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AN EXPERIMENTAL ANALYSIS OF INTERNAL COMBUSTION ENGINES BY ULTRA-LEAN FUEL INJECTION OPENING PRESSURES WITH VARIOUS BLENDS OF HYDROGEN

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ABSTRACT

This paper aims to present the combustion, performance and emission analysis of dual fuel operated internal combustion engine experimentally. With higher rate of depletion of the conventional fossil fuels, the quest for an appropriate alternative fuel has gathered great attention in past three decades. As the world finds itself in the midst of universal energy shortage and alarming rate of environmental issues, compounded a parallel need of reducing pollutants along with energy generation. Hydrogen energy is an abundant energy source and its working methodology should address this problem to some extent. Though internal combustion engines are the most trusted power sources in the transportation sector, due to stringent emission norms and rapid depletion of petroleum resources there has been a continuous effort to use alternative fuels. The engine was operated under dual fuel mode at constant speed of 1500 rpm. During starting of experiment, engine run with pure diesel mode and once the engine reaches to the rated speed enrichment fuel is inducted in the mixing chamber. The enrichment used with varying the blend percentage 10%, 20% by mass of fuel. Operating the engine at variable load at an Ultra-Lean fuel injection opening pressures of 220 bar (optimum pressure) at compression ratio of 17.5.

KEYWORDS: Dual Fuel, Hydrogen, Diesel Engine, Injection Opening Pressure, Compression Ratio.

INTRODUCTION

Over the past decades the fossil-fuel reserves in the world are diminishing at an alarming rate and a lack of crude oil is expected at the early decades of this century. As a well-known fact, the energy resources for the major prime movers are discounting from the world, leaving toxic and fatal foot prints on the environment and human health. Global concerns on sustainable energy use and environmental protection call for innovative power train technologies. In this concern gaseous fuels have achieved a prominence as internal combustion engine fuels, mainly Hydrogen separately attracts many researchers for their advantages, in fact it has got own disadvantages such as high emission of oxides of nitrogen due to Hydrogen. The combination of this fuel under constant operating conditions such as injection opening pressure and compression ratio affect the performance, combustion and emissions in case of compression ignition engines. In this investigation series of experimental cycles were conducted with injection opening pressure and compression ratio iterations were done with varying percentage of Hydrogen and the results were compared with pure diesel. Diesel is one of such a fossil fuel which is used in the compression ignition engines, where compression ignition engines are the majorly used prime movers in medium and heavy vehicles, generators, pumps and machineries in most of the developed countries. But the amount of pollutants such as CO_2, CO, NO_x and unburnt hydrocarbons that are thrown out into the atmosphere through the exhaust emission of automotive vehicles is also increasing. So the compression ignition engines have occupied irreplaceable designation whereas replacement of fuel has been found. Hydrogen is one such fuel which has already shown off itself as a remarkable fuel for spark ignition engine, and also become a beckoning fuel for compression ignition engine from researchers. The fossil fuel that is the breath fuel for the compression ignition engines is getting depreciated as a common knowledge [1] and leaving exhaust engines as the traits a human health and atmosphere. To the grounds, the researchers around the world are in chase of a duck soap solution for the problem. For dual-fuel engine, various methods were applied to induct gaseous fuel into diesel engine to achieve the mentioned combustion modes, such as carburetion, continuous manifold induction, timing-controlled manifold/port hydrogen injection, direct hydrogen injection [2]. Natural gas (NG) has been widely used in modern

