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EFFECT OF EGR ON CI ENGINE FUELLED WITH DIESEL AND HYDROGEN

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Abstract - *Environment issue is a principle during force which has led to a considerable effort to develop and introducing alternative fuel for transportation. Smoke, Oxide of nitrogen and Particulate matter are high emission from the diesel engine. So research focus to low pollutant fuel such us Hydrogen is the most promising among alternative fuel. It is clean burning characteristics and effective performance attracts more claims compared to other fuels. This paper about normal DI CI engine was converted to operate as gas engine. Hydrogen induced at the intake manifold at pressure of 2 bars along with recirculates outlet gas and air. The experimental investigation by enrichment of hydrogen without EGR, with 10% EGR and with 20% EGR. The rate of hydrogen was set constantly at 2 LPM. This paper provided a potential to investigate the effect of the addition of H2 with EGR, without EGR ratio on the performance such us Brake thermal efficiency and Specific fuel Consumption, on the combustion ignition delay (Ignition postpone) and combustion duration and on the emission characteristics Oxide of nitrogen, Carbon monoxide and Smoke on a CI engine.*

Key Words: Alternative fuel, Exhaust gas recirculation, Diesel engine, Hydrogen, litre per minute (LPM)

1. INTRODUCTION

Now a days in daily life Diesel engines are indispensable. Due to rapid growth in vehicle population deplete resources and engine performance was concern for environment has put additional requirement. Toxic emission from industrial processes and engine Outlet gases like NOX, SOx and PM has under restriction due to climate change in recent conference. There on IC engine research active interest toward upgrade performance, renewable fuel and harmless pollutant emission due to strict engine emission norms. To rectifies problem by enhance hydrogen as alternative source replaced for fossil fuel [1]. There my few modifications to use hydrogen fuel is could be the main attraction point of view fuel hydrogen on existing engine. The addition manifold injection technique is complex modification [2,3].

H_2O emission during the combustion of hydrogen as fuel as main plus point. But still expensive process for separation of hydrogen because it is not freely available [4]. Moreover, there should be staunch safety mechanism implemented at the actual usage point as hydrogen is highly inflammable. On commercial scale of automobile gasoline engine have don't implemented in automobiles, but researchers make modification from the conventional gasoline engine with hydrogen as fuel [6].

There by higher octane number for hydrogen researchers such fuel in gasoline engine. No researchers taken modify portion on existing diesel engine as hydrogen fuel due to higher self-ignition temperature [7]. When lean mixture operating condition, using hydrogen fuelled in engine faces to problem is higher NOx emission. Thereby the higher flame temperature of hydrogen on modified engine lead to higher NOx emission. Heffel et al, experimental modified ford ZETEC engine with hydrogen and cooled EGR. Reported that level of NOx emission compared with non-EGR mode at rate of hydrogen on 20 LPM [3].

To operate as HCCI engine mode by using hydrogen , the cylinder gas temperature should be increased adequately high so on appropriate time taken for hydrogen to reach an auto ignition on the cylinder[9].to attain the auto ignite hydrogen by a pilot diesel injection around 10° to 60° CA before TDC. [10–13]. Hydrogen high diffusivity is the main criteria as fuel . Hence, supply of less quantity of hydrogen either by manifold or direct injection in-cylinder could reduce heterogeneity of spray diesel and sequent combustion [14].For all load range exhibit the similar brake thermal efficiency on hydrogen engine [15]. Methods for hydrogen implement like continuous manifold injection, continuous carburetion ,pulsed manifold injection and low pressure direct injection have been proposed in previous researches [16,17]. Previous studies show with the supply of 0.15 kg/h of hydrogen leads to upgrade in brake thermal efficiency of 1.29%.there with approximately similar brake power develop with enriched hydrogen , a higher thermal efficiency and a lower emission compared to diesel engine of the similar load ranges [18,19]. Combustion knock, higher level of pressure rise, and temperature are few problems should carefully deal by proper study to control it [20,21].Renxu Niu et al (2016) China, in this work with under four different excess air ratio(1, 1.2,1.5 and 1.8) on the different hydrogen fractions (3.9%, 5.3%, 7.2%, 8.9% and 10.5%) at engine speed of 1500 rpm. Result shows that 42% peak in-cylinder pressure at λ= 1.2 than neat gasoline condition with 7.2% of hydrogen addition fraction, At hydrogen additional fraction from 3.9% to 10.5% with λ = 1.8, raised 18% to 31% the effective thermal efficiency.

