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Influence of gaseous fuel induction on the various engine characteristics of a dual fuel compression ignition engine: A review

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ABSTRACT

Currently, the unsustainable fossil fuels have been chiefly used for power generation in CI engines. From the standpoint of fossil fuels depletions and environmental concerns, it is imperative to hunt out alternative energy resources that could replace hydrocarbon fossil fuels in the existing engines. In this regards, enormous studies have focused on the utilization of renewable fuels along with conventional petroleum fuel in existing compression ignition (CI) engine. The induction of gaseous fuels under dual fuel mode have emanated as a potential energy carrier to address the environmental aspects related to CI engines. This review focussed to analyze the influence of gaseous fuels (like H_2, biogas, syngas) addition to CI diesel engine under dual fuel mode with diesel/biodiesel as a pilot fuel. Various engine characteristics such as combustion, performance, and emission of the dual fuel CI engine using gaseous fuels as a secondary fuel were analyzed and compared with CI engine working under single fuel mode. Findings of some experimental studies have been presented in the form of graphs for selective important parameters as case studies. The overall impression from the review suggests that the performance of the dual fuel CI engine slightly deteriorates while enriching the gaseous fuel, but the improvement in environmental emissions have been reported. Furthermore, various approaches are discussed comprehensively in order to evaluate the performance of dual fuel CI engine along with a check on harmful emissions.

1. Introduction

Today's world is mainly relying on CI engines for power generation, especially in the transport sector. Furthermore, the power generation by burning petroleum diesel fuel in CI engines comes at dual crises of fossil fuel depletion and environmental degradation. It is a cogent proof that the combustion of these fuels has a fatal impact on the environment, which leads to deteriorated air quality because of the emission of air pollutants such as oxides of nitrogen (NOx), particulate matter (PM) and secondly, ignites the climate change issue due to the release of carbon dioxide (CO_2) into the atmosphere [1–3]. In fact, India is already the fourth largest greenhouse gas emitter of the world which is expected to reach the top position in the near future [4]. No doubt, the dwindling fossil-fuel reserve, and the environmental pollutants are the well-known pressing issues that need to be addressed today. Fossil fuels, at present, constitute about 80% of the total energy share with almost 50% of it being associated with the transportation sector, which is mainly based on diesel engine [5]. It would be interesting to know that, more than 6.5 million diesel engines exist at present in the Indian farming sector for various activities [6]. Therefore, to address these aforesaid dilemmas, it is imperative to move towards an eco-friendly fuel to power CI engines. The mitigation of greenhouse gas emissions from the environment is the key motivation for the utilization of renewable fuels in CI engine. The worldwide share of renewable energy is about 9% and will rise up to 12% by 2040 [7]. The worldwide automotive fuel consumption in the automotive sector is shown in Fig. 1.

Worldwide research is focussed on appropriate technology as well as alternative fuel that would be used in these existing diesel engines with no or fewer noxious pollutants. Use of sophisticated electronic controllers in CI diesel engine enables reduced emission and better fuel efficiency in comparison to previous counterpart [8]. However, the positive effects of this technology are overshadowed by its high price tag; hence, can't be commercially employed. In the last few decades, various alternative fuels have been proposed, targeting at cleaner and sustainable energy sources in order to counteract the consequences of the emissions from the CI engines. These include vegetable oil, alcohols, biofuels, compressed natural gas (CNG), natural gas (NG), liquefied petroleum gas (LPG), syngas, methane (CH_4), biogas, hydrogen (H_2), etc for the replacement of diesel fuels used in CI diesel engine [9,10]. Studies are being focussed on the usage of gaseous fuels like natural gas

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Nomenclature

CI	Compression Ignition
IC	Internal Combustion
H_2	Hydrogen
BP	Brake Power
BSEC	Brake Specific Energy Consumption
SEC	Specific Energy Consumption
BSFC	Brake Specific Fuel Consumption
ITE	Indicated Thermal Efficiency
BTE	Brake Thermal Efficiency
EGT	Exhaust Gas Temperature
CR	Compression Ratio
CV	Calorific Value
ATDC	After Top Dead Centre
BTDC	Before Top Dead Centre
CA	Crank Angle
CO	Carbon Monoxide
A/F	Air Fuel Ratio
BMEP	Brake Mean Effective Pressure
IMEP	Indicated Mean Effective Pressure
LPM	Litre Per Minute
HC	Hydrocarbon
NOx	Nitrogen Oxide
PM	Particulate Matter
DI	Direct Injection
IDI	Indirect Injection
HCCI	Homogenous Charge Compression Ignition
CO	Carbon Monoxide
CO_2	Carbon Dioxide

for CI engines worldwide, because of their better mixing characteristics with air. Hydrogen is also one of the commonly known clean energy resources; but, discovery of environment friendly technique to produce H_2 at a lower price is the challenging task for research.

