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Effect of different technologies on combustion and emissions of the diesel engine fueled with biodiesel: A review

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ABSTRACT

Due to the shortage of the conventional fossil fuels and air pollution from combustion, new, sustainable and cleaner fuel resources are urgently required. Biodiesel has been introduced as a potential and alternative fuel for years. Biodiesel can be produced from different sources such as vegetable oils, animal fat, waste oil, etc. All of them are renewable and do not affect the food security. When biodiesel is used as a fuel resource for diesel engines, the performance and emission characteristics such as brake thermal efficiency (BTE), brake specific fuel consumption (BSFC) and brake power are almost maintained while hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM) is decreased significantly. However, higher NO_x concentration is observed. This disadvantage of using biodiesel or biofuels in general is improved in recent years. The purpose of this work is to do a comprehensive investigation of different approaches applying to biodiesel fueled engine like biodiesel additives, exhaust gas recirculation (EGR), water injection (WI), emulsion technology (ET), injection strategy modification, simultaneous technologies (ST), combustion chamber geometry modification and low temperature combustion (LTC) mode. By the way, the impacts of these technologies on engine performance and emission characteristics are summarized. Upon the comparison, using LTC mode is more efficient and feasible than the others. It can reduce both NO_x and PM emissions simultaneously by up to 95% and 98%, respectively, while engine performance is slightly reduced. Looking inside the LTC mode, the most efficient model is the reactivity controlled compression ignition (RCCI) combustion system. Applying RCCI combustion model might lead to the increase of CO and HC emissions, but this issue can be easily solved by using some available technologies.

1. Introduction

In recent decades, total worldwide energy consumption has been increased significantly. It leads to the global warming phenomenon result in higher average temperature of the earth [1] and threatening the energy security [2]. The rate of energy consumption will reach about 53% by 2030 [3] as reported by IEA (International Energy Agency). Thus the depletion of fossil fuels is appeared in clear vision in the near future. In addition, emissions from burning petroleum-derived fuels affected adversely both the environment and human health [4,5]. To cope with this issue, almost every country in the world released the emission legislations which are more and more stringent [6]. For all of those reasons, the alternative, sustainable fuels that can gradually replace the fossil fuels are urgently required. Among the proposed alternative fuels for diesel engines, biodiesel was considered as a reliable potential candidate.

Biodiesel fuels are formulated from animal fat and vegetable oil, which are non-toxic and more bio degradable [7], eco-friendly and more reliable [8]. Biodiesel is now widely accepted as a comparable fuel to fossil diesel owing to its several favorable factors like availability, higher lubricity, and lower exhaust emissions. Conversely, biodiesel fuel has some disadvantages such as lower heating value, higher density, higher viscosity and higher nitrogen oxides (NO_x) emission compared to conventional diesel [9]. Regarding NO_x emission, due to strict emission standards might lead to a significant barrier to using biodiesel it is necessary to be concerned about combustion and emissions of the diesel engine fueled with biodiesel. In the literature, there are different approaches to improve diesel engine's performance and emission when shifting to use biodiesel fuel.

