Production of Biodiesel from Cannabis sativa (Hemp) Seed oil and its Performance and Emission Characteristics on DI Engine Fueled with Biodiesel Blends

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Abstract - *The present work evaluates the possibility of using Cannabis sativa (commonly known as Hemp) seed oil as an alternative fuel for diesel engine. Biodiesel is produced from the cannabis sativa seed oil by single step base catalytic transesterification process. The study deals with the physicochemical properties of cannabis sativa biodiesel and has been compared with the base diesel. It has been observed that the properties of biodiesel are compatible with the base diesel under the ASTM D6751 limits respectively. Cannabis sativa biodiesel are blended in different proportion with base diesel such as B10, B20, B30, B50 and B100 and are tested in a Kirloskar TV1 single cylinder, four strokes DI engine under different loading conditions. Results illustrate that the brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC) for B10 and B20 were similar to base diesel. In case of engine emissions, cannabis sativa biodiesel blends gave an average reduction in hydrocarbon (HC), Carbon monoxide (CO) and carbon dioxide (CO_2) compared to base diesel. However cannabis sativa biodiesel blends emitted high levels of nitrous oxide (NO_x) compares to base diesel. Smoke opacity improved simultaneously at full load up to 10% respectively. This study gives a direction of renewable fuel blends to replace diesel for fueling diesel engine thereby reducing the dependency of fossil fuels.*

***Key Words*: DI Engine, Cannabis sativa methyl ester, transesterification, performance, emissions.**

Nomenclature

CSME	Cannabis sativa methyl ester
bTDC	Before top dead Centre
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
Kg/kW-hr	kilogram per Kilowatt-hour
HC	Hydrocarbons
CO	Carbon monoxide
CO_2	Carbon dioxide
NOx	Oxide of nitrogen
PPM	Parts per millions
EGT	Exhaust gas temperature
ASTM	American society for testing materials
BP	Break power

1. INTRODUCTION

1.1 Fossil fuel scenario

Today, 86% of the world energy consumption and almost 100% of the energy needed in the transportation sector is met by fossil fuels. The limited availability of resources of fossil fuels and increased demand in various fields such as power generation, transport, and agriculture triggered the research in finding out alternate sources to replace or reduce the dependency of fossil fuels. Among the alternate fuels alcohols and biodiesel from various vegetable oils are the major resources [1]. The demand for non-renewable energy sources is increasing day by day due to modernization and mechanization. The usage of edible oil from food crops for the production of biodiesel is limited in countries like Africa, china, India and Bangladesh etc. Because of their abundant need for domestic purposes which made researchers to narrow down and sharpen their focus of extracting biodiesel from non-edible feedstock.

1.2 Biofuel - a solution

Biodiesel is an alternative fuel similar to conventional or ‘fossil’ diesel. Biodiesel can be produced from straight vegetable oil, animal oil/fats, tallow and waste cooking oil. The process used to convert these oils to Biodiesel is called transesterification. Biodiesel has many environmentally beneficial properties. It is one of the largest sources of energy reserves in the world as it approximately supplies 14% of world’s energy consumption [2]. Many initiatives are being given for promoting the biofuels. Among the biofuels, biodiesel gets more momentum as it has properties similar to the properties of diesel fuel [3]. Biodiesels are biodegradable, renewable and more environment friendly than petroleum based fuels [4]. There are more than 350 oil bearing crops that have been identified, among which only pongamia, jatropha curcas, Neem, Hemp, Mahua, Calophyllum inophyllum and cottonseed oils are considered as potential alternative fuels for diesel engines. Apart from the renewability, the advantages of biofuel are as follows: High oxygen content, higher flash point and higher lubricity that produce complete combustion in comparison with conventional diesel fuel [5]. Further, the environmental benefit is another investigation factor due to lesser greenhouse effect, less air pollution, less contamination of water, soil and reduced health risk [6].

Numerous studies have been conducted on biodiesel in the past few decades. Several production methods have been reported that include blending of oils, micro emulsion, pyrolysis and transesterification [7, 8]. A transesterification reaction is used to produce biodiesel from the renewable lipid feedstock by mixing with alcohol in the presence of a catalyst, during which the backbone of triglyceride is replaced with three alkyl groups of the alcohol. Catalysts for transesterification can be alkali, acid, enzyme, and heterogeneous catalysts. Since the base-catalyzed transesterification is rapid and easy to scale-up, it has been widely used in industry [9, 10].