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vehicles and its application in diesel engine is normally in diesel-NG dual-fuel mode. Researchers [3-5] are conducted experiments on a diesel and natural gas fuelled dual-fuel single-cylinder diesel engine. The results indicated that the ignition delay of diesel-NG dual-fuel operation was extended than normal diesel operation. The peak heat release rate and cylinder pressure decreased with the increase of NG addition at low to medium load but increased at higher load due to the fast burning rate of diesel-NG cooperated combustion. Drastically increase of CO/HC as well as decrease of particulate became the trade-off effect for diesel-NG dual-fuel engine. The control of CO emission can be fulfilled by intake air pre-heating and increasing of pilot diesel [6]. A slight decrease of NO emission was also observed. Poompipatpong and Cheenkachorn [7] focused on the effect of engine compression ratio and speed on the emissions of a four-cylinder diesel-NG dual-fuel engine. They found that higher compression ratio and higher engine speed can achieve higher thermal efficiency and lower CO emission. But lower thermal efficiency was still observed at lower engine load. For diesel-natural gas fuelled dual-fuel engine, lower thermal efficiency, extremely higher CO/HC emission at low to medium load will be the main limitation for ULSD-Methane dual-fuel engine without modification. Hydrogen as a peculiar fuel has many special properties, such as wide flammability, fast burning velocity, low ignition energy and non-carbon, which can have combined with other gaseous fuel so as to improve the overall energy utilization efficiency. Lata et al. [2], [13], [14] conducted theoretical and experimental study on diesel engine using LPG and hydrogen mixture as gaseous fuel. The major finding indicated that the low efficiency at lower load for diesel-LPG dual-fuel engine was removed by inducing hydrogen into LPG fuel when engine was operated at higher than 10% of full load. Gatts et al. [8] further studied the combustion efficiency of hydrogen by measuring the unburned hydrogen exhaust. They suggested that the combustion efficiency of hydrogen was engine load dependent and the hydrogen should be supplemented at higher load to achieve higher hydrogen energy conversion efficiency and better diesel fuel efficiency. In terms of emissions characteristics, the experimental results were consistent. As indicated by [9-11], the HC/CO/CO2/PM gradually reduced with the increase of hydrogen addition. NOx emission decreased at low to medium load with small amount of hydrogen input but increased at higher load due to the high combustion temperature of hydrogen which enhanced the NOx formation. The thermal efficiency was engine load, speed and hydrogen amount dependent as reported by Miyamoto et al. [12].

Nomenclature			
NOx	Oxides of Nitrogen	CA	Crank Angle
CO	Carbon Monoxide	HI	Heat input
BTE	Brake Thermal Efficiency	CI	Compression Ignition
UHC	Unburnt Hydrocarbon	LHV	Lower Heating Valve
PPM	Parts Per Million	mH2	Mass of Hydrogen
IOP	Injection Opening Pressure	mD	Mass of Diesel
% H2	Percentage of Hydrogen		
ROPR	Rate of Pressure Release		
ROHR	Rate of Heat Release		

Approaches for Controlling NOx for Ultra-Lean Combustion

In an ultra-lean burn engine, adjusting the air/fuel ratio towards the ultra-lean operation side increases the volume of air available for the combustion process. This increases the heat capacity of the mixture and lowers the combustion temperature, resulting in lower NOx formation. EGR (whether internal or external) decreases oxygen attention in the combustion chamber by diluting the entering ambient air with exhaust. During combustion, the lower oxygen content has the effect of dropping flame temperatures, which in turn decreases NOx production since the NOx production rate is exponentially proportionate to flame temperature.

Applications of an Ultra-Lean Combustion

A large benefit of ultra-lean burn is operating the engine with the throttle more open, and therefore reduced pumping losses. There is another not so widely known benefit and that air is a better gas for transferring work to the piston than exhaust gas alone (thermodynamically to do with the ratio of specific heats at constant pressure and volume). However, a large problem with running lean is that there is an excess of NO_x to CO (carbon monoxide) and HC (hydrocarbons).

