iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 **Issue:** V **Month of publication:** May 2017

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Diesel Engine with Hydrogen in Dual Fuel Mode: A Review

Ganesh Kerkal[1], Krishna Pawale[2], Amol Dhumal[3]

[1,2,3] *Asst. Prof., D.Y. Patil Institute of Engineering , Management and Research, Pune., Mechanical Dept., SPPU*

Abstract: Depleting fossil fuel resources and increased energy demand forced automobile companies to search clean alternative. There are also Concerns for global warming and tightened emission norms. For this there are different alternative fuels. Out of which Hydrogen is a carbon free with excellent combustion characteristics.

In this study, Effect of Hydrogen addition on diesel engine in dual fuel mode performance and emissions were studied. It shows that effect on Diesel engine has positive impact on emission but lack of power may feel at high load condition. Hydrogen has high flame speed, require low ignition energy, very small quenching thickness and wide flammability all these factors create a very serious safety concern. But this can be overcome by on board hydrogen generation by electrolysis. HHO gas is a mixture of Hydrogen and Oxygen and it is generated by water electrolysis.

Keywords: Hydrogen, Dual Fuel Mode, HHO Gas, Electrolysis, Emission, Engine Power.

I. INTRODUCTION

By using alternative fuel the reliance on petroleum-based fuel can be reduced, which is need of this current era, where energy security is becomes prime concern for every country. In this work, hydrogen was used as a supplementary fuel in a commercial diesel engine to replace a part of the diesel fuel burned in the engine. The engine exhaust emissions in diesel engine with hydrogen as supplementary fuel were of primary interest. Many Automobile companies are developing engines that efficiently exploit the potential of hydrogen. The main advantage of hydrogen as fuel is that, if hydrogen is produced by using renewable energy then vehicle will not produce any carbon dioxide emissions. Also, hydrogen combustion will not emit pollutants with the only exception of Nitrogen oxides. Therefore near future hydrogen will be prime alternative fuel which gives environment friendly sustainable transport system [1].

History of hydrogen as a fuel for I. C. Engine is more than 200 years old. In 1807, Franc¸ois Isaac de Rivaz made a major breakthrough by running internal combustion engine with the hydrogen and oxygen. In 1808 they use this engine to propel vehicle that is considered as the world's first internal combustion engine. In 1863, E´tienne Lenoir invented an automobile with hydrogen as a fuel [2]. But after this two experience, hydrogen does not receive major attention largely because of technological inventions in gasoline engine such as carburetors which makes them more reliable and powerful. Apart from these two remarkable experiences of the past, Mazda launched its first prototype car using a wankle engine driven by hydrogen in early 1990s to the BMW Hydrogen 7 and H2R of the latest 2000s. Mostly gasolines like operation for hydrogen fuel are proposed by researchers. Many gasoline engines have been modified for hydrogen injection, combustion rate is controlled by a spark and load is controlled by throttle [1].

Research on the duel fuel engine using Hydrogen as supplementary fuel has adequate published literature. But most of researcher use hydrogen as supplementary fuel in SI Engine where direct injection and port injection studied. N. Saravanan, G.Nagarajan [3] et al studied hydrogen with Di ethyl Ether and found this combination give better brake thermal efficiency of 30% along with substantial reduction in NOx emission when compared with Diesel engine. In case of diesel engine, in dual fuel mode different gaseous fuels such as LPG [4,5], methane [6,7], natural gas [6], hydrogen–methane(HCNG)[8], HHOCNG[8] combinations were studied. D.B. Lata et al[5] investigate the effect Hydrogen and LPG mixture as a secondary fuel in diesel engine. Most of the research on dual fuel engine focuses on deciding maximum limit and optimum rate of supplementary gaseous by considering performance and emission characteristics.

