Fuel 236 (2019) 890–911

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Review article

An overview on the light alcohol fuels in diesel engines

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ARTICLE INFO

Keywords:
Light alcohols
Methanol
Ethanol
Diesel engines
Biodiesel

ABSTRACT

One of the most useful characteristics of the science is its cumulative concept. This work was done as an attempt to contribute this nature. As many reports have revealed that petroleum based fuels are depleting and releasing harmful emissions to the natural atmosphere, law makers contemplate to eliminate or at least mitigate these issues for the near future. In order to deeply address these issues, many studies have been proposed on the usage of alternative fuels such as methanol and ethanol to diminish exhaust gas pollution released from the internal combustion engines and to replace conventional fuels with alternative fuels that have extensive feedstock. Light alcohols (methanol and ethanol) are the most promising fuels in internal combustion engines thanks to their extensive feedstock, low-emissions, low-cost and easy-adaptability to the engine technologies. It has been recorded in the recent past that many researches have worked on light alcohol effects especially in diesel engines. In the light of the previous literature, this present paper reviews the past works to identify the effects of light alcohols on performance, combustion and emissions in the internal combustion engines including the productions, economic benefits, applications, demand and supply, environmental and human impacts of light alcohols. Various applications of light alcohols in diesel engines with diesel, biodiesel, the blends of diesel/biodiesel and diesel/biodiesel/esters in the internal combustion engines are summarized.

1. Introduction

Biofuels are gaining attention as promising sustainable sources to replace conventional fuels while legislation restrictions have been made on the usage of fossil fuels to diminish greenhouse gas effects and preserve natural resources. Although, it is well known that biofuels can be alternative for the petroleum-based fuels, the use of conventional fuels has been rising every year. It was reported that more than 84% of carbon emissions have been released to the atmosphere from fossil based fuels since the 1980's [1].

Biofuels meet a considerable part of energy demand while making a remarkable reduction impact on greenhouse gases, air pollution and cost of energy [2,3]. The renewable fuels can be benefited as pure or blend with fossil fuels to satisfy many of the energy needs for transport systems, heating and industrial processes [4,5].

Diesel engines are commonly used in various areas like industry, agriculture and transportation owing to their convenient properties such as high thermal efficiency, reliability, adaptability and low costs. Meanwhile, it is thought that diesel vehicles are among environmental pollutants and play a major role in development of energy shortage. So as to abate energy shortage and meet the new emission regulations, alternative fuels are among the most effective solutions [6,7].

Alternative fuels such as alcohols have been widely used as additives in CI engines. Although alcohols have economic benefits in diesel engines in comparison with conventional diesel and can directly be used as a single-fuel or additive in diesel engine without any engine modifications [8], there are some difficulties needed to be eliminated regarding utilization of alcohols, blending with diesel fuel, low lubricity, difficulty of vaporization and high auto-ignition temperature. These difficulties can be overcome by several methods such as using additives or increasing intake air temperature [9,10]. Mixing alcohols with diesel fuels is another approach of removing lubricity and vaporization problems. But alcohols and diesel fuel are not miscible and require co-solvents or emulsifiers in order to blend these liquids. However, these methods are expensive and the mixing process could become troublesome due to blending, separation, splashing, heating or other steps [11]. Even though alcohols are immiscible with diesel fuel, they are miscible with biodiesel. In certain limitation of alcohols, diesel/biodiesel/alcohols can be used in the same mixture without any miscibility problems [12].

Ethanol (ethyl alcohol) and methanol (methyl alcohol) are two types of light alcohols [13]. Methanol (CH_3OH) fuel is being considered as one of the optimal fuels for internal combustion (IC) engines [14,15]. Furthermore, ethanol (C_2H_5OH) is considered to be one of the most

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https://doi.org/10.1016/j.fuel.2018.08.138
Received 14 April 2018; Received in revised form 11 June 2018; Accepted 30 August 2018