It is not that the engine produces more NO_x it's just that there is too little CO & HC to reduce the NO_x in the "three-way" catalyst (this is why it's called a 3-way cat because the 3 major pollutants reduce and oxidize each other). The only company I know using lean-burn gasoline engines at the moment is BMW with their efficient dynamics. On the NEDC test (the fuel consumption and CO_2 test quoted by governments and manufacturers) at the very low power points they run lean and then collect the NO_x in very expensive NO_x trap catalysts. They then have to regenerate the trap using an excess of fuel to clear the NO_x, preferably when the engine runs rich at high-load. This is probably the way to keep large multi-cylinder engines in the future with ever tightening fuel consumption regulations, because the alternative for reducing fuel consumption is using downsized and down speeded engines running at stoichiometric. The engines designed for lean burning can employ higher compression ratios and thus provide better performance, efficient fuel use and low exhaust hydrocarbon emissions than those found in conventional petrol engines. Ultra-lean mixtures with very high air-fuel ratios can only be achieved by Direct Injection engines.

Hydrogen Flow Measurement

The hydrogen flows were measured by using a specially designed flow meter. To damp the pressure fluctuations in the intake line, which particularly occur with large displacement single cylinder engines, flash back arrestors for hydrogen is located at the inlet of the engine. When the hydrogen supply was increased the diesel injection was automatically decreases by the governor mechanism of the engine to maintain the speed constant. For hydrogen flow meters see Fig. 1.

***Fig. 1. Photographic view of Hydrogen Flow meter*.**

Experimental PROCEDURE

The experiments were conducted with ultra-lean fuel injection opening pressure at 220 bar were done with varying percentage of hydrogen substitutions and the results were compared with pure diesel. The engine used in the present study is a Kirloskar AV-1, single cylinder direct injection, water-cooled diesel engine with the specifications given in Table 1. While a schematic view of the experimental setup is shown in Fig. 2. Diesel injected with a 3 holes injector each with nozzle diameter of 0.15 mm. The engine is coupled to an Eddy current dynamometer. Engine exhaust emission was measured. At each cycle, the engine was operated at varying IOPs and the emissions were noted. The experiment was carried out by keeping the compression ratio constant i.e.16.5:1. The exhaust gas analyser used is MN-05 multi gas analyser (5 gas version) is based on infrared spectroscopy technology with signal inputs from an electrochemical cell. Non-dispersive infrared measurement technique used for the measurement of CO, CO_2, and HC gases. Each individual gas absorbs infrared radiation that can be used to calculate the concentration of sample gas. Analyser uses an electrochemical cell to measure oxygen concentration. It consists of two electrodes separated by an electrically conducted liquid or cell. The cell is mounted behind a poly tetra fluro ethene membrane through which oxygen can diffuse. The device therefore measures oxygen partial pressure. If a polarizing voltage is applied between the electrodes the resultant current is proportional to the oxygen partial pressure.

