

# EXPERIMENTAL INVESTIGATION ON PERFORMANCE OF SUGARCANE STRAW PYROLYSED BIO- OIL IN DIESEL ENGINE

Dr.J.Kuberan<sup>1</sup>, S.Dany vijaya balan<sup>2</sup>, D.Anbarasan<sup>3</sup>, R.Dhanush kumar<sup>4</sup>,  
G.Arimarthana pandiyan<sup>5</sup>

<sup>1</sup> Professor, Department of mechanical, S.K.P Engineering College, Tiruvannamalai, Tamilnadu, India.  
<sup>2,3,4&5</sup> students, Department of mechanical, S.K.P Engineering College, Tiruvannamalai, Tamilnadu, India.

\*\*\*

**Abstract** - Under the renewable energy context, sugarcane biomass pyrolysis has been growing as a convenient route to produce bio-oil, which can be set into the chemical industry and refineries as building blocks or combustion fuel. In this work sugarcane straw was submitted to direct pyrolysis at 650°C, in presence of nitrogen. Sugarcane straw was also pyrolysed as a model for comparison, in order to determine the viability of processing different sources of raw biomass. The physicochemical characterization of the biomass precursors as well as of the bio-oils was also carried out, which points both biomass feedstocks as suitable for bio-oil production in terms of viscosity, surface tension, density and acidity. The bio-oil obtained from sugarcane straw presented higher carbon and hydrogen content as well as lower oxygen content. On the other hand, the metal content is higher in the bio-oil obtained from sugarcane straw, in special the iron and potassium contents in the bio-oil from sugarcane straw. Aliphatic and aromatic compounds as well as carbohydrates scaffolds were identified as the main components of the bio-oil. GC-MS analyses showed aromatic products from lignin fragmentation and free sugars and sugar derivatives.

**Key Words:** diesel engine, sugar cane straw (SCS), FTIR, Brake power.

## INTRODUCTION

Sugarcane is a first-rate source of biomass in Brazil, where the sugar and alcohol industries are well established and have a high capacity of production. Energy supply has vital importance for economic growth, social development, human welfare and improving the quality of life. With increasing trend of modernization and industrialization, the World energy demand is also growing at faster rate. Since their exploration, the fossil fuels continued as the major conventional energy source. In the recent years, serious efforts have been made by several researchers to use different sources of energy as fuel in existing diesel engines. Bio-fuels made from agricultural products (oxygenated by nature) reduce the world's dependence on oil imports, support local agricultural industries, and enhance farming incomes. Moreover, they offer benefits in terms of reduced smokiness or particulate matter from diesel engines. Bio-fuel is the most used renewable fuel in compression ignition (CI) engines. The advantages of bio\_fuel as diesel fuel are the minimal

sulphur and aromatic content, and the higher flashpoint, lubricity and cetane number. The majority of the literature agrees that particulate matter (PM), un burnt total hydrocarbons (THC) and carbon monoxide (CO) emissions from biodiesel are lower than from conventional diesel fuel. Increasing demand of fuel day by day its consumption and hazards cause serious intensive attention is required for this problem. Also an Improvement of fuel properties is essential for suppression of pollutant and optimization of engine performance.

## SUGARCANE STRAW AS BIO - FUEL

### Determination of the Bio-Oil Physicochemical Properties

The preparation of the bio-oil samples for characterization was carried out as follow: crude bio-oil was filtered to remove solid residues, and then solubilized in acetone. The insoluble material was filtered out under reduced pressure to give the polar fraction. Subsequently, the residue was suspended in toluene to extract the non-polar components; the solid residue was filtered out again under reduced pressure. The polar and non-polar fractions were combined and the solvent was removed in a rotary evaporator. The water content was determined by Karl Fisher titration using a 841 Methrom equipment, applying the methodology used to determine water in petrochemicals (ASTM D6304). The preparation of the bio-oil samples for characterization was carried out as follow: crude bio-oil was filtered to remove solid residues, and then solubilized in acetone. The insoluble material was filtered out under reduced pressure to give the polar fraction. Subsequently, the residue was suspended in toluene to extract the non-polar components, the solid residue was filtered out again un-der reduced pressure. The water content was determined by Karl Fisher titration using a 841 Methrom equipment, applying the methodology used to determine water in petrochemicals (ASTM D6304).

