Biofuel Production Using Butanol and Used Transformer Oil

J.Antony Pradeep, K.Kishore Kumar, UG Scholars,
D.Balasubramanian Asst Prof.,
Dept. of MECH, Mookambigai College of Engineering, Pudukkottai.
J.Josaline Priska, Asst Prof., Dept. of EEE, M.A.M College of Engineering, Trichy.

ABSTRACT: *Energy demand of the world increases tremendously. The use of fossil fuels to this extent makes it limited and it is an important cause for global warming. To reduce the emission of greenhouse gases and fossil fuel usage, many developments were made using renewable energy. Ethanol was used as a substitute for gasoline lately but it is highly corrosive and need separate tankers for transportation. Instead of using ethanol, butanol will give high mileage, less corrosive and has higher flash and boiling point than ethanol. In this project, biofuel is produced by transesterification of butanol and used transformer oil with KOH as catalyst. Glycerol is a by-product in this process. It can be used as a substrate for the microbial production of plastics and in anaerobic digestion.*

Index Terms: *Ethanol, Butanol, KOH, Transesterification, Glycerol.*

I. INTRODUCTION

The world's demand for energy continues to increase at a predicted annual rate of 1.8%, especially as countries develop, while at the same time the supply of energy appears limited. The reason for this is that 75–85% of the world's energy is supplied by the fossil fuels and the supply of these is finite. In addition, the burning of fossil fuels has increased the greenhouse gases that are responsible for global warming.

In addition, the world's population is expected to expand at about 1% per year, which will mean that global energy requirements will continue to rise. Alternative sources of energy, which are renewable and with sustainable supplies, are required. Biological-based fuels can be solid, liquid and gaseous, and the physical state of the fuel greatly influences the way it is used.

The first-generation biofuels are represented by biomass, biogas, biodiesel and ethanol. The second-generation biofuels will be produced from ligno-cellulose biomass and wastes. Second-generation biofuel production will compete less with food crops. The direct production of hydrogen and extraction of oil for biodiesel from microalgae are third-generation biofuels which will not compete with food crops.

Oil makes up 35% of the world's primary energy supply and the majority of this oil is used to produce the transport fuels petrol, diesel and kerosene. If biofuels are to be used to replace the liquid fuel produced from oil, the scale of the replacement needs to be appreciated.

Biofuels have three major advantages over gasoline and diesel fuel produced from oil. First, while oil resources are concentrated in a small number of countries, to reduce their dependence on imported oil. Second, if these crops are not used faster than they are replenished by new plant growth, there is no net increase in CO_2 emissions, unless existing grasslands or forests are cleared to plant biofuel crops. Third, biofuels are available now, are easy to store and transport, can be distributed through existing fuel networks for use in motor vehicles.

II. AN OVERVIEW OF TRANSFORMER OIL

Transformer oil is an almost colourless liquid consisting a mixture of hydrocarbons which include paraffins, naphthalenes and aromatics. The transformer oil is obtained after distilling off the lighter fractions in the process of crude distillation. The oil thus obtained is first treated with sulphuric acid, then treated with alkali to neutralize the acid, thoroughly washed with water, filtered and dried. Presence of even a trace of water in transformer oil reduces its insulation strength considerably.

When in service, the liquid in a transformer is subjected to prolonged heating at high temperatures of about 95°C, and consequently it undergoes a gradual ageing process. With time the oil becomes darker due to the formation of acids and resins, or sludge in the liquid. The original chemical properties of transformer oil change gradually, rendering it ineffective for its intended purpose after many years.

It offers the following advantages: High dielectric strength, Low viscosity, Freedom from inorganic acids, alkali and corrosive Sulphur, Good Resistance to Emulsification, Freedom from Sludging under normal operation, Rapid setting of arc products, Low pour point and High Flash point.

The flash point (min) and pour point (max) are 140°C and −6°C respectively. The dielectric strength of new untreated oil is 12 MV/m (RMS) and after treatment it should be greater than 24 MV/m (RMS).

