To evaluate the performance and emission characteristics of Hybrid (dual) biodiesel diesel blend on single cylinder diesel engine

[1]K G Mer, [2]P. P. Rathod, [3]A. S. Sorthiya
[1]PG Student, [2] Professor, [3]Associate professor
Department of Mechanical Engineering,
Government Engineering College, Bhuj (Gujarat), India

***Abstract* - Alarming situation of world fossil fuel and environment degradation has been stimulating the researchers and engineers to find new sources of fuel, which must be renewable, economically available and environment friendly. In this regard biodiesel has one of the most substantial alternative renewable fuels for diesel engine. Biodiesel has made from different feedstock depending on the availability. This study is related to effect of fatty acid composition on combustion characteristics, properties and emission of biodiesel. The main advantage of biodiesel is that it potentially reduces the key pollutants like CO, HC, PM and smoke opacity but on other hand it has increased NO_x and BSFC. The results of the study show that biodiesel with high saturate fatty acid has shorter delay period, low NO_x, high CN, high CV and higher oxidation stability, which has favourable aspect but on other hand it has high viscosity and high cold flow properties which is unfavourable. But biodiesel with high unsaturated fatty acid has low viscosity, low cold flow properties, longer delay, high NO_x, low CN, low CV and lower oxidation stability. In this research to take advantage from both type fatty acids simultaneously combine the PME (saturated fatty acid) and KME (unsaturated fatty acid) to form hybrid biodiesel and blends of hybrid biodiesel in diesel, which is somewhat superior in case of physio-chemical properties, performance and emission.**

***Keyword* - hybrid biodiesel; fatty acid; properties; performance; emission**

1. INTRODUCTION

The socio-economic growth of the society, the energy requirement has increased globally this leads to diminishing resources of petroleum day by day, as well as increasingly stringent regulations, pose a challenge to science and technology. Diesel engines are being extensively utilized in transportation, industries and agriculture worldwide due to their high economic advantage and durability. They have appealing features including robustness, high torque, and lower fuel consumption under certain conditions. To provide an effective way to fight against the problem of petroleum base fuel crisis and the influence on environment stimulating the researchers and engineers to find new renewable fuel that meet the stringent emission norms.

The vegetable oil has one of the most preferable alternative fuels that replace the conventional petroleum diesel fuel. The development of vegetable is not new, Rudolf diesel tested peanut oil as fuel for engine for the first time in august 10, 1893. Also during World War II, vegetable oils were used as fuel in emergency situations. In principle, any vegetable or seed oil which essentially comprises hydrophobic substances primarily of the fatty esters of glycerol, so- called triglycerides of long chain saturated and unsaturated fatty acid can be used in diesel engines. This fuel is biodegradable, non-toxic and has performance and emission profile comparable to diesel. It has been found that the neat vegetable oils can be used as diesel fuels in conventional diesel engines, but this leads to a number of problems. The injection, atomization and combustion characteristics of vegetable oils in diesel engines are significantly different from those of diesel. To reduce these problems and to decrease viscosity, different methods have been adopted; namely, blending, micro emulsion, transesterification, preheating and pyrolysis (thermal cracking). From these, transesterification is the most common method. Transesterification is primarily used to convert vegetable oil in to fatty acid alkyl esters (FAAE), which is known as biodiesel. Biodiesel conform the ASTM (American Society for Testing and Materials) specification for use in diesel engine.

1.1 Feed stocks for Biodiesel production

In general, biodiesel feedstock can be divided into four categories.

1. Edible vegetable oil: Sunflower, Rapeseed, Rice bran, Soybean, Coconut, Corn, Palm, Olive, Pistachia Palestine, Sesame seed, Peanut, Opium Poppy, Safflower oil etc.
2. Non-edible vegetable oil: Jatropha, Karanja or Pongamia, Neem, Jojoba, Cottonseed, Linseed, Mahua, Deccan hemp, Kusum, Orange, Rubber seed, Sea Mango, Algae and Halophytes etc.
3. Waste or recycled oil
4. Animal fats: Tallow, yellow grease, chicken fat and by- products from fish oil etc.

The biodiesel obtain from above feed stokes have different physio- chemical properties, performance and emission. The difference in above parameter is mainly due to the type of fatty acid composition present in their chemical structure.