### Preparation and Characterization of the Sugarcane Straw Samples

The sugarcane samples used in this work are from a special variety rich in fiber, developed for energetic purpose and provided by the company Canaveral's. The

sugarcane was dried and milled. A random sampling of the sugar- cane was carried out, and two feedstock’s for the pyrolysis studies were selected: sugarcane *in natura* (whole sugarcane), producing the bio-oil named BIOSC, and sugarcane straw (green and dry leaves), giving the bio-oil named BIOS. Granulometric analyses (ASTM E828) were carried out using a set of W.S. TYLER Stainless Steel Test Sieves. The humidity of the fresh sugarcane samples was determined for the sugarcane *in natura* and straw. Analyses to determine the fractions in weight for humidity, volatiles, ashes and fixed carbon on the dry samples were carried out. The humidity was determined according to the regulation ASTM E871, the samples were oven dried at 104°C - 110°C under air circulation until no mass variation was observed. The volatile fraction was determined by heating the samples in an open crucible at 850°C for six minutes, according to the regulations ASTM E872 and ASTM E897.

The ashes were quantified by heating the samples at 750°C for two hours, according to the regulation ASTM D1102. The calorific power was determined by the calorimetric bomb technique (ASTM D2015), where the heat released by the combustion of the biomass with oxygen (initiated by an electric ignition) was measured. The water-bath temperature was measured over time, and from the plots of heating and cooling, the energy released during the combustion process was determined. The experiment was conducted under adiabatic conditions, which allowed the determination of the superior calorific power at constant volume, which can be converted to inferior calorific power by analytic calculations.

**Table1:** Physiochemical properties of sugarcane straw oil

Properties	Sugarcane Straw	Sugarcane
Water content %	5.3	5.5
Viscosity (Pa-s)	0.5	0.4
Acidity(mgKOH/g)	44.9	50.6
Density (g/mL)	1.22	1.22
Surface Tension (mN/m)	26.1	23.8
C (wt/wt%)	59.54	61.23
H (wt/wt%)	6.66	7.13
N (wt/wt%)	0.75	0.69
O (wt/wt%)	33.05	30.95

**WORKING METHOD**

**Extraction of Bio-oil**

The reactor is placed on the floor with temperature indicator. The outlet of the reactor is directly connected to the condenser using a stainless steel tube which can withstand high temperature. Another one inlet is connected to the reactor from the nitrogen cylinder. The

condenser is firmly connected with help of alloy gasket. Counter flow condenser here selected. The flow of water is directed against the direction of pyrolysis gases. The condensate drips into the gas liquid separator. The non condensable gases rise to the neck of other tube and pass through the exhaust tube to gas burner. To measure the temperature outside the reactor the thermocouple is connected to the digital temperature indicator. Using setup button set the temperature level. The set up reach that temperature automatically off the supply. The temperature reduces the temperature of automatically power on. In this pyrolysis setup, chipped material are filled the reactor initially, and then closed the reactor with the help of bolt. Here gasket was used to prevent leakage. Then supply nitrogen gas from the cylinder to reactor the time period of 3-4 minutes supplied, after that it will be closed. Switch on the supply, initially set the temperature up to 600°C in the temperature controller. Condenser water is supplied from inlet to outlet. Gases are collected in the balloon. Finally note the time taken to reach the temperature up to 600°C. Cooling time of the reactor is 16-18 hours. Finally we have collected the pyrolysis oil, char and gases.



**Fig1;** Sugarcane Straw Bio - Char

**METHODOLOGY**

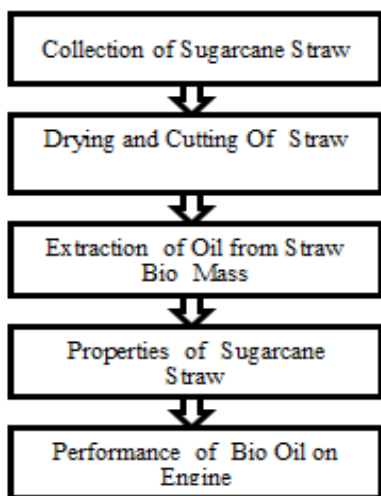


Fig 2 : Methodology of bio-oil preparation



Fig 3: Sugarcane Straw Bio – oil blended with Diesel

Table 2: properties of bio-oil

PROPERTY	SUGARCANE STRAW
Density(g/mL)	1.19
Calorific value (KJ/kg)	43850
Flash point °C	74
Fire Point °C	105
Viscosity(cP)	0.623
Cetane Number	36.9
Pour Point	4°C

