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A numerical and experimental assessment of a coated diesel engine powered by high-performance nano biofuel

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ABSTRACT

The main aim of the present research is to effectively utilize the biofuel along with nano additive (Cymbopogon flexuosus biofuel with cerium oxide) powered with a coated and uncoated diesel engine. The work is further extended to study the thermal–stress analysis of the coated engine, to empathize the physical mechanism underlying the impact of coated engine on the engine behavior. In connection with this, for the present work, a novel biofuel and oxygenate additive was preferred. Biofuel- Cymbopogon flexuosus was extracted through the steam distillation technique and oxygenate additive - cerium oxide nano additive was synthesized using combustion technique. Focusing on the coating material, YSZ (Yttria-stabilized zirconia) is preferred, as it is highly used in the high-temperature application and were evaluated based on the thermal–stress analysis. From the simulation study using FEA (finite element analysis), the average temperature, and thermal stress were higher and heat flux, were noted to be lower for coated piston, confirming the substantial improvement in thermal efficiency in the experimental study. As a next step, YSZ was coated on the engine piston, valves and cylinder head by plasma spray coating technique. From the experimental assessment of test samples such as D_{100}, B_{100}, B_{25}, in a uncoated engine and B_{25} + (A) - Cymbopogon flexuosus biofuel – 25% and diesel – 75% + 20 ppm cerium oxide nano additive) in a coated and uncoated engine. It was identified that the thermal efficiency of the engine was enhanced by 1.75% as on compared with the conventional engine for the modified fuel blend. In the emission point of view, fuel-based emissions such as hydrocarbon; carbon monoxide and smoke were reduced with a penalty of increased oxides of nitrogen emission.

1. Introduction

The current scenario world is clambering with two main trouble such us fossil fuel demand and environmental emission scarcity [1]. In this regard, a better way to overcome this crisis is to find an alternate energy for the petroleum-based fuels [2]. Among the non-renewable fuel competitors, biofuel is leading its rivals to substitute fossil fuels in the transportation sector for cross over the fuel and emission scarcity. Recent day's biofuel has been earning more attention owing to their cunning characteristics namely renewability in nature and greener emission [3]. Many numbers of positive points listed when biofuel consider as an alternate transport fuel namely mass availability, eco-friendly, renewable, biodegradable and sustainability [4].

In particular, researchers are concentrating on the biofuel derived from the agricultural fermentation, biological waste regeneration, and biomass especially. It can be used in a conventional diesel engine without any major modification that emits minimal toxic emission except for nitrogen oxide [5]. Biofuels are also alcohols, which need certain engine modification for its optimal running condition in the diesel engine. In the circumstance of nonrenewable petroleum-based fuel scarcity, all around the world, a number of research works have been done with vegetable oil, biomass, animal fats, waste cooking oil and biofuel [6]. Many of the researchers proved using biofuel in CI (Compression Ignition) engine resulted in reduced efficiency due to minimal calorific value caused by lower hydrogen and availability of the oxygen in biofuel. Interestingly, exhaust emission was reduced because of oxygen content in biofuel compared with diesel fuel [7]. Researcher Dhinesh et al performed a study on a naturally aspired diesel engine using Cymbopogon flexuous biofuel. From their observation, they concluded that B20 blend had higher efficiency and better fuel economy than other blend but it lies lower than diesel fuel [8]. Sanjid et al. analyzed the impact of palm, mustard, waste cooking oil and Calophyllum inophyllum on compression ignition engine. From their observation, they concluded that mustard oil biofuel resulted in reducing the oxide of nitrogen than another biofuel [9]. Researcher Kezrane Cheikh et al. tested their conventional engine powered with the blend

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Nomenclature

YSZ	Yttria-stabilized zirconia
FEA	Finite Element Analysis
CI	Compression Ignition
TBC	Thermal Barrier Coating
LHR	Low Heat Rejection
BP	Brake Power
BTE	Brake Thermal Efficiency
BSEC	Brake Specific Energy Consumption
CA	Crank Angle
CO	Carbon Monoxide
HC	Hydrocarbon
NO_x	Oxides of Nitrogen
Ppm	Parts per million
TDC	Top dead Centre
ASTM	American Society for Testing and Materials
RPM	Rotation per minute
FTIR	Fourier-transform infrared spectroscopy
HSU	Hartridge Smoke Unit
FEA	Finite Elemental Analysis
PSZ	Partially Stabilized Zirconia
DOF	Degree of Freedom

of waste cooking oil and they report that a 100% wco blend earned higher in-cylinder pressure than diesel fuel owing to shortened the ignition delay for the addition of biodiesel [10]. It was concluded that the direct usage of biodiesel in conventional engine, has certain negative impact such us higher fuel consumption, lower thermal efficiency, less cloud and pour point and higher nitrogen oxide to overcome this negative points the easiest way is the adulteration of fuel by adding additives such us oxygenated additives, anti-oxygenated additive and nano additives [11].

It is identified that the usage of the oxygenated additives affirmed to ignite the fuel more expeditiously and diminish engine exhaust pollution drastically [12]. The addition of Butylated hydroxytoluene and n-butanol antioxidant additive with waste cooking oil diminished the NOx emissions, because the antioxidant additive has the capability to quench the free radicals throughout combustion phase by Senthur Prabu [13]. Vijayakumar Chandrasekaran et al. reported that on experimenting copper oxide as a nano additive [50 ppm] with B20 of Mahua oil in a diesel engine would reduce the incomplete combustion products, and enhance the cold start and thermal efficiency. Nevertheless, to employ the copper oxide nano additive in fossil fuel engine may cause negative consequences, enhanced the rate of fuel consumption and nitrogen oxides emission was discovered [14]. It was identified that the engine resulted in higher power output on using the anti-oxidant [15], metal-based fuel born additives [16] namely iron, copper, cerium, and platinum, and it encourages the fully complete combustion [17].

The majority of the investigator have proved that thermal insulation can reduce the heat transfer rate and improve the thermal efficiency and the heat availability in the engine exhaust [18]. The low heat rejection engine makes use of various ceramic coatings materials such as Mullite, TiO_2, Al_2O_3, $MgO–ZrO_2$, YSZ and etc. It can be coated on the piston, cylinder parts and valves. Among which the partially stabilized zirconia (6–9% yttria stabilized Zirconia) was mostly used especially for Thermal Barrier Coating (TBC) material due to its demonstrated greater performance and its ability to withstand high temperature [19]. The researcher Bahattin İşcan et al., studied the influences of low heat rejection concept using waste vegetable oil on compression ignition diesel engine. From the observation, they found that higher power and torque of the engine was obtained with the simultaneous reduction of the engine emission except for NOx emission [20]. On the experimental investigation with the fly ash-coated low heat, rejection engine powered by rice bran methyl ester and Pongamia methyl ester and its blend 20% by volume basis. The test result exhibited lower fuel economy and higher power out and as well as improved the engine exhaust except for oxide of nitrogen reported by Mohamed Musthafa [21]. Low Heat Rejection (LHR) engines had one added advantage it aided to effectively utilize the lower cetane fuel than uncoated engine due to higher temperature accumulate inside the combustion chamber because of thermal insulation [22]. Since the temperature in the combustion chamber is higher in the LHR engines than that of uncoated engines, it is possible to use lower cetane number fuels in LHR engine especially biofuel in an effective manner [23]. All the researchers corresponded with one important point, that the NOx emission of the LHR lies higher for all the fuels especially for the biodiesels and vegetable oils owing to heat insulation [24]. The test was carried out with low heat rejection engine the materials of 88% ZrO2, 4% MgO and 8% Al_2O_3 coated for 400 µm on piston bowl, cylinder head and valves. Selman Aydin, studied the LHR engine performance, combustion and emission profile from their observation they concluded that partial improvement in fuel economy, brake thermal efficiency, CO, HC and smoke emission [25]. On analyzing the influence of thermal insulation in a conventional engine and they reported that diminution in fuel consumption with a slender increase in thermal efficiency is possible with the LHR [26]. Even if, in adverse, some of them reported no melioration in the efficiency [33].

At the end of the detailed discussion carried out, it was identified that plant-based biofuel with lower viscosity stays as a potential source for a substitute for diesel fuel. Hence, the Cymbopogon flexuosus a plant-based renewable biofuel has been preferred for this present research work. In this regard, as the first phase of research, the test fuel such as raw biofuel, 25% blend of biofuel was prepared. Further, a novel oxygenated additive, cerium oxide was synthesized and mixed with the 25% blend of the biofuel. Prior to the handle the engine modification of coating the engine with low heat rejection material of YSZ (Yttria-stabilized zirconia) a finite elemental analysis study was carried out using ABAQUS. For the study, the engine piston was modeled using CATIA, a 3D modeling tool, and the temperature distribution, heat flux and thermal stress in YSZ coated piston and conventional aluminum alloy piston was investigated. As the second the phase of the research work, the engine was coated with the YSZ (Yttria-stabilized zirconia) material, and the engine behavior with the test fuels considered was studied.

2. Materials and methods

2.1. Test fuel preparation

To handle the fast fossil fuel depletion, the author has preferred Cymbopogon flexuosus biofuel as an alternative energy source for this current research work. Cymbopogon flexuosus, a plant-based biofuel highly available in India and Srilanka. The biofuel is exacted from the stacks of the plant through steam distillation technique. The detailed oil extraction technique and the Fourier-transform infrared spectroscopy (FTIR) results have been mentioned in the previous research work of the author by himself [11]. The viscosity of the oil lies closer to the diesel fuel, which is the eye-catching property of this novel biofuel. To begin with, the raw oil B_{100} (Cymbopogon flexuosus 100%) and B_{25} (Cymbopogon flexuosus 25% and diesel fuel 75%) were prepared on a volume basis for the experimental analysis. Later, the cerium oxide nano additive [31,36] was synthesized and characterized for the present research work. The detailed description on the synthesized and characterized has been already discussed in the author previous research work by himself [27]. The next test fuel of considered is B_{25} +