Research Article

Performance Investigation of Inclusion of Hydrogen to Compression Ignition Diesel Engine with Bio Diesel Mingles

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ABSTRACT

The goal of dropping the emission of nitrogen oxide (NOx), in CI engine with blended bio fuel is an effective alternative fuel for fossil fuels in requisites of pollution reduction in emission and efficiency increased in engine. The performance and emission characteristics of a CI engine and the thermal effectiveness augmented by persuade of hydrogen with bio fuel is studied in this research. The steadiness of combustion by addition of hydrogen and the efficiency of NOx reduction also retained using HGBD as a fuel.

Keywords: CI engine; thermal efficiency; emission; hydrogen and bio diesel blends (HGBD).

INTRODUCTION

Internal combustion engines have become an requisite and essential role of our daily life. However, diesel engines produce striking such as impetuous and intermittent noises, which are unpleasant [1-3]. Combustion noise may be altered by using another type of fuel. Hydrogen is the largest part of potential fuels because it has dirt free burning characteristics and healthier performance matched up to other fuels. Though, hydrogen cannot be used as the solitary fuel in a CI engine, because the compression temperature is not enough to kick off combustion due to its elevated self-ignition temperature [4]. The noticed advantages of this are generally lesser Carbon monoxide emissions, HC and PM, but with ultimately augmented NOx emissions compared to fossil diesel fuels. That's why an ignition source is obligatory whilst using it in a CI engine. The easiest method of utilizing hydrogen in a CI engine is to run in the dual fuel mode in the company of diesel fuel that be capable of perform as an ignition source for hydrogen. Various investigations have been described on the co-combustion of hydrogen-diesel combustible mixtures [5-7]. Miyamoto et al. [7] researched the performance characteristics of the diesel-fuelled engine with hydrogen supplemented to the ingestion air at delayed injection timings. They also examined the response of diesel-fuel injection timing on the maximum rate of in-cylinder pressure rise for a diesel engine with addition of hydrogen to the ingestion air. The result demonstrated in the case of a diesel-fuel injection afterward TDC with addition of 10 vol% hydrogen to the ingestion air, the maximum rate of in-cylinder pressure rise was comparatively low than that without hydrogen addition at elevated loads for a naturally pursued diesel engine. Hydrogen is actually the best assuring alternative fuels. Hydrogen combustion actually not generates CO_2 and smoke, since that termed as a carbon-free fuel. Ikegami et al. [5] exposed that hydrogen fueled CI engine with fuel leakage from the injector could support ignition of the hydrogen fuel.

When burned in IC engines, hydrogen have been professed as an on-site carbon free energy carrier with excellent combustion characteristics[11, 12]. Adorable combustion properties such as a fast flame propagation speed and wide lean operational range make H_2 an distinguished fuel for SI engines [13,14]. By mixing H_2 into the intake mixture, hydrogen can also be burned in CI engines. The compressed H_2-air mixture is ignited by a pilot diesel spray as the compression stroke finished. An efficient and reliable approach to burn various effervescent fuels such as H_2 in CI engines, dual fuel operation has been suggested [15-22]. Various researches investigated the benefits and penalties associated with the substitution of nature diesel by H_2. These include the enhancement to the BTE, NOx emissions enhance, retarding the start of combustion, improving the heat release process, and currently the on-site emissions reduction of carbon dioxide (CO_2). The previously done research work on H_2-diesel blended dual fuel engines was performed using modest single cylinder diesel engines, such as the research indicated by Varde and Frame [18].

A cram on the properties of hydrogen addition to precise biodiesel was initiated by Bika et al. [19]. Recently, various researchers observed the properties of H_2 addition on the performance as well as the combustion characteristics of multi-cylinder, less function diesel engines [19-22]. The addition of H_2 to these less function diesel engines was found to enhance substantially the emissions of NO2 accompanied with a reduction in NO emissions. For example, Shirk et al. [20] examined the properties of H_2 addition on the fatigue emissions of a 1.3-liter (L), turbocharged, light-duty diesel engine. The addition of H_2

slightly reduced the emissions of NOx while its effect on the BTE was relatively small. The dissever should create these components, reintegrating the applicable criteria that follow. Hydrogen has been injected to CI engine. Meanwhile, hydrogen have injected to dual-fuel type diesel engines in which diesel-fuel combustion is ignition source for hydrogen [7-11,13-15]. These researches rendered hydrogen to ingestion air while the diesel fuel was injected directly into the cylinder.