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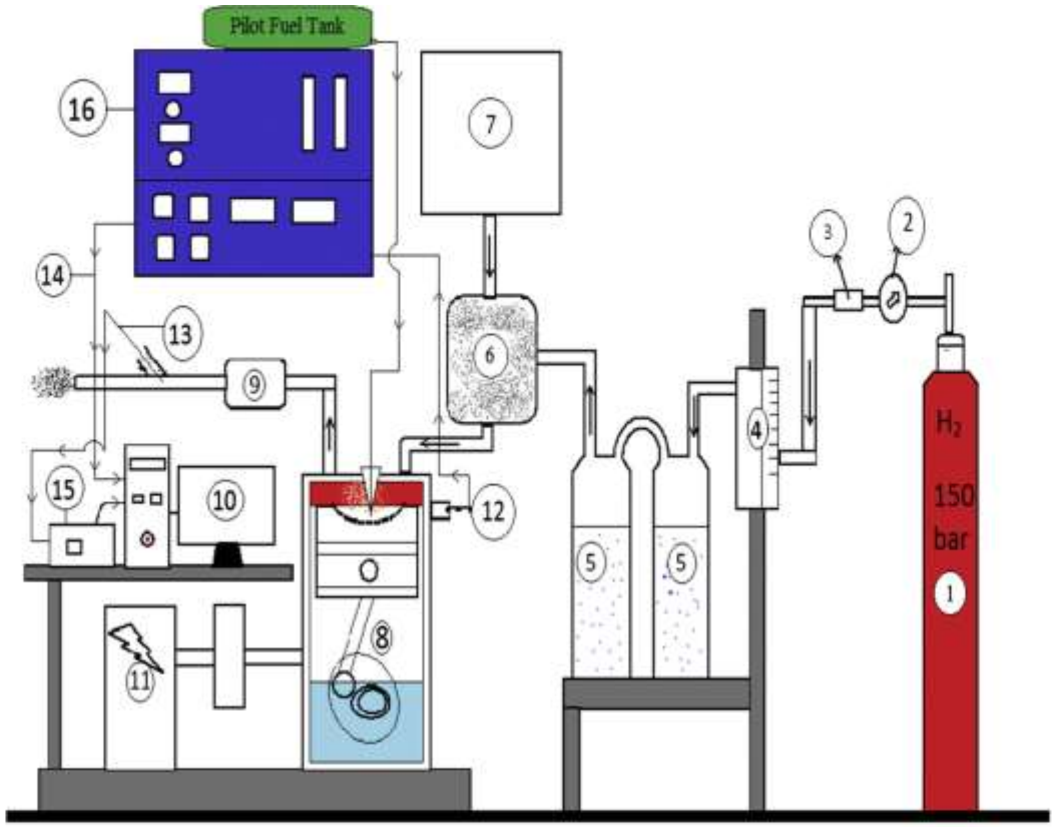

1.H_2 gas cylinder 2.Pressure gauge 3.Back flash arrestor 4.Flow meter 5.Flame arrestor 6.Mixing chamber 7.Air tank 8.Engine 9.Exhaust gas calorimeter 10.PC 11. Eddy current dynamometer 12.Piezoeletric sensor 13.Exhaust gas sensor 14. Sensor to PC 15.Exhaust anlyser 16.Control panel

Fig. 2. Schematic view of experimental setup

Table 1. Engine Specifications

Type	Four-stroke, single cylinder, compression ignition engine, with variable compression.
Make	Kirloskar AV-1
Rated power	3.7 kW, 1500 rpm
Bore and stroke	80 mm 110 mm
Compression ratio	16.5:1
Cylinder capacity	553 cc
Dynamometer	Eddy current dynamometer
Orifice diameter	20 mm
Fuel	Diesel and hydrogen
Calorimeter	Exhaust gas calorimeter
Cooling	Water cooled engine
Starting	Hand cranking and auto start

RESULTS AND DISCUSSION

The combustion in the dual fuel engines is basically controlled by the Hydrogen-Diesel air mixing process which is influenced by the spray characteristics, air motion and the percentage substitution of Hydrogen. The ultra-lean fuel injection opening pressure, compression ratio and the fuel-air mixing characteristics directly affect the combustion phenomenon. The effect of characteristics on the in-cylinder pressure, performance and emission trends are presented in this study. Evaluation of ignition delay is a very important parameter which effects on the in cylinder pressure hence a detailed discussion of ignition delay is presented with the variation of Hydrogen substitutions. Effect on performance, combustion and emissions of a diesel engine with variable fuel combination at ultra-lean fuel injection opening pressure of 220 bar at 17.5 CR.

Brake Thermal Efficiency

Fig. 3. As the ultra-lean fuel injection opening pressure was 220 bar the size of fuel droplets become small and fine and hence proper atomization of ultra-lean fuel and more spray penetration. Since the additions of hydrogen to diesel directly increases the brake thermal efficiency because of its unique characteristics such as wide flammability limits that accelerates the combustion phenomenon and raise the brake thermal efficiency. Under full load conditions at 10%, 20% of hydrogen substitution. Brake thermal efficiency was observed to be more than that of pure diesel respectively. There was a mild knocking at 20% of hydrogen, hence brake thermal efficiency was considered to be optimum.

