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Abinash Biswal
Indian Institute of Technology Hyderabad


B. Ashok
VIT University


Saravanan Balusamy
Indian Institute of Technology Hyderabad

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Experimental Investigation of Lemon Peel Oil-Gasoline Blends as a Fuel in Spark Ignition Engine

Abinash Biswal
IIT Hyderabad, Kandi-502285, India
Email: me14m16p000001@iith.ac.in

Shashi Shankar Jha
IIT Hyderabad, Kandi-502285, India
Email: jhashankariith@gmail.com

Ashok Bragadesh
VIT University, Vellore-632014, India
Email: ashok.b@vit.ac.in

Nanthagopal Kasianantham
VIT University, Vellore-632014, India
Email: knanthagopal@vit.ac.in

Pankaj S Kolhe
IIT Hyderabad, Kandi-502285, India
Email: psk@iith.ac.in

Saravanan Balusamy
IIT Hyderabad, Kandi-502285, India
Email: saravananb@iith.ac.in

Abstract
The present study is to investigate the suitability of lemon peel oil as a partial substitute to conventional gasoline. Lemon peel oil is a novel alternative biofuel derived from fresh lemon rinds. In this work, lemon peel oil is blended with gasoline at concentrations of 10% and 20% by volume. Then, a comparative analysis of performance and emission characteristics are evaluated in a single cylinder, four stroke, spark ignition engine at a constant speed for neat gasoline and biofuel blends under various loads. The result shows a marginal increase in brake thermal efficiency at lower loads for biofuel blends. However, the cyclic variability is very high at part load conditions. The unburnt hydrocarbon emission is reduced, but the carbon monoxide emission is increased little when the engine is operated with blended fuel as compared to sole gasoline. At full load, the performance of blended fuels is similar to the gasoline.

Keywords: *Lemon peel oil; Biofuel; Gasoline blends; SI engine performance; Coefficient of Variation*

I. INTRODUCTION

The dependency of the fossil fuel resources and the necessity of reducing the greenhouse gas emission are the driving factors to look for the renewable fuel sources[1]. Alternative fuels derived from biomass are the attractive options for the possible replacement of fossil fuels in the transportation segment [2], [3]. Many comprehensive studies have been done with different alcohols under various compositions in SI engines around the globe in the past one decade [4], [5]. Ashok et al. [6] used a novel, renewable biofuel for diesel engine applications, which was extracted from lemon peel through a steam distillation process. This biofuel has unique features of low viscosity and low cetane rating. The experimental results indicated that the diesel engine operation with 100% lemon peel oil improved the brake thermal efficiency and reduced the fuel consumption.

In the current scenario, the production of alternative fuels from renewable energy sources for SI engine applications would be the top most priority and the present need also. Notably, the biofuel obtained from the lemon peel has been the source of attention due to its abundant availability and many suitable properties such as low viscosity and low boiling point for SI engine applications. However, the suitability of lemon peel oil in SI engine has not been studied so far. This has motivated us to investigate the effect of lemon peel oil on gasoline engine characteristics under various operating conditions. Initially, lemon peel oil is blended with gasoline at concentrations of 10% and 20% by volume and these blends are named as LPO10 and LPO20. The performance, combustion and emission characteristics of SI engine have been assessed for the two biofuel blends and the results are compared with conventional gasoline. The entire investigation is performed at various engine load conditions.

II. LEMON PEEL OIL PRODUCTION AND FUEL PREPARATION

In the present work, a steam distillation process is employed for the extraction of lemon peel oil (LPO) from waste lemon peels [6]. The LPO is blended with gasoline by 10% and 20% on volume basis. The properties of the LPO is given in Table 1. The density and kinematic viscosity of the LPO are comparatively higher than gasoline. The calorific value of LPO is slightly lower than gasoline, which may influence in fuel consumption for achieving the same power output.

Table 1: **Properties of Gasoline and LPO**

Properties	Gasoline	LPO100
Density @ 15°C (kg/m^3)	737	853
Kinematic viscosity @ 40°C (cSt)	0.67	1.06
Lower calorific value (MJ/kg)	44	41.51
Research octane number (RON)	87	80

Table 2: **Specifications of the test engine**

Make	Kirloskar TV1
Bore × Stroke	87.5 mm × 110 mm
Connecting rod length	234 mm
Cubic capacity	662 cm^3
Compression ratio	10: 1
Cooling medium	Water cooled
Rated power	4.5 kW @ 1800 rpm