From the literature review, it is found that most of the research works have been carried out on a number of alternative fuels in diesel engines especially biodiesel produced from different kinds of vegetable oils, and very limited work has been done on biodiesel produced from Cannabis sativa seeds. Si-Yu, Stuart et al. [11] Converted industrial hemp seeds into methyl esters, and compared Physico chemical properties of hemp biodiesel with base diesel and concluded that quality of biodiesel was found to be comparable with the ASTM D6751. Stamenkovic et al. [12] Studied the methanolysis of hempseed oil catalyzed by potassium hydroxide using the full central composite rotatable design. More favorable optimum reaction temperature and methanol: hempseed oil molar ratio (43.4 °C and 6.4:1) than the latter (56.8 °C and 8.5:1) at a somewhat higher catalyst loading (1.2% versus 1.0%).

1.3 Cannabis Sativa (Hemp oil) as Biodiesel

One promising source for biodiesel production is the fiber crop Cannabis sativa. It is an annual herb and its cultivation has a low cost and a low environmental impact. Cannabis sativa plant grown in temperate zones as an annual cultivation from seed and can reach a height of up to 5 meters (16 feet). Seeds have high oil content, ranging from 26% to 42% [13]. In addition, cannabis sativa has advantage as a fuel source. It has a high biomass content which can be fermented to create low carbon fuels, such as bioethanol or biobutanol. Moxley et al. [14]. Has successfully recovered 96% of the glucose from the hemp's cellulosic herds, which allows for the recycling of this hemp fiber industry waste product In fact, industrial hemp is one of the few plants that produce high yields of both oil and biomass, which means it, can be used to produce both biodiesel and bioethanol.

2. MATERIALS AND METHODS

2.1 Biodiesel production

C. Sativa seeds are crushed in mechanical expeller machine to obtain crude oil from the seeds. Biodiesel is prepared from C. Sativa oil by single-step base catalyzed transesterification process. The mixture of crude oil, 300 ml of methanol (molar ratio of 6:1) and 5.5 g of sodium hydroxide (NaOH) (1 wt.%) as catalyst is heated in a 1000 ml round bottom flask on a heating mental integrated with a magnetic stirrer rotating at 600 rpm. The entire mixture is stirred rigorously and heated at a temperature of 70 °C for 2 hours Chemical reaction takes place. The mixture was transferred to a separator funnel, allowing glycerol to separate by gravity for 2 hours. Phase separation occurs with top layer biodiesel and bottom layer containing by product glycerol and unreacted methanol which are drawn out of the flask. The biodiesel obtained in the process is further washed with distilled water for 8-10 times to remove acids till the pH of water is reached and again the product is heated above 100 °C to separate the moisture from the biodiesel. Thus pure Cannabis sativa biodiesel is obtained.

2.2. Characterization of oil

The quality of oil is expressed in terms of the physicochemical properties such as kinematic viscosity, density, calorific value, flash point of cannabis sativa biodiesel were determined by following ASTM methods and compared with base diesel. The results are given in Table 1 along with recommended values for biodiesel limits (ASTM D6751). It is comprehended that the physicochemical properties of biodiesel differ from that of conventional diesel; which could affect the diesel engine performance and emission characteristics without any further modification required to be done on the engine.

2.3 Experimental set-up

Experimental investigation is carried out on a typical Kirloskar TV1 single cylinder, four strokes constant speed diesel engine. Fig.1 shows the pictorial view of DI Engine setup. Test engine specification is shown in table.2 Engine is coupled with a water cooled eddy current dynamometer along with load cell. Load on the engine is varied with the help of the controller provided on the dynamometer. Fig.2 shows schematic arrangement of the experimental setup. Exhaust gas emissions such as HC, CO, CO_2, and NOx were measured by AIRREX HG-540 Gas Emission Analyzer, AVL 437C Smoke meter is used to measure smoke opacity. Engine performance parameters such as brake thermal efficiency, specific fuel consumption, Exhaust gas temperature, Emissions and smoke opacity are quantified.