Abbreviation:

FAME	Fatty acid methyl ester
FA	Fatty acid

PME	Palm methyl ester
KME	Karanja methyl ester
HB	Hybrid biodiesel (50% PME and 50% KME).
HB10	10% HB and 90% diesel
HB20	20% HB and 80% diesel.
HB30	30% HB and 70% diesel.
HB50	50% HB and 50% diesel.
CV	Calorific value
CN	Cetane number
BP	Brake power
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
EGT	Exhaust gas temperature

1.2 Fatty acid composition in biodiesels

Fatty acid composition is an important property for any biodiesel feed stock. The transesterification reaction of row oil produces biodiesel fuel corresponding to the fatty acid profile of its parent oil and hence it determines the properties produce biodiesel. The fatty acid composition and distribution of some oils are generally aliphatic compounds with a carboxyl group at the end of a straight chain. The carbon chain lengths of fatty acid of different biodiesels are from C8 to C22. The most common fatty acids with their chemical structure as shown in table: 1, from them some fatty acid chin contain carbon double bond in their structure. On the basis of the double bond, fatty acid alkyl ester can be classified as **saturated (free of double bond), monounsaturated (single double bond)** and **polyunsaturated (double bond ≥ 2)** [1, 2].

Table: 1 Chemical structure of common fatty acids [3].

Name of fatty acid	Chemical name of fatty acids	Structure (CXX:Y)	Formula
Lauric	Dodecanoic	C12:0	$C_{12}H_{24}O_2$
Myristic	Tetradecanoic	C14:0	$C_{14}H_{28}O_2$
Palmitic	Hexadecanoic	C16:0	$C_{16}H_{32}O_2$
Stearic	Octadecanoic	C18:0	$C_{18}H_{36}O_2$
Arachidic	Eicosanoic	C20:0	$C_{20}H_{40}O_2$
Oleic	cis-9-Octadecenoic	C18:1	$C_{18}H_{34}O_2$
Linoleic	cis-9,cis-12-Octadecadienoic	C18:2	$C_{18}H_{32}O_2$
Linolenic	cis-9,cis-l2,cis-15-Octadecatrienoic	C18:3	$C_{18}H_{30}O_2$

Where CXX:Y = XX indicates number of carbons, and Y number of double bonds in the fatty acid chain.

Biodiesel contain saturate fatty acid have some advantage likes good ignition quality good oxidation stability, high CN, high CV, low iodine number, low NO_x, low PM and low smoke opacity but also have some drawbacks like high cold flow properties and high viscosity. On the other end biodiesel contain unsaturated fatty acid (linolenic, linoleic, oleic)have low cold flow properties and low viscosity, but have poor oxidation stability, low CN, low CV, high iodine number, high NO_x, high PM and smoke opacity[7, 4]. In this study we combine palm methyl ester (PME) and karanja methyl ester (KME) to form hybrid biodiesel. The PME has content 43% palmitic, 40% oleic, 10%linoleic and other fatty acid in their structure, while KME content 45- 71% oleic, 9-18% linoleic, 2-9% stearic and other [7, 4]. In study we prepare hybrid biodiesel and its blend in diesel and evaluate the properties, performance and emission characteristics of Diesel, PME, KME, HB, and its blend of HB in diesel.

2. FUEL PREPARATION

The two biodiesels (karanja methyl ester and palm methyl ester) are parched from SVM Agro Processor Nagpur, which is prepared by transesterification process. The hybrid biodiesel (HB100) are prepared by Ultrasonication method of mixing KME and PME in 50:50 proportion. The hybrid biodiesel blends with diesel were prepared in different proportions as: HB10 (10%hybrid biodiesel + 90%diesel), HB20, HB30 and HB50 by volume basis.

3. PROPERTIES MEASUREMENT

The various properties like kinematic viscosity, density, calorific value, flash point temperature, cloud point temperature, pour point temperature, Sulphur content and Water content of baseline fuel, hybrid biodiesel and its blends were determined by using different methods and compared with diesel properties. Properties test has performed at Microtex Research & Analytical lab Baroda. Also has been comparing the properties of baseline fuel and hybrid biodiesel on the basis of type of fatty acid present in there constitute.

3.1 Viscosity of fuels

Viscosity is very important properties of biodiesel for satisfactory operation in CI Engine. Vegetable oils have viscosity generally 10 times higher than diesel and it has not as per ASTM standard for CI engine fuel. Higher viscosity generate operational problem in CI Engine like poor atomization, excess penetration and poor mixing with air that leads to incomplete combustion. Viscosity has reduced by pre-heating the oil and by transesterification of vegetable oil. The U tube viscometer is used for determining the kinematic viscosity. The viscosity of KME is $4.45 mm^2/s$, PME $4.90 mm^2/s$ and HB $4.71 mm^2/s$ which are as per the ASTM limits. Biodiesel viscosity also depends on the fatty acid composition. Pratas et al. [5] and G Knothe, 2005 [6] show that the viscosity of all esters increases with the ester chain length (number of carbon atoms) and decreases with its level of unsaturation. Here viscosity of KME is lower compared to PME due to more unsaturated fatty acid present in there constitute. The viscosity of HB is lies in range of viscosity of KME and PME. The viscosity of HB lends HB10 and HB20 close to D100.