Nox Emission Mechanism

Impact of hydrogen addition on combustion

The NOx emissions of combustion devices burning fuels that are Nitrogen (N)-free can be formed through the below given mechanisms: a) NOx thermal mechanism dominated by the local temperature of the combustion products; b) the prompt NOx mechanism observed mainly at fuel-rich mixture and unburned fuel-air mixture prior to the arrival of the fore-flame; and c) the N_2O intermediate mechanism occurring mainly at small load operation of diesel engines, and gas turbines [13]. When operated under medium to high load, the local combustion temperature of a diesel engine is usually higher than the threshold temperature for the formation of NOx through NOx thermal mechanism. Comparatively, the N_2O intermediate mechanism induced to contribute significantly to NOx formation in diesel engines and gas turbines at small load operation where the engine-out NO_2/NOx ratio is known to exceed 10% [24].

Among these, the contribution of the prompt mechanism to the formation of NOx in diesel fuelled engines is relatively small. The formation mechanism of NO_2 has been researched by various researchers [2, 5, 6, 23-26]. It was noticed that the Nitrogen oxide formed in the flame region could be converted to NO_2 via reactions such as $NO + HO_2 <=> NO_2 + OH$. Past research reported the salient role of HO_2 in potentiating the conversion of NO to NO_2. The HO_2 part of a molecule can be formed by another reaction $H + O_2 + M <=> HO_2 + M$. Processes having the potential to substantially raise the concentration of HO_2 were hoped to extend the formation of NO_2. For example, the HO_2 part of a molecule organized in the relatively low-temperature unburned mixture region prior to the fore flame. The HO_2-rich mixture reacts with the NO molecules transported from high temperature combustion regions and enhances the formation of NO_2.When present at a suitable temperature, the unburned fuels contusing hydrogen could oxidize in the presence of O_2 and formHO_2, which might enhance the formation of NO_2. This might help to describe the significant enhancing property on the formation of NO_2 when H_2 was blended into the ingestion mixture of diesel engines as reported in the literature [10,20-22]. Varde et al. [9] researched a happening of decreased diesel matter in the exhaust by articulating less quantities of gaseous hydrogen in the ingestion of a diesel engine. The result shows that smoke decreased with the extended hydrogen addition. However, NOx and combustion noise increased because sharp combustion occurred as a result of very high combustion speed of hydrogen.

Geo et al. [9] expressed that dual-blend fuel operation of rubber seed oil and its blend with hydrogen. The results narrates that Nox emission increased with the extended hydrogen energy fraction for RSO and RSOME. Tomita et al. [14] suggested a double fuelled engine with hydrogen and diesel-fuel under the PCCI (Premixed Charge Compression Ignition) condition. Hydrogen was provided to the ingestion port and diesel fuel was provided directly into the combustion chamber. The diesel-fuel was mixed thoroughly with hydrogen-air mixture and combustion became gentle as best diesel fuel injection timing was maintained.

EGR is efficient in reducing NOx, and avoiding knocking, however the smoke emission increases with EGR in conventional diesel engines. Hence, EGR is restricted to a very small EGR rate. Since then smokeless diesel combustion has been explained with a enormous EGR. Smoke-less and NOx-less combustion was made successful by this method and it is termed as Low Temperature Combustion method [15-18]. Smoke formation depends on combustion high temperature and correspondence ratio.

Impact of hydrogen on biodiesel blends

The diminution of fossil diesel fuels, global warming distress and the harder limits on synchronized pollutant emissions persuade the exploit of renewable fuels. Biodiesel is the majority used renewable fuel in CI engines. The greater part of the researches accepts that PM, THC and carbon monoxide emissions from biodiesel are inferior to natural diesel fuel [1-3]. The oxygen content of biodiesel [4,5] that stimulates a added whole and cleaner combustion process is the main factor. The biodiesel usage could lead to more effective THC, CO and particulate matter oxidation [6] and increased NOx emissions [7-9], depending on the engine technology employed, combustion characteristics and other physical and chemical properties of the biodiesel comparatively with nature diesel. The additional feature which justifies the PM reduction with revere to diesel is the nonexistence of pungent compounds in biodiesel [3, 10].

