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Emission Characteristic of a Dual fuel Compression Ignition Engine Operating on Diesel + Hydrogen & Diesel + HHO gas with same Energy Share at Idling Condition

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Abstract. Clean burning nature and renewability of hydrogen makes it viable and alternative / supplementary fuel for utilization in IC engine. In the past two decades, researchers have gained interest in using hydrogen in Internal combustion (IC) engines. Electrolysis is the widely used technique for production of hydrogen. The effect on emission parameters of using hydrogen and HHO gas in a dual fuel engine at idling condition was focused in this research work. HHO gas was synthesized from stored cylinders of hydrogen & oxygen in 2:1 ratio. The mixture of H2 and O2 are produced in stoichiometric ratio similar to electrolysis of water. Effect of introduction of hydrogen gas and stimulated HHO gas on emission characters such as unburnt hydrocarbon (UHC), carbon dioxide (CO_2), oxides of nitrogen (NO_x) and smoke of the engine were noted at idling condition (1700 rpm). Engine was supplied with 6, 12, 18, 24, 30, 36 LPM of hydrogen and 9, 18, 27, 36, 45, 54 LPM of HHO gas where the composition of mixture was maintained in the ratio of 2:1 and energy supplied by Hydrogen and HHO gas remains same. Introduction of hydrogen and HHO gas has reduced the total diesel fuel consumption and formation of CO2 at all operating condition than neat diesel operation. There was slight increase in UHC emission with hydrogen and by substituting HHO gas the UHC emission was reduced.

1. Nomenclature

ANN – Artificial Neural Network
BP – Brake Power
BT- Brake Torque
BTE – Brake Thermal Efficiency
BSFC – Brake Specific Fuel Consumption
CNG – Compressed Natural Gas
CI – Compression Ignition
CO – Carbon Monoxide
CC - Cubic Centimeter
CO_2 – Carbon dioxide
DC - Direct Current
HHO – Hydrogen and Oxygen in 2:1 composition
HC- Hydrocarbon

LM – Levenberg Marquardt
LPM –Litres per Minute
MPFI – Multi Point Fuel Injection
NOx –Oxides of Nitrogen
OER – Overall Equivalency Ratio
PM – Particulate Matter
PB – Palm Biodiesel
SI – Spark Ignition
SFC – Specific Fuel Consumption
TDC – Total Diesel Consumption
TE – Thermal Efficiency
UHC – Unburnt Hydrocarbon
VE – Volumetric Efficiency (%)

2. Introduction

Dependency on hydrocarbon fuel, associated with pollution created by combustion has increased the need for research in alternative fuels for powering automobiles. The use of hydrocarbons in automobiles produces harmful emissions such as oxides of nitrogen, carbon dioxide, carbon monoxide and smoke (PM) which are the significant contributors for global warming. Apart from affecting the environment, it also affects the human respiratory system. The governments of respective state have introduced strict emission parametric norms to be followed in the automobile industries to reduce the emission. The need for alternative fuel increases, one such alternation for conventional fuel is hydrogen gas. Hydrogen is produced from techniques such as stream reforming of hydrocarbons, direct water splitting through solar and electrolysis of water. Due to clean burning nature and combustive properties of hydrogen, it is a vital substitute for use in automobile application.

The electrolysis of water can be described as the process of splitting hydrogen and oxygen by passing a DC through electrodes. During electrolysis process hydrogen and oxygen are in 2:1 ratio. In electrolysis process if the electrodes are separated H_2 & O_2 will be produced separately at their respective electrode's sites. In case the electrolyser design does not have a separation between electrodes the gas produced will be mixture of H_2 and O_2 gases which is termed as HHO gas. Names such as hydroxyl, HHO, oxyhydrogen, Brown's, and hydrogen rich gas etc. usually used to denote the gas produced from electrolysis [1]. The particles present in HHO gas are H_2, O_2, water vapour and Santilli magnecule [2]. The proposal suggested by "Santilli" on existence of new type of molecule that contains magnecule structure was opposed by Calo [3]. Further rebuttals by "Calo" was opposed by Cloonan [4] and Kadeisvili [5]. Various investigations are being carried out around the globe for better utilization of HHO gas in engine systems. These researches aim at reducing the overall emission and hydrocarbon dependency for automobile application and local power generation.

