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Towards keeping diesel fuel supply and demand in balance: Dual-fuelling of diesel engines with natural gas

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ABSTRACT

With the continuous growth of energy demand for the commercial transport sector, the market share of diesel vehicles is rising in several areas worldwide. Global demand for transport energy is therefore believed to be strongly skewed towards heavier fuels; particularly diesel. The strengthen emissions legislation is another issue facing the current generation of diesel engines; where there is an increasing concern with their high NOx and PM emissions. Dual-fuelling of diesel engines with natural gas (NG) stands as an attractive solution to reduce the dependence on diesel fuel and mitigate the harmful effects of diesel engines emissions. The main attractions of NG as a contributor to a more sustainable fuel market include its lower carbon content and relatively higher natural reserves, in addition to the renewable aspect of methane production from biogas.

In dual-fuelling strategy, most of the engine power output is provided by the NG, while a pilot amount of diesel fuel is used as an ignition source for the NG-air mixture. While the concept is not new and it has been deliberated lengthily in the past two decades, several uncertainties still exist as relative to engine combustion, exhaust emissions, and practicality. The present contribution aims at critically reviewing part of the prevalent literature about NG-diesel dual-fuel engines; highlighting the concepts and challenges. Throughout this review, several topics are explored and evaluated based on research importance and maturity. The overview of these works indicates that research effort in this field could be broadly categorized into fuel delivery researches or charge composition studies; where each category is directly linked to either the NG or the pilot fuel. Following this, a roadmap for future research directions in the field is presented, to spot some potential topics for proceedings and continuation.

1. Document layout

A critical review of previous studies investigating NG-diesel dual-fuel engines is presented. The aim is to provide an overview of the drivers of current research, examine the progress that has been made in recent years, and identify the requirement for and the potential of further research. While there have been some reviews related to the topic one way or another, they were not aiming at the target of the present work; as discussed in the final part of Section 2.2. For that reason, it is considered timely to offer this comprehensive review.

The work starts with providing an outlook for global energy demand and the need to the transition into a more sustainable transport, where the use of alternative fuels plays a larger role. The potentials of NG are then highlighted, and related reviews on the topic are discussed. Progress and recent trends in NG-diesel dual fuel engines are critically analysed, with an intense focus on the effects of different parameters on engine combustion and emissions. On the light of that, future directions of research in the field are highlighted, while some topics that

Abbreviations: AFR, air-to-fuel ratio; BMEP, brake mean effective pressure; BSFC, brake specific fuel consumption; CAD, crank angle degree; CDO, conventional diesel operation C/H, carbon-to-hydrogen ratio; CN, cetane number; COHR, center of heat release; COV, coefficient of variation; DEE, diethyl-ether; DF, dual-fuel; DFO, dual-fuel operation; DI, direct Injection; DME, dimethyl-ether; ECU, electronic control unit; EGR, exhaust gas recirculation; EI, emission index; FAME, fatty acid methyl esters; FDD, flame development duration; GCI, gasoline compression ignition; GHG, greenhouse gas; GID, gaseous-fuel ignition delay; HCCI;, homogeneous charge compression ignition; HPDI, high-pressure direct injection; HRR, heat release rate; HTHR, high temperature heat release; HTR, high temperature reaction; IDI, indirect injection; IHR, integrated heat resale; LHV, lower heating value; LTHR, low temperature heat release; LTR, low temperature reaction; MEUI, mechanically-actuated electronically-controlled unit injection; MN, methane number; NEDC, new European driving cycle; NG, natural gas; NGV, natural gas vehicle; NTC, negative temperature coefficient; OEC, oxygen enriched combustion; OECD, organization for economic cooperation and Development; PCCI, premixed charge compression ignition; PINGDE, pilot ignited natural gas diesel engine; PPME, pongamia pinnata methyl ester; RME, rapeseed methyl ester; ROHR, rate of heat release; R/P, reserves–to–production ratio; SOC, start of combustion; TDC, top dead center; WI, Wobbe index; W/O, water-in-oil

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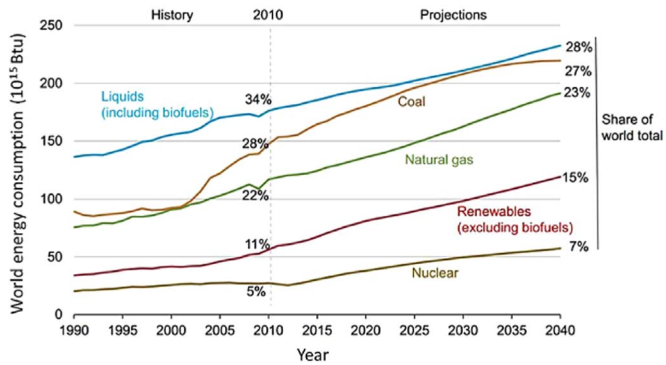

Fig. 1. World energy consumption by fuel type, 1990–2040 (quadrillion Btu). Adapted from [3].

involve a more sustainable operation of dual-fuel engines are discussed. Finally, the overall conclusions and recommendations are presented.