2.4 Test procedure

The fuels used in this study include diesel fuel, biodiesel (CSME) and its blends. The experiments were carried out by using neat diesel as the base fuel denoted as Base Diesel, (10% Biodiesel + 90% base diesel) denoted as B10, (20% Biodiesel + 80% base diesel) denoted as B20, (30% Biodiesel + 70% base diesel) denoted as B30, (50% Biodiesel + 50% base diesel) denoted as B50, and (100% Biodiesel) denoted as B100 at different engine rated power. Two fuel tanks are used for storing diesel fuel and biodiesel separately with a burette and three way stop cock as shown in Fig.2 the fuel is changed from base diesel to biodiesel by operating individual valves provided in each fuel tank and a three way stop cock. Before running the engine to a new fuel, it was allowed to run for sufficient time to consume the remaining part of fuel from the previous experiment. The engine was started initially with diesel fuel and warmed up to obtain its base parameters. The experiments are carried out at ignition timings of 23 °CA bTDC and injection pressure of 200 bars then, the same tests were performed with biodiesel and its blends. For each test fuel and in each load approximately three times readings were taken to get an average value. When the engine reaches the stabilized working condition, performance parameters like BTE, BSFC, EGT and Emissions for HC, CO, CO_2, NOx and smoke opacity were measured.

Fig-1 Pictorial view of DI Engine setup

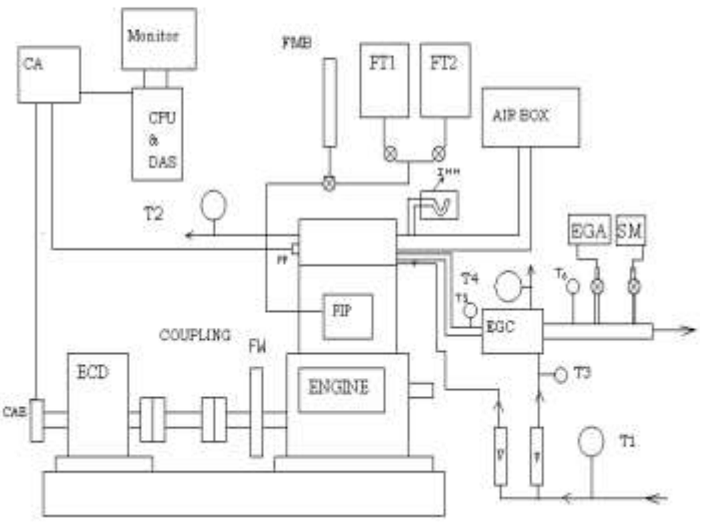

Fig-2 Schematic arrangement of DI Engine set-up

Table -1: Physico-chemical properties of Hemp biodiesel and base Diesel

Property of fuel and its unit	ASTM Test method	C. Sativa biodiesel	Base Diesel	ASTM D6751 Limits
Density at 15°C (kg/m^3)	D-4052	0.81	0.828	0.86-0.89
Kinematic viscosity at 40°C (mm^2/s)	D-445	4.82	2.52	1.90-6.0
Flash point (°C)	D-93	176	53	130 min
Cloud point (°C)	D-2500	3.7	-3	-3 to12
Pour point (°C)	D-97	-1	-2.2	-15 to 10
Gross calorific value (kJ/kg)	D-4809	41742	42600	Above 37365
Acid value (mgKOH/g)	D-664	0.41	0.35	0.50
Refractive index	D-542	1.4712	1.483	-
Carbon residue (wt. %)	D-4530	0.39	-	0.05 max
Water content (wt. %)	D-513	0.001	-	0.05 max
Sulfur contain (wt. %)	D-2622	0.034	-	0.05 max
Sediment (wt. %)	D-473	0.001	-	0.01
Cetane number	--	55	46.2	47 Min
Saponification value (mg KOH/g)	IS1448 P55	177	-	-

3. RESULTS AND DISCUSSION

3.1 Oil yield

The crude oil obtained from the cannabis sativa seeds using mechanical expeller were calculated to 40% oil yield. After the transesterification process 92% of methyl ester yield was obtained with a molar ratio methanol to oil 6:1. Following is the equation to calculate yield of oil extraction.

$$\text{yield\%} = \frac{\text{weight of refined biodiesel}}{\text{weight of oil used}} \times 100$$

Table-2: Test engine specification

Particulars	Description
Engine Model	Kirloskar TV1
Engine type	Single cylinder, Four stroke, DI engine
Bore diameter	87.50 mm
Stroke length	110.00 mm
Connecting rod length	234.00 mm
Compression ratio	18:01
Swept volume	661.45 cc
Rated power	3.5 kW
Rated speed	1500 rpm
Dynamometer	Eddy current
Fuel ignition timing	23 °C bTDC
Fuel injection pressure	200 bar