In the past two decades, research in the field of engine is boom due to search of alterative source of power. HHO gas seems to be a vital substation for conventional hydrocarbon fuel, which is generated in electrolysis of water. The investigation on use of HHO gas has been carried out by larger research communities. In a non-modified engine, gas will be induced in the inlet manifold. Yilmaz et al. [6] used a non-modified CI engine in which generated HHO gas was supplied in inlet manifold along with air/ Fuel during suction stroke after passing through water separator. It was noted that engine torque was increased by 19 % and SFC reduced by 14 % on an average. The emission such as CO and HC were found to be reduced by 13.5 % and 5 % respectively. Bari and Esmaeil [7] also used a conventional non modified CI engine for experimentation where up to 32 LPM HHO gas was introduced after passing through two flame arrestor and a drier unit. It was noted that BTE was increased by 3 % and SFC was reduced by 15 %. The CO emission showed negligible variation and CO_2 got reduced by 3-4 %, whereas NO_x increased by 70 PPM and HC reduced by 100 PPM. Similar research conducted by Samuel and Mc Cormick [8] used a Compression Ignition engine that was supplied with HHO gas as supplementary fuel showed reduction in BTE by 5.4 % and increased rate of pressure rise by 59 %. As flow rate of gases increased carbon monoxide and carbon dioxide got reduced and oxides of nitrogen increased. Manu et al. [9] used a commercial non modified CI engine. They used a dry type electrolyser to generate HHO gas. Experiments were conducted at flow rates of 0.89, 1.37, 1.66 and 2 LPM. It was noted to decrease emission parameters and increase in performance parameters of the engine. In an extended work in which two – zone combustion model was developed for the same engine and the results were analysed [10].

Masjuki et al. [11] supplied supplementary fuel of HHO gas at 4×10^{-6} m^3/s . Blends made of PB20 and diesel were used as secondary fuel. Emission such as carbon monoxide and hydrocarbon were reduced by 20 % and 10 % and NO_x was increased by 25%. Diesel fuel consumption got reduced by 5 % and torque increased by 2%. Durairaj et al. [12] in his study used an CI operating on diesel and biodiesel prepared from esterification process. The supplementary fuel HHO gas was preheated before being supplied into the manifold. It was reported to reduce emission and increase performance characters. Kenanoglu et al. [13] used a CI engine in which soybean biodiesel fuel blend (B25) was used as secondary fuel. HHO gas was substituted at the flow rate of 3, 5 & 7 LPM. In this research ANN model with Levenberg-Marquardt (LM) training function was used to validate the experimental analysis of engine torque, power, and NO_x. The result showed that the ANN system predicted the data accurately by 95.82 %, 96.07%, and 92.35% of engine torque, power, and NO_x respectively. 10 LPM of HHO gas was induced in inlet manifold by Baltacioglu et al. [14]. Blends of sunflower oil and diesel were used as igniting fuel (Secondary fuel). NO_x emission was increased by 20 % whereas CO_2 and CO emissions were reduced by 12 % and 22 % respectively than neat diesel fuel operation. Brake power and brake torque were increased by by 13 % and 9 % respectively and reduced the fuel consumption (BSFC)by 10%. Birtas and Chiriac [15] experimented in a CI engine operating in dual fuel mode where HHO gas was induced with different energy shares corresponding to 1.46 %, 3.38 % and 5.85 % of the total energy fraction. Brake thermal efficiency of this operation was noted be decreased from 29.75 % to 29.57 %.

Two fuel blends made from mixture of Biodiesel, Ethanol and Diesel where experimented by Baltacioglu et al. [16] in a CI engine. One litre per minute of HHO gas was induced in the manifold along with air during suction stroke. Composition of sample A and B are (A) 10 % of bio diesel, 5% of Ethanol, 85 % of diesel and (B) 15 % of bio diesel, 5% of Ethanol, 80 % of diesel by volume share. For all the operating conditions BP and BTE were increases. Simultaneously there was a reduction in SFC. CO emission was reduced by 8.39 % and 12.20 % for both fuels blend A & B respectively. NO_x emission was increased by 8.57 % and 9.47 % in an average respectively for both the fuels blend. Arat et al. [17] investigated two different fuel combinations - sample1 and sample 2 in a CI engine. Sample 1 operated on mixture of HHO gas + diesel and sample operated on mixture of HHO gas + CNG + diesel. The result showed that both the Sample 1 & 2 both increased the BT, BP and TE by 2.75 % and 4.75 %, 3.18 % and 6.85 %, 3.4 % and 6.28 % respectively. It was reported that the exhaust gas temperature for speed below 1800 rpm was low and high for higher rpm. CO_2 was reduced by 9 % and 9.65 % and NO_x dropped by 11.76 % and 28.4 % for both the Sample 1&2 respectively. The CO emission got reduced by 15 % for sample 1 and increased for sample 2 by 16%.