**ANALYSIS OF SUGARCANE STRAW BIO-OIL**

**FTIR ANALYSIS**

**(Fourier Transform Infrared Spectrographic)**

FT-IR consists of a moving mirror, fixed mirror, beam splitter, IR radiation source and detector. Instead of using monochromator, Michelson interferometer is used for analysis of IR radiation after passing through sample. Radiation from IR source is collimated by mirror and the resultant beam is divided at beam splitter. Half of beam passes through mirror (fixed) and half refracted to moving mirror. After reflection by these two mirrors, two beams recombined at beam splitter and passes through cell and after that radiation is focused to detector. Movable mirror, moves back and forth at a distance of 21 cm. If round trip distance between beam splitter and fixed mirror is identical to that of beam splitter and movable mirror, then only the radiation from two mirrors arise in phase at beam splitter, cell and to detector. As the movable mirror changes its position, the distance between mirror and beam splitter no longer identical and radiation of fixed wavelength will arrive in phase only to cell and detector. FTIR is an analytic technique used to identify organic, polymeric, and in some cases, inorganic materials. It is observed from the graph that a initial OH content is high and carbon content is less. At last carbon content is high It is inferred that an initial combustion is not uniform and good and after that the combustion is good and it also infers that the OH lead to after burning and hence NOx may be low at exhaust.

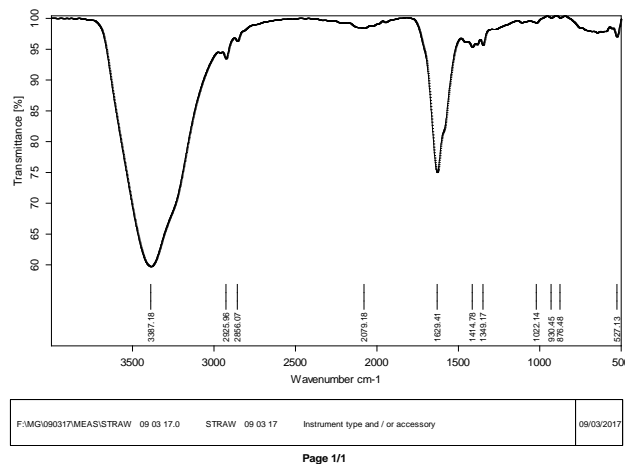


Fig 4: Infrared Spectrographic

**GAS CHROMATOGRAPHY-MASS SPECTROMETRY (GC-MS)**

It is a method that combines the features of gas-liquid chromatography and mass spectrometry to identify different substances within a test sample. It is primarily used for: Identification or characterization of analyses within the sample - Increased analytical sensitivity in the

absence of a compound or element specific detector such as ECD, NPD, FPD or chemiluminescence. It is done in two ways –1.Screening of all the elements present in the sample2. Focus on particular element. We found all the chemical compounds present in the sugarcane straw bio oil

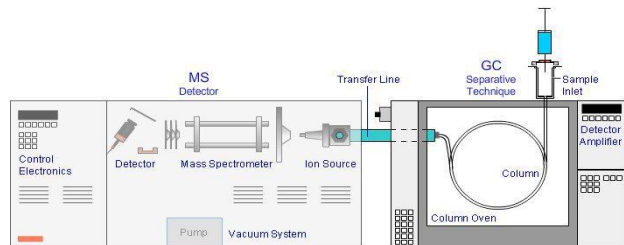


Fig 5: GC-MS schematic diagram

CHARACTERIZATION OF BIO FUEL IN GC/MS TEST

RT	Scan #	Probabiliy	Compound Name	SI	RSI	Cas #
5.12	14.000000	7.44	Cucurbitacin B, dihydro	263	324	13201-14-4
5.12	14.000000	4.96	Ethanethioamide, Nphenyl	251	428	637-53-6
5.12	14.000000	3.60	1Methoxy1,4cyclohexadiene	242	578	2886-59-1
5.12	14.000000	3.60	3,4Dimethoxyphenethyl Alcohol	242	376	7417-21-2
5.12	14.000000	3.60	Cyclononasiloxane, octadecamethyl	242	356	556-71-8
5.32	36.000000	69.1	Phenol, 2,6dimethoxy	764	801	91-10-1
5.32	36.000000	20.32	Phenol, 2,6dimethoxy, Acetate	727	775	944-99-0
5.32	36.000000	7.42	Phenol, 3,4dimethoxy	714	775	2033-89-8
5.32	36.000000	69.10	Phenol, 2,6dimethoxy	712	747	91-10-1
5.32	36.000000	20.32	Phenol, 2,6dimethoxy, Acetate	705	754	944-10-1
5.41	46.000000	81.48	Cholestan3one, oxime, (5à)	458	744	6626-72-8
5.41	46.000000	6.96	Cholestan3one, oxime	368	406	2735-21-9
5.41	46.000000	6.15	6Ketocholestanol	365	472	2731-23-9
5.41	46.000000	1.45	Cholestan3one, oxime	326	350	1175-06-0
5.41	46.000000	6.95	Phenol, 2,6dimethoxy, acetate	314	341	2735-21-9

