International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.8, No.8, pp 188-193, 2015

Using hydrogen as a fuel in diesel engine – A Review

S. R.Premkartikkumar

School of Mechanical and Building Sciences,Thermal & Automotive Division,
VIT University,Vellore,India.

Abstract: Rapid exhaustion of fossil fuel, exponential increase of automotive vehicles and stringent emission norms force the researchers to find out an alternative fuel which can be used in diesel engines with less modification or without any modification. The present paper reviews the effect of using hydrogen as a fuel in diesel engine. In this review, the investigations done by the researchers were categorized into three forms. First one was inducting hydrogen into diesel engine by the way of carburetion, second one wasinducting hydrogen into diesel engine by the way of manifold and port injection and third one was inducting hydrogen into diesel engine by the way of in-cylinder injection. In all the categories, the data of diesel fuel operation was taken as a base line configuration to examine the effectiveness of the diesel-hydrogen dual fuel combustion.The review showed that the use of hydrogen as a fuel in a diesel engine, keep the combustion temperaturehigh and increases NO_Xemission and reduces smoke emission. It may be concluded that hydrogen is one of the fuels of future.
Keywords:hydrogen;dual fuel;NO_X emission.

Introduction

The diesel engine has been used as an efficient prime mover for a long time. Because of their superior fuel economy, they are mostly used in heavy duty areas. Due to their high efficiency and comparatively low pollutant formation characteristics, their application to lighter duty vehicles, like small goods carriers and passenger cars have drawn much attention in recent years. This development was augmented by the energy crisis in 1973. Also in recent years, the prominence to conserve petroleum based fuels has provided the motivation for several studies on the development and testing of alternate fuels in diesel engine. Among these substitutes, the hydrogen has been found to yield some beneficial effects in spray combustion. Significant beneficial results have been achieved by the use of hydrogen as dual fuel with diesel [1-7].The use of hydrogen as a dual fuel needs considerable safety precautionary measures. Since, the ignition energy of hydrogen is very low. It may back fire during the operation of the engine. Generally, in order avoid any mishap, it is advisable to use flame traps and flame arrestors. They may be of wet type or of dry type.

Hydrogen Induction Methods

Carburetion

Carburetion is the simplest technique for inducting the fuel - air mix into the cylinder. The air flows through a venturi nozzle where its velocity gets increased. This leads to a pressure drop in the throat of the venturi. Its magnitude depends on the air flow rate and this draws the fuel into the air stream [8]. Thus it controls the power output of the engine by varying the amount of fuel - air mix drawn into the cylinder. The technique of carburetion was used to operate hydrogen engines by several researchers [1-7]. The advantage of this technique is that it does not require a high pressure hydrogen supply. This technique also allows the fuel to mix uniformly with the air before being allowed into the cylinder, leading to a more efficient combustion. However, this technique reduces power by 15% [9].

Inlet manifold and port injection

As the name implies, inlet manifold and port injection methods use a constant amount of air induction through the inlet manifold per cycle and the fuel is injected into the air stream by a low pressure injector [9]. The power output of the engine can be controlled by the amount of fuel injected into the air stream, thus allowing the lean burn combustion. In inlet manifold or port injection method, the injection of the fuel can be scheduled to start sometime after the inlet valve is opened. This increases the cooling effect of pre-inducted air. This eventually eliminates the hot spots and the pre-ignition [7]. This also reduces the peak combustion temperature and leads to reduction in NO_X emission [10].

Direct Injection

The problem of back fire can be eliminated altogether if there is no combustible mixture present in the inlet manifold at any time during the combustion cycle [9]. This can be achieved with direct injection of the hydrogen gas into the cylinder. Most researchers adopt this technique of fuel induction to avoid such unwanted combustion phenomena [11-19]. In direct injection technique, only air is inducted during intake stroke. The high pressure gaseous hydrogen is injected into the cylinder at some time during the compression stroke and is ignited soon afterwards. The high pressure injection of hydrogen creates high turbulence in the fuel - air stream. This assists the mixing of the fuel with the air and forms more homogenous mixture of fuel and air.