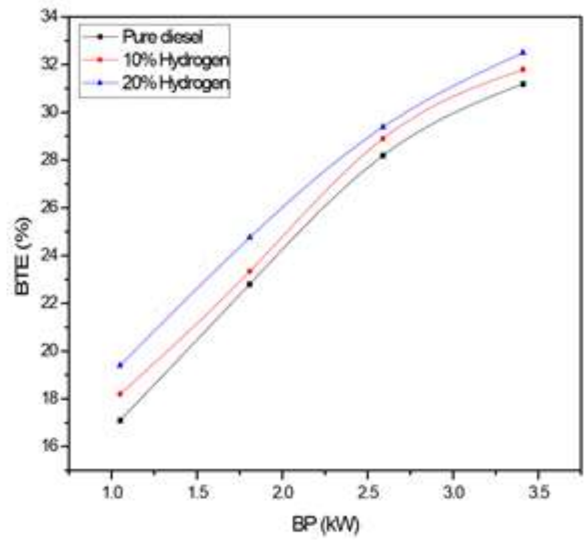

Fig. 3. Variation of brake thermal efficiency with Brake Power

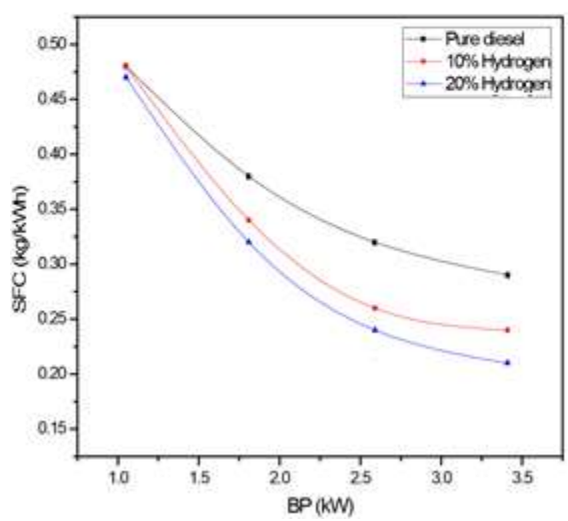

Fig. 4. Variation of SFC with BP

Specific Fuel Consumption

Fig. 4. For a dual fuel mode operating as hydrogen-diesel, as the ultra-lean fuel injection opening pressure causes the uniformity in mixture formation with hydrogen which assist the better combustion to increase the performance [15]. Hence SFC was found to be minimum for maximum percentage of hydrogen substitution. The optimal substitution i.e. 20% of hydrogen, SFC was found to be 0.21 kg/kWh, which is 19% less than pure diesel mode.

Carbon Monoxide

Fig. 5. It was depicted that the formation of CO was minimum for dual fuel mode at any percentage substitution of hydrogen in comparison with pure diesel. As the CO content gradually decreased up to 75% load for pure diesel mode and even for all hydrogen substitutions. But as the load increased to full load, there was a sharp rise in CO formation because at 220 bar the fine size droplets did not have sufficient time for complete combustion. Hence at full load the optimal CO content was 0.11% vol. and it was 47.6% less than that of pure diesel.