RT	Scan #	Probability	Compound Name	SI	RSI	Cas #
10.45	572.000000	42.00	Cycloheptasiloxane, tetradecamethyl	438	549	107-50-6
10.45	572.000000	42.00	Cycloheptasiloxane, tetradecamethyl	419	565	107-50-6

10.45	572.000000	15.33	Heptasiloxane, hexadecamethyl	415	471	541-01-5
10.45	572.000000	10.21	Isobenzofuranone, 6(dimethylamino)	403	418	1552-42-7
10.45	572.000000	7.21	Cyclotetrasiloxane, octamethyl	393	418	556-67-2
30.97	2767.000000	28.68	Phenol, 2,6dimethoxy, Acetate	347	642	107-50-6
30.97	2767.000000	23.11	Cholestan3one, oxime, (5à)	336	618	107-50-6
30.97	2767.000000	20.42	Cholestan3one, oxime	325	587	541-01-5
30.97	2767.000000	28.68	6Ketocholestanol	319	569	1552-42-7
30.97	2767.000000	28.68	Cholestan3one, oxime	317	557	556-67-2

Table 3:Characterization of bio-fuel

INFERENCE FROM GC/MS TEST

- Since the alcohol content is high it help the oil for better combustion
- Phenol has high auto ignition temperature and high boiling point it helps the oil ignition capacity and it increases the spray property of the oil
- Pyrazine is an alkene compound which has low boiling point and low flash point it affects the tendency of spray property of the oil and it ignites first during combustion
- Benzene compounds are the aromatic compounds which has the flash point
- Oil also contains some acids but these acids are less toxic and it will never injures the humans and the percentage of acid is less when we compared with other compounds present in the fuel so it also consider as a good property of the fuel.

ULTIMATE ANALYSIS

Ultimate analysis is used to find out the contents present in the sugarcane straw bio oil.

- 1)It is used to find out the percentage of such elements present in our sugarcane straw bio fuel.
- 2)It is help full to make further study and to create a proof for the calorific value
- 3)It helps us to interpret how the combustion may takes place in the engine and how the emissions may occur.

**COMPONENTS PRESENT IN BIO-FUEL OF THE ULTIMATE ANALYSIS**

**Table 5:**Components on bio-fuel

S.NO	COMPONENT	TEST METHOD	%
1	HYDROGEN	ASTMD5291-02	32.34
2	OXYGEN	ASTMD5373	30.02
3	CARBON	ASTMD5291-02	35.54
4	NITROGEN	ASTMD5291-02	2.10
5	SULPHUR	ASTMD1552-95	BLQ(LOQ:0.01)



**Fig5:** Performance testing Diesel Engine

**BLQ: Below Limit of Quantification**

**LOQ: Limit of Quantification**

**EXPERIMENTAL ANALYSIS**

**ENGINE PERFORMANCE AND EMISSIONS**

A single cylinder, four strokes, naturally aspirated, air cooled diesel engine of 4.4kW power output is used for this experiment. This engine is used to conduct the entire analysis of the project. The cooling method is providing water jacket around the heat transfer surface, and continuous flow of air is there. This arrangement ensures that there is no temperature raise inside the engine in all varying loads.