Results and Discussions

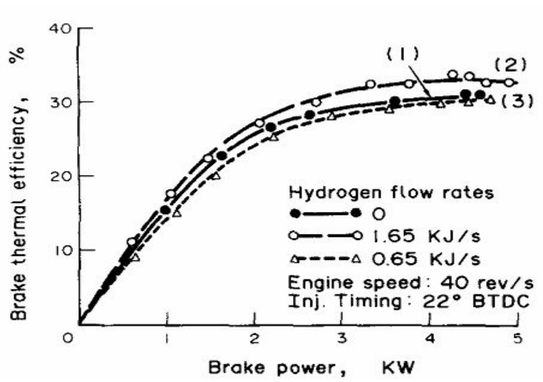

Figure 1. Variation of brake thermal efficiency with brake power for different flow rate of hydrogen [20]

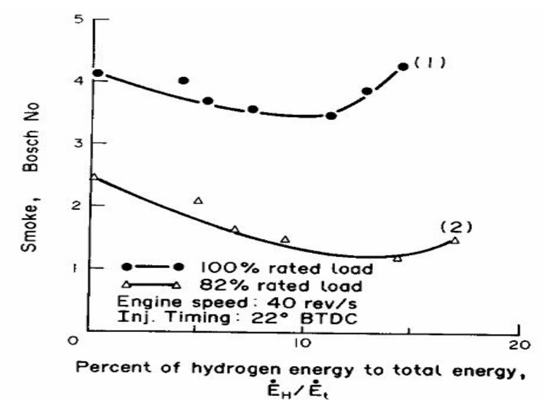

Figure 2. Variation of smoke emission with different energy share percent of hydrogen [20]

Vardeand Frame [20] carried out an experimental study to investigate the possibility of reducing diesel particulates in the exhaust of the diesel engine by aspirating small quantities of gaseous hydrogen in the intake of the engine. For this study, they used a single cylinder, naturally aspirated, four stroke, DI diesel engine with compression ratio of 17.4:1. They found that hydrogen flow rate equivalent to about 10% of the total energy, substantially reduced smoke emissions at part loads. At the full rated load, reduction in smoke levels was limited. They related this to the lower amounts of excess air available in the cylinder. In their experiment, they found that the engine thermal efficiency was dependent on the portion of hydrogen energy, out of the total input energy supplied to the engine.**Figure 1 and 2** Show the variation of brake thermal efficiency with brake power for different flow rates of hydrogen and variation of smoke emission with different energy share percent of hydrogen respectively.

Saravanan et al [21] made an experimental investigation in a diesel engine using hydrogen as fuel with diesel as an ignition source for hydrogen. Hydrogen was injected into the intake port, while diesel was injected directly inside the cylinder. They varied the injection parameters such as injection timing and injection duration of hydrogen for a wider range at a constant injection timing of diesel as 23^o BTDC. They kept hydrogen flow rate as 10 lpm for varied load conditions. Their results showed that the brake thermal efficiency got increased from 23.6% to 29.4% for the injection timing of 5^o ATDC with injection duration of 90^o CA compared to diesel. But the maximum brake thermal efficiency obtained was 31.67% at 15^o ATDC with 60^o CA duration but at this condition they observed a knocking of the engine. The increase in brake thermal efficiency was attributed to better mixing of hydrogen with air that resulting in enhanced combustion. They found, the NO_X emission was minimum of 783 ppm for the injection timing of 5^o ATDC with the injection duration of 60^o CA compared to diesel of 1981 ppm at 75% load. **Figure 3** shows the variation of NO_X emission for various load range of the engine.The NO_X emission for diesel fuel operation at full load was 1806 ppm, whereas it got reduced to 888 ppm with injection duration of 90^o CA with injection timing of 5^o ATDC. The lowest NO_X of 705 ppm was obtained at full load with 60^o CA while the injection was made at TDC. The reduction was due to the operation of hydrogen engine at leaner equivalence ratios. **Figure 4** shows the variation of HC for various load range of the engine.At no load the HC was 3 ppm for the start of injection at 5^o AGTDC with 90^o injection duration for hydrogen operation compared to 19 ppm for diesel. At full load the hydrogen operated dual fuel engine resulting in increase in HC compared to diesel. For hydrogen operation it was 7 ppm at the injection timing of 5^o AGTDC with 90^o injection duration compared to diesel which was 42 ppm. The reduction in HC was due to the higher burning velocity of hydrogen; the absence of carbon in hydrogen fuel also reduced the HC emissions to a great extent. At 75% load condition the hydrogen operated engine at the injection timing of 5^o ATDC and with 90^o injection duration, the smoke value was 0.4 BSN whereas for diesel it was 2 BSN. The lowest smoke value of 0.3 BSN was observed at the injection timing of TDC with 60^o injection duration. At full load for the start of injection at 5^o ATDC with 90^o injection duration, the smoke of 0.3 BSN was obtained compared to diesel of 3.8 BSN. They observed that at no load the CO levels of hydrogen operated engine at all operating conditions was less than diesel. The CO of 0.01% vol. for hydrogen operation at injection timing of 5^o ATDC and 90^o injection duration compared to that of diesel of 0.17% vol. At 75% load the peak pressure was 64.3 bar for the start of injection at 5^o ATDC with 90^o injection duration for hydrogen compared to diesel operation of 68.9 bar. At full load the hydrogen operated dual fuel engine resulted in an increase in peak pressure compared to diesel. The peak pressure for hydrogen operation was 71.7 bar at an injection timing of 5^o ATDC and 90^o injection duration compared to diesel of 73.7 bar. This was due to higher burning velocity of hydrogen, which made combustion as instantaneous.

