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The influence of fuel composition on the combustion and emission characteristics of natural gas fueled engines

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ABSTRACT

As global energy demand rises, natural gas (NG) plays an important strategic role in energy supply. Natural gas is the cleanest fossil fuel that has been investigated extensively for use in spark-ignition (SI) and compression-ignition (CI) engines. This paper reviews the research on the effects of natural gas composition on combustion and emission characteristics of natural gas fueled internal combustion engines (ICEs) and reports the most achievements obtained by researchers in this field. It has been reported that the engine performance and emission are greatly affected by varying compositions of natural gas. The most important NG fuel property is the Wobbe number (WN). Generally, it was agreed by researchers that the fuels with higher hydrocarbons, higher WN, and higher energy content exhibited better fuel economy and carbon dioxide (CO_2) emissions. Nitrogen oxides (NO_x) emissions were also increased for gases with higher levels of higher WN, while total hydrocarbons (THCs), carbon monoxide (CO), showed some reductions for these gases. On the other hand, particulate matter (PM) emissions did not show any fuel effects. Moreover, adding of small fractions of higher alkanes, such as ethane and propane, significantly improved ignition qualities of natural gas engines. The results presented provide a good insight for researchers to pursue their future research on natural gas fueled ICEs.

Contents

1. Introduction

In recent years, shortages of crude oil, increasing of fossil fuel prices and the tightening of environmental regulations have led to development of alternative fuels application in internal combustion engines. Natural gas is one of such fuels available in large quantities in many parts of the world at attractive prices. Natural gas consumption is forecasted to be doubled between 2001 and 2025, with the most robust growth in demand expected among the developing nations [1]. As shown in Fig. 1, the share of NG has been progressively increased within the energy market in the past three decades [2]. Natural gas is a potential alternative to conventional liquid fuels (i.e. gasoline and diesel) for use in automotive engines [3–7]. Natural gas is a mixture of various hydrocarbon molecules. Commercial natural-gas compositions vary from 85% to 96% methane. NG also contains heavier hydrocarbons such as ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}), and inert diluents such as molecular nitrogen (N_2) and carbon dioxide (CO_2). Sulfur compounds and other hydrocarbon species are also available within NG.

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Nomenclature

Greek

φ	equivalence ratio

Abbreviations

SI	spark ignition
CI	compression ignition
NG	natural gas
ICE	internal combustion engines
THC	total hydrocarbon
NO_x	nitrogen oxides
PM	particulate matter
NMHC	non-methane hydrocarbons
HCHO	formaldehyde
CNG	compressed natural gas
NGV	natural gas vehicles
WN	Wobbe number
MN	methane number
CARB	California air resources board
RPM	revolutions per minute
WOT	wide open throttle
EGR	exhaust gas recirculation
EOBE	effective on-board energy
TWC	three-way catalyst
PN	particle number
CP	combustion potential
HHV	higher heating value
LHV	lower heating value
SG	specific gravity
IANGVs	international association for natural gas vehicles
LPG	liquefied petroleum gas
HCCI	homogeneous charge compression ignition
A/F ratio	air–fuel ratio
SOC	start of the combustion
TDC	top dead center
NH_3	ammonia
CA	crank angle
BSFC	brake specific fuel consumption
BMEP	brake mean effective pressure
DI	direct injection
IDI	indirect injection
DF	dual fuel
RTC	refuse truck cycle
CBD	central business district
FTP	federal test procedure
DME	dimethyl ether

The geographical source, time of year, and treatments applied during production or transportation have great influence on levels of these species [8–12]. The typical composition of natural gas in percentage is illustrated in Fig. 2. Therefore, natural gas does not describe a single type of fuel or a narrow range of characteristics.

Natural gas is a clean burning fuel as compared to the conventional liquid fuels like diesel or gasoline. It has a high octane number and therefore it is suitable for engines with relatively high compression ratio. It has a high self-ignition temperature, so it requires intense source of energy to enable combustion, i.e. glow plug, spark plug or pilot liquid fuel. It mixes rapidly with air to form homogenous air fuel mixture for efficient combustion inside engine cylinder and substantial reduction in harmful emissions [13,14]. A number of research works have been conducted in the literature on utilization of natural gas in SI and CI engines. Comparing natural gas and diesel engine emissions, it was found that natural gas fueled SI engine emissions of total hydrocarbon (THC), nitrogen oxides (NO_x), and particulate matter (PM) were significantly lower than that of the diesel fueled engine. In addition, another study showed that natural gas SI engines have the potential to achieve a reduction in carbon monoxide (CO), CO_2, NO_x, and non-methane hydrocarbon emissions compared to gasoline engine emissions [5,15–18]. The number of compressed

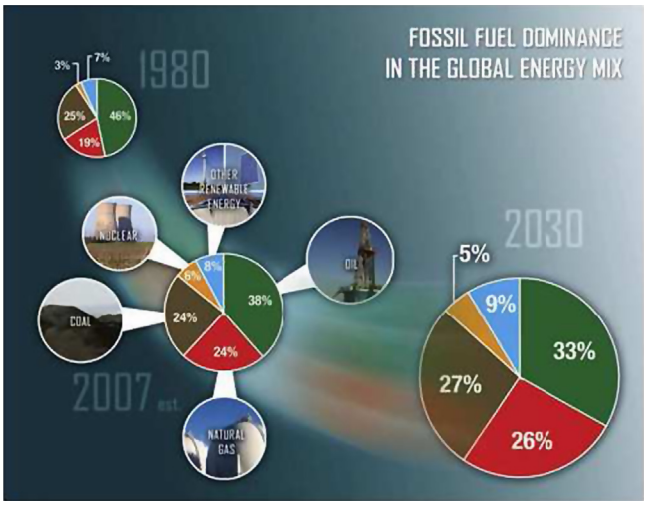

Fig. 1. The share of World energy, past, present and future [2].

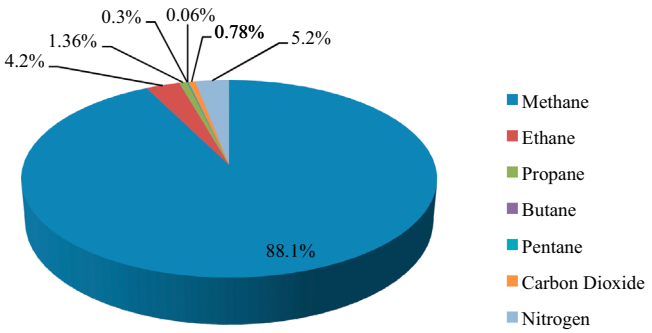

Fig. 2. Typical natural gas composition by volume.

Table 1
Properties of natural gas, gasoline and diesel fuels [18].

Fuel property	Gasoline	Diesel	CNG
Chemical formula	C_4–C_{12}	C_4–C_{12}	CH_4
Molar mass (g/mole)	114	170	19
Carbon content (%)	85	86	75
Hydrogen content (%)	15	14	25
Oxygen content (%)	0	0	0
Carbon-to-hydrogen ratio	0.54	0.516	0.25
Cetane number	5–20	40–50	–
Octane number	86–94	–	> 120
Auto-ignition temperature (K)	533	483	853
Stoichiometric air/fuel mass ratio	14.7	14.6	17.2
Boiling point at 1 atm (K)	300–498	450–643	111.4
Lower heating value (MJ/kg)	43.44	42.5	47.14
Liquid density (kg/m3)	737	831	465