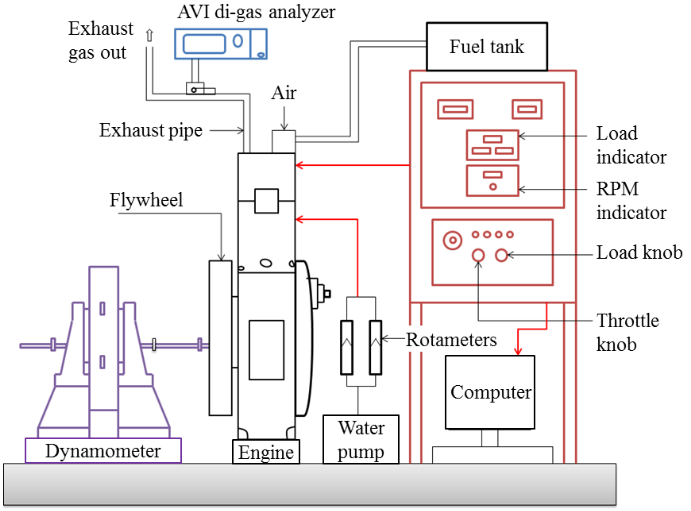

Figure 1: **Schematic representation of the engine setup**

III. EXPERIMENTAL SETUP

The engine used for the present investigation is a single cylinder, four stroke, vertical, water-cooled, variable compression ratio and carburetor-mode SI engine, which is connected to eddy current dynamometer for loading tenacity. The engine setup is provided with necessary instruments for combustion pressure and crank-angle measurements (Fig. 1). The technical specifications of the gasoline engine are listed in Table 2. In the present research work, AVL Digas 444 exhaust gas analyzer is used to measure the relative volumes of certain gaseous constituents in the exhaust gases. Initially, the spark ignition engine is fueled with gasoline and then operated with LPO blends. Each experiment is carried out three times at each condition and the error bar was plotted in terms of $\pm 1\sigma$ standard deviation. For each operating condition the spark timing was fixed at 18^0 BTDC.

IV. RESULTS AND DISCUSSION

A. Brake thermal efficiency

The brake thermal efficiency (BTE) is an indication of how effectively the available chemical energy of fuel is transformed to mechanical work at the crankshaft. For constant speed engine, BTE is directly depends on the fuel consumption and lower calorific value. The variation of BTE with brake mean effective pressures (BMEP) for various blends of LPO and neat gasoline fuel is depicted in Fig. 2. The BTE of all tested fuels increase with the increase of engine load. At lower BMEP, LPO10 has the maximum efficiency value but at higher BMEP the gasoline results are better. This trend is due to the vaporization of LPO fuel during the compression stroke, which provides the charge cooling effect thus reducing the compression work [7], [8].

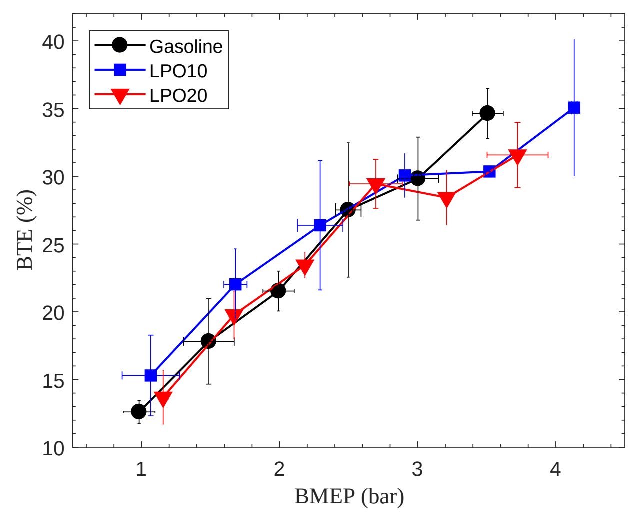

Figure 2: **Variation of brake thermal efficiency with brake mean effective pressure.**

B. Incylinder pressure

The variation of pressure inside the cylinder with respect to crank angle is shown in Fig. 3. The pressure values are averaged over 50 cycles and mean values are plotted. As the engine load increased from 30% to 60%, the throttle valve opening for test fuels also increased to support the increased engine load due to the increase in need for more airfuel mixture. As noted from Fig. 3, the incylinder gas pressure is comparatively higher for LPO10 and LPO20 fuel blends especially at high engine load.