Then emission such us UHC and CO emissions decreased but Nox emission simultaneously increase with hydrogen addition fraction it could be balance by lean burn condition at large range[5].

1.1. Hydrogen in CI engine

The idea in IC engines using of hydrogen is not new. In the absent of air preheating is not possible in CI engine because of its auto-ignition temperature is 858 K for hydrogen[4]. The alternative method for implement hydrogen with diesel fuel, induction of hydrogen on intake along with air and by pilot injection of diesel on compression stroke. Hydrogen combustion is major different from hydrocarbon fuel combustion. Thereby having more extensive flammability for hydrogen than diesel fuel. Some major properties of diesel and hydrogen are indicated in Table 1. As the flame velocity of hydrogen is high, extremely quick combustion usually takes place [4].Hydrogen requires minimum ignition energy of 0.02 mJ, which enables the engine that uses hydrogen to run on even extremely lean mixtures.

The experimental investigation by enrichment of hydrogen without EGR, with 10% EGR and with 20% EGR. The rate of hydrogen was set constantly at 2 LPM. This paper provided a potential to investigate the effect of the addition of H2 with EGR, without EGR ratio on the performance such us Brake thermal efficiency and Specific fuel Consumption, on the combustion ignition delay (Ignition postpone) and combustion duration and on the emission characteristics Oxide of nitrogen , Carbon monoxide and Smoke on a CI engine.

TABLE -1: Properties of Hydrogen with Diesel

Properties	Diesel	Hydrogen
Chemical composition	Cn H1.8n (C8-C20)	H2
Auto-ignition temperature (K)	530	858
Minimum ignition energy (mJ)	-	0.02
Flammability limits (volume %in air)	0.7-5	4-75
Cetane number	40–55	-
Octane number	30	130
Diffusivity in air/(cm2/s)	–	0.63
Density 160 °C and 1.01 bar/(kg/m–3)	833–881	0.0838
Flame velocity/(cm/s)	30	265–325
Net heating valve/(MJ/kg)	42.5	119.93

1.2. Exhaust Gas Recirculation

To control NOx emission effective and economic method could exhaust gas recirculation (EGR) in IC engine. The main exhaust component gases such us NOx, HC, Smoke, CO and particulate matter in CI engine. To reach volumetric efficiency , thereby attain the exhaust gas temperature is to be higher than normal intake air. A little quantities of fresh air entered the combustion chamber during the recirculation of exhaust gas feeding. Their effect on exhaust emission by the oxygen level reduction in combustion chamber. The specific heat of charge increased by induced of exhaust gas in to engine cylinder. This results in suppressed combustion rate of air-fuel mixture. By decrease oxygen content of air influence to decrease combustion rate so the peak temperature will reduced.

Thus, lead to NOx creation in the engine is decreased. The percentage of EGR (Ꞃ (EGR)) in the engine is defined as

$$\eta\ (EGR) = \frac{\text{Volume of EGR}}{\text{Total charge into the cylinder}} \times 100 \qquad (1)$$

AFT is decreased because of increase inert gases concentration in combustion chamber [8].Higher soot and PM causes at full loads while usage of EGR, this problem due to reduce in diffusion combustion. On the part and lower load certain unburned HC shorten in HC emission on next cycle. In this paper, the engine was experimental investigation at different EGR rates with Hydrogen flow at 2 LPM . With 10% EGR and 20% EGR is that exhaust gas granted on inlet air and hydrogen mixture. In this paper, the combustion parameters, Performance and emission characteristics were analyzed.

2. EXPERIMENTAL SETUP

The schematic diagram of experimental setup is shown in Fig. 1. In this paper, for experimental investigation on a four stroke, direct injection diesel engine used. The specifications of the test engine are listed in Table 2.

