Experimental Investigation of Biofuel Gasoline Blends In a PFI Spark-Ignition Engine

R. Narayanamoorthy[#1], S. Sivaprakasam[2], P. Sivaraj[3]

[#1]Research Scholar and Assistant Professor, Department of Mechanical Engineering, Faculty of Engineering and Technology, Annamalai University, Tamilnadu – 608002, India

[2]Professor, Department of Mechanical Engineering, Faculty of Engineering and Technology, Annamalai University, Tamilnadu – 608002, India

[3]Associate Professor, Department of Manufacturing Engineering, Faculty of Engineering and Technology, Annamalai University, Tamilnadu – 608002, India

[1]rnm.lme@gmail.com, [2]rgssiva2002@gmail.com, [3]cemajorsiva@gmail.com

Abstract - *To reduce the usage of gasoline extracted from fossil fuel resources, there is a need for a sustainable alternative fuel that has the potential to replace gasoline. In this work, the oil extracted from the leaves of Basil oil (BO), which gives a low cetane number, was investigated in the port fuel injection installed spark-ignition engine to study its feasibility as a replacement for gasoline fuel. Initially, the basil oil was taken to GC_MS and FTIR analysis to study the chemical compounds and types of chemical bonds present in it. Then three BO blends were prepared by blending BO in the ratio of 10:90, 20:80, and 30:70 with gasoline. The blends were undergone a phase separation test and the fuel properties of sole BO and its blends were measured. The blended BO fuels were tested experimentally to find out their impact on the performance, emission, and combustion characteristics of the engine. The results show that the performance of the BO blends is lesser than that of gasoline. At maximum engine brake power, the BTE of BO10 (Basil oil 10% + Gasoline 90%) is 25.08% which is 1.74% lesser than the BTE given by gasoline. The NOx emission of BO10 is 318 ppm which is about 6.4% lesser than gasoline. The levels of CO and HC emissions are increased with an increase in the blending ratio of BO in the gasoline. Though the BO blend performance is not equivalent to that of gasoline, a suitable engine modification can improve its performance.*

Keywords: *Biofuel, Performance, Gasoline, Basil oil, Blends, emissions*

I. INTRODUCTION

In the road transportation sector, Gasoline and Diesel engines are the most commonly used prime movers globally. For the past 2 decades, when it comes to a light-duty passenger vehicle, the market for diesel engine cars has been significantly higher when compared to gasoline engine cars because of better fuel efficiency, lower maintenance cost, and lesser fuel price [1,2]. Especially in a country like India where half of the country's population belongs to economic class, so most of the people prefer to buy diesel engine cars.

But, currently, the trend has been reversed after the implementation of BS-VI emission norms in April 2020 [3]. The NOx and Soot emission are major concerns with diesel engines which are having a significant negative impact on the environment causing various health effects [4,5].

In order to meet the stricter BS-VI norms, Diesel engines need either engine up-gradation or after-treatment methods. Since the technological up-gradation in the engine side to curb the emission is almost got saturated, the automobile manufacturers and researchers turn towards the development of newer and optimization of existing after treatment technologies [6]. These after-treatment techniques add up a significant amount to the overall cost of diesel cars and make their cost higher than gasoline cars [7]. Whereas modern-day gasoline engines with a 3-way catalytic converter are very effective in meeting the BS-VI emission standards. Also, the price gap between gasoline and diesel fuel is reduced drastically [8]. These factors drive people towards buying gasoline cars in the coming years. In this trend, gasoline usage and demand can rise steeply in the coming days [9]. On the other hand, the greenhouse gas (CO_2) emission from automobiles also possess a major threat to the environment by causing global warming and climatic changes [10,11]. The oil extracted from plant/crop-based biomass or various parts of a tree can be regarded as renewable and sustainable alternative fuels to reduce the dependency on fossil fuel based petroleum products. Also, the plant's natural ability to absorb the CO_2 gas makes them a CO_2 sink [12]. Generally, fuels with high octane number are selected as an alternative to gasoline fuel to overcome the knocking tendency and also to improve thermal efficiency [13]. Alternate fuels such as lower order alcohols, LPG, and others are already experimentally proven as gasoline substitutes [14,15]. Currently, the researchers are trying to use bio-oils having low viscosity cum low cetane (LVLC) number fuel property as a gasoline substitute in a spark-ignition engine. These special bio-oils can be used directly as fuel without the need for the conversion of raw oil into methyl esters [16]. This includes pine oil, the oil obtained

from peels such as orange peel oil and lemon peel oil. Babu et al. experimental results proved that blending pine oil with gasoline up to 20% by volume improved the engine performance without any knocking tendency [17]. Terpineol, extracted from pine tree resin, has shown a higher octane rating than conventional gasoline. The terpineol 30% blend displayed increased combustion peak pressure when compared to gasoline [18]. Biswal et al. [19] and Velavan et al. [20] experimental studies of PFI engine powered by lemon peel oil (LPO) blends have found that the LPO blends improved the combustion characteristics, increased the engine BTE slightly, and reduced the HC, CO emissions when compared to sole gasoline.

It is observed from the literature survey is that no work was reported on Basil oil as a biofuel alternate to gasoline fuel. Therefore, in this work, the Basil oil, extracted from the leaves of Basila plant (Ocimum basilicum L.) has been tried as an alternative by blending it in the gasoline fuel to find out its effects on the engine characteristics of MPFI system installed SI engine. The BO was blended in the sole gasoline in various volume proportions and their impact on the combustion peak pressure, brake thermal efficiency, and harmful emission constituent present in the exhaust gases at various engine load conditions were studied.