Table 2 physio-chemical properties

Property	Diesel	Karanja Biodiesel (KME)	Palm biodiesel (PME)	Hybrid biodiesel (KME:PME=50 :50)	HB10	HB20	HB30	HB50
Higher calorific value (MJ/ kg)	45.8	36.60	39.23	37.91	45.1	44.4	43.2	42.1
Density (kg/m^3)	810	865	878	876	818	826	830	845
Kinematic viscosity @ 40ºC (mm^2/ s)	3.20	4.45	4.90	4.71	3.27	3.35	3.46	3.97
Cloud point, ºC	-12	-3	15	7	-11	-9	-4	1
Pour point, ºC	-17	-4	14	6	-15	-13	-6	-1
Flash Point, ºC	76	168	184	176	84	98	117	131
Sulfur content (ppm)	50	12	1.6	7.2	44	38	26	24
Water content(%W/W)	0.06	0.01	0.03	0.02	0.05	0.04	0.03	0.03
Oxidation stability(h at 120°)	-	4.2	8.7	6.4	-	-	-	-

3.2 Calorific value (CV)

The heat of combustion or calorific value of a fuel is an important measurable parameter as it shows the amount of heat liberated by the fuel within the engine that enables the engines to do the work. The digital bomb calorimeter is used to find out the calorific value of fuels. The CV of KME, PME and HB are 36.60, 39.23 and 37.91 MJ/ kg respectively, which is considerably lower than petroleum diesel of 45.8 MJ/kg. It is mainly due to the biodiesel contain about 10-12% (w/w) O_2. G Knothe, 2005 [6] reported that the Calorific value increases with the chain length of fatty acid. Also biodiesel from saturated fatty acid has higher CV than highly unsaturated fatty acid.

3.3 Density

Density is notable properties of fuel because injection systems, pumps, and injectors must deliver the amount of fuel precisely adjusted to provide proper combustion. The density of biodiesel is measured using gravimetric test methods. All biodiesel fuels PME, KME, HB and its blend are denser and less compressible than the diesel fuel. One of the factors that contribute to the increase in biodiesel density is molecular weight of biodiesel. Despite the higher density of biodiesel compared to diesel, energy content of which is lower both on a mass and a volume basis compared to diesel fuel. Thus more fuel injected into the combustion chamber in order to gain the same power as the diesel from the engine. Density of a fuel has direct effects on the engine performance characteristics. The higher density will increase the diameter of the fuel droplets. Since the inertia of the big droplets is big, their penetrations in the combustion chamber will be higher, as well On the other hand, a fuel with lower density and viscosity will improve the efficiency of atomisation and air–fuel mixture formation. Thus, the change in fuel density will affect the engine output power due to the different mass of injected fuel.

3.4 Flash point

The flash point is defined as the temperature at which the fuel will start to burn when it comes to contact with fire. It is used in shipping and safety regulations that define flammable and combustible materials. Although this property does not affect the combustion directly, it is important when regard with storage, fuel handling and transportation. The closed cup method used for measuring the flash point of biodiesel and diesel. The flash point of all biodiesels fuel will always be far higher than diesel fuel. There are several factors that affect the change in biodiesel flash point, with residual alcohol content being one of them. In addition, the flash point is also influenced by the chemical compositions of the biodiesel; including the number of double bonds, number of carbon atoms, and soon.

3.5 Cloud and pour point

Pour points can be defined as the lowest temperature at which the fuel can still flow and cloud point is the lowest temperature at which cloud of wax crystals formed when cooled. All the biodiesel have higher cloud and pour points than conventional diesel fuel due to having higher amount of saturated fatty acids, and this pour and cloud point property is one of the most crucial obstacles against the widespread biodiesel usage, especially in cold climate conditions. Biodiesels with significant amounts of saturated fatty compounds exhibits higher cloud point and pour point. The cloud and pour point of PME is 15°C and 14°C respectively and it is due to higher saturate fatty acid in there constitute compared to KME having higher unsaturated FA. Cold flow properties problem of PME considerably solved by formatting hybrid biodiesel of them or blending into diesel. Shown in chart by forming hybrid biodiesel cloud and pour point temperature of PME reduce to 7 °C and 6°C respectively.

3.6 Oxidation stability

Oxidation stability is one of the major issues affecting the use of biodiesel because of its content of polyunsaturated methyl esters. Stability of biodiesel is inferior compared to petro-diesel and therefore doping of biodiesel in petro-diesel will affect the stability of fuel significant. Stability of fatty compounds is influenced by factors such as presence of air, heat, traces of metal, peroxides, light, or structural features of the compounds themselves, mainly the presence of double bonds (G Knothe, 2003 [8]). Auto-oxidation of biodiesel occurs due to prolong exposure to air during storage. The oxidation stability decreased with the increase of the contents of polyunsaturated methyl esters.

