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Research article

Effect of electrochemical conversion of biofuels using ionization system on CO_2 emission mitigation in CI engine along with post-combustion system

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ABSTRACT

Global warming caused by greenhouse gas emission is a major threat in recent times. Carbon dioxide (CO_2) is a major source of greenhouse gas emission from CI engine. The present study aims to investigate the effect of pre-combustion, oxygenate and post-combustion system with biofuel blends in single cylinder CI engine on CO_2 emission. All the experiments were conducted in a single cylinder CI engine with 5.2 kW rated power at 1500 rpm at 50% and 100% load. Diesel is replaced with Karanja oil methyl ester (KOME) and both are taken as baseline data. Low carbon biofuel namely orange oil (ORG) was blended on an equal volume basis with KOME and tested. Zeolite based post-combustion capture system (ZPCS) and fuel ionization filter (FIF) as pre-combustion capture system was tested along with 20% methanol (M) blend with KOME-ORG. FIF electrochemically ionizes the fuel molecules and aids in quick dispersion of the ions for improved combustion. Hydrocarbon based biofuels are converted to carbon, hydrogen and oxygen ions, where hydrogen takes part in combustion and oxygen enhances the combustion process. At 100% load, CO_2 emission for KOME-ORG + M20 + FIF + ZPCS is 68% less compared to KOME. The combination also reduces NO and smoke by 48% and 51% compared to KOME at 100% load. The combined effect of FIF, ZPCS and methanol aided in the simultaneous reduction of NO, smoke and CO_2 emission.

1. Introduction

Carbon dioxide (CO_2) is unregulated emission indirectly affecting the ecosystem by causing 'global warming.' In India, due to increased population of diesel-fuelled vehicles, the CO_2 emission is five times higher compared to gasoline-fueled vehicles. The adverse effects of these pollutants include severe health issues on human and atmosphere like acid rain, global warming, ozone depletion, and nutrition enrichment [1]. Intergovernmental Panel of climate change (IPCC) forecasted an increase of 1–2 °C earth's surface temperature by 2020 and 2–5 °C by 2070. The IPCC also predicted that Asia would experience a rise in temperature, longer summer heat spell, increase in extreme rainfall and an increase in sea levels in coastal areas around Indian ocean, northern and southern Pacific ocean [2]. One of the popular methods to mitigate CO_2 emission is by replacing conventional fossil fuel with biofuels because it is carbon-neutral.

In India, non-edible biofuels like Jatropha, Karanja and Mahua are available in abundant without much commercial application [3]. Jatropha and Karanja biodiesel are 'second-generation fuels' because of their innate ability to grow even in a wasteland with the minimum water requirement [4]. The present yearly production rate of Karanja oil is 200 t (metric tons) with only about 6% utilization by villagers for daily activities [5]. The authors also discussed some of the improved methods of oil extraction from seeds and converting the raw oil to biodiesel. Many researchers [6–12] conducted experiments using karanja oil biodiesel as fuel in diesel engine and concluded that karanja oil biodiesel is a good replacement for diesel fuel to meet the energy crisis. Chauhan et al. [8] compared performance, emission and combustion characteristics of karanja oil biodiesel and diesel blends in single cylinder CI engine with diesel. They concluded that NO and CO_2 emissions were higher with karanja oil biodiesel with a reduction in smoke emission. Suresh et al. [10] observed similar results and they concluded an increase in NO and CO_2 emission with karanja oil biodiesel due to the presence of oxygen and higher carbon content. Lokesh et al. [13] investigated life cycle assessment of Pongamia (Karanja) biodiesel production and concluded that on an average 2.5 tons of CO_2 is absorbed by 1 ha of plantation per year. They have also stated that one-hectare plantation yields approximately 100 kg of crude karanja oil. The authors of the current research studied the effect of low-carbon biofuels on CO_2 emission in a karanja oil methyl ester fueled CI engine, as a full trial test in the laboratory [14]. Low carbon fuels like eucalyptus oil, pine oil, orange oil and camphor oil were blended on an

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Nomenclature

KOME	Karanja oil methyl ester
NO	nitrous oxide
CO_2	carbon-di-oxide
ZPCS	zeolite based post-combustion capture system
TDC	top dead center
CI	compression ignition
ORG	orange oil
KOME-ORG	Karanja oil methyl ester + orange oil (50–50)
M	methanol
rpm	revolutions per minute
FIF	fuel ionization filter
HC	hydrocarbon
CO	carbon mono oxide
KOME-ORG + M20	Karanja oil methyl ester + orange oil + methanol (40-40-20)

equal volume basis with KOME. The trials revealed that KOME and orange oil (50–50) blend emitted less CO_2 emission compared to other low-carbon biofuel blends with KOME. The results also showed a marginal reduction in smoke emission and an increase in NO emission for the blend compared to KOME.