II. FUEL PREPARATION AND PROPERTIES

The Basil oil (BO) is extracted from the Basil leaf through the steam distillation process. Basil is a plant that belongs to the annual herbaceous type, it can grow up to a height of 100 cm and is also known as a kitchen herb. It has its native in tropical regions covering from Africa to Asia. The size of the leaves varies with cultivation variety and it is segregated into small and large leaves. In this work, the basil oil was bought commercially from an essential oil manufacturing industry, Chennai.

Table 1a. Fuel properties of gasoline and BO

Properties	Gasoline	Basil Oil
Heating value (MJ/kg)	46.9	40.37
Density @ 20°C (kg/m^3)	744.6	870
Flash point (°C)	-38	72
Viscosity (mm^2/s)	1.04	3.94
Boiling point (°C)	25-215	215
Cetane number	-	12

Table 1b. Fuel properties of BO blends

Properties	BO10	BO20	BO30
Heating value (MJ/kg)	46.51	45.6	44.78
Density @ 20°C (kg/m^3)	743.1	748.3	752.6
Viscosity (mm^2/s)	1.33	1.57	1.86

Initially, a phase separation test was conducted for Basil oil (BO). A 100 ml of BO was taken and blended with 100 ml of sole gasoline using a magnetic stirrer device and the blend was kept in a glass container at room temperature for 14 days. It was found that BO showed good miscible characteristics with gasoline and no phase separation was observed between the gasoline and basil biofuel. Then blends were prepared by taking Basil oil: Gasoline on the ratio of 10:90, 20:80, and 30:70 by volume. The various fuel properties were measured according to ASTM standards for sole gasoline, Basil oil, and BO blends and given in table 1a and 1b respectively.

When comparing the fuel property of basil oil with gasoline, it is found that the calorific value of basil oil is about 84% of that of gasoline. The viscosity of BO is higher than that of gasoline, but the viscosity of the BO blends is under the gasoline engine standards up to 30% blending ratio. The fuel flow restriction will be slightly high for BO blends due to the high viscosity and density nature shown by BO oil. Both factors adversely affect the spray atomization and mixing process. Also, the higher boiling point of BO lowers the evaporation rate. The BO gives a higher flash point compared to gasoline which affects the engine cold start ability. Further, the availability of an O_2 atom in the BO chemical structure improves combustion and reduces emissions. Complete details about the test blend preparations and their designations were given in table 2.

Table 2. Test Fuel Designations

Composition	Designation
100% gasoline	Gasoline
90% gasoline + 10% Basil oil	BO10
80% gasoline + 20% Basil oil	BO20
70% gasoline + 30% Basil oil	BO30

III. GC_MS STUDY OF CAMPHOR OIL

A. Gas Chromatography-Mass Spectroscopy (GC_MS) analysis

The GC_MS analysis for BO was carried out to find the major chemical components present in it. Figure 1 shows the GC_MS analysis of BO and the list of major components present in the BO with corresponding retention time are given in Table 3. The BO shows the presence of oxygen monoterpenes (70.8%), aromatic compounds (11.3%), sesquiterpene hydrocarbon (8.1%), and monoterpene hydrocarbons (2.6%). Monoterpenes have the ability to replace gasoline fuel due to their high energy density and low freezing point. Linalool is the compound present in major quantity in BO which accounts for 51.6%. The presence of oxygenated compounds is an added advantage that improves the combustion process and reduces emissions. The GC_MS study of camphor oil was performed to find out the constituents present in it and it is shown in figure 1. The intensity vs retention time graphs helps to identify the various constituents present in the camphor oil. The key compounds present in the camphor oil are identified and listed in table 3 by matching their corresponding retention time with the compounds present in the mass spectral library. The results showed the strong presence of aliphatic and

aromatic hydrocarbons in the camphor which makes it a potential candidate to partially replace fossil fuel based fuels. ll paragraphs must be indented. All paragraphs must be justified, i.e. both left-justified and right-justified.
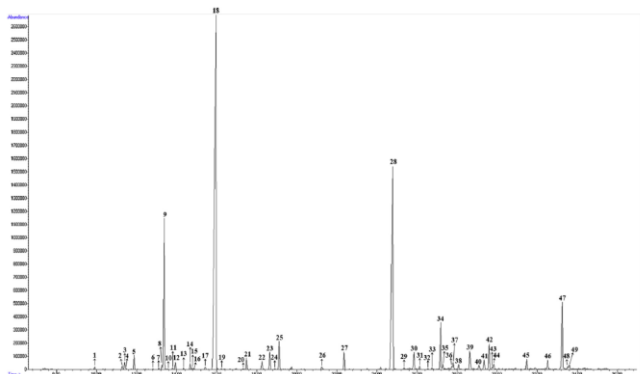

Fig. 1 Camphor oil GC_MS study

Table 3. Key Components present in the Camphor oil

Constituents	Molecular formula	Retention time (min)	%
Linalool	$C_{10}H_{18}O$	18	51.6
1,8-Cineole	$C_{10}H_{18}O$	28	12.7
Eugenol	$C_{10}H_{12}O_2$	9	10.5
Epi-α-Cadinol	$C_{15}H_{26}O$	47	3.0
α-trans-Bergamotene	$C_{15}H_{24}$	34	2.9
α-Terpineol	$C_{10}H_{18}O$	25	2.3
γ-cadinene	$C_{15}H_{24}$	37	1.2
Isobornyl acetate	$C_{12}H_{20}O_2$	42	1.1
Camphor	$C_{10}H_{16}O$	25	1.0
Myrcene	$C_{10}H_{16}$	27	0.9
Germacrene D	$C_{15}H_{24}$	39	0.9
β-Elemene	$C_{15}H_{24}$	30	0.8
δ-Terpineol	$C_{10}H_{18}O$	33	0.7
Spathulenol	$C_{15}H_{24}O$	23	0.6
Total			90.2
Oxygen monoterpenes			70.8
Aromatic Compounds			11.3
Sesquiterpene Hydrocarbon			8.1
Monoterpene Hydrocarbons			2.6
Aliphatic Esters			0.4

