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Alternative fuels for internal combustion engines

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Abstract

This review paper covers potential alternative fuels for automotive engine application for both spark ignition (SI) and compression ignition (CI) engines. It also includes applications of alternative fuels in advanced combustion research applications. The representative alternative fuels for SI engines include compressed natural gas (CNG), hydrogen (H_2) liquefied petroleum gas (LPG), and alcohol fuels (methanol and ethanol); while for CI engines, they include biodiesel, di-methyl ether (DME), and jet propellent-8 (JP-8). Naphtha is introduced as an alternative fuel for advanced combustion in premixed charge compression ignition. The production, storage, and the supply chain of each alternative fuel are briefly summarized, and are followed by discussions on the main research motivations for such alternative fuels. Literature surveys are presented that investigate the relative advantages and disadvantages of these alternative fuels for application to engine combustion. The contents of engine combustion basically consist of the combustion process from spray

Abbreviations: BSFC, brake specific fuel consumption; Btu, British thermal unit; CAI, controlled auto-ignition; CFR, cooperative fuel research; CI, compression ignition; CN, cetane number; CNG, compressed natural gas; CRDI, common-rail direct injection; CO, carbon monoxide; CO_2, carbon dioxide; CTL, coal to liquid; DME, di-methyl ether; DI, direct injection; EA, elemental analysis; EGR, exhaust gas recirculation; FIE, fuel injection equipment; FSII, fuel system icing inhibitor; FT, Fischer Tropsch; GCI, gasoline compression ignition; GDI, gasoline direct injection; GHG, greenhouse gas; GTL, gas to liquid; HC, hydrocarbon; HCCI, homogeneous charge compression ignition; HTR, high temperature reaction; IEA, International Energy Agency; ICE, internal combustion engines; ISFC, indicated specific fuel consumption; JP-8, jet propellant-8; LCA, life cycle assessment; LHV, lower heating value; LPDI, liquefied petroleum gas (LPG) direction injection; LPG, liquefied petroleum gas; LPLi, liquid phase LPG (liquefied petroleum gas) injection; LTC, low temperature combustion; LTR, low temperature reaction; MPCI, multiple premixed compression ignition; NA, naturally aspirated; NO_x, nitrogen oxides; PCCI, partially-premixed charge compression ignition; PDPA, phase Doppler particle analyzer; PFI, port fuel injection; PM, particulate matter; PN, particulate number; RCCI, reactivity controlled compression ignition; RME, rapeseed methyl ester; RON, research octane number; R/P, reserves-to-production; SI, spark ignition; SMD, Sauter mean diameter; SOC, start of combustion; SOI, start of injection; SFC, single fuel concept/specific fuel consumption; TEM, transmission electron microscopy; TDC, top dead center; TGA, thermogravimetric analysis; TTW, tank-to-wheel; TWC, three-way catalyst; WCO, waste cooking oil; WTT, well-to-tank; WTW, well-to-wheel; XPCI, X-ray phase-contrast imaging.

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development, air–fuel mixing characteristics, to the final combustion product formation process, which is analyzed for each alternative fuel. An overview is provided for alternative fuels together with summaries of engine combustion characteristics for each fuel, in addition to its current distribution status and future prospects.

Keywords: Alternative fuels; SI engines; CI engines; Advanced combustion

1. Introduction

1.1. Background

Internal combustion engines (ICEs) are machines that convert the heat produced from combustion into mechanical work. The main subjects of this paper are reciprocating engines, such as spark-ignition (SI) and compression-ignition (CI) engines. They have been widely adopted as power sources for passenger and commercial vehicles, electricity power generation, and in other industrial fields, due to their high power density and high efficiency. The combustion process is one of the most important energy conversion methods where the chemical energy of fuel is directly converted into heat. Therefore, it is possible to say that human activities are greatly driven by and rely on fossil fuel energy.

Population growth over the last decades has led to tremendous growth in fossil energy demand. Fortunately, predictions of fossil fuel exhaustion keep expanding, owing to the improvement of drilling technologies, and the emergence of large quantities of shale gas (natural gas) reserves. Therefore, despite the evolution of modern and renewable energy sources, such as nuclear, solar, and wind energy, combustion technologies will continue to play an important role in the energy conversion field.

The two major fuels that had been developed and widely used along with the development of the ICEs and the automotive industries over the past century are gasoline and diesel. The combustion of gasoline fuel undergoes flame propagation after an initial spark event igniting the homogeneous air–fuel mixture in SI engines, while the combustion of diesel fuel is driven by the auto-ignition of the fuel exposed to high temperature gas, heated by compression in CI engines. Despite the long history of a steady supply chain and the determined position of gasoline and diesel as conventional automotive fuels in the market, the search for alternative fuels gradually started to emerge back in the 1980s [1].

1.2. Definition of alternative fuels and their importance

The definition of alternative fuels may vary depending on the context. The current study defines alternative fuels as those other than conventional gasoline and diesel fuels, covering a wide variety in terms of final forms and manufacturing sources. For example, ethanol fuel is considered an alternative for SI engines, regardless of its original source from either conventional crude oil or any renewable biomass. The alternative fuels defined by the Energy Policy Act (EPAct) also cover a vast amount of non-conventional fuels, including alcohols, such as ethanol (including blends with gasoline over 85%); natural gas and liquefied fuels domestically derived from natural gas; liquefied petroleum gas (LPG); coal-derived liquid fuels (CTL); hydrogen (H_2); biodiesel (B100); fuels, other than alcohol, derived from biological materials; and fuel that is substantially non-petroleum that yields substantial energy security and environmental benefits.

The significance of using alternative fuels can be attributed to the following aspects:

(1) pursuing energy sustainability through the extended usage of those alternative fuels derived from renewable energy sources and mitigating the concerns of limited fossil fuel energy;
(2) improving engine efficiency and engine-out emissions with the aid of superior physical or chemical properties of alternative fuels compared to those of conventional fuels; and
(3) relieving the unbalanced usage of conventional petroleum-based fossil fuels.

The search for stable energy supplies from various energy resources together with the associated shift toward renewable energies is necessary, because most energy resources currently rely on fossil fuels, which are of finite availability. Despite the projection that conventional liquid petroleum-based fuel would still dominate transportation fuels for the next 50 years [2], the desire for energy security (energy sustainability) and concern for reducing greenhouse gas (GHG) emission have also led to the increased usage of renewable biofuels. The use of fossil fuels is a major contributor to CO_2 emissions, where human activities generate about 25 billion tons of CO_2 annually [3]. The use of renewable biofuels can form a CO_2 life cycle, which from a social perspective can contribute to total CO_2 emission mitigation. For example, a full life cycle assessment (LCA) that was performed