Diesel engine with hydrogen in dual fuel mode has been proposed by some researchers with manifold injection in a traditional Diesel engine [1-5,8-15]. Hydrogen has very high self ignition temperature of 858 K, making it hard to ignite by compression alone therefore an ignition source is required to burn in an IC engine [3]. For ignition source, low self ignition temperature is required so first obvious choice will be Diesel fuel because it has low an autoignition temperature of 525 K. This diesel engine with hydrogen in dual fuel mode is beneficial since the diesel fuel is being replaced by carbon less hydrogen, which reduces emissions impacts.

The major disadvantage of dual fuel engine is the storage and safety of two fuels. As we have to store two fuels it adds extra weight especially for gaseous fuel. Gaseous fuel has low energy density therefore they also consume more space. This main disadvantage can be overcome by producing hydrogen gas on board by using electrolysis. Hydrogen gas produced by electrolysis also contains oxygen which is also combustion promoter. This mixture of hydrogen and oxygen called HHO Gas or Hydroxy Gas or Brown gas. This effect of HHO gas addition also studied by S. Bari , M. Mohammad Esmaeil et al.[11] And Hsin-Kai Wang a, Chia-Yu Cheng et al[16] and both reported better combustion and emission performance compare to base diesel engine.

II. COMBUSTION AND PERFORMANCE ANALYSIS

A. Combustion Process Of Duel Fuel (H_2-Diesel) Engine

Combustion process in dual fuel engine is a mixture of combustion process of S. I. Engine and C. I. Engine. As hydrogen is a S I Engine fuel it need ignition source such as spark but we are using hydrogen in C I Engine therefore we use diesel fuel. Hydrogen is injected in intake manifold therefore we get homogenous mixture of air and hydrogen. Then towards top dead centre diesel fuel is injected which creates multiple ignition source therefore it causes volumetric combustion of premixed hydrogen or it will create multiple turbulent flame [7].

Generally in dual fuel engine major portion of the energy is released from the combustion of gaseous fuel and a small portion of energy is provided by diesel liquid fuel. But for addition of hydrogen in diesel engine in dual mode major energy is released from diesel engine and small portion of energy up to 40 % is provided by Hydrogen. A gaseous fuel induction in hydrogen-diesel dual fuel engine also gives higher efficiency [11, 12].

In dual fuel engine there are two strategies for gaseous fuel introduction in the cylinder. First will be easy, cost effective induction in the intake manifold and second will be direct injection method. The flame front travel in case of induction is more rigorous and uniform because of homogenous mixture of Hydrogen and air. Where for direct injection flame front is not uniform and slow. In induction method, the combustion velocities are at least 23% higher than that of direct injection method[12]. Gregory K. Lilik et al[2] reported that by using induction method engine volumetric efficiency drastically reduces.

B. Heat Release Rate

Eiji toita et al.[9] investigate effect of Hydrogen addition on single cylinder diesel engine keeping equivalence ratio 0.4 and found that heat release rate does not change much compare to diesel operation between injection timing 2.5 and 23.7 degree BTDC and in general it is lower. M.Masood et al[12] also find similar result of low heat release rate but at low load only. As the load and percentage of hydrogen substitution increases the heat release increases. When we compare heat release rate of diesel engine and dual fuel engine with hydrogen at higher load and at higher hydrogen level is always higher because hydrogen burns faster having flame speed nine times higher than diesel. N. Saravanan ,G. Nagarajan, G et al reported heat release rate is 21% higher for dual fuel mode with 7.5 lpm hydrogen flow rate than the diesel fuel mode. For diesel – hydrogen duel fuel engine, there are two methods in which we can supply hydrogen to engine either induction of hydrogen in intake manifold or direct injection of pressurized hydrogen in the combustion chamber. M.Masood et al[12] shows that heat release rate per crank angle in case of induction is around 17% higher than that of injection because of higher premixed combustion.

C. Ignition Delay

The ignition delay period may be defined as the time lag between diesel injection and detectable rise in cylinder pressure [13]. Ignition delay period increased slightly with the addition of hydrogen and LPG [9,13]. This is due to the addition of hydrogen or LPG or a mixture of LPG and hydrogen in the charge reduces the air intake ultimately oxygen in the cylinder or loss of the very reactive OH radical in the reaction with molecular hydrogen because of formation of intermediate compounds. At higher concentration of hydrogen plus LPG in the mixture, ignition delay decreases due to addition of significant amounts of energy and species [9,14].