B. Fourier Transform Infrared Spectroscopy (FTIR) analysis

The FTIR analysis gives details about the types of chemical bonds present in a substance. Figure 2 depicts the FTIR spectra of Basil oil and Table 4 gives the types of bonds that correspond to the peaks found in the FTIR spectra of BO along with the compound groups they belong to. The peaks 2968.5, and 2919.31, corresponds to stretching and the peak 1450.49 cm-1 corresponds to bending of the C-H bond,

which belongs to the alkane group. The 1640.49, and 1611.55 cm-1 peaks represent the stretching of carbon-carbon double bond (C=C) belongs to the alkene group. The peaks between 1300 and 1100 cm-1 represent the stretching C-O bond, which confirms the oxygen atom availability in the BO. The presence of paraffin (alkane), olefins (alkene), and an aromatic group compound in the BO are significant. This makes BO, a suitable candidate to replace the gasoline fuel partially in a spark ignition engine.
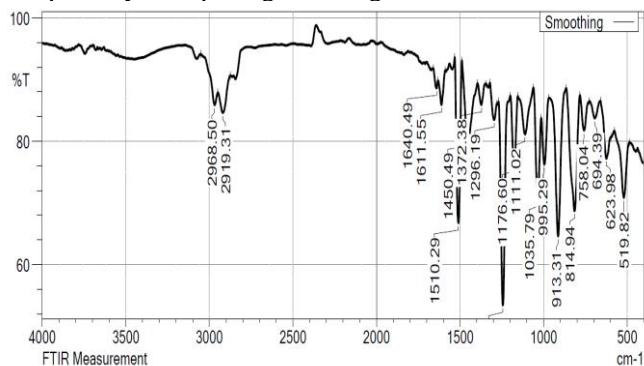

Fig. 2 FTIR analysis of Basil oil

Table 4. Chemical bonds present in the Basil oil

S. No	Peak (cm⁻¹)	Intensity	Type of Bond	Group
1.	519.82	70.85	C-Br stretching	halo compound
2.	623.98	77.20	C-I stretching	
3.	694.39	83.75	- C-H out-of-plane bending vibrations (CH=CH-(cis))	Alkane
4.	758.04	81.77	C-H bending	1,2-disubstituted
5.	814.94	68.70	C-H bending	1,4-disubstituted
6.	995.29	76.26	C=C bending	Alkene
7.	1035.79	70.64	S=O stretching	Sulfoxide
8.	1111.02	81.16	C-O stretching	Aliphatic ether
9.	1176.60	76.32	C-O stretching	Esters
10.	1244.11	53.42	C-O stretching	
11.	1296.19	83.50	C-O stretching	
12.	1372.38	85.93	O-H bending	Phenol

13.	1450.49	80.45	C-H bending	Alkane
14.	1510.29	66.75	N-O stretching	Nitro compound
15.	1611.55	85.94	C=C stretching	Alkenes
16.	1640.49	88.62	C=C stretching	
17.	2919.31	84.63	C-H stretching (CH_2)	Alkanes
18.	2968.50	85.90	C-H stretching (CH_3)	

IV. EXPERIMENTAL SETUP

The experiment was conducted in an MPFI fuel injection system installed spark-ignition engine. The standard fuel injection pressure used was 5 bar. The detailed engine specifications such as bore diameter, stroke length, the compression ratio are given in Table 4. Engine load was varied using an eddy current dynamometer, which was coupled to the engine crankshaft. The butterfly valve mounted in the throttle system was adjusted to maintain an engine speed of 2500 rpm constantly. Fuel consumed per unit time at each load condition was measured with the help of an electronic weighing machine and stopwatch. AVL digas analyzer was used to measure the harmful constituents such as CO, NOx, and HC present in the exhaust gases. The standard engine spark timing corresponds to maximum brake torque at each load condition when fueled by gasoline was set.

The in-cylinder pressure with respect to crank angle position was measured using a pressure transducer and a crank angle encoder. The transducer was installed in the spark plug. The data acquisition system collects the electric signal from the pressure transducer and converts it into digital form. The pressure data were stored in the computer and accessed using "AVL Indicom software". Figure 3 depicts the research engine experimental setup. The uncertainty in the measuring parameters was analyzed and give in table 5.
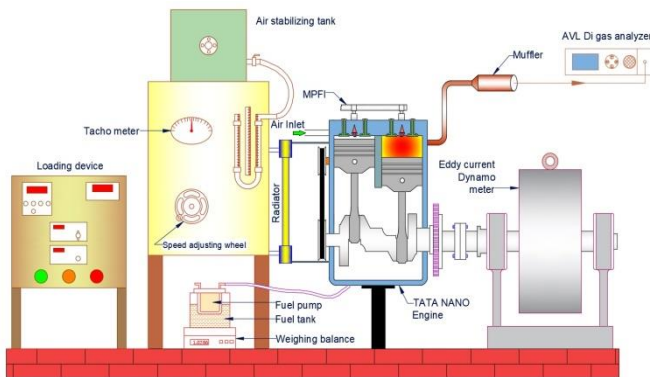

