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A review of the effect of hydrogen addition on the performance and emissions of the compression – Ignition engine

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ABSTRACT

Diesel engines produce high emissions of smoke, particulate matter and nitrogen oxide. The challenge now is to decrease exhaust emissions without making any major changes on their mechanical configuration. Therefore, adding hydrogen becomes a natural choice to enhance the performance and emissions of diesel engines. This paper offers an overview of the effect of hydrogen additional to the diesel engine. The overall finding from the review suggests that the air–fuel ratio, engine speed, and engine load play a key role in the performance and emission of diesel engines with hydrogen enrichment. The brake thermal efficiency (BTE), brake power output, brake means effective pressure (BMEP), and specific energy consumption (SEC) are dependent on the operating conditions of the engine when adding the hydrogen. It is also found that increasing the percentage of hydrogen will affect emissions, so that the reduction in unburned hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO_2), particulate matter (PM), and smoke are observed when adding the hydrogen. However, nitrogen oxide (NO_x) is increased when enriching H_2, but this increase in NO_x can be controlled by numerous injections, exhaust gas recirculation (EGR) or water injection as well as exhaust after-treatment as has been discussed in this paper.

Contents

1. Introduction

One of the issues associated with the petroleum-based engine is high emissions production, including carbon dioxide, carbon

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monoxide, hydrocarbons, particulate matter and nitric oxides [1,2], which can contaminate the environment. There have been many methods applied to reduce emissions. Diesel Particulate Filter (DPF) and Selective Catalytic Reduction (SCR) were used to reduce PM and NO_x emissions, respectively. These methods are based on the use of precious and expensive metals as catalysts and also devices are tough in retrofitting to the engines of vehicles. Accordingly, alternative fuels are promoted and developed as an alternative to traditional fuels to achieve those goals. To this end, hydrogen is considered to be the best additive candidate to be blended into diesel in order to satisfy the characteristics which are required by the engine [3].

The addition of hydrogen to conventional hydrocarbon fuels was recommended as a method to enhance the performance, as well as improve emissions, of internal combustion engines. Likewise, several studies have examined the performances of spark ignition engines using hydrogen–gasoline fuel [4–6] and hydrogen–natural gas fuel [4,7]. Furthermore, several researchers have proposed hydrogen addition to conventional diesel fuel in the internal combustion (IC) compression ignition (CI) engine as a method to enhance the performance of diesel engines. This is because it increases the *H*/*C* ratio of the whole fuel and decrease the combustion duration (due to hydrogen's high speed in terms of flame propagation with respect to other fuels [8,9]. Additionally, the injection of small amounts of hydrogen fuel to a diesel engine can reduce the heterogeneity of a diesel fuel spray, resulting from hydrogen's high diffusivity. It allows the enhanced combustible mixture to be premixed with air with more uniformity [8].

Normally, the combustible mixture offers improved homogeneity and better circumstances for the whole combustion process. Moreover, faster combustion approximates constant volume leading to an increase in the efficiency of the engine [4,8,10]. The main shortcomings of consuming hydrogen as a fuel include: high in-cylinder peak pressures and temperatures, combustion knock, higher emissions (NO_x), and high self-ignition temperature [4,9–12].

One of the most promising of renewable fuels is Hydrogen, since it is naturally accessible on the earth and can be generated from different resources like fossil energy and biomass [13,14]. In comparison with diesel, hydrogen can be consumed as the only fuel in a spark ignition (SI) engine; however, it cannot be employed in a CI engine because of its higher ignition point [15,16]. Due to safety reasons, the use of hydrogen in internal combustion engines necessitates extra care. In addition, the hydrogen injection technique also plays a significant role in preventing undesired explosions. Hence, direct injection is regarded as a preferred technique, compared to port injection, in order to avoid the backfire effect [17,18]. Backfire is defined as a combustion which occurs during the intake stroke as a result of hot spots, and can also happen in the intake manifolds [19]. For safety reasons, it is crucial to prevent any unwanted combustion behavior [18].