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Nomenclature

IEA	International Energy Agency
HTC	High Temperature Combustion
IMEP	Indicating Mean Effective Pressure
CR	Compression Ratio
DI	Direct Injection
CI	Compression Ignition
TC	Turbocharged
LHR	Low Heat Rejection
PM	Particulate Matter
HC	Hydrocarbon
CO	Carbon Monoxide
BSFC	Brake Specific Fuel Consumption
EAT	Exhaust After-treatment
TDC	Top Dead Center
PCCI	Premixed Charge Compression Ignition
ATDC	After Top-Dead-Center
EN14213	European Union Standards (Bio-Heating Fuels)
HCCI	Homogeneous Charge Compression Ignition
BTE	Brake Thermal Efficiency
SOI	Start of Injection
CFD	Computational Fluid Dynamics
NA	Naturally Aspirated
LL	Low Load
HL	High Load
ml	Medium Load
AC	Air Cooled
WC	Water Cooled
CS	Constant Speed
DE	Diesel Engine
CA	Crank Angle
rpm	Revolutions per minute
PAHs	Polycyclic Aromatic Hydrocarbons
JB	Jatropha Biodiesel
TOME	Tall Oil Methyl Ester
KB	Karanja Biodiesel
RB	Rapeseed Biodiesel
WCB	Waste Cooking Biodiesel
RCCI	Reactivity Controlled Compression Ignition
CSB	Cottonseed Biodiesel
SB	Soybean Biodiesel
SFB	Sunflower Biodiesel
COB	Corn Oil Biodiesel
RBB	Rice Bran Biodiesel
TPB	Thevetia Peruviana Biodiesel
JOB	Jojoba Biodiesel
MB	Mahua Biodiesel
CB	Colza Biodiesel
PKB	Palm Kernel Biodiesel
COME	Castor Oil Methyl Ester
CnB	Canola Biodiesel
FOB	Fish Oil Biodiesel
BTDC	Before Top-Dead-Center
AASTM D6751	ASTM D6751-01 American Society for Testing and Materials (Biodiesel Standards), USA
EN 14213	European Union Standards (Biodiesel)
DPPD	N,N′-diphenyl-1,4-phenylenediamine
ODA	Octylated Diphenylamine
PPDA	p-phenylenediamine
BHT	Butylated hydroxytoluene
EDA	Ethylenediamine
NPAA	4-nonyl phenoxy acetic acid
DEE	Diethyl Ether
EHN	2-ethyl-hexyl nitrate
DMC	Dimethyl Carbonate
TCC	Toroidal Combustion Chamber
SCC	Shallow Depth Combustion Chamber
HCC	Hemispherical Combustion Chamber
UBHC	Unburn Hydrocarbon
FAAE	Fatty Acid Alkyl Esters
TBHQ	Tert-butylhydroquinone
MBEBP	2,2′-methylenebis (4-methyl-6-*tert*-butyphenol)
PHC	Pyridoxine Hydro Chloride
DEA	Di-Ethyl Amine
TPB	Thevetia Peruviana Biodiesel
LOME	Linseed Oil Methyl Ester
PME	Palm Methyl Ester
H50	50% Honne oil

Sivalakshmi et al. [10] analyzed the impacts of biodiesel fuel on NO_x emission and their countermeasures. They concluded that using biodiesel reduces the carbon monoxide (CO), hydrocarbon (HC) and smoke emissions, but NO_x increased. Similar reports have also been presented by other researchers [11–13]. The common known mechanism for the formation of NO_x emission during combustion includes thermal, prompt, and NNH mechanisms [12,14], in which the thermal and prompt mechanisms are the most important ones in biodiesel combustion [15]. Thermal NO_x is originated from high local temperature due to excess hydrocarbon oxidation. Prompt NO_x is produced by the formation of free radicals in the front flame. It was reported that NO_x concentration was mainly affected by the prompt mechanism in biodiesel combustion [16–18] (see Fig. 1).

Combustion and emission characteristics of diesel engine operated

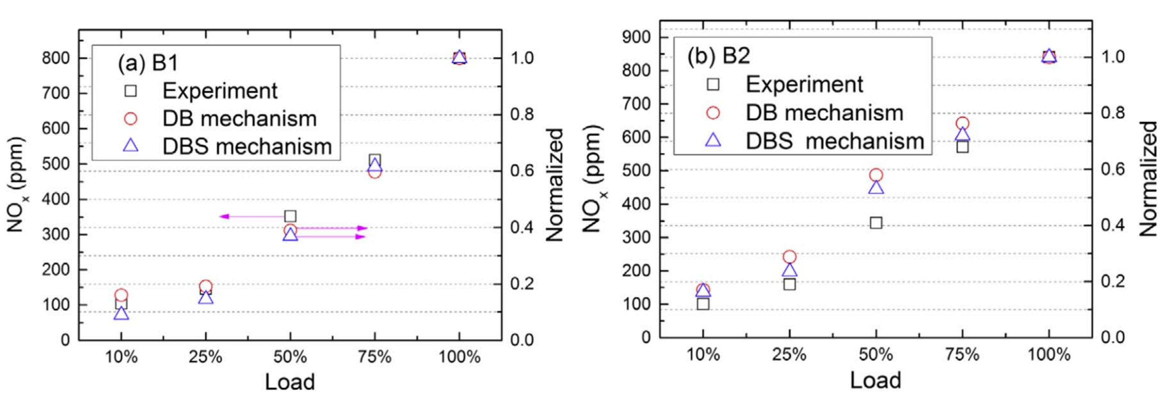

Fig. 1. NO_x emission trends prediction testing [16–18].