Fig. 3 Research Engine Setup

Table 5. Engine Specifications

Engine type	: Spark Ignition with MPFI system
Engine Bore Diameter & Stroke length	: 73.5 mm (square engine)
Capacity	: 624 cc
r_c	: 9.5
Spark Timing (MBT)	: 23° CA bTDC

*r_c = Compression ratio; MBT = Maximum Brake Torque

V. ENGINE OPERATING PROCEDURE

The engine was started and operated for 15 minutes at a speed of 2500 rpm without any load on the engine. The engine was operated at an atmospheric temperature and humidity of 32°C and 70% respectively. The engine load was varied from 1.6 kW to 8 kW (maximum load) with a step of 1.6 kW. During the conduction of the experiment, the parameters measured are

1. The quantity of fuel consumed by the engine (kg) for a minute
2. Exhaust gas temperature
3. The levels of CO, HC, and NO in the exhaust gas were measured

The exhaust gases present in the di-gas analyzer probe were purged down completely before taking the next reading. The aforementioned parameters were measured three times at each operating condition and the average value was taken for the analysis. The cylinder pressure was measured for 100 consecutive cycles and finally, the values were averaged while exporting the data. The same software automatically calculates the heat release rate from the measured pressure value using the equation derived from the first law of thermodynamics.

Table 6. Uncertainties of Measuring Quantities

Measuring Devices	Measurand	Accuracy	% Uncertainty
AVL Digas Analyzer	Carbon monoxide (CO) Hydrocarbon (HC) Nitrogen Oxide (NO)	± 0.02% ± 05 ppm ± 10 ppm	± 0.2 ± 0.1 ± 0.2
Load cell unit	Load	± 0.1 kg	± 0.2
Magnetic Speed Sensor	Engine Speed	± 10 rpm	± 0.1
Electronic Weighing Machine	Fuel consumption	± 0.002 kg	± 0.2
Stop Watch	Time taken	± 0.1 sec	± 0.1

VI. RESULT AND DISCUSSION
A. Brake Thermal Efficiency (BTE)

Figure 4 shows the trend of the engine BTE for sole gasoline and BO blends at tested brake powers. The common trend observed between the test fuels is that the BTE increases with an increase in engine brake power. This is owing to a rise in in-cylinder temperature with an increase in engine load, which enhances the burn rate and results in better combustion. A steep increase in BTE is observed up to 4.8 kW and then the trend starts to flatten. This is because, a larger quantity of fuel is injected at higher load conditions, which takes more time to form a proper air fuel mixture and does not have enough time for complete combustion [22]. This in turn reduces the combustion efficiency and lowers the steep increase in BTE.

The BO blends showed lesser BTE when compared to gasoline. The BTE of BO10, B20, and B30 at 1.6 kW is 11.85%, 11.45%, and 11.01% respectively whereas, for gasoline, it is 12.49%. At 8 kW, the gasoline, B10, B20, and B30 blends give the BTE of 26.82%, 25.08%, 24.35%, and 23.38% respectively. From the results, it is found that the BTE decreases steadily with the increase in the blending ratio of basil oil in the gasoline at all the tested engine brake powers. The reason is that the high viscosity and density of BO impose a restriction on the fuel flow which leads to the formation of bigger size fuel droplets when compared to droplets formed by gasoline fuel. The bigger droplets take a longer time to evaporate and mix with air. This leads to an improper mixture formation and subsequently affects the combustion process adversely. The impact of adverse effect increases with BO blending concentration in the gasoline. Also, the influence of these inimical effects on the BTE is higher at higher loads due to larger fuel injection quantity. Secondly, the calorific value of BO is lesser than gasoline which also contributes to a significant reduction in BTE for BO blends. Due to the aforementioned reasons, the BTE is lowered for BO blends.
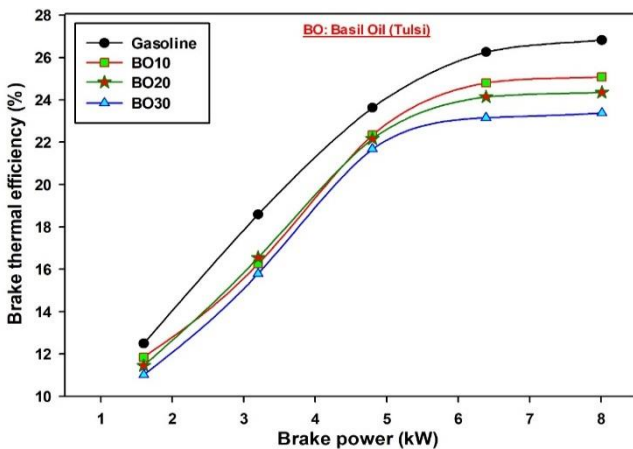

Fig. 4 Brake Thermal Efficiency given by BO blends and gasoline at different brake powers

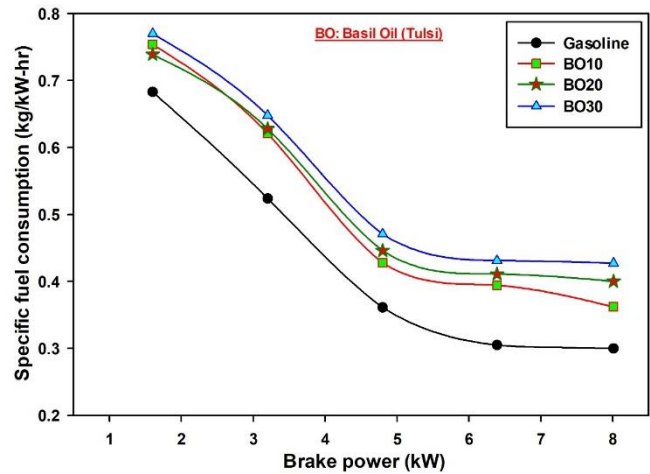### B. Brake Specific Fuel Consumption (BSFC)