Physical constants of Transformer oil

Property	Recommended value
Permittivity	2.2
Thermal conductivity	0.12 W/m deg C
Specific Heat	2.06 kJ/kg deg C
Coefficient of Expansion	0.00078/ deg C
Mean density factor	0.00065/ deg C

Figure 1: Transformer Oil

III.   BIO-BUTANOL

Butanol is an alcohol which has been considered as liquid fuel as it has similar properties to ethanol but has higher energy content. Butanol will give a higher mileage and can be mixed at any proportion with petrol. Butanol has been used as an industrial solvent, paint thinner and a component of brake fluids. It is less corrosive than bioethanol and can be transported through existing pipeline whereas ethanol has to be carried in tankers, by rail or on barges. It is also safer as it has a higher flash and boiling point. With all these advantages over ethanol it is perhaps not surprising that a number of ethanol plants have switched to butanol. At present much of the butanol used is produced from petrochemicals but there is a renewable method of producing butanol using microorganisms. Ananaerobic organism which was later named as *Clostridium acetobutylicum* that produced both acetone and butanol when grown on starch. Acetone was also being used as a solvent in the production of aircraft dopes and for the production of textiles and isoprene.

The reasons for using butane are,

1. The process uses renewable substrates.
2. Butanol can replace ethanol as a liquid fuel.
3. The newer strains can grow on waste starch and whey and metabolic engineering is being attempted so that it can be grown on cellulose.
4. The waste can now be treated anaerobically forming biogas.
5. The process may be able to operate at 60°C so that the solvents can be removed as they are formed.
6. Solvent may be recovered during fermentation using reverse osmosis, perstraction, pervaporation, membrane evaporation, liquid–liquid extraction, adsorption and gas stripping. Any process that avoids distillation will be considerably cheaper and able to compete with fossil fuels.

Butyl alcohol is used as a diluent/reactant in the manufacture of urea/formaldehyde and melamine/formaldehyde resins. When used as an industrial intermediate, butyl alcohol is consumed by chemical conversion to the desired product.

Butyl alcohol is used to a lesser extent as a solvent and in formulations to make, dyes, lacquers, resins and varnishes. It is used to make rubber cement, safety glass, rayon, waterproofed cloth, artificial leather, raincoats, motion picture and photographic film. It is used as a softener in the fabrication of cellulose nitrate plastics. It is also used in the manufacture of pharmaceuticals,inmicroscopy, in veterinary medicine, as a dehydrating agent, in perfumes, fruit essences, and as a flavoring agent in foods and beverages.

Physical Data of Butane

Molecular formula	:	$C_4H_{10}O$	
Molar mass	:	74.12 g/mol	
Boiling range at	:	116 –	118 °C
Auto ignition temp	:	345 °C	
Density at 20 °C	:	0.809	– 0.811 g/cm3
Refractive index	:	1.39	– 1.400
Solidification point	:	– 89.3 °C	
Chemical Nature	:	$CH_3CH_2\ CH_2\ CH_2OH$	

IV.   ENVIRONMENTAL EXPOSURE AND FATE

BA is listed as a Toxic Release Inventory (TRI) chemical under EPCRA 313 in the United States. In the U.S., due to the physical chemical properties of BA, workplace exposure during manufacture and use as an industrial intermediate is limited by closed processing. For the same reasons, exposure is not anticipated during the formulation of butyl alcohol into various products as asolvent. BA is shipped in road and rail cars, and by ship. Most environmental releases of n-butyl alcohol would occur through evaporation during its use as a solvent.

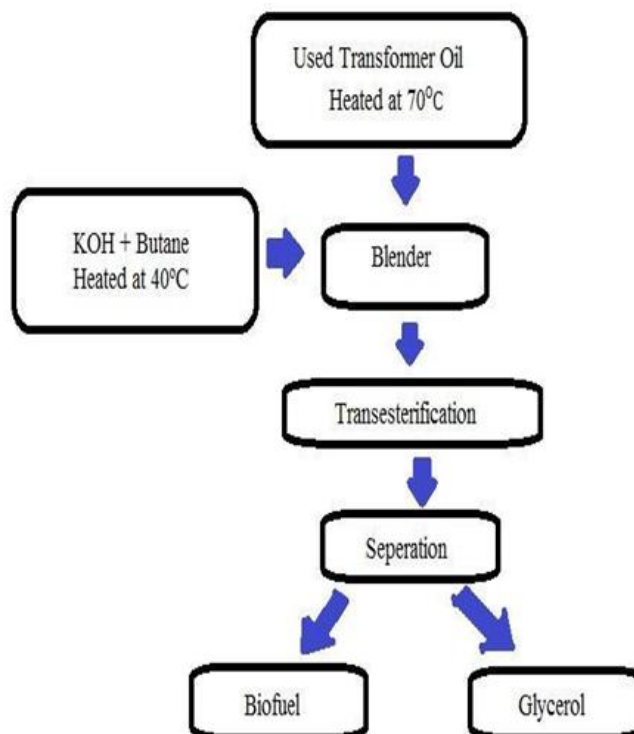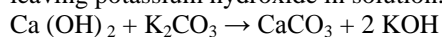## V.   BIODIESEL PROCESSING FROM USED TRANSFORMER OIL