**SPECIFICATIONS**

**Single cylinder, vertical, water cooled, 4-stroke diesel engine.**

Make	KIRLOSKAR
Bore	87.5mm
Stroke	110 mm
Cubic capacity	1323 cc
Speed	1500 rpm
Power	5HP/3.7 kW
Compressoin ratio	16 : 1
Fuel	High speed diesel oil
Calorific Value	44000 KJ/kg
Specific gravity of oil	0.8275
Type of loading	Mechanical Loading

**Table 6:**Specifications of diesel engine

The Kirloskar engine is one of the widely used engines in agriculture pump sets, farm machinery and medium scale commercial purposes. The setup consists of a single cylinder ,four strokes, naturally aspirated, water cooled Diesel engine connected to eddy current dynamometer. This eddy current dynamometer is used for loading the engine. The engine is interfaced with Engine Soft Software for the measurement of combustion parameters. It is provided with necessary instruments for Combustion chamber pressure and crank-angle measurements. For the measurement of cylinder pressure, a pressure transducer is fitted on the engine cylinder head and a crank angle encoder is used for the measurement of crank angle and TDC position. The pressure and crank angle signals are fed to a data acquisition card fitted with Pentium 4PC. The engine speed is sensed and indicated by an inductive pickup sensor in conjunction with a digital rpm indicator, this is a part of eddy current dynamometer. The liquid fuel flow rate is measured on the volumetric basis by a transmitter. Provision is also made for interfacing airflow, and load measurement. The airflow is measured using an orifice meter and the exhaust gas temperatures are recorded with thermocouples. The set up has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring transmitter. Rotometers are provided for cooling water and calorimeter water flow measurement. The various components of experimental setup are shown in figure.

**EXPERIMENTAL PROCEDURE**

- 1)Calculate maximum load to be applied for a selected engine.
- 2)Check the fuel supply, water circulation in the water system and lubricating oil in the oil sump.
- 3)Ensure no load condition. The engine is started and allowed to run on idle speed for a few minutes .Gradually

the engine is loaded by mechanical brake method and the speed is maintained constant.

4) Make sure the cooling water is supplied to the brake drum. Load the engine in steps of 0%, 25%, 50%, 75% & 100% of maximum load to be applied.

5) Note the corresponding readings of spring balance, fuel consumption, manometer reading.

6) After taking the readings, unload the engine, allow it to run for few minutes and then stop the engine.

In each set of test readings, fuel consumption, cylinder pressures at different crank angles, exhaust gas temperatures and concentrations of CO, CO<sub>2</sub>, HC, NO<sub>x</sub> emissions are taken at nine different loads.

**PERFORMANCE GRAPHS:**

**BRAKE POWER VS SPECIFIC FUEL CONSUMPTION**

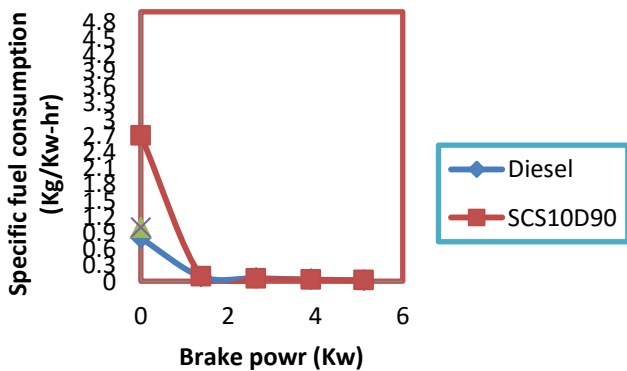


CHART 1:BP VS SFC

The performance of the diesel engine of diesel and additive bio-fuel, the specific fuel consumption almost near to the diesel.

**BRAKE POWER VS BRAKE THERMAL EFFICIENCY**

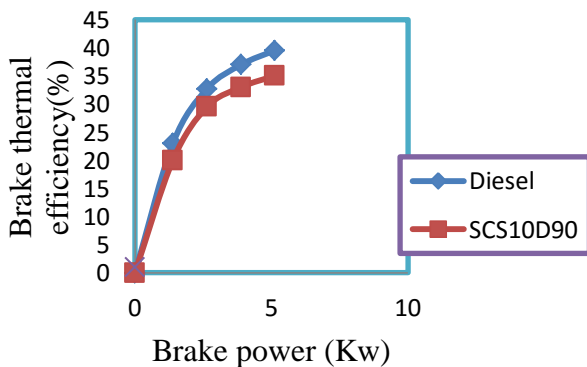


CHART 2: BP VS BTE

The performance of the diesel engine of diesel and additive bio- fuel, the brake thermal efficiency almost near to the diesel.