Because of Longer ignition delay the more diffusion of diesel and then lean premixed combustion occurs. Specific heat ratio for both hydrogen and air is same but heat transfer coefficient for Hydrogen is higher. Therefore a heat transfer losses increase which leads to lower gas temp and this may lead to higher ignition delay [9].

D. Pressure Vs. crank angle curves:

Eiji TOMITA et al[9] investigated effect of different injection timing on performance of dual fuel (Diesel –Hydrogen) engine and found that for all injection timings peak pressure is always higher for hydrogen substitution however effect of load clearly visible. As load on engine increases rate of pressure rise and peak pressure both are high where more complete combustion of the fuel

Volume 5 Issue V, May 2017
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

occurred but for lower load this effect diminishes [2,3,9,10,17]. Also at higher load diesel percentage is higher therefore more number of ignition centres is available. S. Bari , M. Mohammad Esmaeil et al[10] also pointed out that faster hydrogen combustion result in higher peak pressure closer to TDC and therefore, will produce a higher effective pressure to do work. Therefore to improvement in the efficiency occurs. N. Saravanan [10] found that at 7.5 lpm hydrogen flow rate the peak pressure occurs 5^0CA earlier than that of diesel. W. B. Santoso [18] investigated effect of hydrogen enrichment specifically at low load condition. During the hydrogen addition, the load and speed were kept constant. Hydrogen flow rates of 21.4, 36.2, and 49.6 lpm were used which replaces diesel fuel around 50, 90, and 97% respectively and found that Hydrogen enrichment lowers the peak pressure, rate of pressure rise and retarded the start of combustion. This is due to the non availability of diesel fuel needed to ignite the premixing of hydrogen with air.

E. Brake Thermal Efficiency

Most of the researcher found that as hydrogen enrichment increases the brake thermal efficiency [3, 4, 11, 12, 17, 18]. Since hydrogen has higher flame velocity and diffusivity than diesel fuel, therefore it mixes with diesel very well and complete heat release rate occur which results in higher brake thermal efficiency. However gaseous complete combustion also increases heat transfer rate because cylinder wall directly come into contact with combustion zone and especially at low load where diesel content is low results in poor combustion therefore brake thermal efficiency may decrease by hydrogen enrichment which is reported by some researcher [2, 8, 18].

D.B. Lata, Ashok Misra , S. Medhekar[14] et al studied the effect of addition hydrogen and LPG in intake manifold and found that The best performances of dual fuel engine obtained by the substitution of 40% of mixture in the ratio LPG: hydrogen; 70:30. This situation is most suited in terms of efficiency and emissions.

M. Masood, M.M. Ishrat, A.S. Reddy[12] et al investigate the effect of hydrogen induction through inlet manifold versus that of direct hydrogen injection on brake thermal efficiency. This study found that for both methods brake thermal efficiency increases as hydrogen enrichment increases. However, the efficiency was higher by around 19% in case of induction through inlet manifold when compared to that of direct injection in cylinder. This is due the homogenous mixer of hydrogen and air (by induction method), burnt completely by the flame initiated by the multiple diesel ignition center and resulted in complete combustion [12].

Vinod SinghYadav,S.L. Soni, Dilip Sharma et al [4] al investigate the effect of EGR and found that addition EGR results in lower engine efficiency. Due to presence of inert gases which replaced oxygen negatively affected the combustion process. This explains result of lower brake thermal efficiency in case of EGR [4].

