSCST for academic projects for 3 consecutive years. Currently pursuing Ph.D research work in the area of alternative fuels for IC engine particularly for diesel engine used in agricultural applications. He has published two research papers in international journals and one in national journals.

Suraj N Hiremath: Worked as Application Engineer in the field of Hydraulic Cylinder and Design for 3 years, Currently pursing Final Sem, M.Tech in Thermal Engineering at Global Academy of Technology. His area of Interest is in CFD Analysis of thermal cooling systems and Fluid Flow analysis.

Dr. Rana Pratap Reddy Has 35 years of experience in the field of teaching and administration in education. He guided 5 Ph.D scholars and guiding 4 research scholars. He has published 126 research articles on biofuels and alternative fuel. Currently he is working as professor and principal of Global Academy of Technology.