3.2. Performance

3.2.1. Brake thermal efficiency (%)

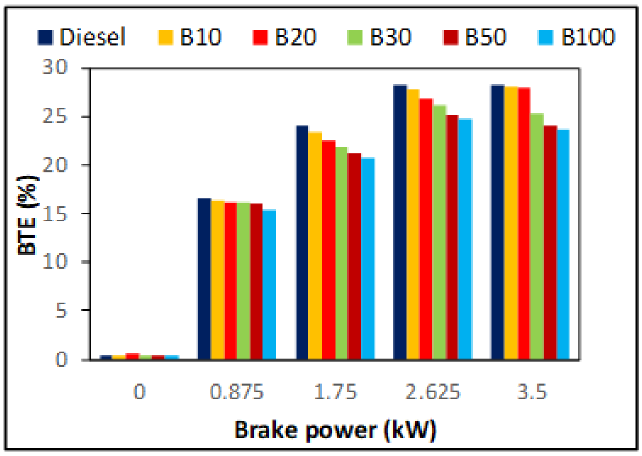

Fig-3: Brake thermal efficiency vs. Brake power

Thermal efficiency is the ratio between the power output and the energy introduced through fuel injection, the latter being the product of the injected fuel mass flow rate and the lower heating value [15]. Fig.3 shows the BTE for all biodiesel blends and base diesel under different brake power. BTE increases with increase in load up to 80% and then decreases at full load due to incomplete combustion The maximum brake thermal efficiencies at full load condition for base diesel, B10, B20, B30, B50 and B100 are 28.2%, 28.1%, 27.9%, 25.3%, 24.1%, 23.6% respectively. From the graph it is clear that BTE of base diesel is higher compare to CSME blends. The reason that CSME is showing low efficiency is due to high density, viscosity and lower heat value of base diesel. The higher viscosity leads to decreased atomization, fuel vaporization and combustion and hence BTE of CSME is lower than base diesel [16]. It is also observed blend B10 and B20 are nearest to base diesel. Thus the difference in BTE between base diesel, B10 and B20 blend is very significant at maximum load. However the BTE of blended fuels is higher than that of neat biodiesel.

3.2.2. Brake specific fuel consumption (kg/kW-hr)

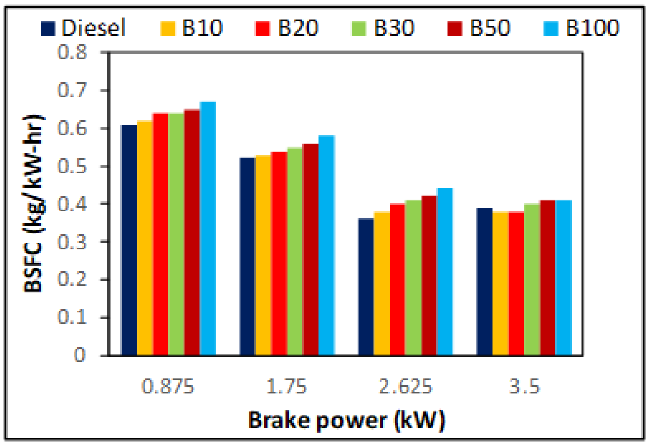

Fig-4: brake specific fuel consumption vs. brake power

The brake specific fuel consumption (BSFC) is the actual mass of fuel consumed to produce 1kW power output in an hour [17]. Fig.4 shows the variation in BSFC of base diesel and all biodiesel blends. It is found that the BSFC of base diesel, B10, B20, B30, B50, B100 were 0.39, 0.38, 0.38, 0.4, 0.41 and 0.41 kg/kW-hr respectively. It is observed that BSFC first decreases for all the test fuels with increase in load i.e. up to 80% and then tends to increase with increase in load. It is noted that BSFC of CSME of all blends is higher than that of base diesel at various loading conditions. But the blend B20 is similar to diesel. This can be attributed to the low calorific values in the biodiesel blends. The percentage of CSME in blends influences the engine economy with better performance. This is due to the influence of lower heating value, higher density and viscosity of biodiesel when compared to diesel. Similar trends were reported earlier [18, 19].