Fig. 5 BSFC for BO blends and gasoline at tested brake powers

Figure 5 depicts the variation in BSFC trend for gasoline and BO blends at tested brake powers. A similar trend observed between the test fuels is that the BSFC decreases with an increase in engine brake power. It is also found that the BO blends show higher BSFC when compared to sole gasoline. The BO bends result in a trend of increasing BSFC with an increase in the volume ratio of BO in the gasoline BO blends. At 8 kW, the BSFC of gasoline, BO10, BO20, and BO30 test fuels is 0.3, 0.362, 0.4, and 0.427 kg/kW-hr respectively whereas at 1.6 kW, the same four test fuels give the BSFC of 0.683, 0.754, 0.739, and 0.77 kg/kW-hr respectively. The reason for the increase in BSFC with BO blends is that lower calorific value, higher viscosity, and density of BO when compared to sole gasoline.

The higher viscosity and density nature of BO affects the fuel flow which subsequently affects the fuel atomization adversely. This reduces the evaporation rate and delays the air-fuel mixture formation. This leads to improper combustion and increases the fuel consumption for BO blends. As the research engine used for investigation is installed with a PFI injection system which injects the fuel right behind the intake valve. The high viscosity nature of BO increases the resistance on fuel flow which might results in higher wall film thickness formation, when compared to conventional gasoline fuel, on the intake valve parts where the fuel is injected. Thus, the BSFC for BO blends is higher than the gasoline fuel.

C. Carbon Monoxide Emission (CO)

Figure 6 depicts the variation in CO emission given by gasoline and BO blends at different brake powers. The parameters that primarily control the formation of CO emission are equivalence ratio and temperature. Rich fuel mixture and low temperature are favorable conditions for CO formation. The trend observed with test fuels is that the CO emission falls rapidly as brake power increased from 1.6 to 4.8 kW and later it starts to increase gradually. This because

at low and higher loads the engine runs with a slightly rich fuel air mixture. Also, the turbulence is low at low load conditions whereas at higher loads the mixture does not have enough resident time to oxidize all the CO formed to CO2 during combustion due to the injection of the larger quantity of fuel [21,23].
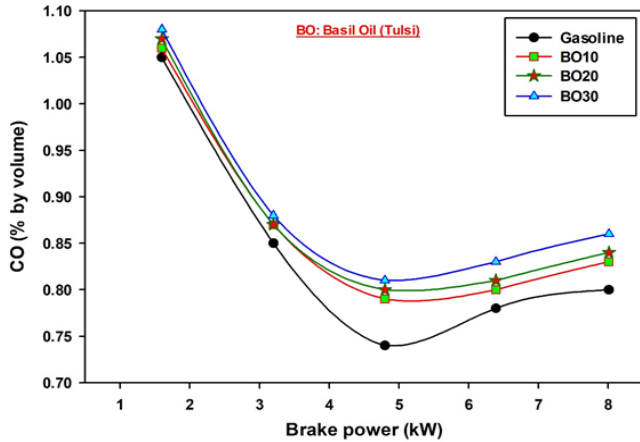

Fig. 6 CO emission of BO blends and gasoline at various brake powers

The BO blends give higher CO emissions compared to gasoline. The CO emission of gasoline, BO10, BO20, and BO30 blends at 8 kW is 0.8%, 0.83%, 0.84%, and 0.86% by volume respectively. At minimum load (1.6 kW), the value of CO emission is 1.05%, 1.06%, 1.07%, and 1.08% by volume for gasoline, BO10, BO20, and BO30 blend respectively. The trend observed with BO blends is that the CO emission increases with an increase in the blending concentration of BO in the gasoline. The formation of locally rich regions owing to improper fuel air mixture caused by the higher viscous and density nature of BO is the most influential factor for the increase in CO emission with BO blends. Though BO shows the presence of oxygen in its molecular structure, its impact on reducing the CO emission is less significant when compared to the adverse impact created by the aforementioned fuel properties of BO.

D. Hydrocarbon Emission (HC)

Figure 7 shows the levels of HC emission observed for gasoline and BO blends at various brake powers. The common causes for HC emissions are flame quenching, crevice volume, and absorption and desorption of fuel from the oil deposits, and incomplete combustion. A similar trend observed for all the test fuels is that the HC emission decreases steeply up to load condition of 6.4 kW and again increases gradually at maximum brake power. This is due to a slightly rich fuel air mixture at the lowest and maximum load condition [24]. This leads to incomplete combustion and results in higher HC emissions. Whereas at medium loads, the Engine runs closer to the stoichiometric ratio which leads to complete combustion. Thus HC emission records lowest at medium load conditions.
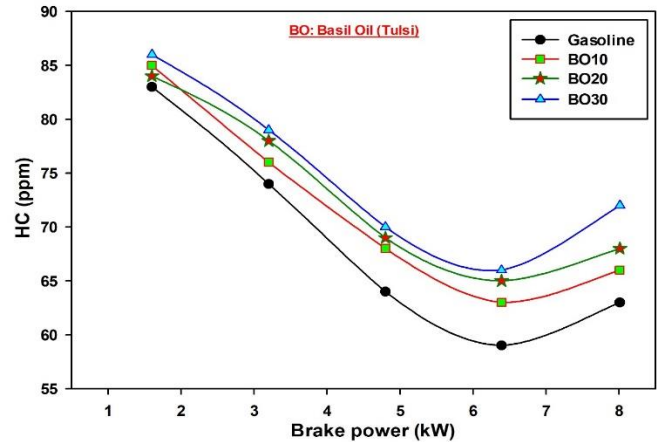