The present study attempted to resolve the tradeoff between NOx and smoke under high load conditions without scarifying indicated thermal efficiency by LTC with hydrogen mixed to the ingestion mixture for the delayed diesel-fuel injection timing in a high-pressure direct injection diesel engine. This paper offers two approaches to LTC. Initially, the injection timing of diesel-fuel was deferred drastically until 2˚ ATDC or high to reduce combustion temperature for hydrogen concentration in ingestion mixture within the flammability choice. Subsequently, amplified EGR rate is done almost up to stoichiometric condition with little amount of hydrogen to decrease combustion temperature considerably.

Experimental setup and materials

The experimental apparatus was lay down as detailed in Fig. 1. The engine was a single cylinder, naturally diligence research engine and engaged a pump-line-nozzle direct injection system as described in Table 1. To load the engine an eddy current dynamometer has been utilized. The Kistler pressure transducer was escalated at the cylinder head through charge amplifier to a data acquisition board to the In-cylinder pressure traces. The digital shaft encoder has been used to measure crank shaft position. Alternate engine test assemble instrumentation was used to observe ingestion air, exhaust gas recirculation, temperatures (oil, air, inlet manifold and exhaust) and pressures. Data acquirement and combustion investigation were conceded out using a personalized Lab VIEW based code. A Horiba Mexa analyzer was engaged to determine the concentrations of gaseous emissions.

Table 1 – Engine specification.

Engine specification	
Number of cylinders	1
Bore (mm)	98.4
Stroke (mm)	101.6
Connecting rod length (mm)	165
Displacement volume (cm^3)	773
Maximum torque (N m) @ 1800 rpm	39.2
Maximum power (kW) @ 2500 rpm	836
Compression ratio	15.5:1
Injection timing (obTDC)	22
Maximum injection pressure (bar)	180
Injection system	Three holes pump-line-nozzle
Engine piston	Bowl-in-piston

The property of hydrogen concentration (1, 1.5 and 2% of volumetric air flow rate) was estimated with the aim of resolving the optimal hydrogen concentration.

Hence, the varied conditions of reticent EGR rate (5%, 15% and 18%) were assessed to overcome the NOx penalty. The basic properties of tested fuels are given in Table 2.