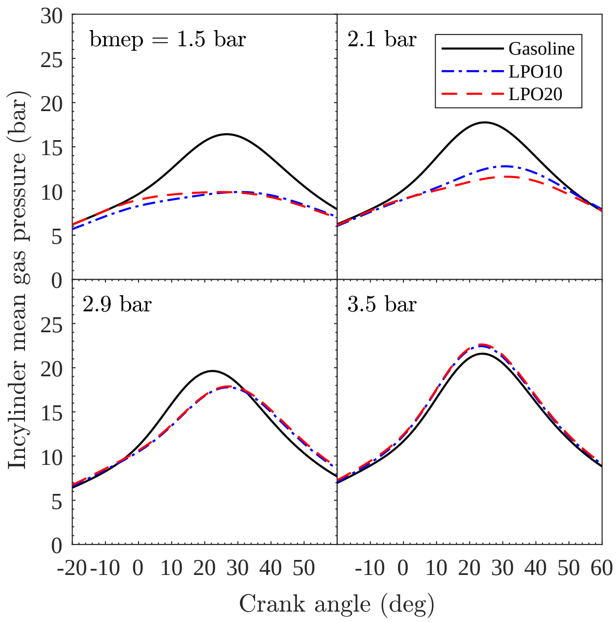

Figure 3: Variation of incylinder mean gas pressure with crank angle for various load conditions.

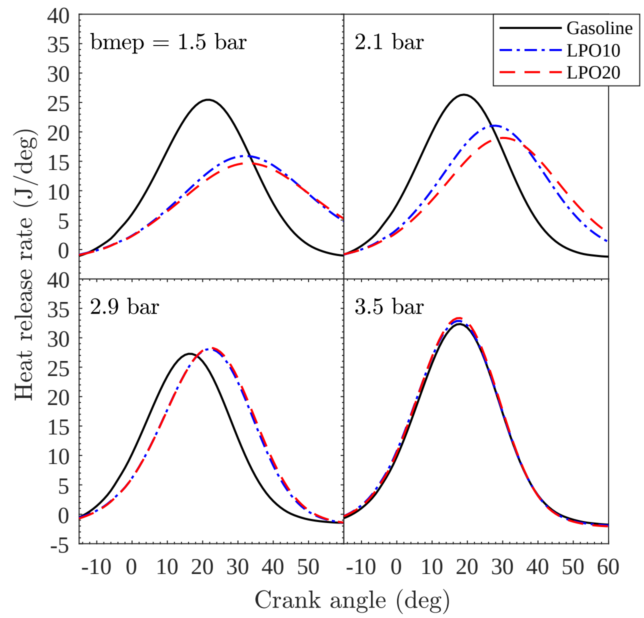

Figure 4: Variation of heat release rate with crank angle for various load conditions.

C. Heat release rate

Heat release rate is calculated based on first law of thermodynamics. The heat release rate is evaluated from the engine cylinder pressure data with respect to crank angle using the following equation:

$$\frac{dQ_{net}}{d\theta} = \frac{\gamma}{\gamma - 1} p \frac{dV}{d\theta} + \frac{1}{\gamma - 1} V \frac{dp}{d\theta} \quad (1)$$

where, p is the incylinder gas pressure, V is the instantaneous cylinder volume and γ is the ratio of specific heat for ideal gas. The variation of heat release rate with respect to crank angle for different test fuel at various BMEP is shown in Fig. 4. At lower BMEP, the peak heat release rate of LPO blends comes after that of gasoline and their values are much lower than that of gasoline. However, at higher BMEP, the LPO blends peak heat release rate point is same as to that of gasoline and the curve is also similar.

D. Coefficient of variation (COV)

In the combustion chamber of an SI engine, variations of pressure exist between the consecutive cycles. One important measure of cyclic variability, derived from pressure data, is the coefficient of variation (COV) for the indicated mean effective pressure (IMEP). It is the standard deviation in IMEP divided by the mean IMEP, and it is usually expressed in terms of percentage. When COV of IMEP exceeds more than 5%, then problem starts in running the engine. Figure 5 shows the COV of IMEP at various engine loads. It is noted from the figure that the LPO blends are advisable for engine running at full load conditions, but not for part load operations due to the poor fuel-air premixing before the combustion takes place inside the cylinder.