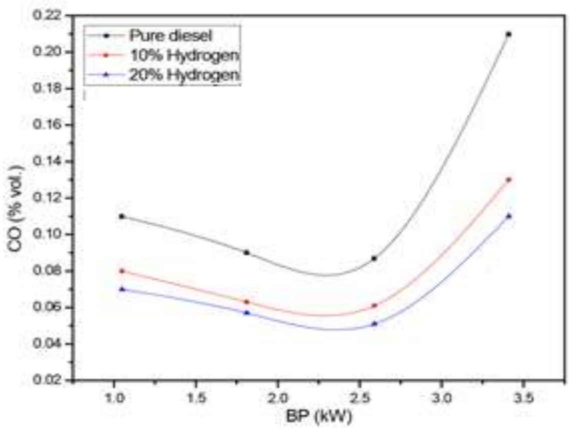

Fig. 5. Depicts the variation of CO emissions with BP

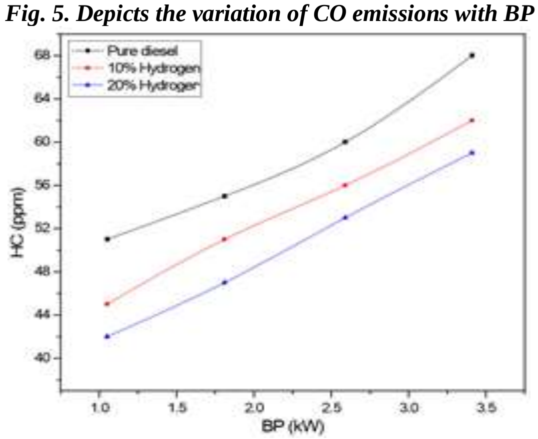

Fig. 6. Variation of HC with BP

Hydro Carbons

Fig. 6. As HC formed in the engine exhaust due to incomplete combustion. At 220 bar ultra-lean fuel injection opening pressure when the hydrogen atoms interacting with the fine diesel droplets extreme atomization and mixing was achieved that accelerates the brake thermal efficiency and lower the HC content in comparison with pure diesel mode. The optimal value was at 20% of hydrogen i.e. HC content was 59 ppm and it was 13% less than that of pure diesel mode.

Oxides of Nitrogen

Fig. 7. The in-cylinder temperature was very high which leads to the formation of NOx due to the presence of excess of oxygen. At 220 bar when the fine fuel droplets react with the hydrogen rapid combustion is achieved and peak temperature was recorded. Maximum amount of NOx was found at 20% hydrogen, which is more than that of pure diesel mode.

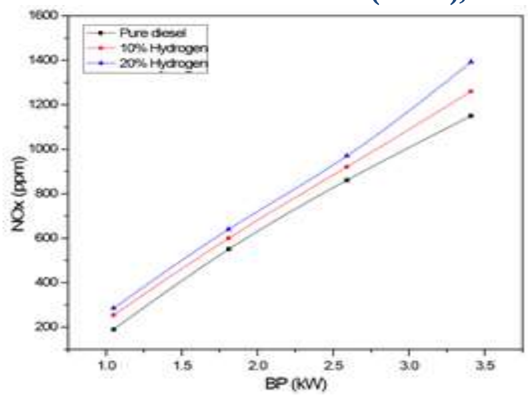

Fig. 7. Variation of NOx with BP

Combustion Parameters

From the ultra-lean fuel injection opening pressure has been found that maximum efficiency and minimum emissions at 220 bar. So combustion parameters are studied only on 220 bar. Fig. 8 shows the cylinder pressure vs. crank angle at full load and at various substitutions of hydrogen at 220 bar. As the substitution of hydrogen percentage in dual fuel mode is increased the rate of pressure rise per crank angle is simultaneously increased because the ultra-lean fuel ignites nearly 2-3 degrees advance than that of the normal diesel fuel. The highest peak pressure was observed for 20% H_2 substitution due to high flammability of hydrogen, rapid combustion, smaller drop size distribution, large jet penetration of the fuel spray makes proper air-fuel mixture and large amount of fuel burnt in the premixed combustion stage.