Indeed, there are review articles published on different strategies and alternatives fuels for CI engines; with some reviews on blending of additives with biodiesel [11,12]. Rajasekar and Datta et al. [13,14] published reviews on CI engines fuelled with biodiesel; their monumental study set a milestone in the field of CI engines. Debnath et al. [15] reviewed the application of emulsion as an alternative fuel. Singh et al. [16] discussed about a methodology for the complete elimination of diesel fuel in their review. Varun et al. [17] reviewed on the studies based on the modification of combustion chamber geometry. Given a multitude of these reviews, it is an apt time to make an attempt to compile and analyze the research studies focussing on the influence of potential gaseous fuels (like H_2, biogas, syngas) induction on the combustion, performance and emission characteristics of a dual fuel CI engine. The emphasis of the current review is the exploration of new alternative and clean renewable fuels to be used in conjunction with diesel in existing CI engines without major modifications.

2. Gaseous fuel as an alternative fuel

Gaseous fuels have been emerging as attractive alternative energy resources to replace diesel fuel either partially or completely in CI engine. The injection of gaseous fuel in CI engine under dual fuel mode is not a new technology; it has been investigated by many researchers with widespread success [18,19]. Usually, gaseous fuel is mixed with the intake air during the suction stroke of dual fuel CI engine, either through manifold injection or through direct injection into the cylinder [20]. Depending upon the availability of fuels, dual fuel CI engines can be switched to either dual fuel mode or single fuel mode. In dual fuel mode, a certain amount of pilot fuel must be sprayed as an ignition source due to high auto-ignition temperature of the gaseous fuel.

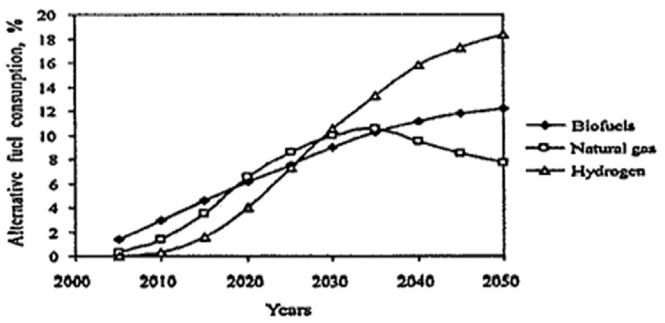

Fig. 1. Projection of worldwide automotive fuel consumption [6].

Usually, the quantity of diesel fuel (pilot fuel) required for adequate ignition is around 10–20% of the quantity required for single fuel mode operation [21]. The main objective of a dual fuel technology is to reduce the consumption of conventional fossil fuels with increased substitution by alternative renewable fuels, which are economically viable and environmental friendly [22].

There are several issues associated with the performance of dual fuel CI engines. For example, at lower load, the dual fuel engine operation tends to exhibit poor thermal efficiency, lower fuel utilization, prolonged ignition delay and higher emissions which are attributed to low ignition ability of gaseous fuels [23]. Moreover, the performance of dual fuel CI engine largely depends on the combustion behaviour, engine operating conditions, and design parameters; such as speed, load, pilot fuel injection timing, compression ratio, inlet manifold condition, pilot fuel mass, the composition of gaseous fuel, etc [24,25]. The present study explores the utilization of mainly three gaseous fuels namely H_2, biogas and syngas in CI engine as an alternative fuel under dual fuel mode. The properties of the H_2, biogas, and syngas are shown in Table 1 [63,83,86,121,131,132].

2.1. Hydrogen as a gaseous fuel

Hydrogen (H_2) has been explored as a fuel for IC engine in the earlier of 20th century but in the last few decades, there has been a strong interest in this area. H_2 as an energy carrier is counted as a very peculiar long-period renewable fuel because of its eco-friendly nature and distinctive properties from the conventional fuel [26]. H_2 as a fuel can be acquired from several resources like biomass, water electrolysis, industrial and chemical wastes, etc [27,28]. H_2 as a fuel has zero carbon content and combustion of H_2 emits water vapour only, which would play a key role in reducing the carbon footprint [29]. Major concerns related to the combustion of H_2 in air are its unique characteristics like high flame speed, high energy density/unit mass, wide flammability range, low ignition energy, high diffusivity, etc [30]. H_2 based dual fuel CI engines suffer an obstacle of premature ignition due to low ignition energy of H_2, which is one of the challenges related to its usage in CI engine. In 1820, the practical attempt was done by Rev. W. Cecil on an H_2-operated engine, in which H_2 gas was used to produce force [31]. Further, over 1000 vehicles were converted to H_2 in Germany and England in 1930 [32]. Various studies have been documented with regard to the technical viability and challenges posed by the utilization of H_2 as a fuel in CI engine in the later 20th Century [37,38].

In 2007, a national H_2 energy roadmap has been formulated by MNRE (Ministry of New and Renewable Energy), which targeted around one million H_2 fuelled vehicles in India by 2020 [33]. Usage of H_2 in CI engine under dual fuel mode and effects on combustion, performance and emission characteristics have been summarized in Table 2.