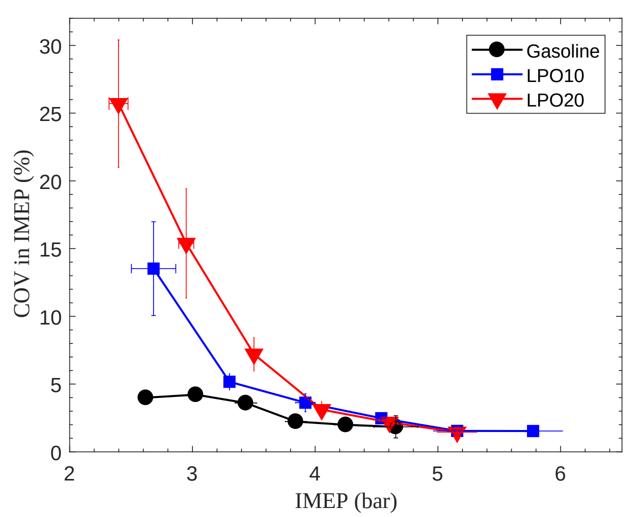

Figure 5: Coefficient of variation in indicated mean effective pressure of fuel blends.

E. Carbon monoxide emission

In Figure 6, the variation of CO emission with BMEP has been shown for all tested fuels. The CO emission is in decreasing trend for all tested fuels at all BMEPs. However, the CO emission for blended fuel is more than that of gasoline fuel. The reason could be the insufficient availability of oxygen in case of blended samples during the combustion process due to the poor fuel-air mixing.

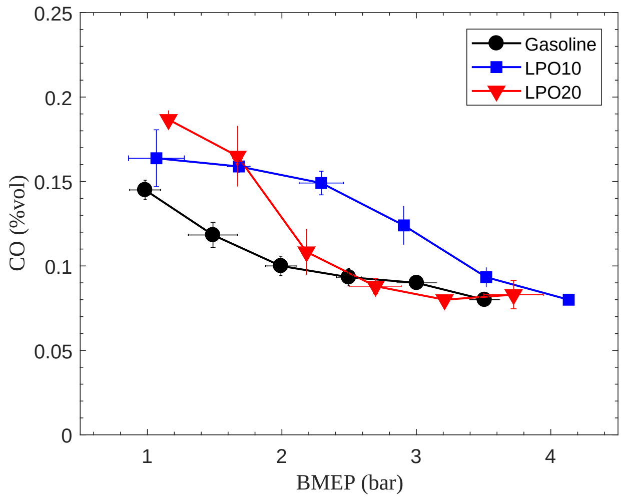

Figure 6: **Variation of carbon monoxide emission with brake mean effective pressure.**

F. Unburned hydrocarbon emission

The unburned hydrocarbon in the exhaust tail pipe originates from various sources such as improper mixing of fuel-air, poor air entrainment, and formation of a number of rich zone regions. Figure 7 shows the variation of unburnt hydrocarbon emission with BMEP. The HC emission is higher for gasoline as compared to the fuel blends at all engine load conditions. This trend could be due to the late combustion phase of fuel blends that reduces the contribution of HC from crevice regions and the post oxidation of unburned HC during the exhaust stroke.

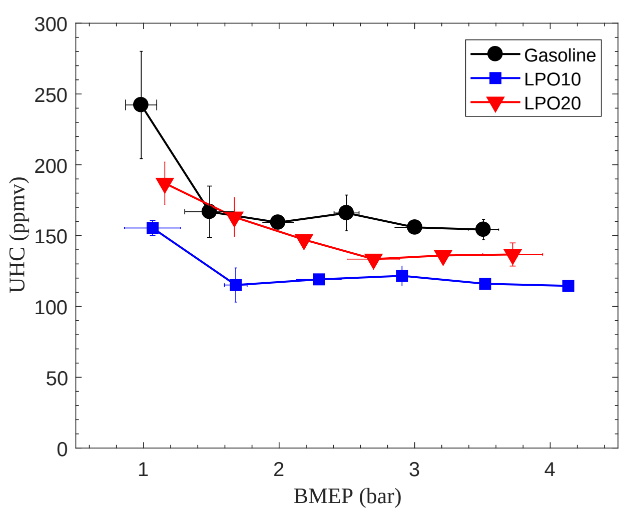

Figure 7: **Variation of unburned hydrocarbon emission with brake mean effective pressure.**

V. CONCLUSION

The following conclusions have been drawn from the present experimental work on Lemon peel oil-gasoline blends:

- The SI engine operation with LPO blends has shown comparable BTE for all loading conditions.
- The COV of IMEP is well within 5% at full load condition, which clearly indicates the stable operation. However, cyclic variability is very severe at part load engine operations due to the poor fuel-air premixing before combustion takes place.
- The incylinder gas pressure and heat release rates of LPO blends are almost equal to gasoline at full load.
- HC emission is lower for LPO blends than that of gasoline. However, CO emissions showed the inverse trend with LPO blends.

From the investigation, the LPO would be viable and feasible renewable biofuel for the partial substitution of gasoline fuel in SI engine.

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