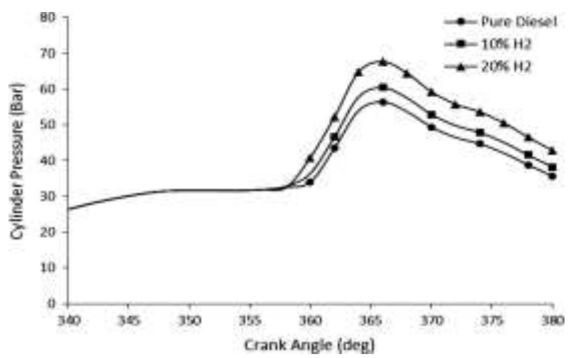

Fig.8. Cylinder pressure vs. crank angle.

Rate of Heat Release (ROHR)

Fig. 9 shows the rate of heat release per degree of crank angle at full load for different substitutions of hydrogen. In this operation, the peak heat release rate was found at 360L crank angle and at 20% substitution of hydrogen. The peak heat release rate for dual mode at 20% hydrogen substitution was 258.3 J/deg CA and 226.8 J/deg CA for pure diesel operation. The peak heat release is more in case of dual mode at 220 bar IOP this is due to fine atomization of fuel for fluent combustion.

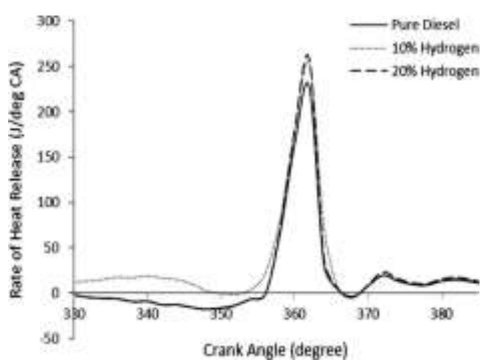

Fig. 9. Rate of heat release at different hydrogen substitutions.

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Rate of Pressure Release (ROPR)

Fig. 10 shows the rate of pressure release per degree of crank angle at 100% load for different substitutions of hydrogen. In this operation, the peak pressure rise was found at 364L crank angle for 20% substitution of hydrogen. The peak pressure rise for dual mode at 20% hydrogen substitution was 12.6 bar/deg CA and 10.5 bar/deg CA for pure diesel operation. The peak pressure rise is more in case of dual mode at 220 bar IOP.

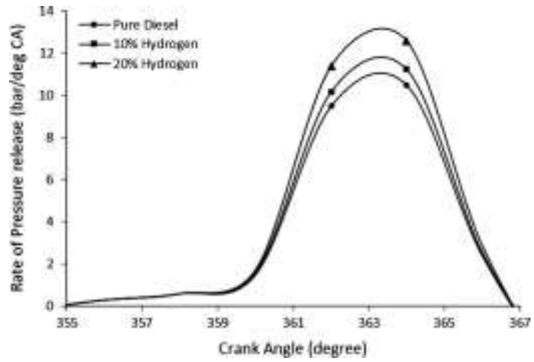

Fig. 10. Rate of pressure release at different hydrogen substitutions

CONCLUSION

The current paper presented the results of H_2 substitution by mass to the ultra-lean fuel with Injection opening pressure and compression ratio at full load conditions. Results summarized the effects on performance, emission and combustion characteristics.

- BTE increases with increase in percentage of H_2 substitution (by mass) compared with pure diesel. SFC decreases with increase in percentage of H_2 substitution (by mass) compared with pure diesel.
- It was noticed that as the hydrogen percentage increases NO_x level also increases at ultra-lean fuel injection opening pressure of 220 bar. The decreasing trend of UHC was observed at ultra-lean fuel injection opening pressure with increase in percentage of H_2 substitution when compared to pure diesel. For 10% H_2 and 20% H_2 substitution at ultra-lean fuel injection opening pressure 220 bar minimum content of UHC was observed. In the dual fuel mode as the percentage of H_2 increased, uniform mixing is achieved with the air that causes minimization in the formation of CO at 220 bar.
- The rate of pressure rise inside the cylinder per degree of crank angle was maximum at 20% of H_2 substitution followed by 10% of H_2 and then for pure diesel. The cylinder pressure obtained in H_2-diesel dual fuel mode is higher than that obtained with pure diesel. The highest peak pressure was observed for 20% H_2 at 220 bar.
- At 220 bar IOP with increase in hydrogen substitution there was an increase in BTE by 2.4% but the penalty of NO_x emissions also increased by 14.1%.

