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Performance Evaluation of Hydrogen-Diesel Dual Fuelled Engine

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ABSTRACT

Environmental concerns and limited amount of conventional fuels have caused interests in the development of alternative fuels like hydrogen for internal combustion (IC) engines. The experiments were conducted on water cooled, direct injection (DI), diesel engine at a speed of 1500 rpm. Hydrogen was stored in a high pressure cylinder and supplied to the inlet manifold through a water-and-air-based flame arrestor. A pressure regulator was used to reduce the cylinder pressure from 140 bar to 2 bar. In this work an attempt has been made to investigate the combustion, performance and emission characteristics of a single cylinder four-stroke compression-ignition engine operated in dual-fuel mode with hydrogen as an alternative fuel. The Timed manifold induction technique has been adopted to induct hydrogen into the engine cylinder. The hydrogen was inducted with a volume flow rates of 5 lpm, 10 lpm, 15 lpm,20 lpm, and 25 lpm respectively by a flow meter. The engine performance, emission and combustion parameters were analyzed at various flow rates of hydrogen and compared with diesel fuel operation. The brake thermal efficiency (BTE) was increased and brake specific fuel consumption (BSFC) decreased for the hydrogen flow rate of 20 lpm as compared to the diesel and lower volume flow rates of hydrogen.

Keywords: *Alternative fuel, diesel engine, dual fuel mode, emission, induction pressure, mass flow rate, timed manifold technique.*