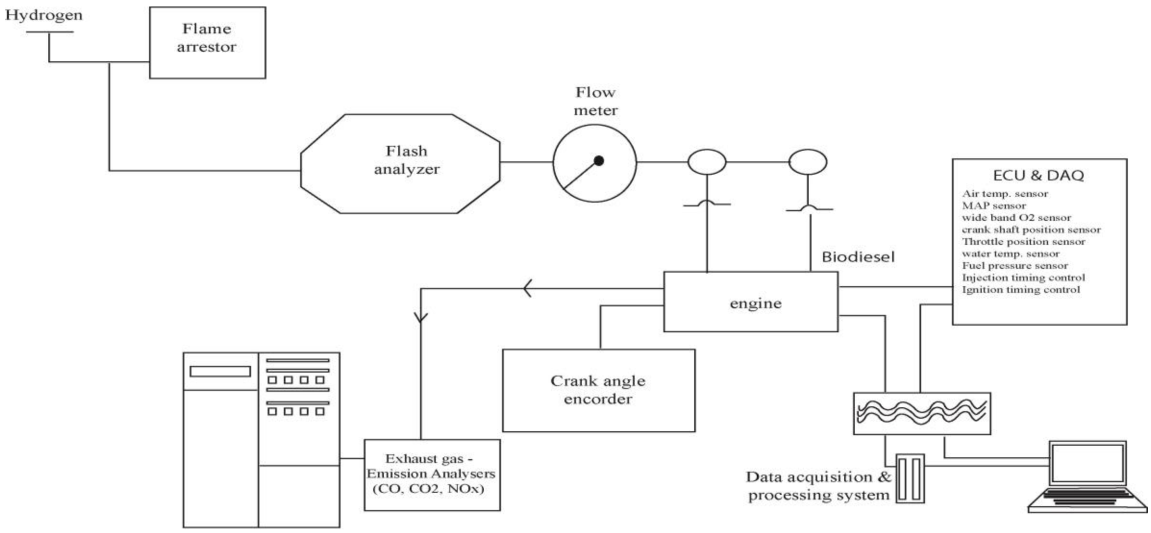

Figure 1: Schematic diagram of the experimental engine setup

A non-dispersive infrared, flame ionization detector and chemiluminescence technique were utilized to measure CO, THC and NOx respectively. To revise extent distribution of particulate matter emitted from the engine, a SMPS, fitted with thermo diluter was fitted. Experiments were carried out at a constant engine speed of 1500 rpm and changeable engine loads of 7 and 9 bar indicated mean effective pressure, representing 40% low and 70% high of ultimate load respectively. The tests were processed out initially using diesel and biodiesel fuels as a instance. B8R and B16R blends were prepared and tested under the same conditions for comparison. Hydrogen mixed with the air before the ingestion manifold valve.

RESULTS AND DISCUSSION

To achieve improved efficiency and emissions using lean burn combustion, it is essential to protected combustion stability in the lean operation condition such that the stable lean burn range is extended. Wobbly slant operation will source deterioration in competence and an augment of unburned hydrocarbon emissions. The NOx reduction also is inadequate through the slender flammability edge. As noticed in preceding research and in this revise, the reason of accretion of hydrogen to a natural gas engine is to take benefit of the wider lean burn uniqueness of hydrogen. In this explore, the slant burn characteristics were processed according to the hydrogen addition ratio as the hydrogen addition was assorted from 10 vol% to 40 vol%.

The covalence values in Fig. 2 explain changes in combustion constancy with the hydrogen count proportion in the fuel at the MBT spark timing of each operation condition. If the covalence value is set as 2% as the typical for an operable stable combustion, it is pragmatic that the flammability edge is absolute by the hydrogen addition.

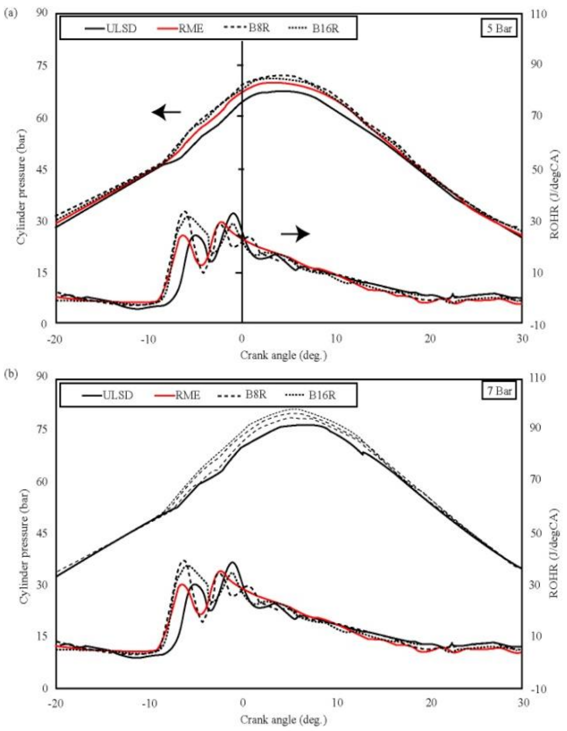

Figure 2: In - cylinder pressure and rate of heat release for the tested liquid fuels: (a) 5 bar and (b) 7bar

Fig. 3 demonstrates the thermal effectiveness against excess air ratio as hydrogen was supplemented. As the leanness was augmented, the thermal effectiveness enlarged; however, when the excess air ratio exceeded a certain level of leanness, the degree ofefficiency decreased due to the degradation in combustion stability.

The additional air ratio of maximum efficiency for each hydrogen addition proportion also denotes a leaner condition with the increase of the hydrogen addition proportion. It is prominent that the thermal effectiveness of 35 vol% hydrogen addition was immensebly less, by 1.5%, than that of the natural gas. The justification behind hydrogen addition at specific excess air proportions was reliable in amending thermal effectiveness is the efficient augmented work in order to the increased laminar flame speed of the mixture, as concluded in Fig. 4, which presents the MBT spark advance timing at each operating condition. An expansion of thermal effectiveness is presumed with an increase of the hydrogen addition proportion due to the anti-knocking characteristics of hydrogen are advantageous to form a increased compression proportion possible as higher hydrogen is mixed [13-15]. Fig. 4 show the results of the dangerous emissions NOx, CO_2 and CO respectively, as a measure of changes in the excess air proportion under the same operating condition as in Fig. 3.