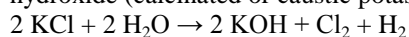**Figure 2:** Biofuel Production

Biodiesel can be produced by Used Transformer oil of esterification Technologies. The oils and fats are filtered and pre-processed to remove water and contaminants. If, free fatty acids are present they can be removed or transformed into biodiesel using special pre-treatment technologies. The pre-treated oils and fats are then mixed with an alcohol Butane and a catalyst KOH. The oil molecules are broken apart and reformed into esters and glycerol, which are then separated from purified. The Used Transformer oil having acid values nearly 1.0 were esterified followed by transesterification. The butyl esters produced by these methods were analyzed to ascertain their suitability as diesel fuels.

VI.   POTASSIUM HYDROXIDE (KOH)

Historically KOH was made by adding potassium carbonate (potash) to a strong solution of calcium hydroxide (slaked lime) leading   to a metathesis. Reaction which caused calcium carbonate to precipitate, leaving potassium hydroxide in solution:

$Ca (OH)_2 + K_2CO_3 \rightarrow CaCO_3 + 2 KOH$

Filtering off the precipitated calcium carbonate and boiling down the solution gives potassium hydroxide (calcinated or caustic potash). The method is analogous to the manufacture of sodium hydroxide:

$2 KCl + 2 H_2O \rightarrow 2 KOH + Cl_2 + H_2$

Hydrogen gas forms as a by-product on the cathode; concurrently, an anodic oxidation of the chloride ion takes place, forming chlorine gas as a byproduct. Separation of the anodic and cathodic spaces in the electrolysis cell is essential for this process.

VII.   TRANESTERIFICATION

Biodiesel is a replacement for diesel and is produced by reacting plant oils and animal fats with an alcohol to form a mixture of fatty acid esters in a reaction known as transesterification. The idea of splitting the triglycerides in fats and oils and using the resulting esters as a fuel has been around for a considerable time. The European quality standards for fatty acid methyl esters, known as biodiesel.

Figure 3: Transesterification Process

Triglycerides are the main component of fats and oils and consist of three long-chain fatty acids linked to a glycerol backbone. When the triglyceride reacts with an alcohol, the three fatty acids are released and combined with the alcohol to form alkyl esters. The reaction can be catalyzed by alkalis, acids, lipase enzymes and inorganic hetero-generous catalysts.

The presence of water and free fatty acids in the oil consumes alkali, and forms soaps which in turn produce emulsions. Emulsions stop the separation of glycerol as the reaction proceeds, which reduce the yield of biodiesel. In extreme cases, the treated oil will set into a gel formed from a combination of glycerol and soap.

An ester yield of less than 5% was obtained in the presence of 0.6% free fatty acids. Therefore, oils containing no water and less than 0.5% free fatty acids are required for successful alkali catalysis. These properties can be obtained with most plant oils, but waste cooking oils, rendered fats and some plant oils contain between 0.7 and 24% water and 0.01–75% free fatty acids. Unfortunately, there are large amounts of unrefined plant oils, waste cooking oils and soap stocks available for biodiesel production.

A two-stage process has been developed where in the first stage acid catalysis is used to esterify the free fatty acids, and the alkali-catalyzed system is used in the second stage to transesterify the triglycerides.

This method is used to convert the Transformer oil in to transformer oil butyl ester. After transesterification, viscosity of BMOBE and AMOBE is reduced by 75-85%. It is also called fatty acid butyl esters, are therefore products of transesterification of Used Transformer Oil and fats with butyl alcohol in the presence of a KOH catalyst. During the reaction, high viscosity oil reacts with butanol in the presence of a catalyst KOH to form an ester by replacing glycerol of triglycerides with a short chain alcohol.[Triglycerides (Transformer oil) + butyl ester + Glycerol].