III. EMISSION CHARACTERISTICS

Emissions from automobiles are currently a major source of air pollution representing 70% of carbon monoxide, 41% of oxides of nitrogen, and 38% of hydrocarbon emissions globally. In diesel engines, there is a trade off between smoke and nitrogen oxide. Smoke and nitrogen oxides cannot be reduced simultaneously. There have been many strategies for this problem. One of the promising strategies is utilization of gaseous fuel. Among various gaseous fuel Hydrogen is considered as a best fuel because of advantageous properties such as a high flame speed, short quenching distance, high heating value and high diffusivity [4]

A. Smoke

mission of smoke is due heterogonous combustion and mixing of the less quantity of pilot diesel fuel injected. Most of researcher found that the smoke in the exhaust of the engine running on the hydrogen and diesel decreases as compared to pure diesel operation[2,3,9,11,17]. Smoke is basically a combustion generated carbonaceous materials (soot) on which some organic compounds are absorbed. Soot is produced from incomplete combustion of hydrocarbon fuels and small portion from lubricating oil [5].The smoke formation increases with load and equivalence ratio. Dual fuel engine uses gaseous fuel as a secondary fuel, which improves fuel air mixing. Therefore major part of diesel fuel burn in homogenous manner and High rate of hydrogen chain oxidation reduces smoke formation [5]. These facts keep engine clean and smoke free.

When hydrogen is mixed with air, less smoke is exhausted because hydrogen does not include carbon atoms in its molecular structure. Whatever smoke formed is due to the combustion of the diesel and lubrication oil [9]. N.Saravanan, G. Nagarajan et al observed that the smoke of 0.8 BSN is in for hydrogen-diesel dual fuel at 75% load operation compared to base diesel fuel of 2.2 BSN [3].

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

B. Hydrocarbon (Hc)

The hydrocarbon emission decreases as hydrogen enrichment increases because hydrogen is carbonless fuel and it promotes complete combustion because high flames speed. While the hydrocarbon decreased slightly with increasing the overall equivalence ratio [9]. Vinod SinghYadav , S.L. Soni, Dilip Sharma et al[4] studied the effect of EGR on emission and found that The HC emission reduced by 5.13% for hydrogen enrichment without EGR compared to pure diesel operation at 80% load. But by using EGR, HC emission increased because non-availability of excess oxygen available for combustion which results in incomplete combustion but still emission has low level compared to neat diesel operation. S. Bari, M. Mohammad Esmaeil et al [11] investigate the effect of HHO Gas addition. HHO Gas contains extra pure oxygen which is very effective in reducing HC emission. So they found that At 19 kW load the HC emission lowered from 187 ppm to 85 ppm with HHO gas flow rate 31.75 lmp. At 22 kW and 28 kW the HC emission lowered from 189 ppm to 93 ppm by adding 29.84 lpm and from 192 ppm to 97 ppm by adding 30.6 lpm of HHO gas addition, respectively. Gregory K. Lilik, Hedan Zhang et al[2] found that HC emissions is decreased roughly 10% compared to the diesel baseline at 15% hydrogen enrichment.

C. Oxides Of Nitrogen (Nox)

Most of the researchers reported that hydrogen enrichment increases the NOx emission [2, 3, 4, 9, 11,]. Vinod SinghYadav , S.L. Soni, Dilip Sharma et al [4] found that because of hydrogen enrichment The exhaust gas temperature is increased from 415^0c for base diesel to the 430 ^{0}C at 80% load. This increase in exhaust gas temperature because of hydrogen enrichment was due to more complete combustion this explains increase in combustion temperature. To reduce combustion temperature they use EGR and found that NOx formation decreased with increase of EGR. As the amount of Hydrogen induction increases, emission of nitric acid (NO) decreases and NO_2 increases. NOx emission is function of Hydrogen enrichment in the intake manifold [7].

For hydrogen enrichment in diesel engine NOx is 21.9 g/kWh compared to 20.65 g/kWh for diesel at 75% load. The higher concentration of NOx is due to the peak combustion temperature [3]. When the value of NOx is large, the heat release rate is also large. Gregory K. Lilik , Hedan Zhang et al[2] made a very important conclusion that because hydrogen enrichment A significant retarding of injection timing by the engine's electronic control unit (ECU). This retarded injection timing directly affect combustion process and NOx emission. Since there are some reports of NOx reduction by using Hydrogen enrichment[12,19] but Gregory K. Lilik , Hedan Zhang et al successfully demonstrate that reduction in Nox is because of retarded injection timing. After locking injection timing they found that there is slight increase in NOx emission by hydrogen enrichment.