In an experiment conducted by Olivares et al. [18] where HHO gas at 1, 2 and 3 LPM are induced in the inlet manifold. HC, CO and CO_2 emission by 22%, 23% and 7% were reduced by substituting at 2 LPM. 15.5 % and 25 % reduction in NO_x was noted with supply of 2 LPM and 1LPM.Sharma et al. [19] used a CI engine for analysing performance and emission formation by inducing HHO gas at 0.25, 0.5 and 0.75 LPM in the manifold. The experimental analysis was validated using the numerical stimulation. Experimental analysis showed an increase in BTE and BESC by 6.5 % and 6 %. CO, HC and smoke emissions showed a significant reduction. However, NO_x got increase because of high operating temperature inside the combustion chamber. The extended research work of Sharma et al. [20] were energy, exergy and emission characters of dual fuel engine was analysed. The result showed that BTE was increased by 6.5% with the supply of 0.75 LPM at 80% loading condition. The emission such as carbon monoxide, unburnt hydrocarbon, and smoke emission got reduced by 53%, 62%, and 49% respectively. At high operating temperature, the NO_x emission was increased by 30%. The work availability, exhaust gas and heat transfer exergy were increased by 6.54%, 5.69%, and 6.36% respectively with 0.75 LPM gas substitution at 80% load. The losses due to heat transfer and exhaust energy losses were increased by 6.29% and 8.55% at optimised working condition.

Jaklinski and Czarnigowski [21] used 5 different engines for conducting experimental analysis at idling condition. They used 3 SI and 2 CI engines where provision was made to induce HHO gas in inlet manifold. Quantity of HHO gas induction influence the emission formation in SI engines whereas in CI engine, the emissions of CO and HC got reduced and NO_x got increased. An Spark ignition engine in which HHO gas supplied at inlet manifold was used by Al-Rousan [22]. In his analysis, TE was increased by 6% and noted 20% reduction in SFC. A study by Musmar and Al-Rousan [23] also presented similar result trends. The emissions of NOx, CO and HC were reduced notably. El-Kassaby et al. [24] also used a SI engine in which MPFI system was used to inject the air/ fuel mixture. The gas was supplied in the manifold. The research reported to have increased the TE by10 % and CO, HC, NO_x emission was reduced by 18 %, 14 % and 15 % on average, respectively. Two different engines having different cubic capacities 150 and 1300 were used for conducting experiment by Nabil and Khairat Dawood [25]. It was noted that there was reduction in primary fuel consumption by 14.8 % and 16.3 % for 150 CC and 1300 CC respectively than diesel operation. Brake power and thermal efficiency were increased by 17.9 % & 27.4 % for 150 CC and 22.4 %, &21% for 1500 CC respectively. HC and CO emissions were also noted to have reduced for both the engines. Usman et al. [26] introduced HHO gas in inlet manifold along with Air/ fuel mixture. It was reported that BP was increased by 7% and BSFC was decreased by 15%. The reduction in emission of CO, CO_2, and unburned hydrocarbons by 21%, 9% and 21.8% was noted. Salek et al. [27] used two different electrolyser design for generating mixture of hydrogen and oxygen. They used a SI engine. The result showed that BTE and SFC both decreased with increase in HHO gas.

The above review of literature shows that researchers were focusing on producing HHO gas at limited flow rate and inducing them into the engine system. This research work uses HHO gas which was prepared using stored hydrogen and oxygen gas cylinders in 2:1 ratio [28]. The generation of HHO gas is influenced by factors like current, no of electrodes, concentration of electrolyte etc [29]. The limitations of the research works were with the amount of gas that can be generated and introduced in the inlet manifold. An elaborative study on emission characteristics of engine carried out at idling condition with different flow rates of stimulated HHO gas was done and reported.

3. Experimental Analysis

A Kirloskar make 4 stroke, vertical positioned single cylinder, water cooled CI engine was used for conducting experiment. Table 1 shows the Specification of the engine used for experimental work. Experiments were conducted at idling condition (1700 rpm). HHO gas was prepared using stored hydrogen and oxygen cylinder gases. The stoichiometric ratio (2:1) of hydrogen and oxygen produced during electrolysis process was considered for synthesising HHO gas. The gaseous mixture was supplied in inlet manifold at 2 Bar pressure. Different flow rates at which hydrogen and HHO gas were supplied are represented in Table 2. The cylinders were attached with regulators for constant delivery pressure and flash back arrestor to arrest the flame coming back from the engine. The composition of the mixture was maintained using a flow meter. Fig 1 shows the picture of Experimental set up used for analysis.

A standard burette was used to measure mass flow rate of diesel. Emissions and smoke were measured using AVL Digas analyser and AVL smoke meter. AVL analyser uses technique such as flame ionisation, chemiluminescence and infrared are used for measuring HC, NO_x and CO_2, CO, respectively.