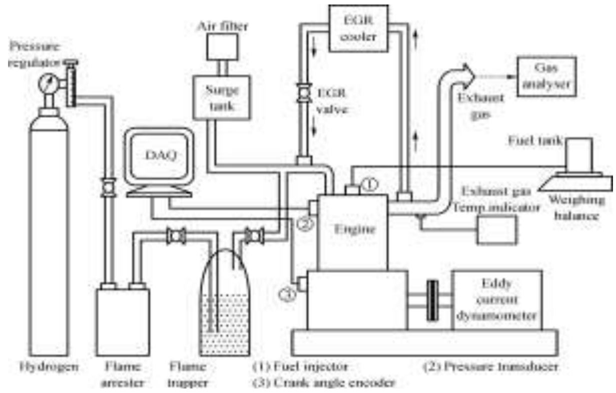

Fig – 1: Schematic diagram of experimental setup

At 150 bar pressure Hydrogen was stored in cylinder and by pressure regulator to an outlet pressure regulated to 2 bars. With the help of control valve fine adjust of hydrogen flow. The rate of flow hydrogen was measured with a thermal mass flow meter. Non-return value (NRV) act as a flow reverse barrier in the system. Flame arrestor placed to next to NRV as the additional safety aspects. In the hydrogen system to suppressed the back fire by water to extinguish the flame on flame trap with sliding sleeve. Next to flame trap with carburetor it functions to control the hydrogen flow into the manifold. This method of mixture preparation with air and fuel (hydrogen) is called mixture enrichment. The hydrogen flow rate was 2 L/min. With 10% EGR and 20% EGR is that exhaust gas granted on inlet air and hydrogen mixture. In this paper, the combustion parameters, Performance and emission characteristics were analyzed.

TABLE -2: Specifications of the test engine

Details	Specification
Rated power& speed	5.2kW & 1500 rpm
Number of cylinders	Single cylinder
Compression ratio	17.5:1
Bore & stroke	87.5mm & 110mm
Injection timing, ºCA bTDC	23
Method of loading	Eddy current dynamometer
Type of injection	Mechanical pump-nozzle injection
Injection timing	23° before TDC
Injection pressure	220 bar
Lubrication oil	SAE 40

3. RESULTS AND DISCUSSION

In this experiment Combustion parameters of Ignition delay and Combustion duration, performance parameters such as brake thermal efficiency, BSEC, volumetric efficiency were determined and emissions such as NOx, HC, smoke and carbon monoxide are measured. The experiment was carried out keeping hydrogen flow remain same as 2 LPM in absence of EGR, addition of exhaust gas recirculation with 10% EGR and 20% cooled EGR.

3.1. Performance Analysis

3.1.1 Brake Thermal Efficiency (η_{bth})

The chart show the comparison of η_{bth} with load for normal diesel, diesel with 2 LPM of hydrogen upgrade without EGR, with 10% EGR and 20% EGR is shown in chart 1. The brake thermal efficiency for hydrogen with diesel as ignition source is 33.6% at 80% load with a flow rate of hydrogen 2 LPM, whereas that of baseline diesel fuel is 30.8%.experiment conclude that flow rate of diesel is inverse of flow rate of hydrogen.

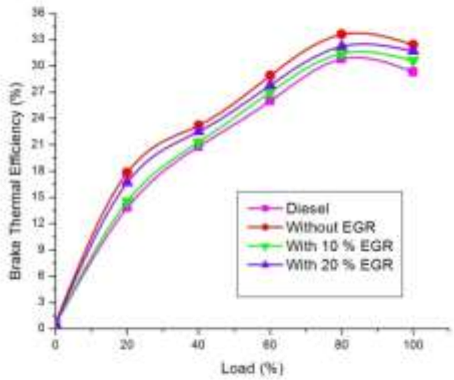

Chart -1: Comparison of η_{bth} with engine load

Thereby the high flame velocity properties in hydrogen enhanced the combustion process effectively and lead to rise the thermal efficiency. Use of EGR has a negative effect on engine efficiency that rises with its percentage of EGR with same 2LPM of hydrogen. At 80% load with 10% EGR brake thermal efficiency is 31.4% and with 20% EGR it is 32.23%. Result shows decrease of η_{bth} in case of EGR, because negative effect on combustion due to less availability of the oxygen concentration on intake air

3.1.2 Volumetric Efficiency (η_{vol})

Chart. 2 shows the variation of ηvol with load for normal diesel, diesel with 2 LPM of hydrogen upgrade without EGR, with 10% EGR and 20% EGR is shown in figure. The η_{vol} obtained for 2 LPM hydrogen enrichment without EGR is 85.02% compared to normal diesel fuel of 85.6% at 80% load.