M. Masood, M.M. Ishrat et al carried out CFD analysis of hydrogen enrichment in diesel engine and revealed that the NOx formation tendency is higher in case of hydrogen enrichment compare to base diesel combustion. It also find that the effect of induction produces more NOx than in direct injection. These results were confirmed by the practical results. The NOx formation because of induction was 33% more than that of the injection at lower percentages of hydrogen enrichment [12].

N. Saravanan , G. Nagarajan[3] compare the hydrogen enrichment in diesel as well as DEE and found that oxides of nitrogen increased by of 13% compared to base diesel however Hydrogen-DEE operation shows significant reduction in NOx compared to diesel.

D. *Carbon Monoxide (Co)*

Hydrogen is a carbonless fuel that is the reason for low CO emission in case of hydrogen enrichment. Also more complete combustion also helps in lowering CO emission [3,4,9,11]. In case of EGR, CO emission increased due to lack of enough oxygen. As load increases more than 70% suddenly CO emission shoots up in all cases due to the less availability of oxygen within the vicinity of combustion level [4]. In the hydrogen assisted diesel dual fuel mode CO emission is 0.43 g/kW h compared to diesel of 0.64 g/kW h. At 75% load the carbon monoxide emission in hydrogen assisted diesel dual fuel mode while that of diesel is 0.316 g/kW h [3].

IV. CONCLUSIONS

The hydrogen assisted diesel combustion overcome the drawback of lean operation of base diesel engine, which are difficult to ignite and results in lower power output, reduction in misfires, improving combustion and emissions. The brake thermal efficiency increased with the increase in percentage substitution of hydrogen but at higher load condition and for low load condition results were reversed. Heat release rate is increases as Hydrogen enrichment increase. Peak pressure and rate of pressure is also on higher side for Hydrogen enrichment however hydrogen replaces incoming air charge so volumetric efficiency drastically reduces. To overcome volumetric efficiency issue and storage of highly inflammable hydrogen, On board hydrogen production along with oxygen by electrolysis process is promising remedy. The emissions of HC, CO_2 and CO were found to be lowered due to complete combustion however NOx increased due to the higher combustion temperature.

A. List Of Abbreviations

1) EGR - Exhaust Gas Recirculation
2) CO2 - Carbon dioxide
3) IC - Internal Combustion
4) LPG -Liquefied Petroleum Gas
5) CNG -Compressed Natural Gas
6) H2- Hydrogen
7) LPG -Liquefied Natural Gas
8) SI- Spark Ignition
9) CI- Compression Ignition
10) DF- Dual Fuel
11) NOx -Nitrogen Oxides
12) DEE- Diethyl Ether
13) TPI -Timed Port Injection
14) CO -Carbon Monoxide
15) SO2-Sulphar Dioxide
16) UBHC- Unburned/partially burned Hydrocarbon
17) DI- Direct Injection
18) BTE -Brake Thermal Efficiency
19) BSFC -Brake Specific Fuel Consumption
20) BSN -Bosch smoke number

REFERENCES

[1] Alberto Boretti, “Advantages of the direct injection of both diesel and hydrogen in dual fuel H2ICE”, International Journal of Hydrogen Energy 36 (2011) 9312-9317.

[2] Gregory K. Lilik a, Hedan Zhang b, Jose´ Martin Herreros c, Daniel C. Haworth b, Andre´ L. Boehman a,”Hydrogen assisted diesel combustion, ” International Journal of Hydrogen Energy 35(2010) 4382 – 4398.

[3] N.Saranan, G. Nagarajan, C.Dhanasekaran and K. M. Kalaiselvan, “Experimental Investigation of Hydrogen Fuel Injection in DI Dual Fuel Diesel Engine” SAE paper; 2007-01-1465 .

