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# Hydrogen effects on the diesel engine performance and emissions

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ABSTRACT

In this research, effects of hydrogen addition on a diesel engine were investigated in terms of engine performance and emissions for four cylinders, water cooled diesel engine. Hydrogen was added through the intake port of the diesel engine. Hydrogen effects on the diesel engine were investigated with different amount (0.20, 0.40, 0.60 and 0.80 lpm) at different engine load (20%, 40%, 60%, 80% and 100% load) and the constant speed, 1800 rpm. When hydrogen amount is increased for all engine loads, it is observed an increase in brake specific fuel consumption and brake thermal efficiency due to mixture formation and higher flame speed of hydrogen gas according to the results. For the 0.80 lpm hydrogen addition, exhaust temperature and NOx increased at higher loads. CO, UHC and SOOT emissions significantly decreased for hydrogen gas as additional fuel at all loads. In this study, higher decrease on SOOT emissions (up to 0.80lpm) was obtained. In addition, for 0.80 lpm hydrogen addition, the dramatic increase in NOx emissions was observed.



## Introduction

Exhaust emissions, the adverse effects of emissions on human health and the environment, and the increasing stringent emissions legislation on the weakening of world oil reserves are strong incentives for alternative fuel surveys. As an alternative fuel, $H_2$ has great potential. An $H_2$-like fuel is of interest, as it clears the combustion properties of $H_2$ and does not perform better [1]. Compressed ignition (CI) engines consume fuel with diesel and $H_2$, offering low emission potential with improved performance [2]. The addition of $H_2$ can cause excessive Soot formation and better thermal efficiency, thus reducing fuel consumption with a nominal power loss. Adding a small amount of $H_2$ to a CI engine increases the overall H/C ratio of the fuel and reduces the heterogeneity of a diesel fuel spray that provides a better flammable mixture through the high diffusivity of $H_2$. It can also reduce the combustion time due to high flame propagation speed [3–9].

In an experimental investigation, the port was injected $H_2$ as the primary fuel and on a CI engine using direct in-cylinder diesel fuel injection to control the ignition, Saravanan et al. [10] reported an increase in nitrogen oxides (NOx) and SD as compared to conventional CI motor operation and an increase in brake thermal efficiency (BTE) for dual-fuel operation. Varde and Varde [11] investigated the effects of burning gaseous fuels with naturally aspirated direct injection (DI) diesel fuel and detected NOx increase while reducing the formation of soot by half of the dry diesel through the addition of H2 at light loads. Lee et al. The injector [12] and the carburetor [13] were operated on $H_2$ mixed with suction air. Electronic injectors using $H_2$ provide better control of injection timing and injection time with faster response at high speed operating conditions [14]. The correct injection timing and the

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elimination of problems such as recoil and pre-ignition are the main advantages of the $H_2$ injection over the carbureted system [15]. Tomita et al. In the work carried out by Ref. [16] $H_2$, a DI-CI motor was mixed with the intake air. It is reported that very low NOx emissions are obtained when injecting is started. It has also been observed that emissions of hydrocarbons (HC) and carbon monoxide (CO) are often reduced due to the lower carbon content in the fuel [17,18]. An experimental study was conducted on a constant CI motor by Saravanan and Nagarajan [19] to improve performance and emissions. NOx emissions reduced conventional man's business to 90% $H_2$ enrichment at medium engine load. On the contrary, NOx emissions at full load increased slightly compared to conventional diesel operation, while SD decreased by 50%. Saravanan et al. In another experimental inquiry carried out by Ref. [20] a binary engine was run on a CI engine using $H_2$ in the fuel mode. Experimental results showed a significant reduction in NOx and a 30% increase in BTE progression compared with diesel.

However, higher NOx emissions with an undesirable effect on the environment are a significant drawback to H2-powered engines. NOx formation becomes important when the combustion peak temperature is above 2200 K [21,22]. Operating the $H_2$ engine with oil-free blends is one of the ways to reduce NOx while maintaining better fuel economy. This results in a lower peak temperature which will slow down the chemical reaction due to cooler combustion which weakens the kinetics of NOx formation [23,24]. The use of $H_2$ in dual fuel mode with exhaust gas recirculation (EGR) technology has resulted in lower NOx emissions with lower SD level and particulate matter [25]. For this reason, the use of EGR is considered to be most effective in improving the exhaust emissions of $H_2$-powered engines.

