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Alcohol and ether as alternative fuels in spark ignition engine: A review

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ABSTRACT

Energy security and global warming concern are the two main driving forces for the global alcohol development that also have the effort to animate the agro-industry. Generally, alcohol and ether fuels are produced from several sources and can be produced locally. Almost all alcohol fuels have similar combustion and ignition characteristics to existing known mineral fuels. Mainly the ether fuels (MTBE and DME) are used as additives at low blending ratio to enhance the octane number and oxygen content of gasoline. The addition of alcohol and ether fuels to gasoline lead to a complete combustion due to the higher oxygen content, thereby leads to increased combustion efficiency and decreased engine emissions. The objectives of this paper are to systematically review the use of alcohols and ethers including butanol, methanol, ethanol, and fusel oil, MTBE, and DME as fuels in SI engine. Also, the current study has investigated the effects of performance (brake torque, brake power, BSFC, effective efficiency, and EGT), emissions (CO, CO_2, NOx and HC) and combustion characteristics of SI engine with alcohol and ether. The increase in engine performance could be attained with an increased compression ratio along with the use of alcohol fuels which have a higher-octane value. Furthermore, alcohol and ether burn very cleanly than regular gasoline and produce lesser carbon monoxide (CO) and nitrogen oxide (NO_x). On the other hand, the energy value of alcohol and ether fuels is approximately 30% lower than gasoline; thereby the specific fuel consumption (SFC) will increase simultaneously when using alcohol and ether as a fuel. Finally, this paper also discusses the impacts of alcohol on engine vibration, engine noise, and potential to be used as a gasoline octane enhancer. Alcohol can be used as a pure fuel in spark ignition engine, but it requires some modifications to the engine.

1. Introduction

Energy security is becoming more important and is one of the worldwide governmental issues. Currently, combustion of conventional fuels such as gasoline and diesel account for more than half the world's primary energy consumption [1–4]. With the increasing cost of fossil oil and global warming continuing to be a dominant environmental concern, it seems that the use of alternative fuels in the future is inevitable. It commonly known that fossil fuels are energy sources that are non-renewable [5]. Alcohols have a long history of approximately 100 years as fuels in internal combustion engines (ICE). Alcohol based fuels may have been regarded as one of the renewable solutions, with a potential to be used in a near CO_2-neutral manner through efficient conversion of biomass. Utilizing alcohol as a fuel in transportation especially in light cars is not new [6,7] but lately begun to interest significant worldwide attention. Alcohols such as ethanol, butanol, methanol, and fusel oil and ethers (methyl tertiary butyl ether (MTBE) and Dimethyl Ether (DME)) are used as fuels in ICE [8–11]. First generation alcohols for

Abbreviations: NAP, national alcohol program; REP, Reid evaporation pressure; ICE, Internal combustion engines; RVP, Reid vapor pressure; LUC, Land-use change; GHS, Greenhouse gases; RON, Research octane number; MON, Moto octane number; TEL, Tetraethyl lead; BTE, brake thermal efficiency; ITE, indicated thermal efficiency; BSFC, brake specific fuel consumption; BMEP, brake mean effects pressure; HECU, hybrid electronic control unit; ▼, decrease or shorter; ▲, increase or prolong; MPFJS, multi-point fuel injection system; CT, cylinder temperature; SI, spark ignition; CT, cylinder pressure; CD, combustion duration; CE, combustion efficiency; FS, flame speed; CS, combustion speed; AK, anti-knocking; VEL, various engine loads; VES, various engine speeds; DISI, Direct Injection Spark Ignition; DMF, dimethylfuran; ROHR, rate of heat release; ROPR, rate of pressure rise; IMEP, indicated mean effect pressure; BMEP, brake mean effect pressure; 3C, three-cylinder; 4C, four-cylinder; SC, single cylinder; 4S, four stroke; CFR, cooperative fuels research; DST, different spark timing; CR, compression ratio; VCRC, variable-compression ratio capabilities; LHOV, latent heat of evaporation; BTDC, before top dead center; GGE, gasoline gallon equivalent

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Spark Ignition (SI) applications have so far largely been based on gasoline-ethanol blends, where current fuel quality standards typically allow between 5–10% inclusions of ethanol within an existing gasoline pool.

Methanol was used as vehicle fuel during the 1930s to replace gasoline supplies for high performance engine [12,13]. Methanol (CH3OH) is the chemically simplest alcohol, with single carbon atom per molecule. Methanol is toxic, tasteless liquid, colorless, and generally known as “wood alcohol" [13]. It has many benefits that distinguish it as an attractive alternative fuel over oil fuels. The first is low cost and it can be produced from several ways such as synthesis gas (mixture of hydrogen and carbon monoxide) that is produced by steam reforming of natural gas, gasification of coal, as well as a production of biomass, all of that are available in abundance or regeneration [14]. The production cost of methanol is around half of the cost of petroleum fuels in Canada. Even though the value is in comparison with the equivalent energy, it is quite low than that of gasoline. The second is low exhaust emission. In addition, due to the lower boiling point of methanol, the fuel will evaporate faster and this is advantageous to engine combustion and thereby, hydrocarbon emissions will be decreased. Furthermore, the high oxygen content of methanol and simple chemical structure can lead to lower emissions and better engine combustion in spark ignition engines [15,16].