For both the gaseous mixtures the experiments were conducted separately.

Table 1 Specifications of the engine

Parameters	**Description**
Engine Make	Kirloskar AV1XL
Bore Diameter	87.5 mm
Stroke Length	80 mm
Engine Volume	481 cc
Maximum Pressure	73.6 bar
Number of cylinders	1
Working cycle	Diesel cycle
Cylinder Arrangements	Vertical
Compression ratio	17:1
Maximum power	5.97 kW
No of stroke	4
Rated speed	2200 rpm
Speed control	Governor mechanism
Number of nozzle holes	3
Injection system	Direct injection

Table 2 Flow rates of hydrogen and HHO gas

Hydrogen (LPM)	Hydrogen + oxygen = HHO gas (LPM)
6	6 + 3 = 9
12	12 + 6 = 18
18	18 + 9 = 27
24	24 + 12 = 36
30	30 + 15 = 45
36	36 + 18 = 54

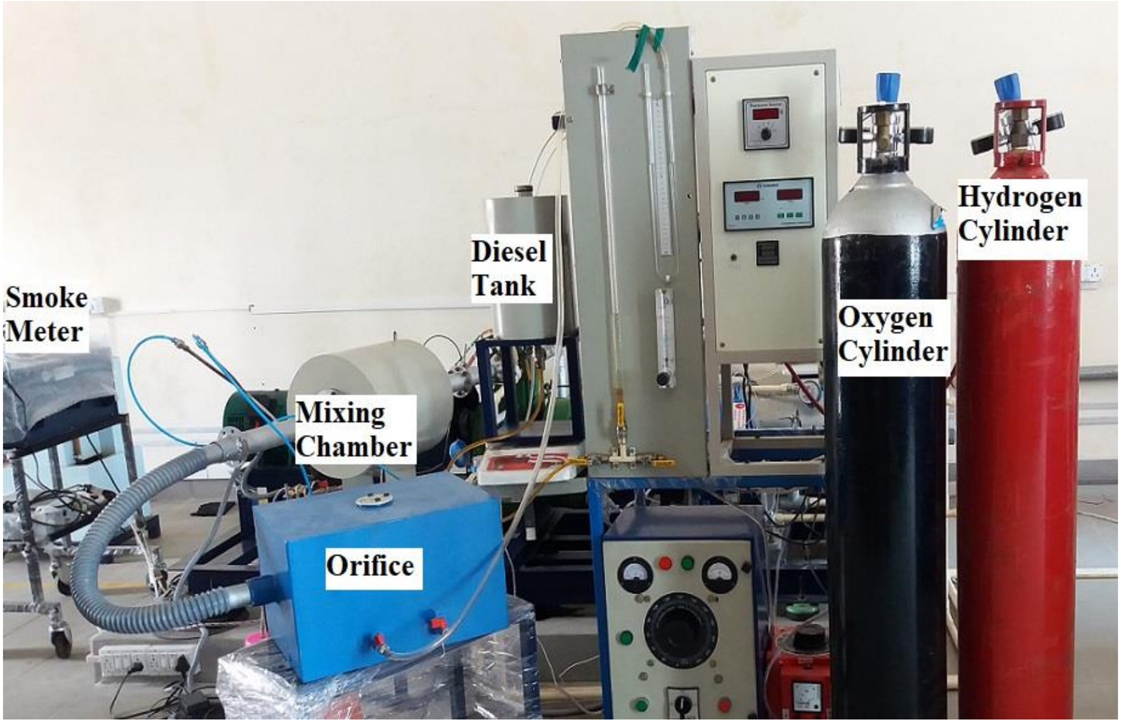

Figure 1 Experimental setup

4. Result and Discussion

4.1. Total Diesel Fuel Consumption

Fig 2 shows the effect of hydrogen and HHO gas induction on diesel fuel consumption. It is seen that as supplementary fuel increases the TDC reduced. The quantity of hydrogen present in HHO gas is as same as that of hydrogen substitution. It was found both the supplementary fuel mixtures showed similar decreasing trend in diesel consumption rate. However, the composition of HHO gas was maintained in 2:1 ratio to keep the percentage of energy share same. The percentage of energy shared by HHO gas is lower than hydrogen for the same flow rate. Benefit of using HHO gas is that it contains oxygen that helps in combustion but does not share energy.