[4] Vinod SinghYadav , S.L. Soni, Dilip Sharma,” Performance and emission studies of direct injection C.I. engine in duel fuel mode (hydrogen-diesel) with EGR” International Journal of Hydrogen Energy 36 (2012)3807-3817

[5] D.B. Lata , Ashok Misra , S. Medhekar, “Effect of hydrogen and LPG addition on the efficiency and emissions of a dual fuel diesel engine”, International Journal of Hydrogen Energy 37(2012) 6084-6096.

[6] Nirendra N. Mustafi and Robert R. Raine,”A Study of the Emission of Duel Fuel Engine Operating with Alternative Gaseous fuels ”, SAE paper ; 2008-01-1394.

[7] Satbir Singh, Shiyu Liu and Hailin Li,”Numerical Investingation of NO2 Formation Mechanism in H_2-Diesel Duel –Fuel Engine ”SAE paper ;2012-01-0655…

[8] Raif Kenanoğlu, Bahattin Tanç, Mustafa Kaan Baltacioğlu, Hüseyin Turan Arat, Mustafa Özcanli, Kadir Aydin And Ertuğrul Baltacioğlu, “Comparison of HCNG and HHOCNG dual fuels usage with pilot injection in a non-modified diesel engine”, Conference Paper · November 2015, https://www.researchgate.net/publication

[9] Tomita E, Kawahara N, Piao Z, Fujita S. “Hydrogen combustion and exhaust emissions ignited with diesel oil in a dual fuel engine”. SAE Paper; 2001. 2001-01-3503.

[10] N. Saravanan , G. Nagarajan, G. Sanjay, C. Dhanasekaran, K.M. Kalaiselvan,” Combustion analysis on a DI diesel engine with hydrogen in dual fuel mode,” Fuel 87 (2008) 3591–3599.

[11] S. Bari , M. Mohammad Esmaeil, “Effect of H2/O2 addition in increasing the thermal efficiency of a diesel engine,” Fuel 89 (2010) 378–383.

[12] M. Masood, M.M. Ishrat, A.S. Reddy,” Computational combustion and emission analysis of hydrogen–diesel blends with experimental verification,” International Journal of Hydrogen Energy 32 (2007) 2539 – 2547

[13] D.B. Lata, Ashok Misra “Analysis of ignition delay period of a dual fuel diesel engine with hydrogen and LPG as secondary fuels” International Journal of Hydrogen Energy 36 (2011) 3746-3756.

[14] D.B. Lata, Ashok Misra,“ Theoretical and experimental investigations on the performance of dual fuel diesel engine with hydrogen and LPG as secondary fuels” International Journal of Hydrogen Energy 35 (2010) 11918-11931.