The main disadvantage of using H2 as a fuel for automobiles is that on-board storage of $H_2$ and $H_2$ supply infrastructures is not available and needs to be developed in the near future [26–28]. One of the feasible solutions to this problem is to produce $H_2$ on board. Using a electrolysis unit, the amount of $H_2$ intake to the intake of the engine is positively affected by the performance of the engine and especially emissions. Gjirja et al. [29] It was observed that a small amount of hydrogen peroxide ($H_2O_2$) was reduced in NOx when fumigated for intake of a motor using an electronic injector. Shirk et al. [30] conducted a series of experiments to investigate the fumigating effects of gas $H_2$ on the intake of bio-diesel fueled CI engines (B20). According to results, engine emissions and efficiency changes were low.

From the literature review, the effect of additional $H_2$ on CI motor on the performance and emission characteristics of the CI engine continue clearly to understand. Therefore, these issues need to be investigated in order to make up for the shortcomings in the literature. For this reason, in this study, effects of $H_2$ added to the intake air of the CI motor on the performance and emission characteristics of a single-cylinder, water-cooled, DI-CI engine were investigated. Hydrogen gas was sent into the intake manifold of the CI engine. The CI engine was analyzed for $H_2$ addition [0.20, 0.40, 0.60 and 0.80 L (lpm) per minute] in the intake air at different engine loads (20%, 40%, 60%, 80% and full load). And constant speed, 1800 rpm.

## Methodology

The diesel engine used for the study was a direct injection, four cylinder; four-stroke, water-cooled engine. Bore to stroke ratio of the engine is 0.82. Compression ratio is 18.5:1. Maximum engine power and moment are 260 kW at 1800 rpm and 1.6 kNm at 1100 rpm, respectively. Engine properties and operating conditions were given in Table 1 and Table 2. Fuel injection pressure and timing are 20 MPa and 18° BTDC, respectively. The engine was modeled in a 3D CFD code. The hydrogen effects were investigated via port injection in a different amount. The results were evaluated to compare the fuel consumption, temperatures, pressures, and emissions. The $H_2$ was fed by hydrogen injector on the intake port for the engine. Hydrogen is calculated in a different amount before it is introduced to the engine by the use of the air inlet manifold. Hydrogen was passed through the intake port and mixed with fresh air. First the engine was run with diesel fuel and investigated. Engine wall temperatures were tuned as a constant temperature, it is accepted that engine reached stabilized operating condition. The engine was operated at a constant speed of 1800 rpm obtained maximum torque with five different percentage of load (20%, 40%, 60%, 80%, and 100%). For all load conditions, single fuel, just diesel fuel was used and investigated before hydrogen addition. After this point some amount of $H_2$ (0.20, 0.40, 0.60, and 0.80 lpm) was sent to the intake port and the amount of diesel was arranged to obtain desired each load regardless of any modification in engine setup. In fact, through the intake port air was enriched by hydrogen and ignited by diesel fuel. After a while, in stabilized model, results were recorded and evaluated. Hydrogen properties were given in Table 3. Brake power, brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC), engine speed, all loads, diesel fuel consumption, exhaust temperature and BTE were also analyzed. Carbon dioxide ($CO_2$), CO, HC and $NO_x$ exhaust emission and soot

**Table 1 – Engine properties.**

| | |
|---|---|
| Combustion system | Four-stroke diesel with direct injection |
| Number of cylinders, Cylinder arrangement | 6 |
| Bore/Stroke, | 0.82 |
| Displacement | 11967 cc |
| Compression ratio | 18,5:1 |
| Rated power | 260 kW at 2200 rpm |
| Maximum torque | 1,6 kNm at 1800 rpm |
| Idle Speed | 1100 rpm |
| Weight, dry | 1000 kg |

**Table 2 – Operating conditions.**

| | |
|---|---|
| Engine speed | 1800 rpm |
| Mass of fuel injection | 12 kg/hr |
| Intake pressure | 1.3 bar |
| Intake temperature | 312 K |
| Hydrogen rates (lpm) | 0.20, 0.40, 0.60, 0.80 |
| Engine load % | 20, 40, 60, 80, 100 |