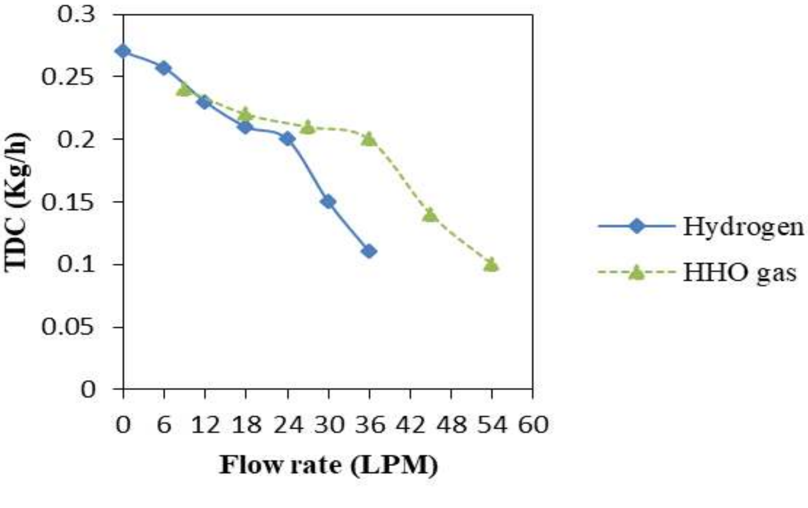

Figure 2 Variation of Total Diesel Consumption

4.2. Unburnt hydrocarbon (UHC)

Burning of lubrication oil and incomplete combustion are major reason for formation of UHC emission. Hydrogen introduction showed reduction in HC emission as shown in Fig 3. High speed of flame and high diffusive nature of hydrogen creates instant combustion. This may also be due homogeneous air/ hydrogen mixture that helps in better combustion. The reduction in UHC emission may also be due to the reduction of in cylinder hydrocarbon fuel injection that reduces the total carbon content of the fuel mixture as the concentration of hydrogen or HHO gas is increased. Existence of oxygen in HHO gas helps in combustion and reduces the formation of UHC at all flow rates than diesel as well as neat hydrogen.

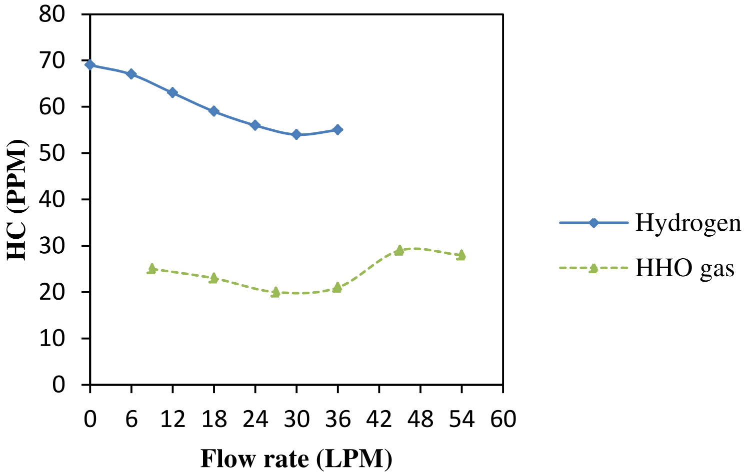

Figure 3 variation of HC emission

4.3. NO_x emission

The important factor that influence the development of NO_x is high operating temperature inside combustion chamber. Formation of rich air/ fuel mixture with introduction of supplementary fuel into combustion chamber reduces the operating temperature. This is due to absorption of heat energy by improperly oxidised hydrocarbon fuel. Fig 4 shows the formation of NOx at different flow rate. Most importantly at idling condition, since there is no applied load the operating temperature is typically low.

Oxygen in HHO gas enables better combustion then hydrogen, so there is slight increase at medium flow rate (24, 30 LPM). Increase in emission of NO_x may also be due to high flame temperature of hydrogen that gets enhances with the presence of oxygen. At 27 LPM of HHO gas substitution maximum of 19 % increase in NO_x than neat diesel operation was noted. At 36, 45 and 54 LPM of HHO gas induction, it was noted to reduce NO_x emission significantly. Though the presence of oxygen enhances the combustion process increasing the flow rate of HHO gas above certain limit increases the air/fuel richness in the combustion chamber. Reduction in air reduces the concentration of N_2 in combustion chamber that in turn reduces the formation of NO_x.