Ethanol is a renewable and attentive fuel commonly produced from biological material through fermentation processes [17,18]. Ethanol was first submitted as an internal combustion engine fuel by the 1930s in the USA and became commonly used since 1970 [19]. Furthermore, in the 1930s, the government of Brazil stimulated gasoline blended with 5% bioethanol [20]. Due to the first oil crisis in 1973, Brazil decided to establish the national alcohol program (NAP) to reduce its reliance on fossil oil [21]. Currently, ethanol is used as fuel, especially in Brazil, while in Canada, the USA, and India. Also, ethanol is used as a gasoline additive to increase the octane rating and improve engine combustion [22,23]. In 2014, the USA was the world's largest ethanol fuel producer, around 60% of ethanol global output, while approximately 23.47 billion liter were produced by Brazil which represents 25% of the global production. On the other hand, the European Union only produced 6% of the global production. China and Canada were the other leading producers. Fig. 1 shows the global ethanol production by country, from 2007 to 2015 as shown the production increased dramatically from 2007 until 2010, while the largest production was in 2015 after a dropped in 2011 and 2012 [24]. Due to the issues of gasoline cost and emission regulations that are becoming more stringent, ethanol could be given more attention as a renewable fuel also to enhance the oxygen and octane value. Intensive study has been done to ensure high ignition temperatures, higher research octane number, lower freezing point, higher heat of vaporization, and low Reid evaporation pressure (REP) of ethanol compared with gasoline [25,26].

So far, experimental studies [27–31] have claimed that the blending of methanol and ethanol decreases the engine emissions compared to fossil fuel especially gasoline. Mainly, in these experimental investigations, the engine emissions have been associated with the oxygen content of methanol and ethanol. It is well-known that the chemical and physical properties of methanol or ethanol are quite different compared to gasoline, especially the heating value which is lower than gasoline. This property explains that the engine will need more quantity of ethanol or methanol blends to give the same engine power compared to gasoline. Also, the octane number of ethanol and methanol is higher than gasoline and the boiling point of alcohols is usually lower than gasoline.

Butanol or butyl alcohol is a four-carbon atom alcohol (C_4H_9OH) that can be used in non-modified spark ignition engines. It is miscible with most solvents and sparingly soluble in water [32]. Butanol is generally produced using fossil fuels, but can also be produced from biomass, in which case it is called bio-butanol. Both bio-butanol and petro-butanol have the same chemical properties [33,34]. Butanol quit similar to gasoline due to the longer hydrocarbon chain, lower oxygen content and higher heating value of butanol compared to methanol and ethanol [35]. Furthermore, butanol, as a promising fuel candidate, has attracted more attention recently. Butanol has several benefits than methanol and ethanol and contains high tolerance to water contamination which permits the use of the existing distribution pipelines [36,37]. Recently, the fusel oil attracts attention by some researchers as blending fuel in SI engine [38]. Fusel oil is a by-product of alcohol production after fermentation during the distillation process and it is a natural source of amyl alcohols [39–41]. In Brazil, fusel oil is usually produced in the proportion of 2.5 L per 1000 L of ethanol [42]. Also in Turkey, 2–3.5 L fusel oil is obtained per 1000 L alcohol manufacture [43]. However, the properties of fusel oil show that it can be utilised as an alternative fuel for SI engines. Fusel oil has the appearance of an efficient alternative fuel which can be used in a gasoline engine; the composition of the fusel oil depends on the type of carbon used in the

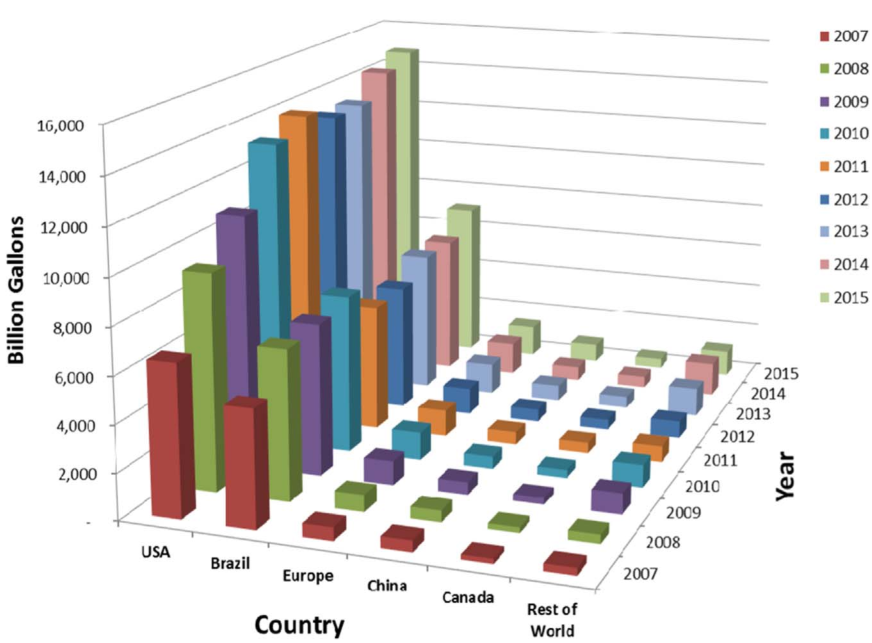

Fig. 1. Global ethanol production by country and year 2007–2015 [24].