REFERENCES

[1] Das LM. Hydrogen engine; research and development programs in Indian institute of technology. Int J Hydrogen Energy 2002; 27(9):953–65.
[2] Lata DB, Misra A, Medhekar S. “Effect of hydrogen and LPG addition on the efficiency and emissions of a dual fuel diesel engine,” in Int J Hydrog Energy. 2012; 37:6084-96.
[3] Papagiannakis RG, Hountalas DT. “Combustion and exhaust emission characteristics of a dual fuel compression ignition engine operated with pilot Diesel fuel and natural gas,” in Energ Convers Manage. 2004; 45:2971-87.
[4] Papagiannakis RG, Hountalas DT, Rakopoulos CD. “Theoretical study of the effects of pilot fuel quantity and its injection timing on the performance and emissions of a dual fuel diesel engine,”in Energ Convers Manage. 2007; 48:2951-61.
[5] Papagiannakis RG, Rakopoulos CD, Hountalas DT, Rakopoulos DC. “Emission characteristics of high speed, dual fuel, compression ignition engine operating in a wide range of natural gas/diesel fuel proportions,” in Fuel. 2010; 89:1397-406.

ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

[6] Papagiannakis RG, Kotsiopoulos PN, Zannis TC, Yfantis EA, Hountalas DT, Rakopoulos CD. “Theoretical study of the effects of engine parameters on performance and emissions of a pilot ignited natural gas diesel engine,” inEnergy. 2010; 35:1129-38.
[7] Poompipatpong C, Cheenkachorn K. “A modified diesel engine for natural gas operation: Performance and emission tests,” in Energy. 2011; 36:6862-6.
[8] Gatts T, Li H, Liew C, Liu S, Spencer T, Wayne S, et al. “An experimental investigation of H2 emissions of a 2004 heavy-duty diesel engine supplemented with H2,” inInt J Hydrogen Energ. 2010; 35:11349-56.
[9] Liew C, Li H, Liu S, Besch MC, Ralston B, Clark N, et al. “Exhaust emissions of a H_2- enriched heavy-duty diesel engine equipped with cooled EGR and variable geometry turbocharger,” in Fuel. 2012; 91:155-63.
[10] Roy MM, Tomita E, Kawahara N, Harada Y, Sakane A. “An experimental investigation on engine performance and emissions of a supercharged H2-diesel dual-fuel engine,” inInt J Hydrogen Energ. 2010; 35:844-53.
[11] Lilik GK, Zhang HD, Herreros JM, Haworth DC, Boehman AL. “Hydrogen assisted diesel combustion,” in Int J Hydrogen Energ. 2010; 35:4382-98.
[12] Miyamoto T, Hasegawa H, Mikami M, Kojima N, Kabashima H, Urata Y. “Effect of hydrogen addition to intake gas on combustion and exhaust emission characteristics of a diesel engine,”in Int J Hydrogen Energ. 2011; 36:13138-49.
[13] Lata DB, Misra A, Medhekar S. “Investigations on the combustion parameters of a dual fuel diesel engine with hydrogen and LPG as secondary fuels,”in Int J Hydrog Energy. 2011; 36:13808-19.
[14] Lata DB, Misra A. “Analysis of ignition delay period of a dual fuel diesel engine with hydrogen and LPG as secondary fuels,” in Int J Hydrog Energy, 2011; 36:3746-56.
[15] Saravanan N, Nagarajan. G. performance and emissions studies on port injection of hydrogen with varied flow rates with diesel as an ignition source. Applied energy, 2010; 87: 2218-2229.

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