The biodiesel standard EN-14214 and IS-15607 used for determining oxidation stability at 110 °C with a minimum induction time of 6 h by the Rancimat method (EN-14112). ASTM standard D-6751 recently introduced a limit of 3 h for oxidation stability by Rancimat test. The oxidation stability of KME is 4.2 h, which is not as per EN standard, on other hand oxidation stability of PME 8.7 h which as per EN standard. One of key way to improve the oxidation stability is KME is to formation of hybrid biodiesel from KME and PME.

4. EXPERIMENTAL SET UP

The single cylinder, air cooled diesel engine coupled with three phase A.C. Alternator has been used for performance and emission testing. The specifications of engine are mentioned below:

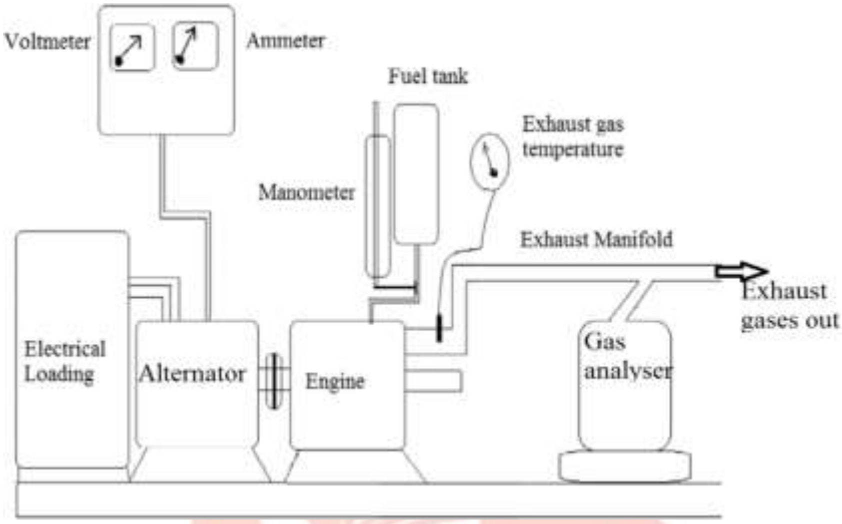

Fig.1 Experimental set up

Table 3 engine specification

Parameter	Specification
Make	Powerlite
Rated brake power	5.65 kW
Speed	1500 rpm
No of Cylinder	1
Method of cooling	Air cooled
Bore × Stroke	87.5 mm × 110 mm
Compression Ratio	18:1

4.1 Testing procedure

The performance and emission characteristics of Diesel, PME, KME, HB, and its blend of HB (HB10, HB20, HB30 and HB50) in diesel are evaluated on diesel engine.

5. RESULT AND DISCUSSION

5.1 PERFORMANCE PARAMETER

The following performance parameter has been evaluated and compared.

5.1.1 Brake specific fuel consumption

Brake specific fuel consumption of all fuels are follow same trend shown in fig.2. It decreases with increasing in brake power. The BSFC of KME, PME, HB and its blend are higher compared to diesel. This increase is due to combined effects of the higher fuel density, viscosity and low heating value of biodiesel. As the BSFC was calculated on weight basis, obviously higher densities resulted in higher values for BSFC as higher mass injection for the same volume at the same injection pressure. In addition also the lower heating value of biodiesel requires that a larger amount of fuel to be injected into the combustion chamber to produce the Brake specific fuel consumption of all fuels are follow same trend shown in fig. It decreases with increasing in brake power. The BSFC of KME, PME, HB and its blend are higher compared to diesel. This increase is due to combined effects of the higher fuel density, viscosity and low heating value of biodiesel. As the BSFC was calculated on weight basis, obviously higher densities resulted in higher values for BSFC as higher mass injection for the same volume at the same injection pressure. In addition also the lower heating value of biodiesel requires that a larger amount of fuel to be injected into the combustion chamber to produce the same power. The BSFC of blend HB10 and HB20 are very close to diesel, while higher blend case increase the BSFC that is due to lower energy content at higher bland. The BSFC of KME is higher compared to PME and it is due to lower heating value of KME while BSFC lies between them.