3.2.3 Exhaust gas temperature (°C)

The variation of EGT with respect to brake power for base diesel, biodiesel and its blend is shown in Fig.5 the EGT increases with increase in load for all tested blends. The EGT of B10 is higher than base diesel due to higher viscosity, which results in poorer atomization, poorer evaporation and extended combustion. B10 shows 561°C of temperature were as base diesel shows 550°C. CSME concentration is increased for B20, B30, B50 and B100 due to viscosity of blends. Furthermore This may be due to there is enough time for complete combustion of biodiesel at low engine speed and long after burning stage because of it has higher viscosity [20].

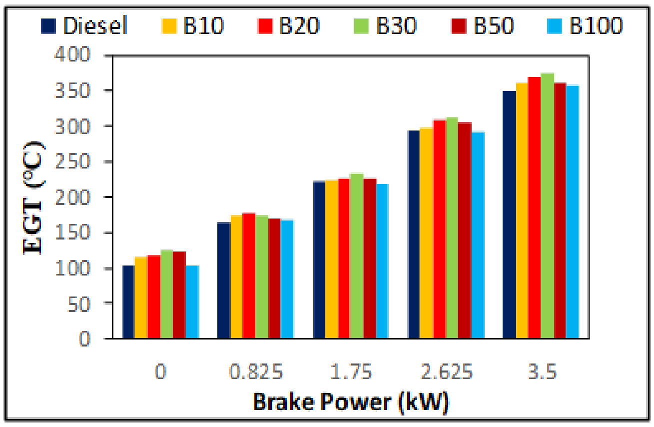

Fig-5: Exhaust gas temperature vs. Brake power

3.3. Emissions

3.3.1. Unburned hydrocarbon emission (ppm)

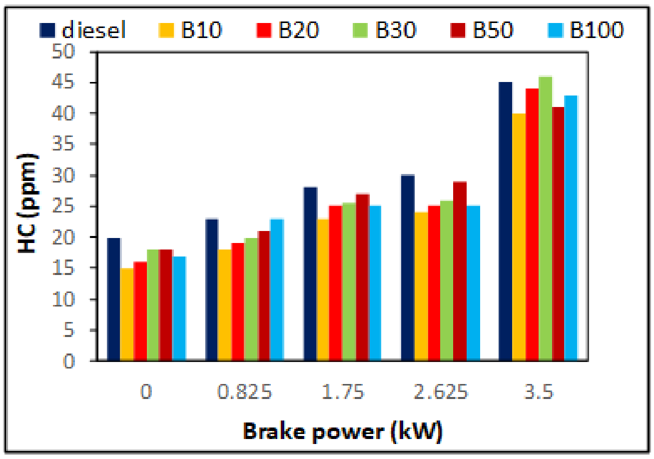

Fig-6: Comparison of unburned hydrocarbon emission for various blends

The values of unburned hydrocarbon (UBHC) emission from the diesel engine in case of CSME blends is lesser than diesel fuel as evident from the Fig.6 The UBHC emissions are found lower at partial load conditions and increases at higher engine load [21]. The UBHC emissions for base diesel, B10, B20, B30, B50 and B100 are 45, 40, 44, 46, 41 and 43 ppm respectively. At full load diesel had highest HC emission of 45 ppm whereas for B10 it shows 40ppm. There was a reduction of 10% HC emission indicates better combustion of biodiesel for B10. This is because of complete combustion of the fuel due to the presence of oxygen content in the biodiesel that leads to faster the combustion chemical reaction [22].

3.3.2. Carbon monoxide (%)

Fig.7 shows the variation in carbon monoxide of all the tested fuels with respect to brake power. It is observed that the variation in CO emissions for all biodiesel blends is fairly small when compared with base diesel. As the load is increased on the engine, there is an increase in CO emission for all the test fuels. The increase in CO emissions level at higher load is due to rich mixture were as lower load results in incomplete combustion of fuel [22]. This is due to presence of higher oxygen content in biodiesel. The reduction in CO emissions for B10, B20, B30, B50 and B100 are 0.13%, 0.14%, 0.17%, 0.18% and 0.21% respectively. The lower CO emissions have been observed with blended biodiesel fuel and least in B10 and B20 samples this may be due to the oxygen content and less C/H ratio of biodiesel that causes complete combustion. However, it is revealed that the decreasing trend of CO emission does not rely on biodiesel percentage in the blends [23].