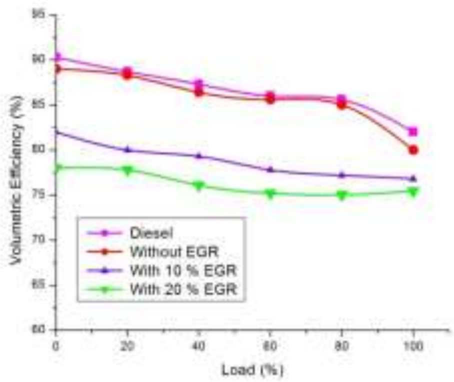

Chart 2. Comparison of η_{vol} with engine load

This reduction in η_{vol} is due to the fact that hydrogen being much less dense than air displaces an appreciable amount of it while being inducted inside the cylinder. When exhaust gas is applied, there is further decrease in ηvol. With 10% EGR it is 77.2% and with 20% EGR it is 75.03% at 80% load. Chart shows that ηvol decreases with the increase in EGR percentage at each load up to 80% loading. When exhaust gas is recirculates to the intake manifold, it occupies a portion of the incoming air. This results in a reduction in ηvol. modification of intake manifold during experiment to induction of exhaust gas and hydrogen. So there is obstacle offered to fresh charge, which further decreases ηvol.

3.1.3 Brake Specific Energy Consumption (BSEC)

Chart. 3 show the variation of BSEC with load for normal diesel, diesel with 2 LPM of hydrogen enrichment without EGR, with 10% EGR, and 20% EGR. It can be observed that BSEC without EGR is 10045 whereas the BSEC of normal diesel is 13500.09, with 10% EGR it is 11050.02 and with 20% EGR it is 12540. All these readings are at 100% load of rated load. BSEC decreases with the increase in brake power. This trend is maintained in all four cases viz normal diesel operation, 2 LPM hydrogen enrichment without EGR, with 10% EGR and with 20% EGR. But BSEC in case of hydrogen enrichment without EGR is low.

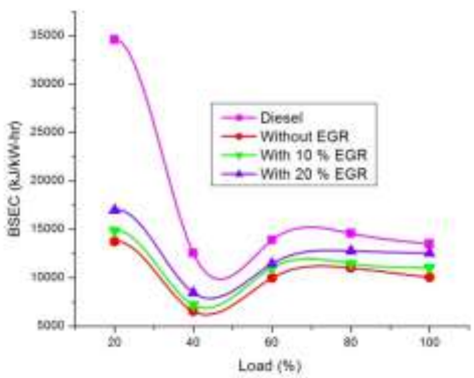

Chart 3. Comparison of BSEC with engine load

3.2 Emission Characteristics:

3.2.1 Carbon Monoxide (CO)

Chart. 4 depict the variation of CO with load. At 100% load CO emission for normal diesel operation is 0.88% by volume, while it is .55% by volume with 10% EGR and .58% by volume with 20% EGR. In case of 2 LPM hydrogen enrichment without EGR CO emission is .45% by volume. Due to absence of any carbon on hydrogen enrichment leads to low CO emission, the yield CO emission is also by the diesel which injected pilot and lubrication oil. On again to less available of oxygen in case of EGR leads to increase in CO emission. Cylinder temperature and reaction speed is inverse of EGR rate At the same time, more recirculate exhaust gas minimizes the O2 concentration. These reasons weaken the oxidation reaction and lead to cause more CO emission.

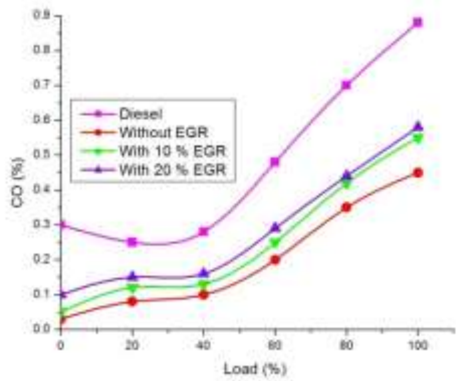

Chart 4. Comparison of CO emission with engine load

3.2.2 Oxide Of Nitrogen (No_x)

Chart. 5 show the variation of NOx with load for normal diesel, diesel with 2 LPM hydrogen enrichment without EGR and the same with 10% EGR and 20% EGR. NOx emission for hydrogen enrichment without EGR is 1604 ppm compared to normal diesel fuel of 1300 ppm at 80% load. The peak Incylinder temperature and high temperature gases residence in cylinder for long span of time were the reason for rise in NOx concentration in the case of enriched hydrogen without EGR. Chart depicts that with 10% EGR NOx formation is 1200 ppm at 80% load and that of 20% EGR is 1150 ppm..