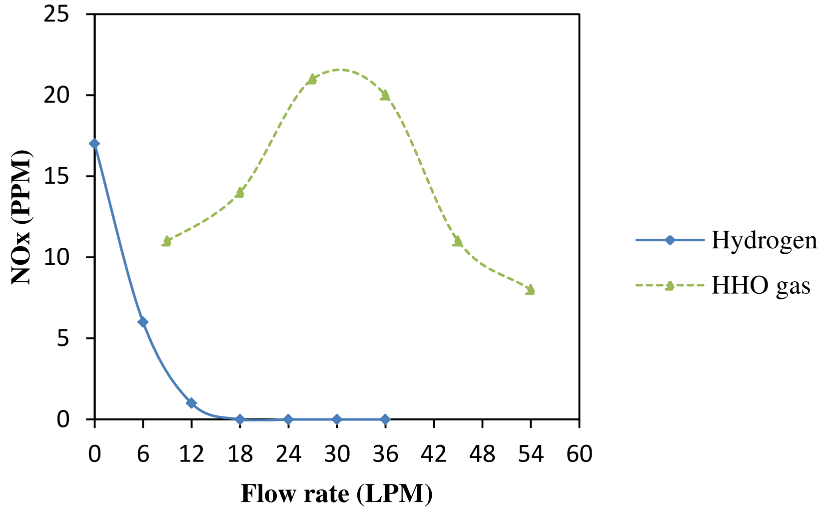

Figure 4 Variation of NO_x emission

4.4. CO_2 emission

Trend in CO_2 got reduced with hydrogen as well as HHO gas introduction in combustion chamber as shown in Fig 5. The direct diesel injection reduced with introduction of supplementary fuel in manifold.

CO_2 is formed out of carbon particle combustion, as there is reduction in total content of diesel there is reduction in formation as shown in Fig 4. The active interaction of oxygen molecule in HHO gas the combustion was complete and hence CO_2 was higher than hydrogen with the same flowrates. Higher HHO gas substitution (45 LPM and 54 LPM) into combustion chamber reduces the air required for combustion and also reduces the in-cylinder fuel injection that results in low CO_2 formation than hydrogen and diesel.

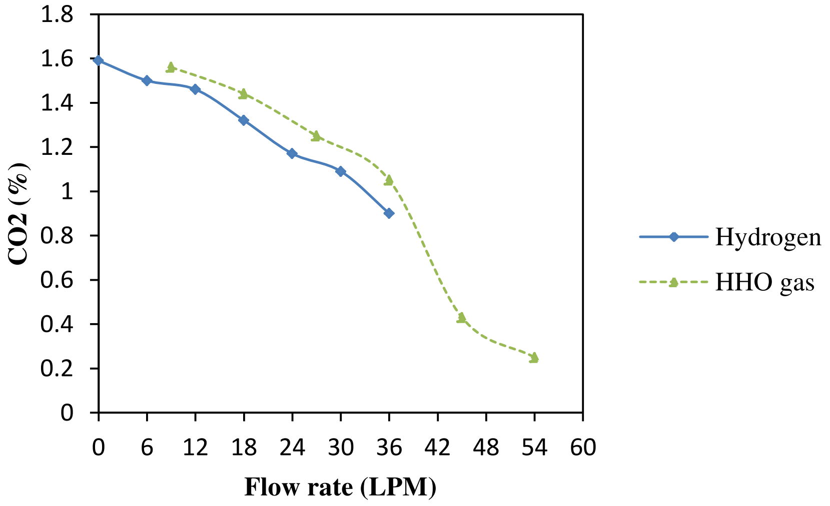

Figure 5 Variation of carbon dioxide

4.5. Smoke emission

Overall rich fuel – air mixture contributes to the formation of smoke. Fig 6 represents the formation of smoke with different flow rate of supplementary fuel. It was noted to get increased with increase in concentration of both the supplementary fuel. Supplying hydrogen in inlet manifold of the engine replaces the air entering the combustion chamber that increased the fuel richness owing to formation of particulate emission. Fast burning nature of hydrogen helps the hydrogen gas combust fast utilizing the available oxygen and leaving out partially oxidised hydrocarbon resulting in particulate emission. The induction of HHO gas, increases the oxygen content of the air/ fuel mixture resulting in efficient combustion that reduces the smoke formation than hydrogen. Overall, particulate emission increased with increase in energy share of HHO gas as well as hydrogen than neat diesel operation.