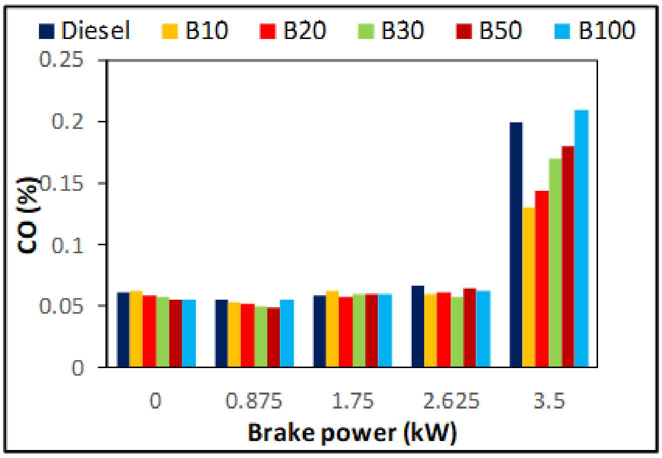

Fig.7: Comparison of Carbon monoxide emission for various blends

3.3.3. Oxides of Nitrogen (ppm)

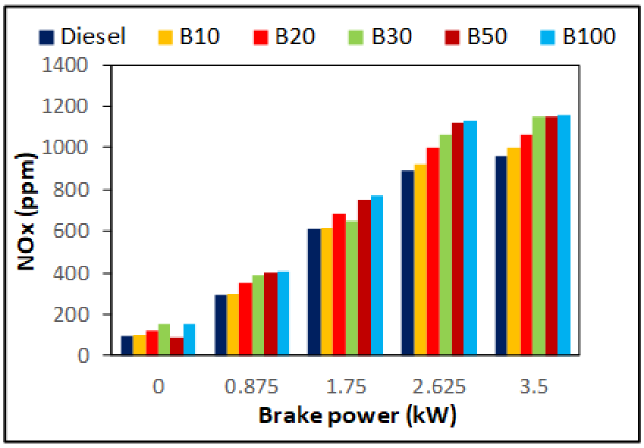

Fig-8: Comparison of Oxide of nitrogen emission for various blends

NOx emission is a generic term of nitric oxide (NO) and nitrogen oxide (NO_2), which is produced from the reaction of nitrogen and oxygen gases in the air during combustion process. The maximum burned gas temperature, the relative concentration of oxygen and the reaction time are the critical variables for NOx formation. The variation in NOx concentration with brake power for B10, B20, B30, B50, B100 and base diesel are 1000ppm, 1060ppm, 1150ppm, 1150ppm, 1160ppm, and 960ppm as shown in Fig.8 NOx emissions of all biodiesel blends are higher than that of conventional diesel. It is found that NOx emission of B10 is increased by 2% when compared to diesel at rated load and for B100 20% hike in NOx emission is greatly influenced by the percentage of biodiesel in blends. A higher cetane number would result in a shortened ignition delay period thereby allowing less time for the air/fuel mixing before the premixed combustion phase. Consequently, a weaker mixture would be generated and burnt during the premixed combustion phase resulting in relatively reduced NOx formation [24]. NOx emissions were found to increase due to the presence of extra oxygen in the molecules of biodiesel blends [25].