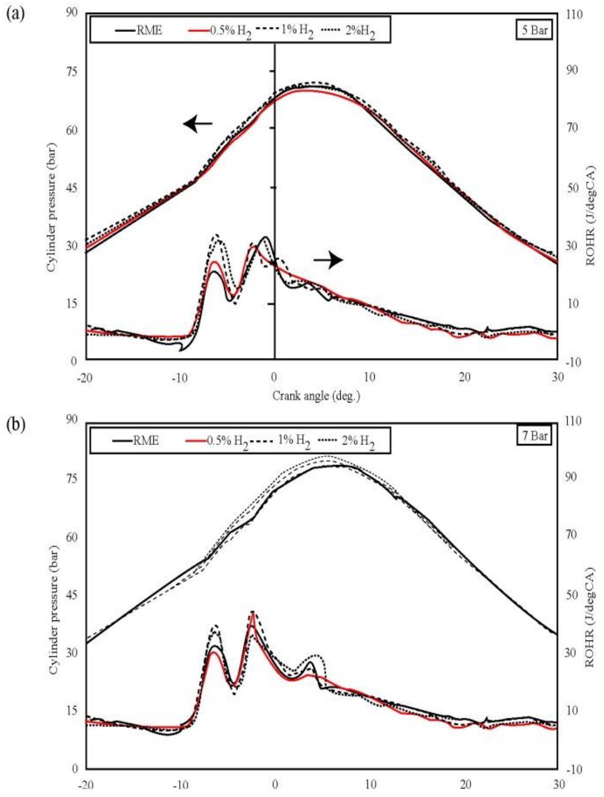

Figure 3: The effect of hydrogen on the combustion characteristics of RME: (a) 5 bar and (b) 7 bar

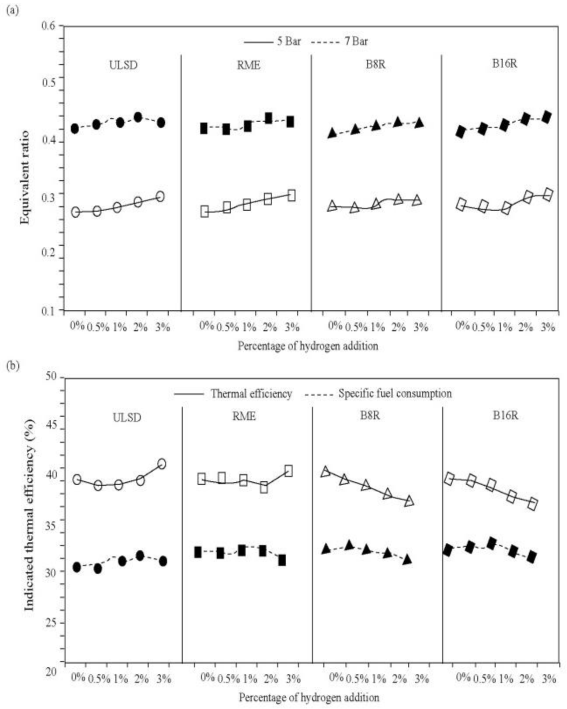

Figure 4: Engine Performance: (a) equivalence ratio and (b) indicated fuel consumption and indicated thermal efficiency

