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Review article

The potential of di-methyl ether (DME) as an alternative fuel for compression-ignition engines: A review

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Abstract

This paper reviews the properties and application of di-methyl ether (DME) as a candidate fuel for compression-ignition engines. DME is produced by the conversion of various feedstock such as natural gas, coal, oil residues and bio-mass. To determine the technical feasibility of DME, the review compares its key properties with those of diesel fuel that are relevant to this application. DME's diesel engine-compatible properties are its high cetane number and low auto-ignition temperature. In addition, its simple chemical structure and high oxygen content result in soot-free combustion in engines. Fuel injection of DME can be achieved through both conventional mechanical and current common-rail systems but requires slight modification of the standard system to prevent corrosion and overcome low lubricity. The spray characteristics of DME enable its application to compression-ignition engines despite some differences in its properties such as easier evaporation and lower density. Overall, the low particulate matter production of DME provides adequate justification for its consideration as a candidate fuel in compression-ignition engines. Recent research and development shows comparable output performance to a diesel fuel led engine but with lower particulate emissions. NO_x emissions from DME-fuelled engines can meet future regulations with high exhaust gas recirculation in combination with a lean NO_x trap. Although more development work has focused on medium or heavy-duty engines, this paper provides a comprehensive review of the technical feasibility of DME as a candidate fuel for environmentally-friendly compression-ignition engines independent of size or application.

Keywords: Di-methyl ether (DME); Compression-ignition engine; Diesel; Alternative fuel

Abbreviations: BSFC, brake specific fuel consumption; BTX, benzene, toluene and xylene; C–C, carbon-to-carbon; CFC's, chloro-fluoro-carbons; C:H, carbon-to-hydrogen ratio; C_2H_2, acetylene; C_2H_4, ethylene; C_3H_3, proparagyl; CH_4, methane; CH_2O, formaldehyde; CI, compression-ignition; CNG, compressed natural gas; CO_2, carbon dioxide; CO, carbon monoxide; CR, compression ratio; DI, direct-injection; DMC, di-methyl carbonate; DME, di-methyl ether; EGR, exhaust gas recirculation; FIE, fuel-injection equipment; H_2, hydrogen; HC, hydrocarbon; HCCI, homogeneous charge compression-ignition; HDV, heavy-duty vehicle; IMEP, indicated mean effective pressure; LDV, light-duty vehicle; LNT, lean NO_x trap; LPG, liquefied petroleum gas; NMHC, non-methane hydrocarbon; NO_x, nitrogen oxide; P_a, ambient pressure; P_{in}, fuel- injection pressure in common-rail; PAH, polycyclic aromatic hydrocarbon; PM, particulate matter; PTFE, polytetrafluoroethylene; SI, spark-ignition; SOF, soluble organic fraction; SO_2, sulfur dioxides; SPI, sustainable process index; syngas, synthetic gas; ULEV, ultra low emission vehicle.

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Contents

1. Introduction

Di-methyl ether (DME) is a liquified gas with handling characteristics similar to those of liquified petroleum gas (LPG) [1]. It can be produced from a variety of feed-stock such as natural gas, crude oil, residual oil, coal, waste products and bio-mass. Many investigations have been carried out on DME to determine its suitability for use as a fuel in diesel-cycle engines [1,2].

DME has the appearance of an excellent, efficient alternative fuel for use in a diesel engine, with almost smoke-free combustion. This is not only because of its low auto-ignition temperature and its almost instantaneous vapourization when injected into the cylinder, but also because of its high oxygen content (around 35% by mass) and the absence of C–C bonds in the molecular structure [1,2]. With a properly designed DME injection and combustion system, nitrogen oxides (NO_x) emissions can also meet ultra low emission vehicle (ULEV) limits [3]. The well-to-wheels energy efficiency of heavy- and light-duty DME-fuelled vehicles is projected to be 22.5% and 19%, respectively [4]. This is comparable to LPG and compressed natural gas (CNG) fuelled vehicles but less than the highest energy efficiency of 26% in direct-injection (DI) diesel fuelled vehicles [4]. On the other hand, the well-to-wheels carbon dioxide (CO_2) emissions of a DME-fuelled vehicle is comparable to those using DI diesel or CNG fuelled engines [4]. However, an oxidation catalyst would be necessary to meet ULEV carbon monoxide (CO) and hydrocarbon (HC) emission limits [5].

DME was also found to be an excellent gas turbine fuel with emission properties comparable to natural gas [6]. DME-fuelled turbine also allows to achieve a significant performance improvement through thermochemical recuperation with 44% higher power output and an 8% decrease of the specific CO_2 emissions compared to the present plant [7]. However, DME is not a suitable fuel for spark-ignition (SI) engines due to its high cetane number, though the burning velocity is similar to hydrocarbon fuels [8]; the easily-induced knock would limit the operation of SI engines.