Experimental Setup & Engine Specification

Figure 4: Experimental Setup of CI engine

Type	:	Water-cooled,constant speed
Speed	:	1500 rpm
Power	:	3.73 KW
Fuel	:	H.S. Diesel
Lub Oil	:	SAE30/SAE 40
LOADING	:	Electrical Loading

Formulae Used
Total Fuel Consumption (TFC)
TFC = (x/t)*specific gravity of fuel*(3600/1000) (Kg/hr)
Where,
X – Quantity of fuel consumed in cc (Burette reading)
t – Time taken for 'X' cc of fuel consumption in sec

Brake Power (BP)
BP = (VI cos□ /AE*1000) (KW)

Where,
V   =   Volts
I   =   Load in Amps
Cos ϕ   =   Power Factor (1)
AE   =   Alternator Efficiency
 (0.80)

Specific Fuel Consumption, (SFC)
SFC = TFC/BP   (Kg/KW.hr)
From the graph drawn between brake power and total fuel consumption. The frictional power is found by the extrapolation method.

Indicated Power
IP = Brake power + Frictional power (KW)

Mechanical Efficiency, (η_{MECH})

η_{MECH} = **(BP/IP)*100 (** % **)**

Brake Thermal Efficiency, (η_{BT})

η_{BT} = **(BP*3600)/ (TFC*CV)*100(** % **)**

VIII.   GLYCEROL UTILIZATION

Glycerol is a by-product of the production of biodiesel by transesterification, and constitutes 10% of the quantities of the oil used. Rather than discard the glycerol formed, some market needs to be found, as any value obtained from glycerol will go some way to reduce the cost of biodiesel. Glycerol can also act as a substrate for anaerobic digestion where it has been shown to stimulate biogas production. It can also be metabolized by some microalgae which can be used as a source of oil or used in anaerobic digestion. Several microbial species can ferment glycerol to produce 1, 3-propanediol. 1, 3-propanediol is used to manufacture polymers (polyesters), cosmetics, foods and lubricants.

Another option is to convert the glycerol by etherification which is butoxy-1, 2-propanediol which is another fuel. Etherification with isobutene in the presence of an acidic ion exchange resin produces butoxy-1, 2-propanediol which has a high octane number (122–128). Thus, this can be an alternative to methyl-tert-butyl ether (MTBE) which is used as an oxygenate. Glycerol has been blended with petrol using a third liquid, ethanol or propanol, to make the two miscible. Finally, glycerol can be used as a substrate for the microbial production of plastics poly (3-hydroxybutyrate) PHB and poly (hydroxyalkanoates) PHA.

IX.   RESULTS AND DISCUSSION

The fuel properties of Used Transformer oil and their blends are shown in figure. The properties of biodiesel and their blends are compared with those of ASTM biodiesel standards. Most of the fuel properties of Used Transformer oil and their blends are comparable to those of diesel. The present results obtained show that the transesterification process improved the fuel properties of the oil with respect to density, calorific value, viscosity, flash point, and fire point. The comparison of these properties with diesel shows that the butyl esters of Used Transformer oil have relatively closer fuel property values to that of diesel. Hence, no hardware modifications are required for handling these fuels (biodiesel and their blends) in the existing engine. The calorific values of all the biodiesel and their blends are lower than that of diesel because of their oxygen content. The presence of oxygen in the biodiesel helps for complete combustion of fuel in the engine.

The flash point of all the biodiesel and their blends is lowered by transesterification, but it is nearly to that of diesel. Addition of a small quantity of biodiesel with diesel increases the flash point of diesel. Hence, it is safer to store biodiesel–diesel blends as compared to diesel alone. It is observed that the typical combustion characteristics of Used Transformer oil biodiesel are in the close range of the requirement of the engine.

Calculation of Properties

EMPTY A in (g)	SAMPLE B in (g)	WATER C in (g)
23.72	66.95	75.68

Table 1: Observation for weight

A - Weight Empty Flask,
B - Weight of empty + sample, C - Weight of empty + Standard
S - Specific gravity of oil (s) = density of sample fluid / Density of stand fluid
D -Density of stand fluid (ρ) = mass/volume
Density of stand fluid (ρ) = mass/volume
Density of sample fluid (ρ) = mass/volume

Specific gravity of oil (s) = mass of sample / mass stand Weight of sample D = A-B = 66.95 – 23.72 = 43.23 g
Weight of standard E = A - C = 75.68 – 23.72 = 51.96 g Specific gravity of oil (s) = 43.23 / 51.96 = 0.832
Density of sample fluid = s*ρ = 1000*0.832 = 832 kg/m^3

Properties of Used Transformer Oil
Kinematic viscosity μ
AR – B/R   A&B is Redwood constant (A=0.26; B=171.5)
= (0.26*54) – (171.5/54) = **10.86 centistokes**
Density ρ
ρ = Tr/ To* ρr   = 32/40*832.26 =**665.81 kg/m^3**
Absolute viscosity ϒ
ϒ = Kinematic viscosity μ *Density ρ = 10.86*665.81
= **7230.6966 centipoises**