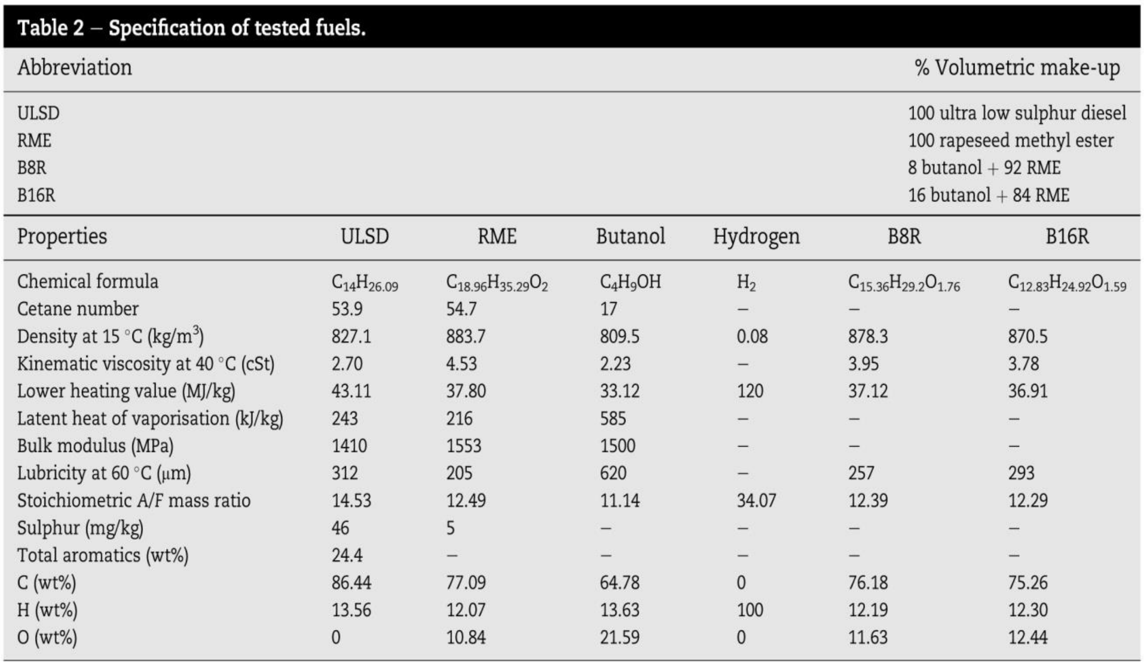

Table 2 – Specification of tested fuels.

Abbreviation	% Volumetric make-up
ULSD	100 ultra low sulphur diesel
RME	100 rapeseed methyl ester
B8R	8 butanol + 92 RME
B16R	16 butanol + 84 RME

Properties	ULSD	RME	Butanol	Hydrogen	B8R	B16R
Chemical formula	$C_{14}H_{26.09}$	$C_{18.96}H_{35.29}O_2$	C_4H_9OH	H_2	$C_{15.36}H_{29.2}O_{1.76}$	$C_{12.83}H_{24.92}O_{1.59}$
Cetane number	53.9	54.7	17	–	–	–
Density at 15 °C (kg/m^3)	827.1	883.7	809.5	0.08	878.3	870.5
Kinematic viscosity at 40 °C (cSt)	2.70	4.53	2.23	–	3.95	3.78
Lower heating value (MJ/kg)	43.11	37.80	33.12	120	37.12	36.91
Latent heat of vaporisation (kJ/kg)	243	216	585	–	–	–
Bulk modulus (MPa)	1410	1553	1500	–	–	–
Lubricity at 60 °C (μm)	312	205	620	–	257	293
Stoichiometric A/F mass ratio	14.53	12.49	11.14	34.07	12.39	12.29
Sulphur (mg/kg)	46	5	–	–	–	–
Total aromatics (wt%)	24.4	–	–	–	–	–
C (wt%)	86.44	77.09	64.78	0	76.18	75.26
H (wt%)	13.56	12.07	13.63	100	12.19	12.30
O (wt%)	0	10.84	21.59	0	11.63	12.44

As shown in Fig. 4 (augmented proportion for better explained comparison), under assured excess air proportion conditions, the level of NOx augmented as hydrogen was mixed. This is due to promoted NOx generation as the high adiabatic flame temperature of hydrogen extends the temperature of the combustion gas.

Also considering the best efficiency illustrated in Fig. 4, NOx emissions are possibly to decrease because of possible stable operation of hydrogen addition with higher excess air proportion conditions. A comparison of NOx emissions with standard gas with the conditions of finest efficiency indicated as 64% reduction of the NOx with the addition of 35 vol% hydrogen and an 78% NOx reduction with 35 vol% hydrogen. The characteristics of CO emissions are actually slight different from that of NOx emissions, as shown in Fig. 4. CO emissions decreased with hydrogen addition at certain excess air proportion conditions, CO emissions are matching or higher at the operating condition of finest efficiency.

CONCLUSION

An analysis to attain NOx reduction was achieved in an heavy duty natural gas engine with the addition of hydrogen to biodiesel blend fuel. As such to endorse the suitability of hydrogen-blended fuel, the thermal effectiveness and emission characteristics were reviewed. Hence performance and combustion attributes of a CI engine and the thermal efficiency augmented by persuade of hydrogen with bio fuel is examined in this research. The steadiness of combustion by addition of hydrogen and the efficiency of NOx reduction also sustained using hydrogen gas blended diesel as a fuel.