3.3.4. Carbon dioxide (%)

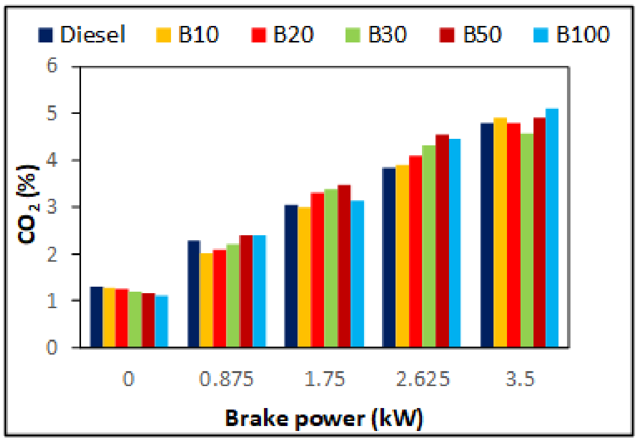

Fig-9: Comparison of Carbon dioxide emission for various blends

The effect of the biodiesel blend on CO_2 emission is shown in fig.9 CO_2 emissions where less up to 30% load after that, CO_2 emission was higher for B100 at maximum load with a value of 5.1% by volume. The variation of CO_2 emission with respect to brake power for base diesel, B10, B20, B30, B50, and B100 are 4.8%, 4.9%, 4.8%, 4.56%, 4.9% and 5.1% respectively. This is because of availability of excess oxygen for complete combustion of fuel and also the Emissions increasing in gradually as the load increases for all the blended fuels. This is due to the effect of lower operating temperature with high latent heat vaporization. CO_2 is the key parameter that indicates the combustion efficiency of a particular fuel. Higher CO_2 emission refers to better combustion [20].

3.3.5. Smoke Opacity (%)

Fig.10 shows the variation of smoke opacity with brake power for base diesel, biodiesel and its blends. The smoke emissions for base diesel, B10, B20, B30, B50 and B100 are 34.6%, 28.1%, 29.4%, 30.2%, 33.1% and 36.8 % respectively. There is a significant reduction in smoke emission of 10% for B10 at full load compared to base diesel because of its oxygenated nature. But at low and middle engine loads the smoke opacity is higher than diesel. This is due to the high viscosity of biodiesel, which results in poor atomization and locally rich mixtures at part load operations. But at high engine loads, smoke opacity of biodiesel and its blends is lower than diesel fuel except for B100. The reduction in smoke opacity of biodiesel is due to the presence of aromatic compounds in the biodiesel and a lower carbon to hydrogen ratio compared to conventional diesel fuel. The carbon content in biodiesel is lower than diesel fuel. The more carbon a fuel molecule contains, the more likely is to produce soot. Conversely, oxygen within a fuel decreases the tendency of a fuel to produce soot [26].

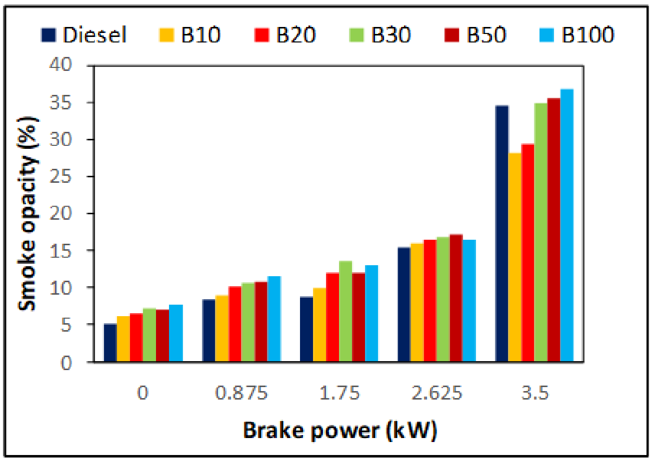

Fig-10: Variation of smoke for different blends of biodiesel

4. CONCLUSIONS

- During the investigation several test were carried out, Diesel engine can perform satisfactorily with cannabis sativa biodiesel and their blends without any engine modifications.
- The oil yield obtain from the cannabis sativa seeds by mechanical expeller is found to be 40% respectively.
- Alkali base transesterification was performed for the production of biodiesel from cannabis sativa oil. The biodiesel yield was calculated to be 92%.
- BTE for B10 and B20 were noted nearly similar to base diesel.
- BSFC for B20 was noted similar to base diesel.
- CO and HC emissions are higher for base diesel and lowest for all the blends because of higher oxygen content.

- CO_2 emissions for B10 and B20 were low compare to base diesel only at lower load condition were as for higher load CO_2 emissions were increasing.
- NOx emissions of all biodiesel blends are higher than that of base diesel. It was found that NOx emission of B10 is increased by 2% when compared to diesel at rated load.
- Smoke opacity was significantly reduced by 10% for B10 at higher load condition. Were as for other blends smoke opacity was higher at low and intermediate load compare to base diesel.

Thus, results indicate that CSME biodiesel can be used as an alternative and environment friendly fuel for a diesel engine. However, detail analysis of combustion parameters for biodiesel blends will surely give an emphasis on the kind of bio-diesel that can be finally used in I.C. engines in the days to come in order to overcome the disadvantages of the petroleum diesel fuel that can be commercially developed as well.

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