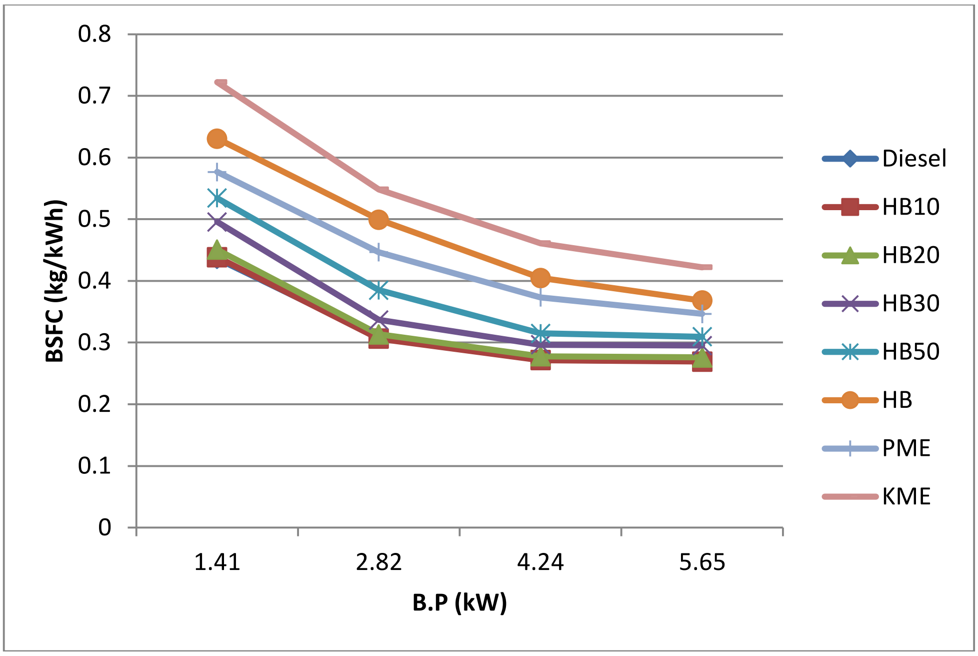

Fig. 2 Brake specific fuel consumption vs. Brake power

5.1.2Brake thermal efficiency

The Brake thermal efficiency vs. Brake power behaviour is shows in fig.3. The BTE of all fuels are increase with increase in brake power. The BTE obtained from KME, PME, HB, HB50 and HB30 are found to be less than that of diesel. The reduction of brake thermal efficiency with biodiesel mixtures was attributed to poor spray characteristics, poor air fuel mixing, higher viscosity, higher volatility and lower calorific value. Also some author reported that that smaller ignition delay of biodiesel resulted in initiation of combustion much before TDC causing increases in the compression work as well as heat loss and leads to reduction in the efficiency of the engine. The BTE of HB10 and HB20 are slightly higher compared to pure diesel. The main reason for increase BTE at lower blend is due to the oxygen content in biodiesel has promoted the complete combustion. Also the lower blends have heating value close to the heating value of diesel. The BTE of PME is higher compared to KME and it is due to high heating value and high Cetane number of PME.

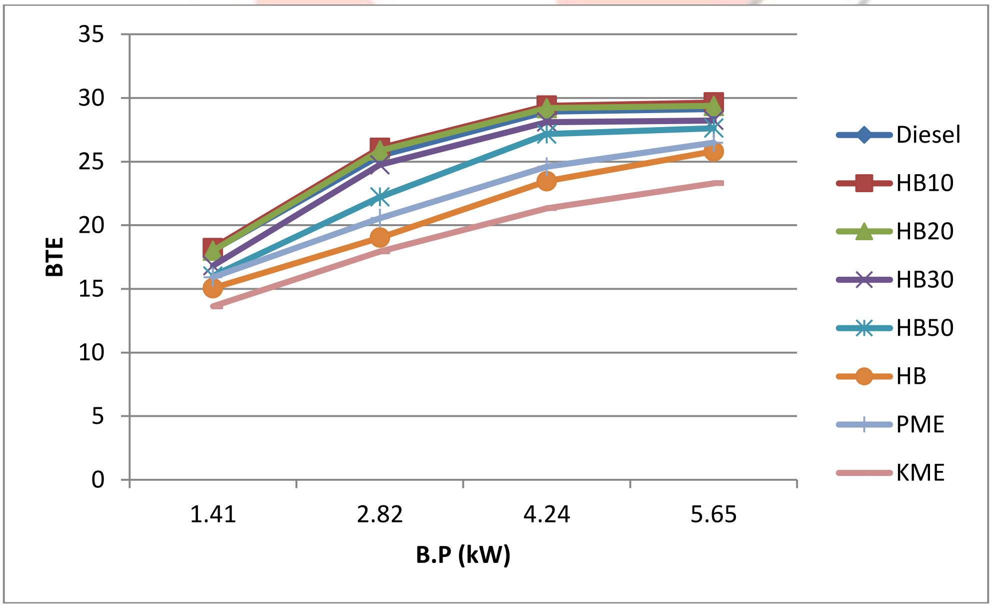

Fig. 3 Brake thermal efficiency vs. Brake power

5.2 EMISSION PARAMETERS

Following emission parameter can be measured with the help of five gas analyser.