The present authors also studied the various post-combustion capture system with KOME-ORG blend [15]. Activated carbon, zeolite and mono ethanolamine based post-combustion capture system were tested with KOME-ORG blend. The tests revealed that KOME-ORG + zeolite emitted minimum CO_2 among the other post-combustion capture system and also aided in the simultaneous reduction of NO and smoke emissions.

A trial test was conducted with a similar engine to identify the optimum oxygenate emitting minimum CO_2. Tests were carried out with blending methanol, ethanol, n-butanol, n-pentanol and acetone 20% by volume with KOME-ORG blend. Tests showed that KOME-ORG + M20 emitted minimum CO_2 among the oxygenates tested and hence taken for this study. Many researchers have studied the effect of using methanol in CI engine with diesel/biodiesel using various methods like blending, emulsification and fumigation [16–22]. They observed that methanol has great potential in reducing CO_2, NO and smoke emission simultaneously from CI engine because of its unique combination of low carbon content and high latent heat of vaporization.

Electro chemical conversion of fuel technique based on magnetic ionization was identified from the literature and tested as a pre-combustion treatment system. Very few studies were done using fuel ionization using magnetic field. Fuel ionization enhances the mixing of air and fuel molecules and subsequently reducing fuel consumption and CO_2 emission [23–27]. All the studies deal with using permanent magnet in fuel line/pump to reform the incoming fuel improved combustion.

Patel. P M et al. [23] and Okoronkwo et al. [24] studied the effect of the electromagnetic field on the ionization and combustion of fuel in a single cylinder CI engine. The permanent magnets were placed in the fuel line with diesel as base fuel. They observed significant reduction in harmful emissions like HC, CO and smoke. They also observed a reduction in fuel consumption due to improved mixing of ionized fuel molecules with air.

Al Ali et al. [25] conducted experiments using magnetic ionization technique in ten different cars. Magnets were first placed in the fuel tank and another magnet in the fuel line. They observed that compared to base diesel, HC emissions were reduced by 70% and NO emission was reduced by 68%. Brake specific fuel consumption was reduced by about 18% with magnetic ionization compared to diesel. The study showed that magnetic treatment of fuel reduced fuel consumption and rate of emission to the atmosphere.

Most of the previous studies carried out with using magnetic fuel ionizers were confined to magnetization of fuels in fuel line/pump. To date, no works were reported with ion exchange along with magnetization as fuel reforming technique with emphasis on CO_2 emission. The main objective of the study is to reduce CO_2 emission from CI engine using pre-combustion, oxygenate and pre-combustion system with biofuel blends. KOME was identified to replace diesel, blending orange oil with KOME reduces CO_2 emission. Oxygenate namely methanol was blended 20% by volume with KOME-ORG blend along with zeolite based post-combustion capture system and pre-combustion treatment system. The effects of these methods on performance, emission and combustion characteristics were also studied.

The novelty of this work is studying the effect of ion exchange using biofuel blends in CI engine to reduce CO_2 emission. This work is an improvement in existing literature, which deals with both magnetization and ion exchange effects on performance, emission and combustion of biofuel blends in CI engine.

2. Materials and methods

2.1. Test fuels

For this study, diesel and KOME form the baseline reference fuel. Orange oil, identified as low carbon biofuel was blended with KOME on an equal volume basis. The blend was made and observed for phase separation for 8 h and no phase separation was found. Oxygenate namely methanol was blended 20% by volume with equal volume KOME-ORG blend. Transparency test was done for KOME-ORG + M20 to check the miscibility of methanol in the blend. Table 1 shows the physicochemical properties of diesel, KOME, orange oil, methanol, KOME-ORG and KOME-ORG + M20.

KOME has a higher number of carbon atoms, higher density and viscosity and less calorific value compared to diesel fuel. Orange oil has only half number of carbon atoms compared to KOME and has low density and viscosity compared to KOME. Methanol has lower cetane number and hence the blend is limited to 20% with KOME-ORG. Methanol has unique combined property of high latent heat of vaporization and low carbon content which makes it suitable for the simultaneous reduction of NO and smoke.

2.2. Test engine

For experimentation, a single cylinder, water-cooled, four-stroke, direct injection, compression ignition engine, which develops 5.2 kW power at 1500 rpm coupled with eddy current dynamometer was used. The engine has a hemispherical combustion chamber with overhead valves. The cylinder head of the engine was modified to install a

Table 1
Properties of diesel, KOME, orange oil and methanol.

Property	Diesel	KOME	Orange oil (ORG)	Methanol
Molecular formula	$C_{14}H_{28}$	$C_{20}H_{36}O_2$	$C_{10}H_{20}O$	CH_3OH
Kinematic viscosity, cSt @ 40 °C	3.6	4.9	3.5	0.59
Density @ 15 °C, g/cm^3	0.840	0.858	0.816	0.792
Lower heating value kJ/kg	42,700	41,200	34,650	19,700
Cetane index	45–55	49	47	5
Flash point, °C	74	135	74	11
Latent heat of vaporization (kJ/kg)	250	< 230	–	1100