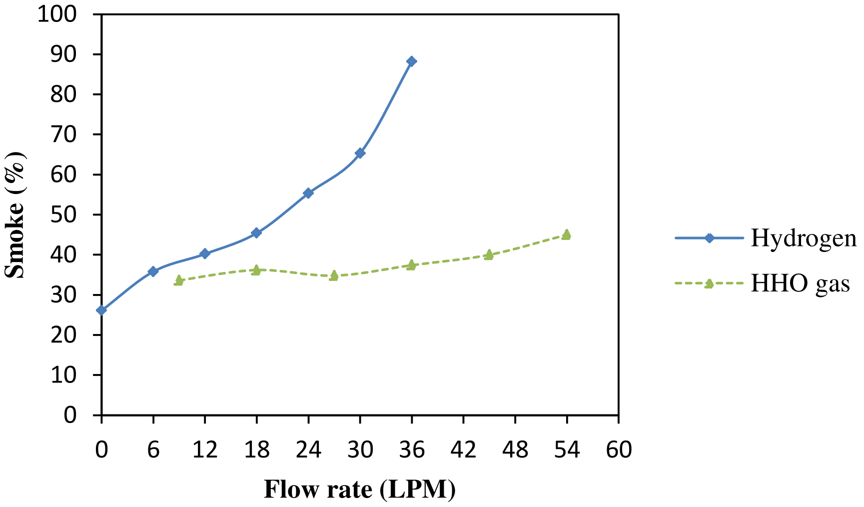

Figure 6 Variation of smoke

5. Conclusion

An experiment was conducted using HHO and Hydrogen gas in a CI engine operating in Dual fuel mode. The engine was set to run in idling condition with the constant speed of 1700 RPM. Following conclusion were obtained from the experimental analysis.

1. The TFC Consumption was reduced with supplementary fuel induction
2. Formation of CO_2 got reduced as the hydrocarbon injection reduced with increase in energy share of supplementary fuel.
3. The smoke emission was found to be higher for all the flow rates.
4. The NO_x emission was observed to be lower with introduction of hydrogen. However, with the addition of HHO gas, it was found to get increased than neat diesel operation.
5. UHC emission was reduced with introduction of HHO gas and increased with hydrogen substitution.

References

[1] Subramanian B, Ismail S. Production and use of HHO gas in IC engines. Int J Hydrogen Energy 2018;43:7140–54. doi:10.1016/j.ijhydene.2018.02.120.

[2] Santilli RM. A new gaseous and combustible form of water. Int J Hydrogen Energy 2006;31:1113–28. doi:10.1016/j.ijhydene.2005.11.006.

[3] Calo JM. Comments on " A new gaseous and combustible form of water ," by R . M . Santilli. Int J Hydrog Energy 2007;32:1309–12. doi:10.1016/j.ijhydene.2006.11.004.

[4] Cloonan MO. A chemist ' s view of J . M . Calo ' s comments on : "" A new gaseous and combustible form of water "' by R . M . Santilli (Int . J . Hydrogen Energy 2006 : 31 (9), 1113 – 1128). Int J Hydrog Energy 2008;33:922–6. doi:10.1016/j.ijhydene.2007.11.009.

[5] Kadeisvili JV V. Rebuttal of J . M . Calo ' s comments on R . M . Santilli ' s HHO paper. Int J Hydrogen Energy 2008;33:918–21. doi:10.1016/j.ijhydene.2007.10.030.