Fig. 7 HC emission given by BO blends and gasoline at various brake powers

The HC emission levels of BO blends are higher than gasoline. The trend found with the BO blends is that the HC emission increases with an increase in basil oil blending ratio in gasoline. At 8 kW, the HC emission of gasoline, BO10, BO20, and BO30 blend is 63, 66, 68, and 72 ppm respectively. Whereas at 6.4 kW, the HC emission is 83, 85, 84, and 86 ppm for gasoline, BO10, BO20, and BO30 respectively. The main reason is that the larger fraction of incomplete combustion observed with BO blends. The higher viscosity and density of BO cause improper air fuel mixture formation [25]. This leads to the formation of local rich regions inside the cylinder which results in partial burning of fuel. Also, the flame speed decreases in the fuel rich mixture which in turn reduces the burn rate and leads to bulk gas quenching. Thus higher amount of HC emission is found with BO blends when compared to gasoline.

E. Nitrogen Oxides Emission (NOx)

Figure 8 depicts the variation in NOx emission observed at different brake powers for gasoline and BO blends. The parameters that primarily control the NOx formation are temperature and oxygen concentration available at the time of the combustion process. It is observed from the NOx emission graph that the emission increases with brake power. The reason behind the rise in NOx is because the increase in in-cylinder temperature with engine brake power. NOx emissions of BO10, BO20, BO30, and gasoline at full load are 263, 293, 318, and 340 ppm respectively. Whereas at 1.6 kW, it is 47, 62, 58, and 75 ppm respectively. The decrease in NOx emission with an increase in BO blend percentage in gasoline is due to incomplete combustion associated with BO blends which in turn reduces the maximum combustion temperature and masks the NO formation. These effects predominate and overcome the effect caused by the inherent oxygen atom available in the chemical structure of BO promotes NO formation.
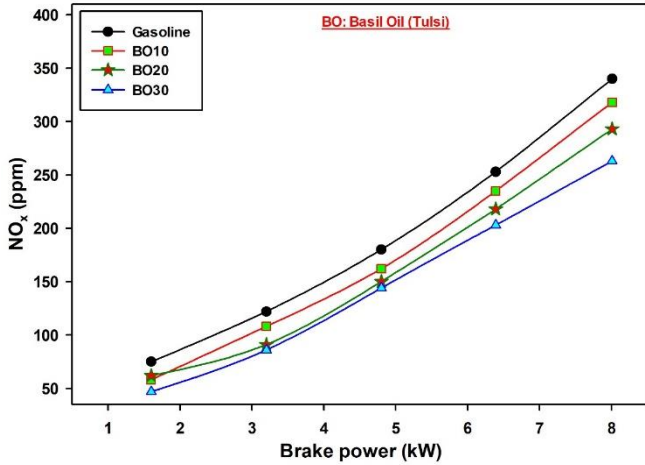
Fig. 8 Trends of NOx for CMO blends and gasoline at various brake powers
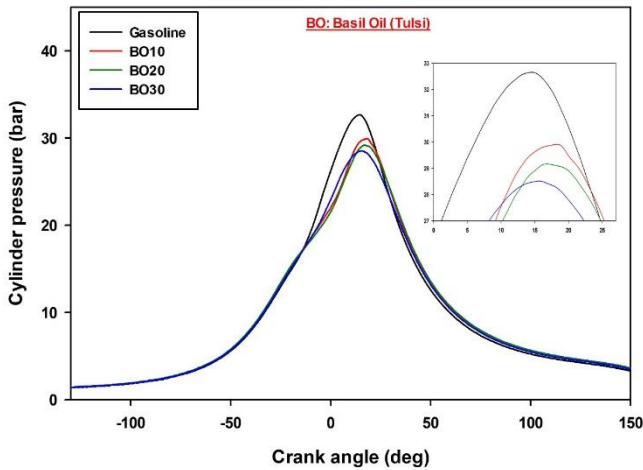
G. Engine Cylinder Pressure

Fig. 9 Engine cylinder pressure at various crank angles for CMO blends and gasoline at 8 kW

Figure 9 shows the cylinder pressure with respect to crank angle for BO blends and gasoline at full load. It is found that the combustion starts early for BO blends than sole gasoline. The reason is that a shorter ignition delay was observed with BO blends. The cylinder pressure decreases with an increase in the proportions of basil oil in the gasoline. The peak pressure is given by gasoline, BO10, BO20, and BO30 is 32.643, 29.907, 29.166, and 28.511 bar respectively. The reduction in-cylinder pressure is because of the high viscosity and density of BO which in turn reduces the mixing rate and results in locally rich fuel air mixture distribution. These fuel rich regions result in a fraction of diffusion flames. The flame speed is limited in diffusion flames due to the rate of diffusion which subsequently lowers the rate of burning and leads to incomplete combustion [24, 25]. Also, the calorific value of BO is lesser than gasoline which lowers the heat energy released during combustion and reduces the cylinder pressure. The crank angle position concerning peak pressure is delayed for all