I. Introduction

The current records of energy consumption in the world and the concerns about global warming have encouraged active research interest in non-petroleum, carbon free compounds and non-polluting fuels ,particularly for transportation ,power generation and agricultural sectors which have caused interests to carry out research and develop feasible alternative fuels as a substitute for petroleum based fuels to meet the increasing energy demand with the minimum environmental and economical impact ,thereby reducing the reliance on fossil fuels. Hydrogen is a fuel without carbon element in its molecular structure and considered as an important fuel alternative than LPG, CNG, and LNG. Anil Singh Bika et al [1], investigated emissions of oxides of nitrogen and particulate matter. They tested soy methyl ester (SME) biodiesel (B99)and low sulfur diesel fuel (BP50) with supplemental hydrogen fueling. Tests were conducted at 20, 40, and 60 % rated load with a constant engine speed of 1700 RPM. They observed that at all conditions there is a significant increase in ratio of NO_2 to NOx in the emissions with increasing amounts of hydrogen. Jiwak.G.Suryawanshi et al [2], developed an experimental set up of HCNG engine, they noticed that the burning velocity increases exponentially with the increase of hydrogen fraction in the fuel blends, the maximum mean gas temperature and maximum rate of pressure rise increased extraordinarily when the hydrogen volumetric fraction increase slightly. Optimum hydrogen volumetric fraction in natural gas, is around 20 % to get the compromise in both engine performance and emissions. B.Rajendraprasad et al [3], used dual fuel (mixing of fuel) mode, they concluded in their experiment Hydrogen reduces the smoke, particulate and soot emissions to the considerable amount by the maximum replacement of 20% in CI engine without sacrificing the engine power output. The problems like pre- ignition and backfire could be eliminated compared to SI engine that make the usage of Hydrogen to be safer in CI engine (mode). K.S.Varde and G.A.Frame [4], investigated the prospect of reducing diesel particulates in the exhaust by take away small quantities of gaseous hydrogen in the intake of a diesel engine. They used a single cylinder direct injection type diesel engine for the experiments. It was found by them out of total input energy supplied to the engine, the thermal efficiency was dependent on the portion of hydrogen energy. They observed from the experiments that there is no significant change in the hydrocarbon emissions but hydrogen energy has been increased with increase in oxides of nitrogen in the exhaust. Talib et al [5], carried out experimental investigation of hydrogen-diesel fuel co-combustion on a naturally aspirated, direct injection diesel engine. The tests were performed by them at fixed diesel injection periods, with added hydrogen to vary the engine load between 0 and 6 bar IMEP. They employed a novel incylinder gas sampling technique to measure species concentrations in the engine cylinder at two inecylinder locations during the combustion process. From inecylinder gas sampling results they showed that NOx levels will be higher between adjacent spray cones, in comparison to within an individual spray cone. Madhujit Deb et al [6] studied a Timed Manifold Injection (TMI) system to vary the injection strategies. From their studies, increasing hydrogen rate, improvement in brake thermal efficiency (η_{bth}) of the engine has been observed with reduction in brake specific energy consumption (b.s.e.c), Soot contents decrease with an increase in indicated specific NOx emissions with the enhancement of hydrogen flow rate. Vinayak V. Khalasi et al [7], used hydrogen as a vehicle fuel in a single-cylinder four-stroke compression-ignition engine due to high temperature reaction, The negative impact on environment was NOx emission but involving the nitrogen in the atmosphere fuel which is far less than the traditional fossil fuels. Miqdam Tariq Chaichan and Dina Saadi Muneam Al-Zubaidi [8], investigated the possibility of improving diesel engine performance by aspirating volumetric quantities of gaseous hydrogen in the intake of a single cylinder diesel engine (Ricardo E6 with four stroke CI engine) variable compression ratio, injection timing and equivalence ratios was used .They showed that the engine could be run with very lean equivalence ratios. They showed that indicated thermal efficiency is increased, and the brake specific fuel consumption reduced with increasing hydrogen volumetric ratio. Lakhan Puri Goswami et al [9], premixed secondary fuel oil with the engine intake air to improve combustion process in engine and reduce the pollutant emissions. They observed that using of dual fuel mixture temperature and also the flame velocity can be increased which creates a lower emission. SR. Premkartikkumar et al [10], carried out experimental investigation of oxygen enriched hydrogen gas of 4.6 lpm with warm diesel fuel in the combustion process of the DI diesel engine,it decreases the fuel consumption and reduction of all engine-out pollutants except oxides of nitrogen (NO_X),and used enhanced combustion phenomena, the pressure and the temperature developed during the combustion is more, resulting in more NO_X emissions. N.Saravanan and G.Nagarajan [11], used manifold injection technique on a single cylinder diesel engine with hydrogen flow rate of 7.5 litres/min, They observed that brake thermal efficiency in port injection increases by 13 % and 16 % in manifold injection at 75 % load, at full load the brake thermal efficiency decreases by 1 % in port injection and 8 % in manifold injection. And reduction in NO_X emission by 4 in port injection and 7 times in manifold injection at full load.At75 % load the NO_X emission reduces by 3 times in both port injection and manifold injection. Iulian Voicu et al [12], worked on a conventional tractor diesel engine running alternatively with B20 and petroleum diesel at different speeds (1400 rpm and 2400 rpm) full load and then, with the same fuels enriched with hydrogen, at 60% load and two speeds. It was found that compared with petroleum diesel, the engine fuelled with B20 has higher NO_X emissions at all speeds and lower smoke and CO emissions, while both fuels combustion closely resembles At 1400 rpm, B20 had higher CO emissions by 9% relative to petroleum diesel and lower emissions of unburned hydrocarbons (THC) by 50%; NO_X and smoke emissions were almost equal. At 2400 rpm, CO emissions were higher by 6% and THC, NOx, and smoke emissions lower by 50%, 2.5% and 11% respectively compared to petroleum diesel fuel. Saravanan et al. [13] carried out an experimental study on a single cylinder water cooled direct injection diesel engine using hydrogen in the dual fuel mode. It was reported that the brake thermal efficiency increases from 23.59% to 29% with an optimized start of injection and duration. The peak pressure increases rapidly when hydrogen is used in the dual fuel mode. The emissions such as NOx, CO, CO2 and HC are reduced drastically.

II. Experimental Methodology:

In the present experiment(fig.1) single cylinder four stroke diesel engine (Kirloskar) is used for testing various diesel and hydrogen fuel mixtures, whose specification are given in table 1. The engine crank shaft is connected to an electrical dynamometer which is used to measure the brake power at a constant speed. Using diesel as a pilot fuel and Hydrogen as a main fuel (i.e Dual fuel mode), a solenoid-operated hydrogen gas injector was fixed on to the engine cylinder head. Hydrogen (purity 99.98%) supplied and stored in special bottles at high pressure was introduced through a dedicated line at low pressure to the engine intake manifold. This line was provided with pressure regulators, two pressure gauges,two thermocouples, precision gas flow meter, flame trap, flame arrestor equipped with one way valve and an emergency rapid stop valve. The instrumentation was adequately selected to ensure safety operation and monitoring of the engine when it was partially fueled with the potentially explosive hydrogen gas. Concerning the engine operating parameters, the instant torque and speed were measured and controlled by an eddy current dynamometer. Engine air consumption was measured by means of a volumetric flow meter type. The exhaust gas analyzer MN-05 (MARS Technologies Inc) is used to measure the exhaust gasses and NOx emissions(fig.2). The pressure of the hydrogen out let is not allowed to exceed 2 bar.