5.2.1 Hydrocarbon (HC):

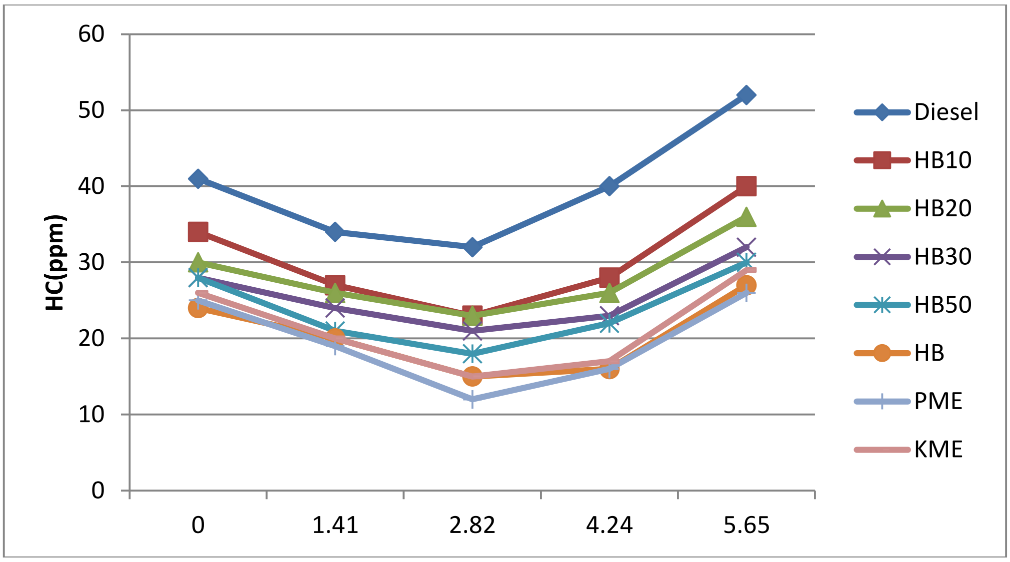

Fig. 4 hydro carbon vs. Brake power

Fig.4 Shoes the behaviour of HC emission with respect to the brake power. HC emission of all fuels first decrease with increase in load, this is due to the temperature rise with load case fuels are easily evaporate and quickly attain self ignition temperature case burned of hydrocarbon fuel. The further increase in load case more fuel to be injected to compensate the load in this case all fuel not find out the oxygen for their combustion its leads to increase HC emission. The HC emission of all blend of HB, PME and KME are considerably lower compared to the conventional diesel. This is mainly due to oxygenate nature of biodiesel fuel case supplement extra oxygen to the combustion process. Also higher Cetane number of biodiesel fuel causes a decrease in HC emissions due to the decrease in combustion delay period. In case biodiesel HC exhaust emissions increase with increased chain length of fatty acid methyl esters due to longer chain length have higher boiling [4]. Here KME continent longer FA chain also lower Cetane number case higher HC emission compared to PME.