Natural gas and bio derived gas research was done in the dual-fuel diesel engine by Sahoo et al. [2]. Furthermore, natural gas use in the spare ignition engine was conducted by Cho and He [20]. Hairuddin et al. accomplished a study on hydrogen and natural gas in diesel homogeneous charge compression ignition (HCCI) engines [18]. On the other hand, no review paper was-written-that focused on the effect of hydrogen on compression ignition engine (using H_2 as main fuel with direct diesel injection). The purpose of this review paper is to investigate the effect of hydrogen addition in diesel fuel engines on performance and emissions. It consists of five sections, where Section 2 discusses the effect of hydrogen addition on performance in compression ignition engine. Section 3 presents the effects of hydrogen addition on emissions. Section 4 will discuss the effects of exhaust gas recirculation (EGR) with hydrogen addition. Lastly, chapter 5 presents the paper's conclusion.

2. Effect of hydrogen addition on performance

2.1. Power output and thermal efficiency

The addition of different ratios of hydrogen (e.g. 5%-10%, 20%, 30%, 40%, and 50% by volume) to the diesel engine and its effect on performance and emission characteristics was investigated by researchers. Shin et al. [21], who indicated that adding hydrogen into diesel fuel improves the diesel combustion and leads to increased engine power [21]. Ghazal [5] reported that air–fuel ratio and engine speed affect power output with hydrogen addition. He found that when adding a percentage of hydrogen (between 5% and 10%) for different speeds and less than 15 of air–fuel (*A*/*F*) ratio, the maximum power output improves. However, for air–fuel ratio higher than 15 and for all engine speeds, the hydrogen addition affects maximum power output only after adding (30–40%) H_2. This results in combustion efficiency improvement and increases in the volumetric heating value of the intake mixture. As shown in Figs. 1 and 2, for high engine speeds, there is a 14% increase in power compared to neat diesel fuel. It produces a 70% increase in power which is a higher output compared to diesel fuel when adding 40% H_2 with higher air–fuel ratio [5].

The effect of hydrogen addition on brake thermal efficiency (BTE) was also examined. An engine's BTE is the ratio of brake output power to input power, and concerns the brake power created by an engine due to the energy provided by the fuel [18]. In this vein, the experimental analysis was conducted to investigate the effect of induction of hydrogen via inlet manifold versus that of direct hydrogen injection on BTE, given in Fig. 3. The BTE increases with the increase in proportional replacement of hydrogen by both techniques; nevertheless, the efficiency was found to be higher by about 19% in induction via inlet manifold as compared to direct injection. This is mainly due to uniform mixing of hydrogen with air (using the induction technique) that forms a homogeneous mixture. This mixture is burnt entirely by the flame, initiated via the diesel injection. It also led to complete heat release [22].

The effect of (*A*/*F*) ratio as well as H_2 concentration in fuel on the BTE for various engine speeds is demonstrated in Figs. 4 and 5. The hydrogen concentration (around 5–10%) with (*A*/*F*) ratio up to 20 brings about the highest BTE in comparison with neat diesel, with no knocking at full load. Combining higher *A*/*F* ratio with high engine speed will, normally result in the maximum BTE for hydrogen concentration of approximately 40%. This is an increase of nearly 30% in comparison with the diesel fuel. The BTE increases with higher addition of hydrogen; however, is limited as a consequence of the problems of knocking. The upsurge in BTE is attributed to hydrogen's improved mixture with air and its faster burning features. This shows that consequential faster flame

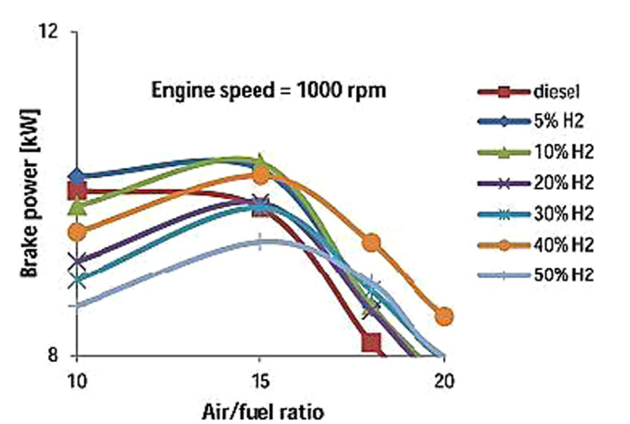

Fig. 1. The brake power versus *A*/*F* ratio for different H_2 concentrations and 1000 rpm [5].