BO blends. This is due to the slow burning rate associated with BO blends. Also, combustion duration is prolonged for BO blends due to slow burning rate which is evident from figure 8.
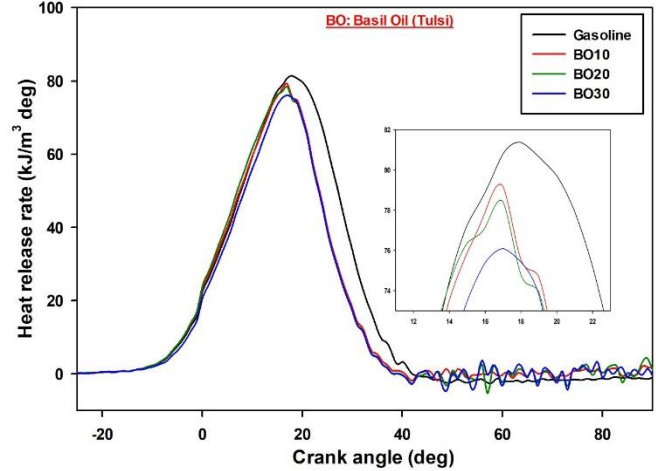
H. Heat Release Rate (HRR)

Fig. 10 Heat release rate at various crank angles for BO blends and gasoline at 8 kW

The heat release rates of gasoline and BO blends at full load are shown in figure 10. It is inferred that the heat release rates are lesser for BO blends than sole gasoline. The value of peak HRR for gasoline, BO10, BO20, and BO30 is 81.37, 79.18, 78.42, and 76.09 kJ/m3.deg respectively. The early start of heat release is observed with BO blends. This is because, BO contains Linalool, which belongs to the alcohol group. The alcohols have faster hydrogen abstract rate, which initiates the combustion early for BO blends [21,23]. The C-H bond, where the OH group is attached, is weak and requires less activation energy. This leads to faster abstraction H atom. The peak HRR crank angle position retarded with an increase in the proportion of BO in the gasoline. The slowing burning rate and incomplete combustion due to improper mixture formation reduce the overall heat release rates for the BO blends [25].

VI. CONCLUSIONS

The fuel properties of the Basil oil are measured to find out its suitability as an alternate fuel to gasoline. Then GC_MS analysis is performed on the extracted Basil oil and the results show the presence of oxygen monoterpene, and aromatic hydrocarbon, which makes it a potential substitute for gasoline. The blend stability test proves that the Basil oil has shown good miscibility and also forms a stable blend with gasoline. Finally, the effect of blending Basil oil in the gasoline on the engine characteristics of a spark-ignition engine is investigated experimentally. The experimental results are enumerated as follows:

1. At maximum load, the BTE given by BO10 is 25.08% which is lower than the BTE of gasoline whose value is 26.82%.

2. The NOx emission decreases whereas CO and HC

increase with the blending ratio of BO in the gasoline.

3. The peak pressure of gasoline and BO10 blend is 32.64, and 29.90 bar respectively and crank angle position corresponds to peak pressure is delayed by 1° CA for the latter when compared to former.

4. Among the BO blends, BO10 gives the maximum heat release rate of 79.18 kJ/m3.deg which is lesser than the gasoline whose value is 81.73 kJ/m3.deg.

Though BO blend results in lesser performance than gasoline, an engine modification such as high-pressure fuel injection, direct injection, piston modification, preheating of fuel to lower the viscosity, and adding an additive to Basil oil blends might improve the engine performance. These improvements can be studied in the future.

REFERENCES

[1] Manoj Babu, C.G. Saravanan, M. Vikneswaran, V. Edwin Geo, J. Sasikala, J.S. Femilda Josephin, D. Das, Analysis of performance, emission, combustion and endoscopic visualization of micro-arc oxidation piston coated SI engine fuelled with low carbon biofuel blends, Fuel. 285 (2021) 119189. https://doi.org/10.1016/j.fuel.2020.119189.

[2] P. Prabhakaran, C.G. Saravanan, R. Vallinayagam, M. Vikneswaran, N. Muthukumaran, K. Ashok, Investigation of swirl induced piston on the engine characteristics of a biodiesel fueled diesel engine, Fuel. 279(2020) 118503. https://doi.org/10.1016/j.fuel.2020.118503

[3] Urdhwareshe R. The Automotive Research Association of India, 2 Wheeler Vehicles : BS VI, (2018) 62.

[4] M. Loganathana, A.Anbarasu. , V.M. Madhavan, K. Arun Balasubramanian, V. Thanigaivelan, M. Vikneswaran, Investigation on the effect of diethyl ether with hydrogen-enriched cashew nut shell (CNS) biodiesel in direct injection (DI) diesel engine, Fuel. 277(2020) 118165. https://doi.org/10.1016/j.fuel.2020.118165.

[5] C. Nandakumar, V. Raman, C.G. Saravanan, M. Vikneswaran, S. Prasanna Raj Yadav, M. Thirunavukkarasu, Effect of nozzle hole geometry on the operation of kapok biodiesel in a diesel engine, Fuel. 276(2020) 118114. https://doi.org/10.1016/j.fuel.2020.118114.

[6] Reşitoğlu2015_Article_ThePollutantEmissionsFromDiese.pdf, (2015).

[7] F.P. Sanchez, A. Bandivadekar, J. German, Estimated cost of emission reduction technologies for LDVs, Int. Counc. Clean Transp. (2012) 1–136.

[8] PTI agency, Drop in petrol, diesel price gap to fuel customers' shift towards petrol, CNG cars: ICRA, Econ. Times.,https://energy.economictimes.indiatimes.com/news/oil-and-gas/drop-in-petrol-diesel-price-gap-to-fuel-customers-shift-towards-petrol-cng-cars-icra/76854112., (2020).