5.2.2 Carbon Monoxide

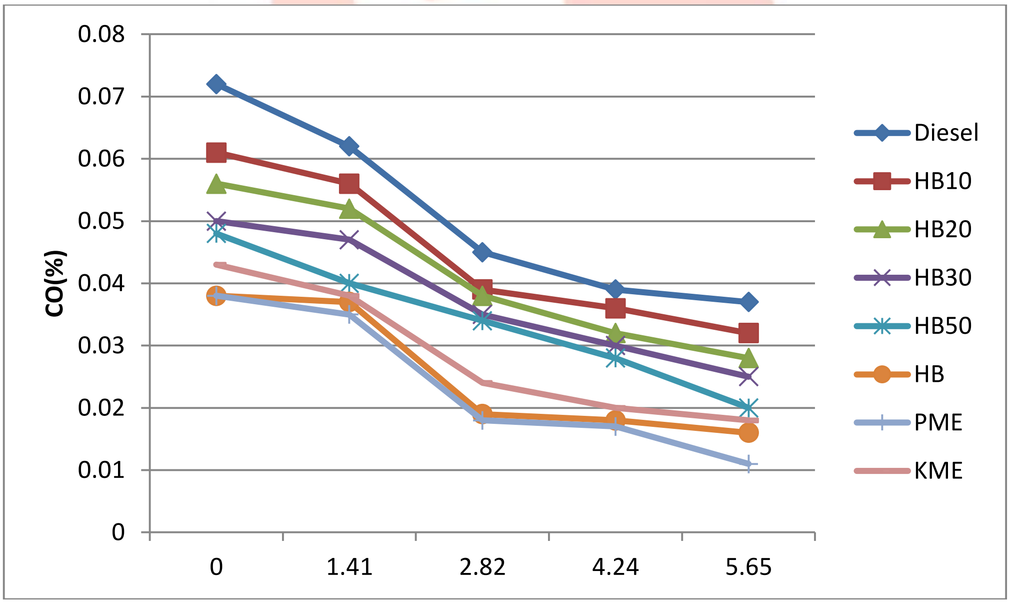

Fig. 5 Carbon monoxide vs. Brake power

The emission of CO with respect to power is shown in fig.5. The percentage composition of CO decreases with increase in BP for all fuel. This trend can be mainly due to higher temperature at full load case easy and quick boiling of fuel which leads to decrease of CO in the exhaust gases. The CO emission of all blend of HB, PME and KME are considerably lower compared to the conventional diesel. The reduced CO emissions were maintained, probably, thanks to the oxygen inherently present in the biodiesel and its blend, which makes it easier to be burnt at higher temperature in the cylinder. The emission of CO of KME is higher compared to PME, this is explained by the higher oxygen content in the shorter fatty acid molecules, which leads to a more complete and cleaner combustion. Also there are methyl's esters with longer chain length have higher boiling and melting points, so they are less likely to be completely vaporised and burnt, thereby increasing CO emissions

5.2.3 Nitrogen oxide (NOx):

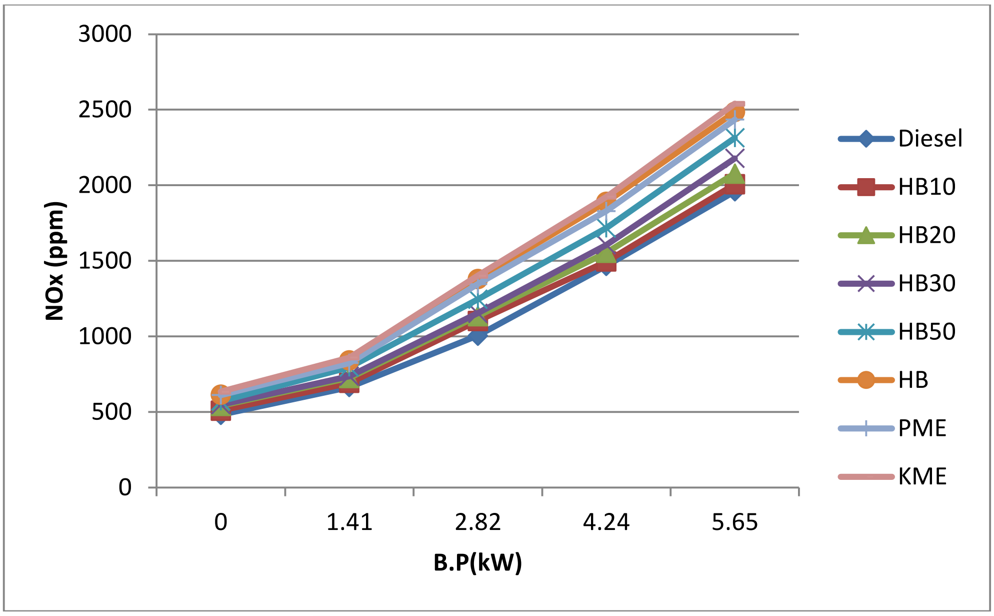

Fig.6 Nitrogen oxides Vs Brake power

The emission of NOx with respect to BP is shown in fig. The NOx is increase with BP for all fuel. The formation of NOx is mainly two reason high temperature and availability of oxygen during combustion. With increase in BP temperature is increased this leads to formation of more NOx. For biodiesel and its blend NOx is higher compared to petroleum diesel, the oxygen enrichment of biodiesel is main case for this behaviour. The increase of proportion of HB in its blend case increase oxygen content which is favourable factor for increase of NOx. The NOx is also affected by type of fatty acid present in the biodiesel. The saturated fatty acid has lower NOx compared to the unsaturated fatty acid [7]. The PME having saturated form of fatty acid has lower NOx compared to KME, while hybrid biodiesel have NOx lies in between PME and KME.