Table 1: Engine Specifications

Name of the Manufacturer	Kirloskar
Method of Ignition	Compression ignition
No. of cylinders	One
Bore	80 mm
Stroke	120 mm
Speed	1500 rpm
Dynamometer	Eddy current loading unit (0-16 Kg)
Rated power	5.2 KW at 1500 rpm
Compression ratio	17.5:1
Type of cooling	Water cooled
Injection timing	23^0 BTDC static
Air box	With orifice meter and manometer
Calorimeter type	Pipe in pipe arrangement
Rota meter	For flow measurement

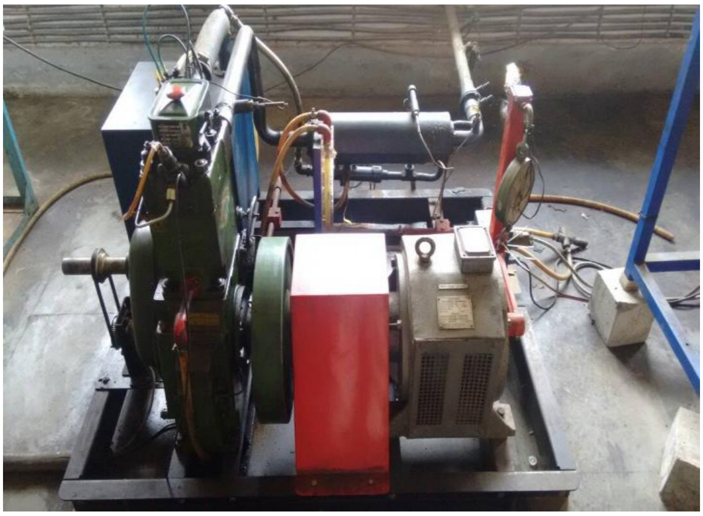

Fig 1: Experimental Engine Setup

Fig 2: Multi Gas Analyzer

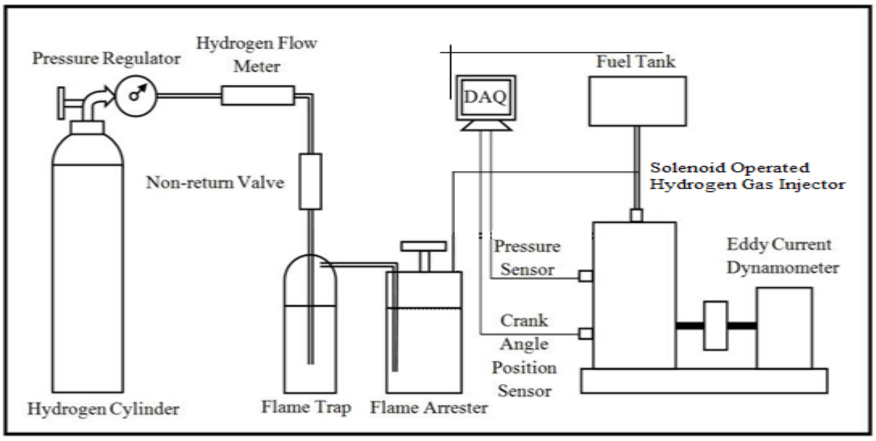

Fig 3: Schematic of Experimental Setup

III. Results And Discussions:

As from the experimental results the graphs are plotted between load and brake power, load and BSFC, and load and break thermal efficiency as shown in the Figures 4, 5, 6 and 7 as below. During the hydrogen addition the load and speed were kept constant. As from the graphs the Brake power reduces from pure diesel to different diesel hydrogen mass flow rates. The results are nearer to the early studies [7, 8]. The Brake power is decreases compared with the pure diesel at constant speed of 1500 rpm as shown in the Fig 4. The increase in break thermal efficiency for hydrogen operation is due to enhancement of hydrogen in air. Increase in thermal efficiency is credited to enhanced combustion because of better combustion rate due to high flame velocity of hydrogen. Brake thermal efficiency has increased due to well mixture formation by the use of hydrogen due to diffusive nature of hydrogen. From the Fig 5, the results are nearer and more than the early studies [14] at partial loads. We may think that the loads are minimum the BSFC values are increases, because initially more fuel is required for combustion process.