**EMISSION GRAPHS:**

**BRAKE POWER VS CARBON MONOXIDE**

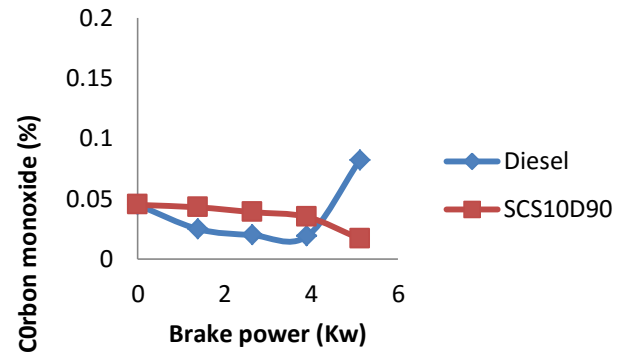


CHART 3:BP VS CO

The carbon monoxide emission results, the additive bio fuel is less than the diesel.

**BRAKE POWER VS CARBONDIOXIDE:**

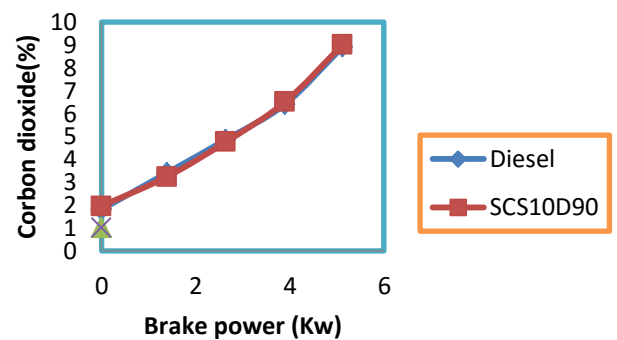


CHART 4: BP VS CO<sub>2</sub>

The carbondioxide emission results, the additive bio fuel is less than the diesel.

**BRAKE POWER VS HYDROCARBON:**

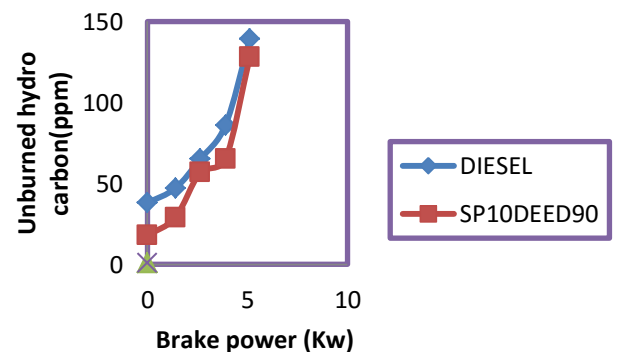


CHART 5:BP VS HC

The hydrocarbon emission results, the additive bio fuel is less than the diesel.

#### BRAKE POWER VS NITROGEN OXIDE:

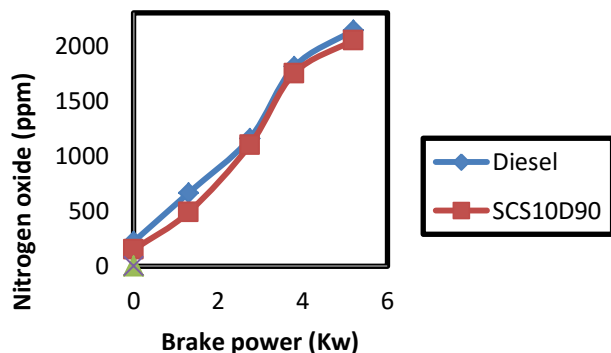


CHART 6: BP VS N<sub>2</sub>O

The nitrogen oxide emission results, the additive bio fuel is less than the diesel.

#### CONCLUSION

The efficiency, combustion and emission characteristics of biodiesel and emulsified fuel (diesel-bio fuel) were investigated on single cylinder four stroke diesel engines.

The brake thermal efficiency of the diesel is 39.5% and emulsified bio fuel is 37% .hence the brake thermal efficiency of emulsified bio-fuel is almost nearer to the diesel.

The specific fuel consumptions of diesel is 0.025 kg/kw-hr and emulsified bio fuel is 0.018 kg/kw-hr .hence the specific fuel consumption of the emulsified bio-fuel is closer to the diesel.

The emission of the carbon monoxide of diesel is 0.082 ppm and emulsified bio-fuel is 0.017 ppm.Hence the emission of carbon monoxide in emulsified bio-fuel is lesser than the diesel.