5.2.4 Carbon dioxide (CO2):

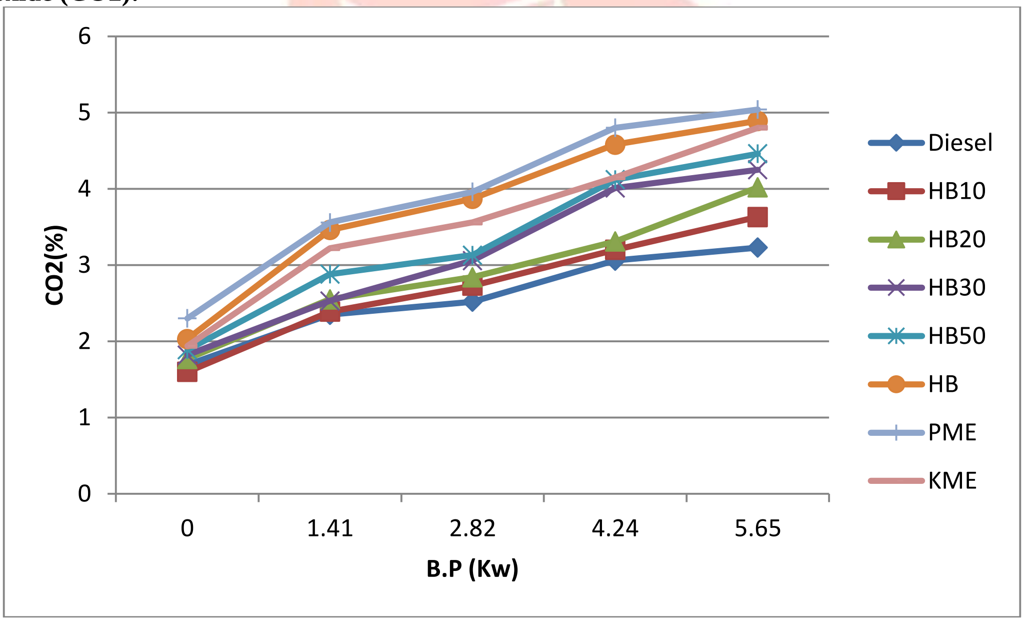

Fig. 7 Carbon dioxide vs. Brake power

Fig.7 shows the CO_2 Vs brake power. The CO_2 increase with increase in B.P. this trend is mainly due to two reason first one is the increase in temperature with BP that leads to more complete combustion of fuel and second one is to increase the quantity of fuel injection at high B.P which case formation of more CO_2. In case of biodiesel and its blends have higher CO_2 compared to the pure diesel. This has due to the oxygen content in their chemical structure case complete combustion of biodiesel content fuel.

6. CONCLUSION:

From above discussion Physicochemical properties of biodiesel derived from different feedstock mainly depend on type of fatty acid ester present in biodiesel composition. Biodiesel contain saturate fatty acid have some advantage likes good ignition quality good oxidation stability, high CN, high CV and low NO_x, but also have some drawbacks like high cold flow properties and high viscosity. On the other end biodiesel contain unsaturated fatty acid (linolenic, linoleic, oleic)have low cold flow properties and low viscosity, but have poor oxidation stability, low CN, low CV and high NO_x. The hybrid biodiesel and its blends are substitute fuel of diesel in diesel engine cans considerably reduction of emission of HC and CO. Also the PME has lower HC and CO compared to KME due to its saturate nature of FA. The NOx of all biodiesel have higher than diesel. BSFC for biodiesel fuels are higher compared to diesel. The BTE of HB10 and HB20 are slightly higher compared to the diesel, while higher blend the BTE is lower compared to the diesel.

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REFERENCES

[1] Niraj Kumar, Varun, Sant Ram Chauhan, "Performance and emission characteristics of biodiesel from different origins: A review", Renewable and Sustainable Energy Reviews, 2013, 21, 633–658

[2] Atabani AE, Silitonga AS, Ong HC, et al. Non-edible vegetable oils: a critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production. Renew Sustain Energy Rev, 2013, 18(0), 211–45.

[3] B.K. Barnwal, M.P. Sharma, "Prospects of biodiesel production from vegetable oils in India", Renewable and Sustainable Energy Reviews, 2004, 09, 363–378.

[4] Wan Nor Maawa Wan Ghazali, Rizalman Mamat, H.H.Masjuki, GholamhassanNajafi, "Effects of biodiesel from different feedstocks on engine performance and emissions: A review", Renewable and Sustainable Energy Reviews, 2015, 51, 585–602

[5] Pratas MJ, et al. Densities and viscosities of fatty acid methyl and ethyl esters. Journal of Chemical and Engineering Data 2010, 55(9), 3983–90.

[6] Knothe G, Steidley KR. Kinematic viscosity of biodiesel fuel components and related compounds. Influence of compound structure and comparison to petrodiesel fuel components. Fuel 2005, 84, 1059–65

[7] Alessandro Schönborn, Nicos Ladommatos, John Williams, Robert Allan, John Rogerson, "The influence of molecular structure of fatty acid monoalkyl esters on diesel combustion" Combustion and Flame, 2009,156, 1396–1412

[8] Dunn RO, Knothe G. Oxidative stability of biodiesel in blends with jet fuel by analysis of oil stability index. J Am Oil Chem Soc, 2003, 80, 1047–8.