REFERENCES

1. Alt N, Sonntag HD, Heuer S, Thiele R. Diesel engine cold start noise improvement. SAE Technical Paper Series; 2005. 2005-01-2490.
2. Sellerbeck P, Nettelbeck C, Heinrichs R, Abels T. Improving diesel sound quality on engine level and vehicle level - a holistic approach. SAE Technical Paper Series; 2007, 2007-01-2372.
3. Bodden M, Heinrichs R. Diesel sound quality analysis and evaluation. In: Proceedings of the fourth European acoustical meeting forumacusticum,Budapest,Hungary;2005. p.1161-4.
4. Das LM. Near-term introduction of hydrogen engines for automotive and agricultural application. Int J Hydrogen Energy 27,2002, 479-87.
5. Saravanan N, Nagarajan G. An experimental investigation of hydrogen-enriched air induction in a diesel engine. Int J Hydrogen Energy 33, 2008, 1769-75.
6. Senthil Kumar M, Ramesh A, Nagalingam B. Use of hydrogen to enhance the performance of a vegetable oil fuelled compression ignition engine. Int J Hydrogen Energy 28, 2003, 1143-54.
7. 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. Int J Hydrogen Energy 36, 2011, 13138-49.
8. R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.
9. Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface,” IEEE Transl. J. Magn. Japan, vol. 2, pp. 740-741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982.
10. M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.

11. Furuhama S. State of the art and future trends in hydrogenfueled engine. Int J Veh Des 4, 1983, 359-85.

12. Das LM. Hydrogen angines: a review of the past and a look into future. Int J Hydrogen Energy 5, 1990, 425-43.

13. Karim GA. Hydrogen as a spark ignition engine fuel. Int J Hydrogen Energy 28, 2003, 569-77.

14. White CM, Steeper RR, Lutz AE. The hydrogen-fueled internal combustion engine: a technical review. Int J Hydrogen Energy 31, 2006, 1292-350.

15. Karim GA. Combustion in gas fueled compression ignition engines of the dual fuel type. Trans ASME, J Eng Gas Turbines Power 125, 2003, 827-36.

16. Sahoo BB, Sahoo N, Saha UK. Effect of engine parameters and type of gaseous fuel on the performance of dual-fuel gas diesel enginesda critical review. Renew Sust Energ Rev 13, 2009, 1151-84.

17. Gopal G, Rao PS, Gopalakrishnan KV, Murthy BS. Use of hydrogen in dual fuel engine. Int J Hydrogen Energy 7, 1982, 267-72.

18. Varde KS, Frame GA. Hydrogen aspiration in direct injection type diesel engine-it's effect on smoke and other engine performance parameters. Int J Hydrogen Energy 8, 1983, 549-55.

19. McWilliam L, Megaritis T, Zhao H. Experimental investigation of the effects of combined hydrogen and diesel combustion on the emissions of a HSDI diesel engine. Paper 2008-01-1787. SAE; 2008.

20. Shirk MG, McGuire TP, Neal GL, Haworth D. Investigation of a hydrogen-assisted combustion system for a light-duty diesel vehicle. Int J Hydrogen Energy 33, 2008, 7237-44.

21. Lilik GK, Zhang H, Herreros JM, Haworth DC, Boehman AL. Hydrogen assisted diesel combustion. Int J Hydrogen Energy 35, 2010, 4382-98.

22. Bika AS, Franklin LM, Kittelson DB. Emissions effects of hydrogen as a supplemental fuel for diesel and biodiesel. Paper 2008-01-0648. SAE; 2008.

23. Miller JA, Bowman CT. Mechanism and modeling of nitrogen chemistry in combustion. Prog Energy Combust Sci 15, 1989; 287-338.

24. Turns SR. An introduction to combustion: concepts and applications. 2nd ed. New York, NY: McGraw-Hill Higher Education; 1999.

25. G. Eason, B. Noble, and I.N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," Phil. Trans. Roy. Soc. London, vol. A247, April 1955. (*references*), pp. 529-551.

26. J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.

27. I.S. Jacobs and C.P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G.T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271-350.

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