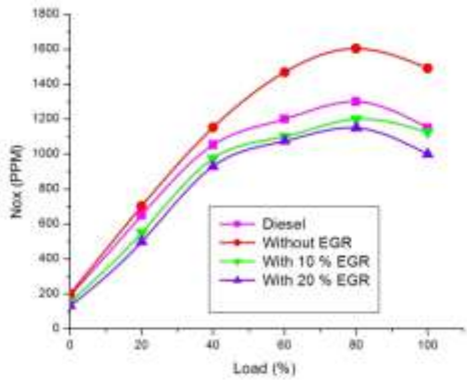

Chart 5. Comparison of NOx emission with engine load

So there by increase in Percentage of EGR in to the cylinder is problem solving method to reduce NOx formation. There with inert nitrogen, CO2 and higher specific heat are the main sources in exhaust gases. When EGR to engine inlet it can reduce oxygen level and act as a heat sink. All the combustion process is delayed with diluted air, premixed combustion, diffusion combustion and late diffusion combustion. On the result whole combustion process is moves further into the expansion stroke, leading to low combustion temperature. Low combustion temperature is the reason of decrease of NOx

3.2.3 Hydrocarbon (HC)

Chart. 6 shows the variation of HC with load for neat diesel, diesel with 2 LPM hydrogen enrichment without EGR and the same with 10% EGR and 20% EGR. It can be observed that HC emission for hydrogen enrichment without EGR is 44 ppm whereas that of neat diesel is 125 ppm, with 10% EGR it is 83 ppm and with 20% EGR it is 94 ppm. All these readings are at 100% load. Due to absence of any carbon on hydrogen enrichment without EGR leads to reduce HC emission. In case of EGR there is lower excess oxygen available for combustion. Lower excess oxygen concentration results in rich A/F mixtures at different locations inside the combustion chamber. This diverse mixture does not combust properly and results in higher HC emission.

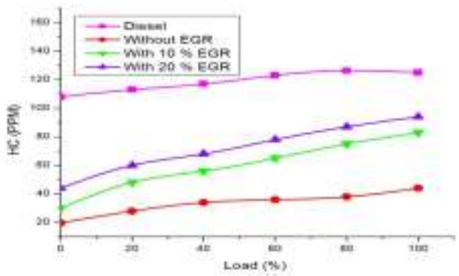

Chart 6. Comparison of HC emission with engine load

3.2.4 Smoke

The variation of smoke level with load is shown in Chart. 7. As load increases, diesel engines tend to generate more smoke.

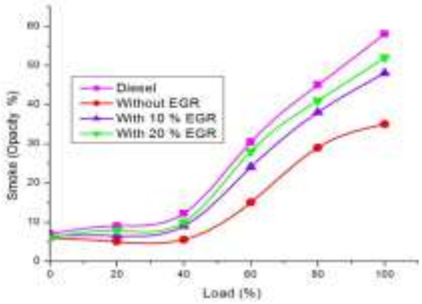

Chart 7. Comparison of smoke emission with engine load

It is observed that at 100% load smoke no in case of diesel is 58 whereas corresponding values for diesel with 2 LPM hydrogen enrichment without EGR and the same with 10% EGR and with 20% EGR are 35, 48 and 52, respectively. Due to absence of any carbon on hydrogen enrichment leads to low smoke emission. Higher smoke level of the exhaust is observed when the engine is operated with EGR compared to without EGR. Smoke level is directly proportional to EGR and engine load. There by less availability of oxygen for combustion of fuel causes to improper combustion and lead to formation of smoke level is higher in using of EGR

3.3 Combustion Analysis

3.3.1 Ignition Delay (ID)

Chart 8 demonstrates the variation of ignition delay with load at 10% and 20% of EGR with hydrogen fuel. It is observed from Chart that the ignition delay (ID) of all the fuels decreases with an increase in engine load. The ignition delay formation is high in neat diesel, which is 18.32 °CA, compared to that without EGR of 18.04 °CA. The ignition delay for 10% and 20% EGR is 18.03 °CA and 17.56 °CA respectively. The ignition delay (ID) is longer for diesel, compared to that with 10% EGR, with 20% EGR and without EGR. The longer ignition delay (ID) is caused by the chemical reaction during the injection time, which slows down the physical delay period.