[6] Yilmaz AC, Uludamar E, Aydin K. Effect of hydroxy (HHO) gas addition on performance and exhaust emissions in compression ignition engines. Int J Hydrogen Energy 2010;35:11366–72. doi:10.1016/j.ijhydene.2010.07.040.
[7] Bari S, Esmaeil MM. Effect of H 2 / O 2 addition in increasing the thermal efficiency of a diesel engine. Fuel 2010;89:378–83. doi:10.1016/j.fuel.2009.08.030.
[8] Samuel S, Mccormick G. Hydrogen Enriched Diesel Combustion 2010-01-2190. SAE Int 2010. doi:https://doi.org/10.4271/2010-01-2190.
[9] Manu P V., Sunil A, Jayaraj S. Experimental Investigation Using an On-board Dry Cell Electrolyzer in a CI Engine Working on Dual Fuel Mode. Energy Procedia 2016;90:209–16. doi:10.1016/j.egypro.2016.11.187.
[10] Manu P V., Jayaraj S, Ramaraju A. CI engine performance analysis in dual fuel mode with hho gas induction. Int J Mech Eng Technol 2018;9:1156–72.
[11] Masjuki HH, Ruhul AM, Mustafi NN, Kalam MA, Arbab MI, Fattah IMR. Study of production optimization and effect of hydroxyl gas on a CI engine performance and emission fueled with biodiesel blends. Int J Hydrogen Energy 2016;41:14519–28. doi:http://dx.doi.org/10.1016/j.ijhydene.2016.05.273.
[12] Durairaj RB, Shanker J, Sivasankar M. HHO gas with bio diesel as a dual fuel with air preheating technology. Procedia Eng 2012;38:1112–9. doi:10.1016/j.proeng.2012.06.140.
[13] Kenanoğlu R, Baltacıoğlu MK, Demir MH, Erkınay Özdemir M. Performance & emission analysis of HHO enriched dual-fuelled diesel engine with artificial neural network prediction approaches. Int J Hydrogen Energy 2020. doi:10.1016/j.ijhydene.2020.02.108.
[14] Baltacioglu MK, Arat HTHT, Ozcanli M, Aydin K, Özcanli M, Aydin K. Experimental comparison of pure hydrogen and HHO (hydroxy) enriched biodiesel (B10) fuel in a commercial diesel engine. Int J Hydrogen Energy 2015;41:8347–53. doi:10.1016/j.ijhydene.2015.11.185.
[15] Birtas A, Chiriac R. A Study of Injection Timing for a Diesle Enigne Engine Operationg With Gas-oil and HRG gas. Sci Bull 2011;73.
[16] Kaan M, Kenanoglu R, Aydın K. HHO enrichment of bio-diesohol fuel blends in a single cylinder diesel engine. Int J Hydrog Energy 2019;44:18993–9004. doi:10.1016/j.ijhydene.2019.02.060.
[17] Arat HT, Baltacioglu MK, Ozcanli M, Aydin K. Effect of using Hydroxy - CNG fuel mixtures in a non-modified diesel engine by substitution of diesel fuel. Int J Hydrog Energy 2015;41:8354–63. doi:10.1016/j.ijhydene.2015.11.183.
[18] Trujillo-olivares I, Soriano-moranchel F, Alvarez-zapata LA, Guadalupe R De, Sandoval-pineda JM. Design of alkaline electrolyser for integration in diesel engines to reduce pollutants emission. Int J Hydrog Energy 2019;44:25277–86. doi:10.1016/j.ijhydene.2019.07.256.
[19] Sharma PK, Sharma D, Soni SL, Jhalani A, Singh D, Sharma S. Characterization of the hydroxy fueled compression ignition engine under dual fuel mode : Experimental and numerical simulation. Int J Hydrogen Energy 2020. doi:10.1016/j.ijhydene.2020.01.061.
[20] Sharma PK, Sharma D, Soni SL, Jhalani A, Singh D. Energy , exergy , and emission analysis of a hydroxyl fueled compression ignition engine under dual fuel mode. Fuel 2020;265:116923. doi:10.1016/j.fuel.2019.116923.
[21] Jakliński P, Czarnigowski J. An experimental investigation of the impact of added HHO gas on automotive emissions under idle conditions. Int J Hydrogen Energy 2020;45. doi:10.1016/j.ijhydene.2020.02.225.
[22] Al-rousan AA. Reduction of fuel consumption in gasoline engines by introducing HHO gas into intake manifold. Int J Hydrogen Energy 2010;35:12930–5. doi:10.1016/j.ijhydene.2010.08.144.
[23] Musmar SA, Al-rousan AA. Effect of HHO gas on combustion emissions in gasoline engines. Fuel 2011;90:3066–70. doi:10.1016/j.fuel.2011.05.013.
[24] EL-Kassaby MM, Eldrainy YA, Khidr ME, Khidr. KI. Effect of hydroxy (HHO) gas addition

on gasoline engine performance and emiss ions. Alexandria Eng J 2016;55:243–51. doi:http://dx.doi.org/10.1016/j.aej.2015.10.016.
[25] Nabil T, Dawood MMK. Enabling efficient use of oxy-hydrogen gas (HHO) in selected engineering applications ; transportation and sustainable power generation. J Clean Prod 2019;237:117798. doi:10.1016/j.jclepro.2019.117798.
[26] Usman M, Farooq M, Naqvi M, Saleem MW, Hussain J, Naqvi SR, et al. Use of Gasoline , LPG and LPG - HHO Blend in SI Engine : A Comparative Performance for Emission Control and Sustainable Environment. Processes 2020;8:1–15. doi:10.3390/pr8010074.
[27] Salek F, Zamen M, Hosseini SV. Experimental study , energy assessment and improvement of hydroxy generator coupled with a gasoline engine. Energy Reports 2020;6:146–56. doi:10.1016/j.egyr.2019.12.009.
[28] Subramanian B, Thangavel V. Experimental investigations on performance, emission and combustion characteristics of Diesel-Hydrogen and Diesel-HHO gas in a Dual fuel CI engine. Int J Hydrogen Energy 2020. doi:10.1016/j.ijhydene.2020.06.280.
[29] Subramanian B, Thangavel V. Analysis of onsite HHO gas generation system. Int J Hydrogen Energy 2020;45:14218–31. doi:10.1016/j.ijhydene.2020.03.159.