The emission of bio-fuel emissions of carbon monoxide, carbon dioxide, hydro carbon ,nitrogen oxide is less than the diesel. because of the bio-fuel which makes the combustion better.

#### REFERENCES

1. M. Oppenheimer, "Global Warming and the Stability of the West Antarctic Ice Sheet," *Nature*, Vol. 393, No. 6683, 1998, pp. 325-332. doi:10.1038/30661

2. C. Okkerse and H. van Bekkum, "From Fossil to Green," *Green Chemistry*, Vol. 1, No. 2, 1999, pp. 107-114. doi:10.1039/a809539f
3. G. W. Huber, S. Iborra and A. Corma, "Synthesis of Transportation Fuels from Biomass: Chemistry, Catalysts, and Engineering," *Chemical Reviews*, Vol. 106, No. 9, 2006, pp. 4044-4098. doi:10.1021/cr068360d
4. Corma, S. Iborra and A. Velty, "Chemical Routes for the Transformation of Biomass into Chemicals," *Chemical Reviews*, Vol. 107, No. 6, 2007, pp. 2411-2502. doi:10.1021/cr050989d
5. J. Zakzeski, P. C. A. Bruijninx, A. L. Jongerius and B. M. Weckhuysen, "The Catalytic Valorization of Lignin for the Production of Renewable Chemicals," *Chemical Reviews*, Vol. 110, No. 6, 2010, pp. 3552-3599.
6. D. Mohan, C. U. Pittman Jr. and P. H. Steele, "Pyrolysis of Wood/Biomass for Bio-Oil: A Critical Review," *Energy & Fuels*, Vol. 20, No. 3, 2006, pp. 848-889. doi:10.1021/ef0502397
7. Pandey, C. R. Soccol, P. Nigam and V. T. Soccol, "Biotechnological Potential of Agro-Industrial Residues. I: Sugarcane Bagasse," *Bioresource Technology*, Vol. 74, No. 1, 2000, pp. 69-80. doi:10.1016/S0960-8524(99)00142-X
8. J. Goldemberg, S. T. Coelho and P. Guardabassi, "The Sustainability of Ethanol Production from Sugarcane," *Energy Policy*, Vol. 36, No. 6, 2008, pp. 2086-2097. doi:10.1016/j.enpol.2008.02.028
9. J. A. Cunha, M. M. Pereira, L. M. M. Valente, P. R. de la Piscina, N. Homs and M. R. L. Santos, "Waste Biomass to Liquids: Low Temperature Conversion of Sugarcane Bagasse to Bio-Oil. The Effect of Combined Hydrolysis Treatments," *Biomass and Bioenergy*, Vol. 35, No 5, 2011, pp. 2106-2116. doi:10.1016/j.biombioe.2011.02.019
10. P. T. Williams and N. Nugranad, "Comparison of Products from the Pyrolysis and Catalytic Pyrolysis of Rice Husks," *Energy*, Vol. 25, No. 6, 2000, pp. 493-513. doi:10.1016/S0360-5442(00)00009-8
11. S. Zhang, Y. Yan, T. Li and Z. Ren, "Upgrading of Liquid Fuel from the Pyrolysis of Biomass," *Bioresource Technology*, Vol. 96, No. 5, 2005, pp. 545-550. doi:10.1016/j.biortech.2004.06.015
12. Oasmaa and S. Czernik, "Fuel Oil Quality of Biomass Pyrolysis Oils—State of the Art for the End User," *Energy & Fuels*, Vol. 13, No. 4, 1999, pp. 914-921. doi:10.1021/ef980272b

13. S. Czernik and A. V. Bridgwater, "Overview of Applications of Biomass Fast Pyrolysis Oil," *Energy & Fuels*, Vol. 18, No. 2, 2004, pp. 590-598. doi:10.1021/ef034067u
14. M. García-Pérez, A. Chaala and C. Roy, "Vacuum Pyrolysis of Sugarcane Bagasse," *Journal of Analytical and Applied Pyrolysis*, Vol. 65, No. 2, 2002, pp. 111-136. doi:10.1016/S0165-2370(01)00184-X
15. M. C. Samolada, W. Baldauf and I. A. Vasalos, "Production of a Bio-Gasoline by Upgrading Biomass Flash Pyrolysis Liquids via Hydrogen Processing and Catalytic Cracking," *Fuel*, Vol. 77, No. 14, 1998, pp. 1667-1675.