Table 2: Nomenclature

DH0	Pure (100%) Diesel and 0% Hydrogen
DH1	90% Diesel and 10% Hydrogen
DH2	80%Diesel and 20% Hydrogen
DH3	70% Diesel and 30% Hydrogen
DH4	60% Diesel and40% Hydrogen
DH5	50% Diesel and 50% Hydrogen

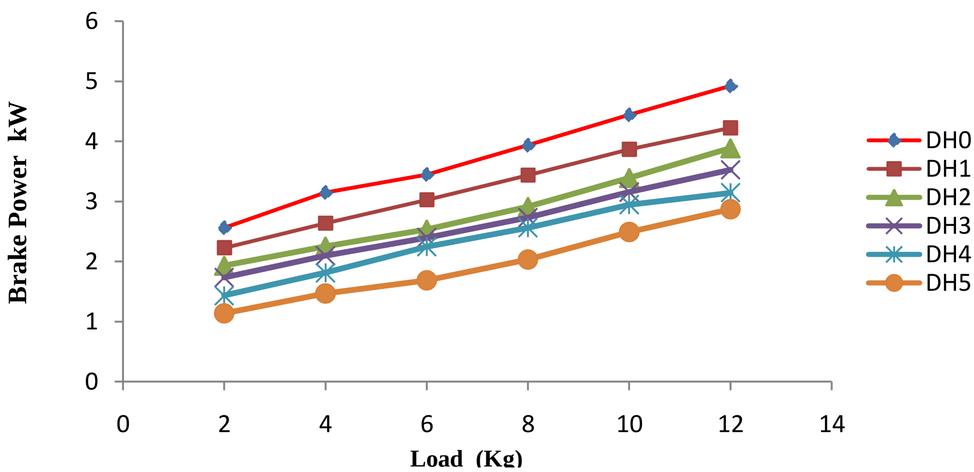

Fig 4: Load Vs Brake Power

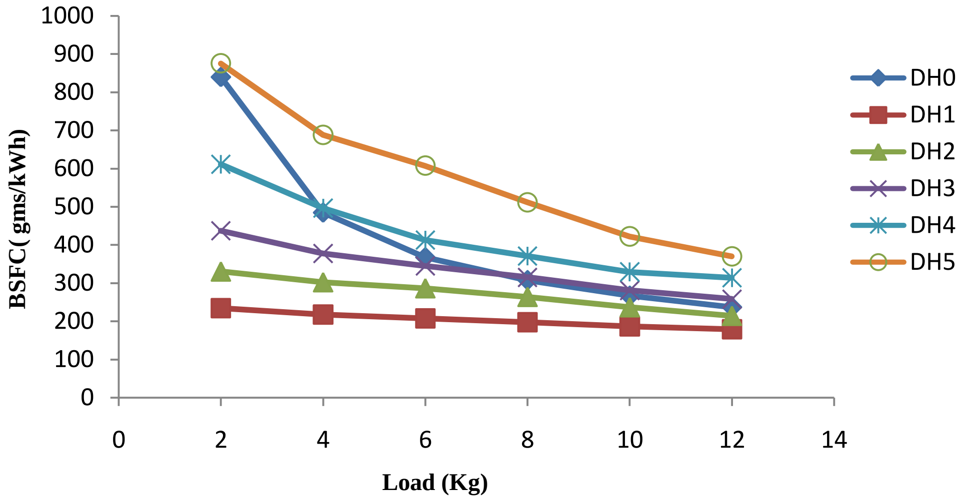

Fig 5: Load Vs BSFC

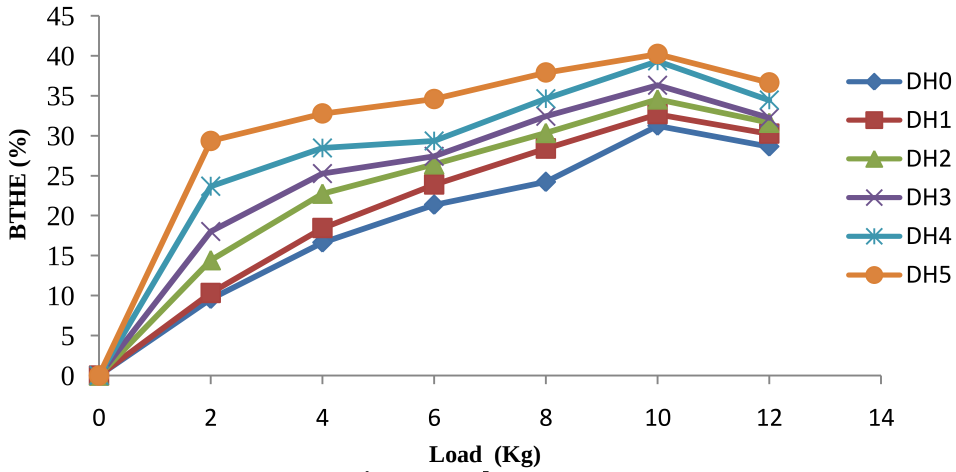

Fig 6: Load Vs BTHE

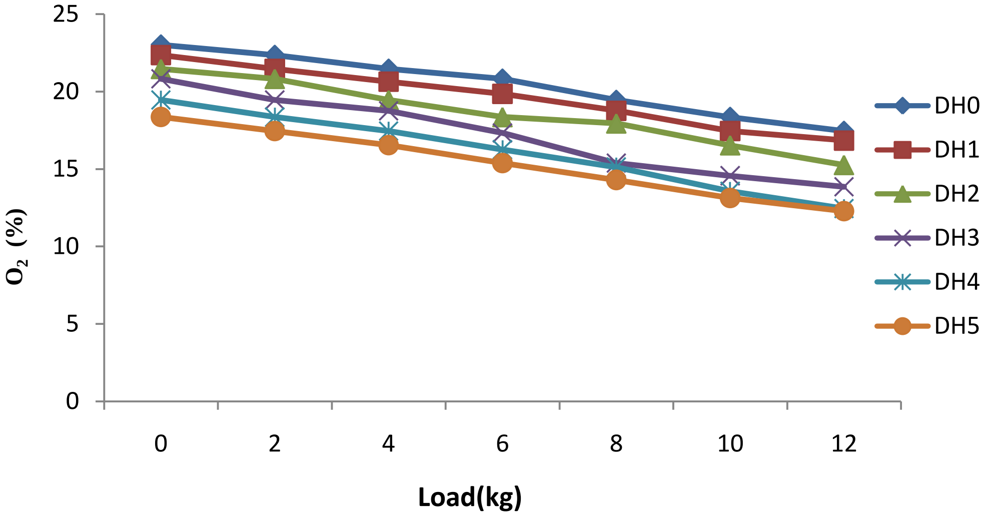

Fig.7: Load Vs O_2 %

The brake thermal efficiency of the engine with hydrogen enrichment reaches to a maximum of 40.22 % at 10 kg load condition with hydrogen injection approach as shown in Fig 6, whereas diesel alone as 29.34%. The results are somewhat nearer and more than the previous studies [4, 13]. From the experiment we may observed that the flow rate of hydrogen started to increases there was a decreases in flow rate of diesel. From the Fig .7, it was found that the percentage of Oxygen (O_2%) decreases when the mass flow rate of hydrogen increases at different load conditions. Percentage of Oxygen (O_2%) reduces due to Oxygen mixed with CO and Nitrogen may form CO_2 and Oxides of nitrogen (NO_X).

IV. Conclusions:

In this work the effect of hydrogen addition on performance, emissions and combustion characteristics at different loads with constant engine speed is investigated. When hydrogen is used as a alternative fuel for a diesel engine the Brake power gradually decreases, when the mass flow rate of hydrogen increases. Increase in thermal efficiency is attributed to enhanced combustion because of better combustion rate due to high flame velocity of hydrogen. Brake thermal efficiency has been increased due to well mixture formation by the use of hydrogen due to diffusive nature of hydrogen. Percentage of oxygen reduces due to oxygen mixed with CO and Nitrogen may form CO_2 and oxides of nitrogen (NO_X).

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