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A review on natural gas/diesel dual fuel combustion, emissions and performance

Lijiang Wei *, Peng Geng

Merchant Marine College, Shanghai Maritime University, Shanghai 201306, China

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ABSTRACT

With the increasing concern regarding diesel engine emissions, including nitrogen oxides (NO_X) and particulate matter (PM), and the rising of energy demand as well, the utilization of alternative fuels in diesel engine has been found to be an attractive solution. Natural gas is a very promising and highly attractive fuel because of its domestic availability, widespread distribution infrastructure, low cost, and clean-burning qualities to be used as a transportation fuel. Natural gas/diesel dual fuel is an operation mode in which natural gas is introduced into the intake air upstream of the manifold and then ignited by the direct injected diesel in the cylinder. The aim of this paper is to identify the potential use of natural gas/diesel dual fuel on diesel engine. In this literature review, the combustion, emission and performance characteristics of natural gas/diesel dual fuel combustion-mode published mainly in scientific journals have been collected and critically analyzed. A wide range of natural gas mass ratio which represents the mass fraction of natural gas in the total fuel and different types of engines were involved. It has been found that dual fuel mode has a lower compression pressure and a longer ignition delay compared with normal diesel mode. The application of dual fuel mode significantly decreases the NO_X, carbon dioxide (CO_2) and PM emissions. However, the hydrocarbon (HC) and carbon monoxide (CO) emissions may increase by several times or even more than 100 times in comparison to normal diesel combustion. And there appears a trade-off relationship between NO_X and HC emissions with dual fuel mode. The engine power is decreased up to 2.1% at dual fuel mode, but the power loss can be reduced or recovered by changing some of the operating parameters. The brake thermal efficiency (BTE) of dual fuel mode is lower at low and intermediate loads, while under high engine load conditions it is similar or a little higher when compared with normal diesel mode, and the maximum increase is about 3%. The COV_{IMEP} seems to be generally higher than normal diesel mode and it decreases with the increasing engine load.

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* Corresponding author.
E-mail address: ljwei@shmtu.edu.cn (L. Wei).

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1. Introduction

Diesel engines are widely used in the world due to their high combustion efficiency, reliability, adaptability and cost-effectiveness [1,2]. However, diesel engines are one of the major contributors to environmental pollutions [3,4]. The main harmful pollutants from diesel engines are NO_X and PM. NO_X emission is one of the major causes of photochemical smog. And it is also a cause of acid rain. Primary PM from diesel engines consists of various types of chemical components such as elemental carbon, organic carbon, inorganic ions, trace elements etc. [5–7]. These particles have extremely harmful effects on human health and environment. Numerous studies have proved that these particles cause respiratory and cardiovascular health problems [8–11] and neurodegenerative disorders [12,13]. Furthermore, the exhaust emissions of diesel engine have been identified as carcinogen by the World Health Organization in June 12, 2012 [14]. Therefore, emission regulations become increasingly stringent to reduce these harmful emissions. On the other hand, energy demand is increasing but the oil resources are diminishing. In order to ease the contradiction between the need for increased energy and the decreasing oil resources while at the same time reduce pollutant emissions, the utilization of alternative fuels has been found to be an attractive solution.

Among the various alternative fuels, natural gas is very promising and highly attractive in the transportation sector. Firstly, natural gas is available in several areas worldwide at encouraging prices. Beside the oil fields and natural gas fields, the natural gas industry is producing gas from increasingly more challenging resource types: sour gas, tight gas, shale gas, coal-bed methane, and methane gas hydrate [15]. Secondly, although the main component of natural gas, namely methane, is a greenhouse gas, natural gas still is an eco-friendly fuel. It can contribute to the reduction of CO_2 emission because it exhibits the lowest carbon-to-hydrogen ratio of all the fossil fuels. Natural gas can also substantially reduce the NO_X emission and at the same time produce almost zero smoke and PM [16–18]; which is extremely difficult to achieve in conventional diesel engines. But on the other hand, in order to avoid its own environmental pollution, we should try to reduce the leakage of natural gas. Thirdly, natural gas is not prone to knock due to its high methane number under normal circumstances. Therefore, it can be used in engines with relatively high compression ratio and obtain a higher thermal efficiency compared with that of normal gasoline engine.

Natural gas has been employed as a supplementary fuel widely in diesel engine for its economical and environmental benefits [19–23]. The main purpose of this study is to provide a comprehensive review of the literatures relate to the potential use of natural gas in diesel engine. In this literature review, a great variety of diesel engine sizes and types were researched at different operation conditions. Single cylinder direct injection research diesel engine was most frequently used and a wide range of natural gas mass ratio was involved. Combustion, emission and performance characteristics are discussed at different sections to get a clear understanding of the natural gas/diesel dual fuel engine.

2. Natural gas as an alternative fuel

The main component of natural gas is methane, which is the simplest hydrocarbon. The combustion of natural gas is clean and emits less CO_2 than almost all other petroleum-derivate fuels. Natural gas has been used to fuel vehicles since the 1930s [24].

2.1. Physicochemical properties of natural gas

Natural gas is a mixture of a variety of gases. It contains some kinds of lightweight alkanes, such as methane, ethane, propane, *n*-butane and isobutane, and pentanes. It may also contain carbon dioxide, nitrogen and trace amounts of water vapor. The composition and content of natural gas varies slightly depending on the source and the production process. The typical component and content of natural gas are listed in Table 1 [15]. Normally, methane accounts for 87–96% of natural gas. Therefore, the physicochemical properties of natural gas are very similar to methane. The properties of natural gas in comparison to diesel fuel and gasoline are given in Table 2 [25–28]. Natural gas is an environmentally friendly alternative fuel for transportation because it contains less carbon per unit of energy than any other fossil fuel and thus produces lower CO_2 emission per vehicle mile traveled. However, it is a little difficult for natural gas to be used in compression ignition engine for