Sl.no.	Temp ^{o}C	Used Transformer Oil		
		μ in cst	ρ in kg/m^3	ϒ in c poise
1	32	11.05	833.26	9196.47
2	40	10.85	665.81	7224.04
3	50	09.23	532.65	4916.36
4	60	07.00	443.87	3107.09

Table 2: Properties of Used Transformer Oil

SI.NO	PROPERTIES	D100	B10	B20	B30	B100
1	Kinematic Viscosity 40°C	4.20	4.9	4.6	4.6	5.3
2	Density kg/m^3	824	818.8	819.4	820.2	828.1
3	Flash point	48	46	47	48	50
4	Fire point	55	52	53	54	58
5	Calorific value kj/kg	44000	43930	43860	43790	43300

Table 3: Properties of diesel & bio diesel

The properties of Used Transformer oil are viscosity and density of oil at 40 degree centigrade pre and post processes are shown. The viscosity and density of oil are varying (13.45 and 700.792) pre and post process.

Model Calculation
Total Fuel Consumption (TFC)
TFC = (x/t)*specific gravity of fuel*(3600/1000) (kg/hr) TFC = 10/45 × 0.818 × 3600/1000 = 0.655 Kg/hr.

Brake Power (BP)
BP = (VI cosϕ)/ (AE*1000)
BP = (230 3 1) / (0.8 1000)
= 0.862 KW

Specific Fuel Consumption, (SFC)
SFC = TFC/BP SFC = 0.655 / 0.862
 = 0.760 Kg/KW.hrf

Frictional Power (FP)
From the graph drawn between brake power and total fuel consumption the frictional power is found by the extrapolation method.
FP = 2.1, 2.5, 3.5 KW

Indicated Power (IP)
IP = Brake power + Frictional power
IP = 0.862 + 2.1 = 2.962 KW

Mechanical Efficiency, (η_{MECH})

η_{MECH} = (BP/IP)*100

η_{MECH} = (0.862/2.962)*100 = 29.10

Brake Thermal Efficiency, (η BT)

η_{BT} = (BP*3600)/ (TFC/CV)*100

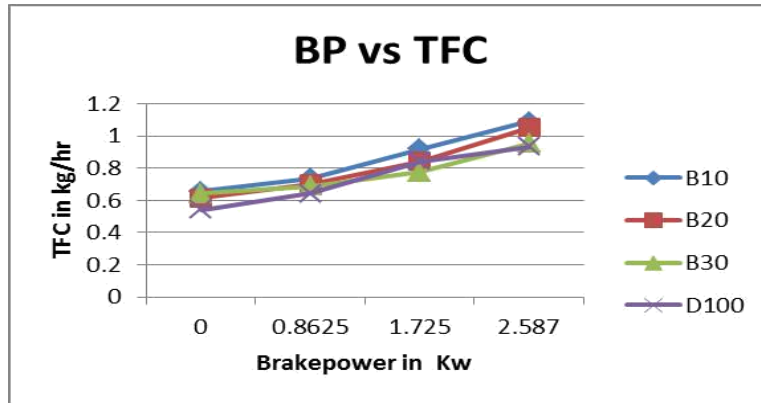η_{BT} = (0.862×3600)/ (0.642×44000)*100=10.98

BP vs TFC

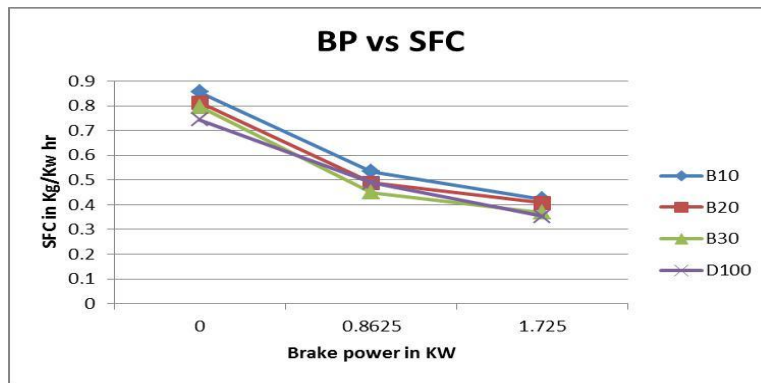*Figure 5:* Brake Power Vs Total Fuel Consumption