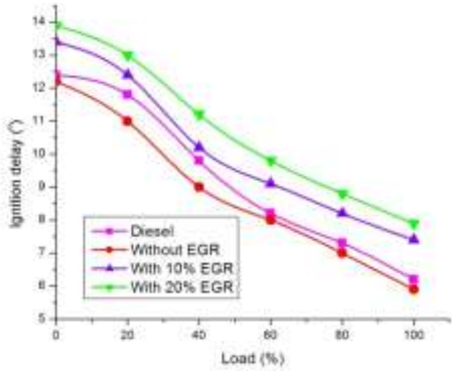

Chart 8. Comparison of ignition delay with engine load

3.3.2 Combustion Duration

Chart 9 illustrates the variation of combustion duration with the load of the engine at 10% and 20% EGRs. This time duration starts from the starting of the heat release to the end of heat release. The combustion duration in normal diesel fuel at full load is 50.34 °CA, while with 20% EGR, it is 54.18 °CA and 53. °CA, and with 10% EGR and without EGR it is 52.28 °CA. increase in combustion duration because of fuel injection on high mass while the load increases, At any particular load, the combustion duration increases as the EGR rate also increases.

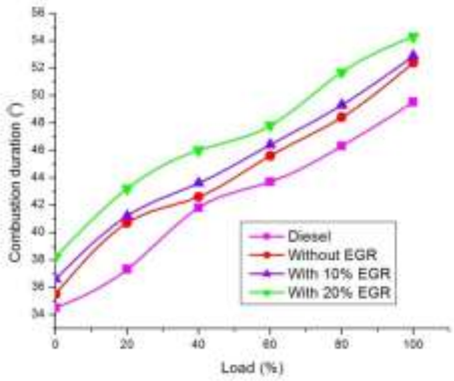

Chart 9. Comparison of combustion duration with engine load

4. CONCLUSION

The experiment was carried out keeping hydrogen flow remain same as 2 LPM in absence of EGR, addition of exhaust gas recirculation with 10% EGR and 20% cooled EGR. The following conclusions are made on the basis of experimental results.

- On comparing of neat diesel with hydrogen supply without EGR has 9.09% Ŋbth higher in percentage. But effect on using EGR has negatory effect on engine efficiency the rise with its percentage; this is due to dilution of EGR.
- Higher Ŋvol for normal diesel operation then hydrogen supply without EGR. There will still more reduction in Ŋvol while using of EGR. Causes for this reduction to replacement of portion of fresh air by hydrogen and recirculate gas.
- Higher BSEC for normal diesel operation then hydrogen supply without EGR. This is due to hydrogen higher calorific valve so there hydrogen operated engine is to be in lean burn conditions. The raise in BSEC in case of EGR is due to negatory effect of on combustion by EGR.
- On comparing of neat diesel with hydrogen supply without EGR has 39% smoke lower in percentage at 80% load. Due to unavailability of carbon in hydrogen fuel smoke emission is reduced. smoke level in higher in EGR supply condition, but while compare to normal diesel still attain lower level of smoke. EGR constricted availability of oxygen for combustion of fuel, which results to raise in smoke level.
- On comparing of neat diesel with hydrogen supply without EGR has 49% CO lower in percentage at 100% load. because of oxygen level is lower with EGR condition still lower CO emission but while compared with hydrogen without EGR is higher.
- On comparing of neat diesel with hydrogen supply without EGR has 64% HC lower in percentage at 100% load. because of oxygen level is lower with EGR condition still lower HC emission but while compared with hydrogen without EGR is higher.
- NOx level is reduced by effective EGR method. At 100% load NOx value for hydrogen enrichment without EGR is 1604 ppm whereas with 20% EGR NOx value is 1150 ppm. This is because of inert gas by exhaust gas suppressed the peak combustion temperature.
- In this experimental investigation on a single cylinder CI engine with hydrogen–diesel blend has proved to be a acceptable approach to minimizing pollution load and improved performance. There on experiment shows that NOx formation problem faced in hydrogen combustion with diesel fuel. EGR technique is used for decrease of NOx level. In doing so there is reduce in performance level and increase in emission level. So lower EGR % is preferred.

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