2. Introduction

2.1. Global energy outlook and transport sector demand

There is a continuous increase in the energy demand worldwide as a consequence of the population growth, along with the improvements in the standard of living. The last 10-year average of growth in world primary energy consumption is 1.9%, although 2015 exhibited below-average growth of just 1.0% (slightly higher than the 0.9% growth recorded in 2014) [1]. The recent slowdown in energy growth could be, in some measure, due to the rebalancing of the Chinese economy away from energy intensive sectors [1]. While consumption and production reached record levels for every fuel type (except nuclear power), energy consumption is expected to increase further in the foreseen future as the world population is expected to grow by 2 billion people in the next 30 years to surpass 9 billion by 2050 [2]. Fig. 1 shows the world energy consumption by fuel type; from 1990 to 2040. Currently, fossil fuels continue to supply most of the world's energy, and they are expected to supply more than three-fourth of total world energy consumption [3]. Increased energy demand necessitates increased fuel production; draining current fossil fuel reserve levels at a faster rate.

While oil remains the world's leading fuel at 32.9% of global energy consumption, more than 60% of the world's current oil reserves are in regions that are in frequent political turmoil; as shown in Fig. 2, which considerably affects the stability of supply distributions [1]. As the internal combustion engines (ICEs), fuelled mostly by petroleum-derived liquid fuels, have been the main source of transport power over the past century and expected to continue service into the present century, the road transport sector, in particular, needs more secure and sustainable future fuel sources.

Basically, world demand for transport fuels is very large and accounts for almost 60% of the total world oil consumption [4]. The demand for transport fuels is expected to grow rapidly as the number of vehicles increases; where the growth is almost entirely from countries outside the Organization for Economic Cooperation and Development (OECD) [3,4]. While the number of personal vehicles is expected to rise to about 1.7 billion in 2040 compared with approximately 825 million at 2010, the fuel demand from this sector is expected to rise only slightly [5]. This is attributed to the prospective reduction in the average vehicle size and the miles driven (compared to today's average vehicle), in addition to the improvement in efficiencies and hybridization [5,6]. Conversely, the energy demand for the commercial transport sector, which includes heavy-duty trucks and marine, is expected to increase by about 75% over the same period; in spite of some gains in efficiency. Consequently, the demand for diesel fuel, the most popular fuel for heavy-duty vehicles, will rise by 85%, while gasoline demand will fall by about 10% over this period between 2010 and 2040 [6]. That is, the increasing demand for transport energy is strongly skewed towards the heavier fuels (particularly; middle distillates such as diesel and jet fuels) [7]. Recently, there has been a slight improvement in oil refinery processes with regard to the quantity of heavy fuels yield compared with gasoline yield. For instance, the U.S. refinery yield of “Distillate Fuel Oil” (general classification for one of the petroleum fractions includes diesel fuels and fuel oils [8]) has increased from 23.9% at 2004 to 29.8% at 2014; in contrast to a reduction of Finished Motor Gasoline yield from 46.8% to 44.9% during the same period [9]. Yet, this seems insufficient to fulfill the growing demand for diesel (and jet) fuel in the foreseeable future; likely it will require pumping more investments in the current refinery courses to yield more diesel and jet fuels in the account of gasoline [6].

Above and beyond, the legislated reductions of certain exhaust gas emissions are another critical issue facing the current generation of ICEs that uses fossil fuel, as those emissions have an adverse effect on the environment and human health and there is universal agreement on the need to reduce them. For instance, the Euro 5 emission regulation that came into force in September 2009 required both gasoline and diesel engines to reduce their emissions of NOx by 25% and 28%; respectively. Further reduction of diesel engines NOx

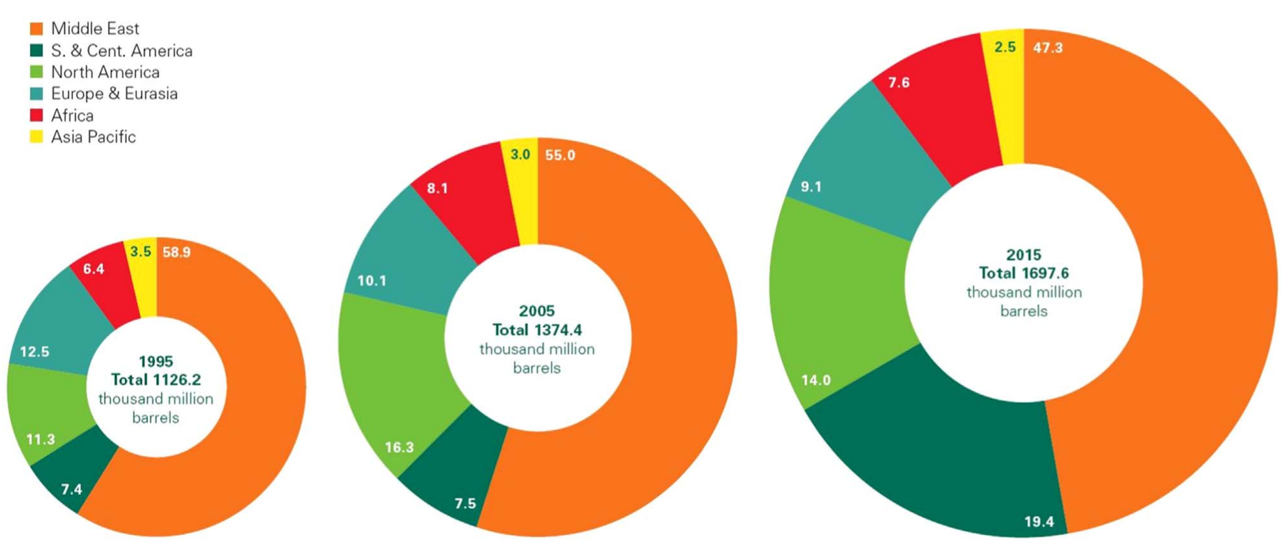

Fig. 2. Distribution of proven reserves of oil in 1995, 2005 and 2015 – (%). Ref. [1].