[9] V. Ravikumar, D. Senthilkumar, C.G. Saravanan, V. Edwin Geo, M. Vikneswaran, C. Solaimuthu, J.S. Femilda Josephin, Study on the effect of 2-butoxyethanol as an additive on the combustion flame, performance and emission characteristics of a spark ignition engine, Fuel. 285(2021) 119187. https://doi.org/10.1016/j.fuel.2020.119187.

[10] A.D. Sagar, Automobiles and global warming: Alternative fuels and other options for carbon dioxide emissions reduction, Environ. Impact Assess. Rev. 15(1995) 241–274. https://doi.org/10.1016/0195-9255(95)91707-F.

[11] G. Archer, T. Earl, E. Bannon, J. Poliscanova, N. Muzi, S. Alexandridou, CO2 Emissions From Cars: The facts, Transp.Environ.53(2018). https://www.dbresearch.de/PROD/DBR_INTERNET_EN-PROD/PROD0000000000346332/CO2+emissions+from+cars:+Regul

ation+via+EU+Emissio.pdf.

[12] S. Thiruvenkatachari, C.G. Saravanan, V. Edwin Geo, M. Vikneswaran, R. Udayakumar, F. Aloui, Experimental investigations on the production and testing of azolla methyl esters from Azolla microphylla in a compression ignition engine, Fuel. (2020119448. https://doi.org/10.1016/j.fuel.2020.119448.

[13] C. Bae, J. Kim, Alternative fuels for internal combustion engines, Proc. Combust. Inst. 36(2017) 3389–3413. https://doi.org/10.1016/j.proci.2016.09.009.

[14] O.I. Awad, R. Mamat, O.M. Ali, N.A.C. Sidik, T. Yusaf, K. Kadirgama, M. Kettner, Alcohol and ether as alternative fuels in spark ignition engine: A review, Renew. Sustain. Energy Rev. 82(2018) 2586–2605. https://doi.org/10.1016/j.rser.2017.09.074.

[15] P. Sakthivel, K.A. Subramanian, R. Mathai, Comparative studies on combustion, performance and emission characteristics of a two-wheeler with gasoline and 30% ethanol-gasoline blend using chassis dynamometer, Appl. Therm. Eng. 146(2019) 726–737. https://doi.org/10.1016/j.applthermaleng.2018.10.035.

[16] P.P. Morajkar, G.D.J. Guerrero Penã, A. Raj, M. Elkadi, R.K. Rahman, A. V. Salkar, A. Pillay, T. Anjana, M.S. Cha, Effects of Camphor Oil Addition to Diesel on the Nanostructures and Oxidative Reactivity of Combustion-Generated Soot, Energy and Fuels. 33(2019) 12852–12864. https://doi.org/10.1021/acs.energyfuels.9b03390.

[17] A. Manoj Babu, C.G. Saravanan, M. Vikneswaran, V. Edwin Jeo, J. Sasikala, Visualization of in-cylinder combustion using endoscope in spark ignition engine fueled with pine oil blended gasoline, Fuel. 263(2020). https://doi.org/10.1016/j.fuel.2019.116707.

[18] R. Vallinayagam, S. Vedharaj, N. Naser, W.L. Roberts, R.W. Dibble, S.M. Sarathy, Terpineol as a novel octane booster for extending the knock limit of gasoline, Fuel. 187 (2017) 9–15. https://doi.org/10.1016/j.fuel.2016.09.034.

[19] A. Biswal, R. Kale, G.R. Teja, S. Banerjee, P. Kolhe, S. Balusamy, An experimental and kinetic modeling study of gasoline/lemon peel oil blends for PFI engine, Fuel. 267 (2020)117189. https://doi.org/https://doi.org/10.1016/j.fuel.2020.117189.

[20] A. Velavan, C.G. Saravanan, M. Vikneswaran, E. James Gunasekaran, J. Sasikala, Visualization of in-cylinder combustion flame and evaluation of engine characteristics of MPFI engine fueled by lemon peel oil blended gasoline, Fuel. 263(2020) 116728. https://doi.org/10.1016/j.fuel.2019.116728.

[21] G. Kasiraman, B. Nagalingam, M. Balakrishnan, Performance, emission and combustion improvements in a direct injection diesel engine using cashew nut shell oil as fuel with camphor oil blending, Energy. 47(2012) 116–124. https://doi.org/10.1016/j.energy.2012.09.022.

[22] V.E. Geo, D.J. Godwin, S. Thiyagarajan, C.G. Saravanan, F. Aloui, Effect of higher and lower order alcohol blending with gasoline on performance , emission and combustion characteristics of SI engine, Fuel. 256(2019) 115806. https://doi.org/10.1016/j.fuel.2019.115806.

[23] M. Vikneswaran, C.G. Saravanan, J. Sasikala, Endoscopic visualization of combustion flame to study the effect of 1,4-dioxane as an additive on the spatial flame characteristics of spark ignition engine, Fuel. 276(2020) 118072. https://doi.org/10.1016/j.fuel.2020.118072.

[24] D. Jesu Godwin, V. Edwin Geo, S. Thiyagarajan, M. Leenus Jesu Martin, T. Maiyalagan, C.G. Saravanan, F. Aloui, Effect of hydroxyl (OH) group position in alcohol on performance, emission and combustion characteristics of SI engine, Energy Convers. Manag. 189(2019) 195–201. https://doi.org/10.1016/j.enconman.2019.03.063.

[25] R. Narayanamoorthy, S. Sivaprakasam, P. Sivaraj, Experimental Analysis of Engine Characteristics of Spark Ignition Engine Fuelled By Low Cetane Fuel, International Journal of Engineering Trends and Technology. 68(2020) 58-65. doi:10.14445/22315381/IJETT-V68I12P211.