BP vs SFC

Figure 6: Brake Power Vs Specific Fuel Consumption

The variations of the total fuel consumption and specific fuel consumption are varying. These values are comparing the values standard diesel. B20, B30 are closer value of diesel and B10 is higher than the others.
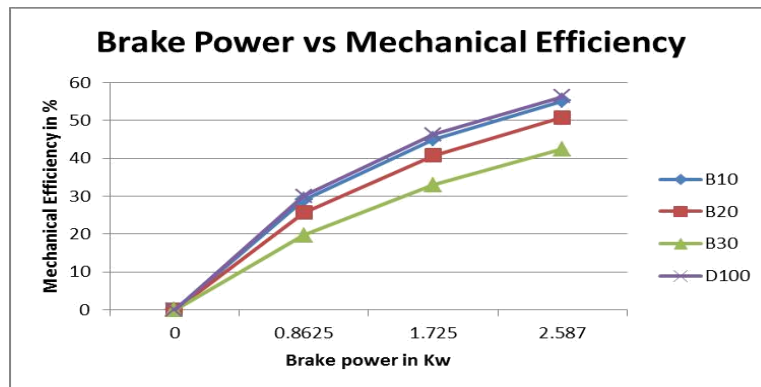
Brake Power vs Mechanical Efficiency

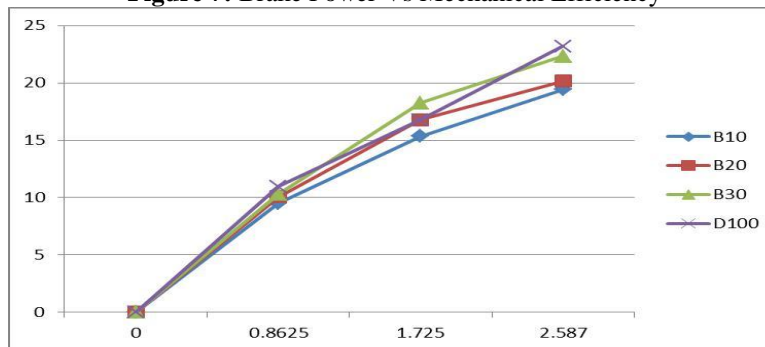*Figure 7:* Brake Power Vs Mechanical Efficiency

Figure 8: Brake Power Vs Brake Thermal Efficiency

Mechanical & brake thermal efficiency of the process are shown in figure mechanical efficiency values are comparing the values of standard diesel. It is closer the maximum efficiency of the blends B10, B20, B30 is up line bp of 2.587. Brake thermal efficiency of the blends is more equal in B10, B20, and the variation of blends in B30. In these results are compared B30 having a most value of diesel and B10, B20 blends.

X.   CONCLUSION

The increased demand for renewable energy sources and developing countries like India's need to secure its energy supply has spurred interest in development of bio fuel production whereas the exhaust emission of the biodiesel is deteriorating the environment also. The aim of the research is analyze the performance characteristics of Used Transformer oil and its blends. Used Transformer oil butyl ester is derived through transesterification process. A single cylinder, water cooled, four stroke diesel engine was used for this work. The following fuels were tested such as diesel, B10, B20, B30 and observe the performance characteristics. Observe results of diesel, Used Transformer oil butyl esters and their blends with diesel by volume were compared. A detailed experimental study was conducted to evaluate and analyze the performance and combustion of Used Transformer oil biodiesel and diesel blends in a fully instrumented single cylinder multi fuel engine.

The conclusions are summarized as follow;

As load applied to the engine increases brake thermal efficiency of the fuel blends also increases. The maximum brake thermal efficiency is 22.32% for B30 at 75% load, which is 0.88% lesser than standard diesel. As the load increases specific fuel consumption of the engine decreases gradually. At 75% load conditions the specific fuel consumption for the blends B20 and B30 is 0.407 kg/ kWh, 0.368 kg/ kWh respectively whereas for standard diesel it is 0.353 kg/ kWh.

As load applied increases exhaust gas temperature get decreased. Lower calorific value of the blended fuel than standard diesel and lower temperature at the end of compression leads to reduction in exhaust gas temperature. As load increases mechanical efficiency of the blended fuel shows steady increase. At 75% load condition the maximum mechanical efficiency obtained from blend B10 and B20 is 55.19% and 50.86 % respectively, whereas for standard Diesel mechanical efficiency is 56.40%.

Comparing these for mechanical efficiency B10 is nearer to Diesel and for brake thermal efficiency B30 is in optimum range. So that B30 is used as better.

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