Volume 5 Issue V, May 2017
ISSN: 2321-9653

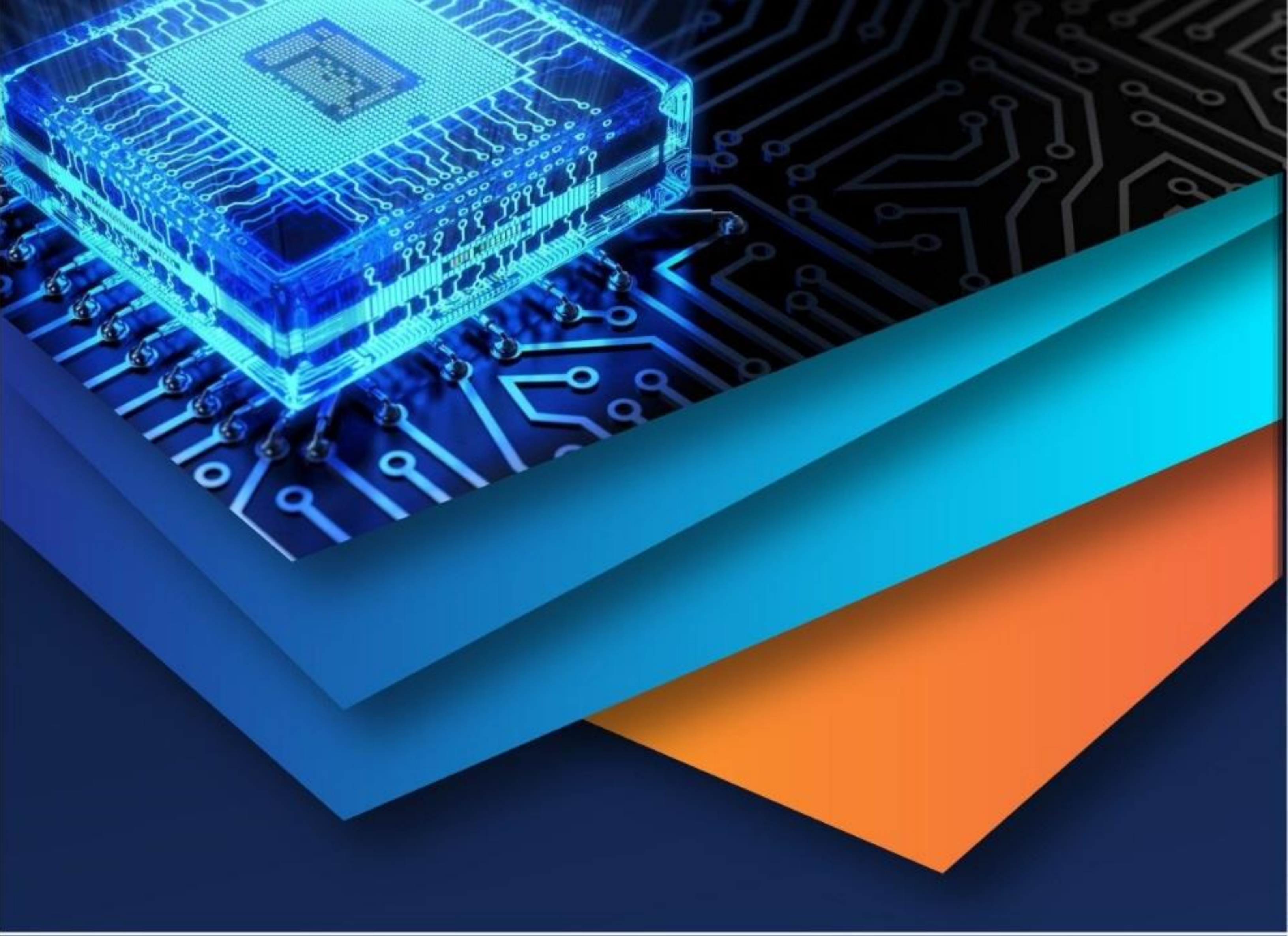
[15] Alberto Boretti “Advances in hydrogen compression ignition internal combustion engines,” International Journal of Hydrogen Energy 36 (2011)12601 -12606.

[16] Hsin-Kai Wang , Chia-Yu Cheng, Kang-Shin Chen, Yuan-Chung Lin, Chung-Bang Chen, “Effect of regulated harmful matters from a heavy-duty diesel engine by H2/O2 addition to the combustion chamber”, Fuel 93 (2012) 524–527.

[17] Haroun A.K. Shahad, Nabeel Abdul-Hadi “Experimental Investigation of the Effect of Hydrogen Manifold Injection on the Performance of Compression Ignition Engines”, World Academy of Science, Engineering and Technology International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:5, No:4, 2011

[18] W.B. Santoso, R. A. Bakar, A. Nur “combustion characteristics of diesel diesel-hydrogen duel fuel engine at low load”, International Conference on Sustainable Energy Engineering and Application 2012

[19] D.B. Lata, Ashok Misra, s. medhekar, “Effect of hydrogen and LPG addition on the efficiency and emissions of a dual fuel diesel engine”, International Journal of Hydrogen Energy 37 (2012) 60 4-60.



10.22214/IJRASET

INDEX COPERNICUS 45.98

IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY