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ORIGINAL RESEARCH ARTICLE

Effect of fuel preheating with blended fuels and exhaust gas recirculation on diesel engine operating parameters

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This study investigates the influence of preheating on fuel properties of biodiesel and its blends on the performance of a diesel engine. Subsequently, the effectiveness of exhaust gas recirculation (EGR) rate for reducing the NO_x emission has also been explored. At 102 °C, fuel-preheating temperature, the average percentage reductions of kinematic viscosity and density of JOME was 49% and 4.3%, respectively with decrease (17.4%) in brake specific fuel consumption (BSFC) and increase (23%) of brake thermal efficiency (BTHE). The comparative study of all fuels with diesel revealed the fact that the blended fuel (40% biodiesel – 40PBD) with preheating (102 °C), is seen to be most efficient when operated without EGR mode. At full load engine testing with same test fuel, BSFC reduces by 19%, BTHE increases by 16%, the exhaust gas temperature (EGT) drops by 6% with slight increase in volumetric efficiency (2%). The carbon monoxide and unburned hydrocarbon emission was reduced by 19.5% and 4.8%, respectively while oxides of nitrogen (NO_x) emission was increased by 17.5% compared to diesel fuel. The inclusion of the EGR rate of 30% for 40PBD test fuel, meaningfully decreases the average NO_x emission by 68.8% with almost insignificant change in engine BSFC and BTHE.

Introduction

The depletion of fuel reserves, rising fuel price and fast industrialization, pollution rules to mineral diesel fuels has forced many countries to search alternative source of diesel fuel energy to realize their energy requirements. Among several alternatives, methyl ester (Biodiesel) produced mainly from non-edible vegetable oils through transesterification is considered as a probable fuel sources for diesel fuel in a compression ignition engine [1]. ''Methyl ester biodiesel'' is a domestic renewable fuel generally made from vegetable, animal fats /oil, tallow and waste cooking oil. The chemical process used to convert these oils to biodiesel is called as, ''transesterification'' [2]. With respect to chemical terminology, ''biodiesel'' is defined as the mono alkyl esters of long chain fatty acids. In order to prepare biodiesel, ethanol or methanol, combined with a vegetable oil or animal fat in the presence of a catalyst can react to form ethyl esters or methyl esters (biodiesel) and glycerin. These esters are another class of oxygenates like alcohols and ethers. Thus, the biodiesels qualifies as fuel based on their comparative characteristics with diesel so that they can be used in compression-ignition (diesel) engines in its pure form with little or no modifications. In specific, Jatropha methyl ester, Pongamia methyl ester and Rapeseed methyl ester are typical choices for fossil diesel fuel substitutes [3]. In many countries, *Jatropha curcas* is being considered among the favorable choices and extensive research works have done due to its strong adaptableness to the situation, mainly in terms of draught flexibility, great endurance level and maximum seed yield [4]. Moreover, the methyl ester (biodiesels) have significant advantages such as, cleaner combustion, insignificant contribution to environmental pollution, biodegradability, non-toxic and lower emissions to diesel fuel [5]. Even though the methyl ester biodiesels have high combustion efficiency and Cetane number, they face challenges of higher NO_x emission with serious difficulties of direct usages in the diesel engines [6]. Biodiesel has higher kinematic viscosity as well as density and lower heating value compared to petroleum fuel (diesel fuel). The properties of injected fuel have a significant effect on fuel injection characteristics which manipulating engine operating parameters of compression ignition engine [7,8]. Past

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Nomenclature

Abbreviation

BSFC	Brake specific fuel consumption (kg/kW h)
BTHE	Brake thermal efficiency (%)
CR	Compression ratio
EGR	Exhaust gas recirculation
EGT	Exhaust fas temperature (°C)
FPT	Fuel preheat temperature (°C)
ID	Ignition delay (°CA)
IP	Injection pressure (bar)
JOME	Jatropha oil methyl ester
PCP	Peak cylinder pressure (bar)
V_d	Engine displacement volume (cc)
C_d	Coefficent of discharge
d_0	Orifice diameter (mm)
Q_{LV}	Lower heating value (MJ/kg)

Symbol

N, W	Engine speed (rpm), engine load (%)
g	Gravitational accelaration (m/s^2)
r	Dynamometer arm length (mm)
t	Time taken for consuming v of fuel (s)
v	Constant volume of fuel consumed (cc)
100D	100% diesel fuel
100BD	100% Jatropha oil methyl ester
100PBD	100% preheated neat JOME
40PBD	40% preheated JOME and 60% diesel fuel
60PBD	60% preheated JOME and 40% diesel fuel
ρ_a, ρ_f, ρ_w	Density of air, fuel and water (kg/m^3)
ΔH	Water column (mm)
θ_{SC}	Angle start of ignition before top dead center
θ_{SI}	Angle start of fuel injection before top dead center

studies on biodiesel reported that, a direct usage of biodiesel in compression engine caused a reduction engine efficiency and increased fuel consumption [9]. Methyl ester biodiesel has lower energy content related to mineral diesel fuel leads lower BTHE of engine, hence to compensate this problem biodiesel require longer injection duration [10]. Higher kinematic viscosity of biodiesel causes larger droplet size, poor fuel atomization, narrower injection spray angle, advanced injection, incomplete combustion and injector clogging [9,11]. The kinematic viscosity of methyl ester (biodiesel) is mostly higher than diesel fuel nearly a factor of two [12,13]. Therefore, important fuel properties of biodiesel need modification in order to make improvement for utilization of biodiesel in diesel engines.

Until now, numerous methods were introduced to advance the fuel properties of biodiesel, namely blending biodiesel with mineral diesel fuel, usage of chemical (additives), and heating biodiesel [14,15]. It is reported that direct implementation all of these methods to biodiesel are not fully promising and practical. Till date, blending of biodiesel is a widely used methods for reducing the kinematic viscosity and density of JOME and applied as a fuel in compression ignition engine under the ASTM blended fuel standard [16]. However, the selection of maximum possible percentage of biodiesel ratio depends on the biodiesel feedstock and their fuel properties differ with respect to feedstock. Hence, the determination of right blend ratio is the most important criteria for utilizing biodiesel in a diesel engine. A few earlier studies indicated that, the maximum blend ratio of biodiesel currently limited to blends of 20% or less as commercial fuels for many countries in existing diesel engine operate without engine modification [17,18]. It was reported that, the brake thermal efficiency of fuel blends was slightly higher while brake specific fuel consumption was found increased with a significant reduction of CO and HC emissions and increase of NO_x emission as compared to diesel fuel. These blends of biodiesel is proved to be very strong potential fuel for the existing diesel engines. Conversely, at higher percentage of blend difficulties associated to degradation of fuel performance [19]. In contrast, plenty of research studies on additives mixed with biodiesel showed that, increasing biodiesel with additive content severely affects engine performance parameters (increased fuel consumption and significantly decreased engine power output) and increased exhaust emission concentrations [20]. However, some previous experimental studies reported that, modifying fuel properties of methyl ester (biodiesel) through heating method at specific temperature before entering the engine fuel injection systems is economical and feasible. It reality it can be possible for static diesel engines without any modifications by operating with biodiesels and overall improvement in efficiency [21,22]. Preheated JOME (biodiesel) can be also be used as a diesel fuel directly or blend in a compression ignition engine.

There are limited research studies for use of preheated biodiesel or biodiesel blend in a diesel engine. Many research studies show the effect of preheated methyl ester oil on fuel properties and on diesel engine parameters [22–24]. The fuel preheating of methyl ester biodiesel at optimal temperature can improve overall engine performance parameters with reductions emissions of CO and HC emission at expense of NO_x emission and can be substitute a diesel fuel without any engine modification. Further, the effect of fuel preheating and blend ratios on engine performance and emission evaluation of diesel engine operated with blend mixtures has been investigated [25]. It is indicated that, 80% preheated biodiesel–diesel blend and 20% ethanol can offer reasonably performance improvements with reduction of CO, HC and NO_x emissions at varying load conditions as compared diesel. The effect of exhaust gas recirculation (EGR) on performance and emission characteristics of diesel engine fueled with 20% biodiesel was investigated [26]. Among, combinations of different EGR rates, 20% EGR rate of diesel engine using 20% biodiesel fuel was suggested optimal for obtaining better performance and minimal NO_x emissions. Saravanan [27] examined the effect of EGR on NO_x emission of diesel engine running with different biodiesel–diesel blends of fuel. It was reported that, the NO_x and smoke emissions were significantly reduced for blends with reasonable drop in engine performance and slight increase exhaust emission (CO and HC) as compared to diesel fuel.

After the exhaustive literature studies, the authors present specifically, the effect of preheating on the fuel properties (viscosity and density) of JOME on performance analysis of a diesel engine. During preliminary experiments, the fuel properties Jatropha oil methyl ester (JOME) has been thoroughly examined with heating

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