Nomenclature

BEV	Battery electric vehicle
BMEP	Brake mean effective pressure
BSFC	Brake specific fuel consumption
BTDC	Before Top-Dead-Center
BTE	Brake thermal efficiency
Bu20	20% Butanol
CA	Crank angle
CI	Compression ignition
CO	Carbon dioxide
CO_2	Carbon monoxide
CP	Cylinder pressure
DBE	Dibutyl ether
DEA	Diethyl adipate
DEC	Diethyl carbonate
DEE	Diethyl ether
DGM	Diglyme
DI	Direct injection
DMC	Dimethyl carbonate
DMCC	Diesel/methanol compound combustion system
DEE	Diethyl ether
DME	Dimethyl ether
DMF	Dimethylfuran
DMF20	20% Dimethylfuran
DMM	Dimethoxymethane
DMM	Dimethoxymethane
E10	10% of Ethanol
EBD	Ethanol-biodiesel diesel blend
EBD-10DEE	Ethanol-biodiesel-diesel blend with addition 10% of diethyl ether
EGR	Exhaust gas recirculation
ETBE	Ethyl tert-butyl ether
EU	European Union
FAME	Fatty acid alkyl ester
FCEV	Fuel cell electric vehicle
H_3PO_4	Phosphoric acid
HC	Hydrocarbon
HRR	Heat release rate
LCT	Lower combustion temperature
LPG	Liquefied petroleum gas
MBD	Methanol-biodiesel-diesel blend
MBD-10DEE	Methanol-biodiesel-diesel blend with addition 10% of diethyl ether
MBD-5DEE	Methanol-biodiesel-diesel blend with addition 5% of diethyl ether
MTBE	Methyl tert-butyl ether
MTG	Methanol-to-gasoline
MTO	Methanol-to-olefins
MTP	Methanol-to-propylene
NO_2	Nitrogen dioxide
NOx	Nitrogen oxides
NTP	Normal temperature (293 °K) and pressure (101325 Pa).
OECD	Organization for Economic Co-operation and Development
PM	Particulate matter
SiO_2	Silicon dioxide
SSP	Smoke, soot or particulate matter emissions
TAEE	Tert-amyl ethyl ether
TAME	Tert-amyl methyl ether
THC	Total hydrocarbon
vol.	Volume basis

important components of biodiesel fuel and promising alternative fuel in IC engines [16–19]. Oxygenates such as methanol and ethanol have been widely used in IC engines because of their improved volatility and higher latent heating properties [20]. Many researchers have been concentrated on improving the blends of diesel fuel, biodiesel and alcohols as an alternative fuel in CI engines. But there are some complications such as lowered heating value, phase separation, pour point and unsafety conditions for storage and transportation of the ternary blends [21].

Biofuels can directly or indirectly be obtained from biomass sources. Biomass resources can be any form of solid, liquid or gaseous [22]. Liquid biofuels from biomass can be produced both from edible and inedible oils [23]. Fuels from bio-origin (directly from vegetable oils) are renewable and sustainable which also have similar properties to conventional diesel fuel and considered as a solution of the IC engine-based problems. On the other hand, the fuels obtained from vegetable oils have high viscosity and lower boiling point, cetane number and volatility values which are very important features for compression ignition (CI) engines. These drawbacks result in engine oil contamination, incomplete combustion, engine deposits and higher exhaust emissions which make these fuels unfavorable for direct use in diesel engines [24,25].

More studies have so far been made on the developing of ethanol and gasoline blends in SI engines in the literature. However, ethanol can be blended with diesel fuel up to 95% of ethanol in CI engines. High concentration of ethanol in CI engines can be used with several changes like increasing compression ratio and additives in order to improve cetane number [26]. Generally, alcohols are used as additives in CI engines and described as to be very helpful for reducing viscosity and density of pure biodiesel fuels because they have lower viscosity and density values in comparison to conventional diesel fuel. Moreover, these additive fuels increase the combustion efficiency of engine and emit lower smoke emissions to the earth atmosphere when blended with diesel duel. In addition, ethanol and methanol have approximately 35% and 30% more oxygen molecules in their molecular structure, respectively, which led more complete combustion and produce lesser exhaust gas emissions [27–29].

There are several applications on the use of alcohols in diesel engines such as direct injection, blending, emulsification and port injection (fumigation) [6,30]. The limit of alcohol in the direct injection method cannot be over 20% due to poor properties of alcohols such as miscibility, heat value and high auto ignition temperature. Therefore, it is difficult to apply direct injection method on the engine. There are many studies that investigated the effect of alcohol usage in IC engines with port injection method as fumigated additive. In the port injection method, diesel is directly injected while alcohol is injected into the intake ports. The blend method is applied as additives to satisfy homogeneity of the mixture. Emulsion method is based on using emulsifier to mix the fuel blend to prevent phase separation which is able to displace up to 25% diesel fuel [30–33]. But the port injection method is allowed to use higher concentration of alcohols in diesel engine in comparison with other methods [34].

As oil price are increased along with the rapid accumulation of greenhouse gas emissions and strict emission legislative regulations, it is necessary to put forward some new, renewable and environmentally friendly fuels instead of conventional fuels to solve these issues. Because of their abundant resources, relatively lower emissions and improved mixing and burning characteristics, the light alcohols, namely methanol and ethanol, have the potential to bring about some solutions to the addressed issues. This paper aimed to deliver comprehensive information including the productions, economic benefits, applications, demand and supply, environmental and human impacts of light alcohols and the emissions and performance effects of these alcohols in diesel engines to lead and contribute researchers in their investigations hereafter.