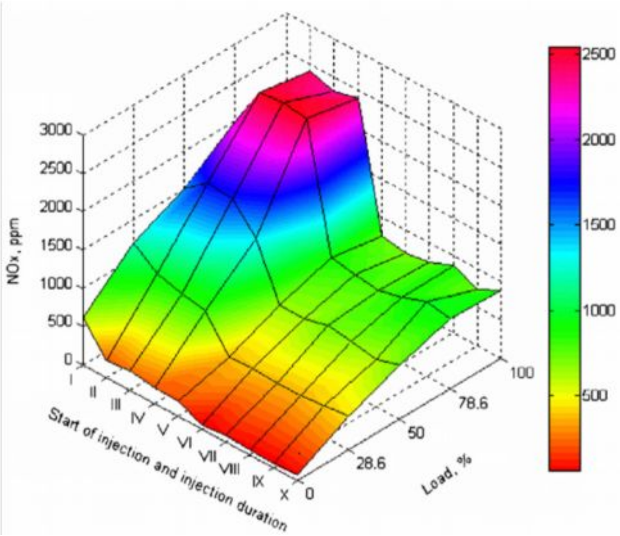

Figure 3. Variation of NO_X emission with different load range of the engine [21]

The peak heat release rate of hydrogen operated engine was 87.6 J/°CA compared to diesel of 81.5 J/°CA. The maximum heat addition also occurred nearer to ITDC for hydrogen operation, which made the cycle efficiency to increase. They concluded that by operating the diesel engine in dual mode with hydrogen, one had to optimize the injection timing and injection duration.

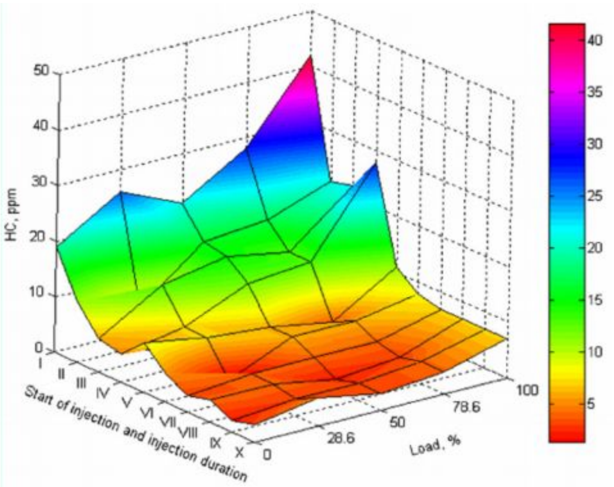

Figure 4. Variation of hydrocarbon emission with different load range of the engine [21]

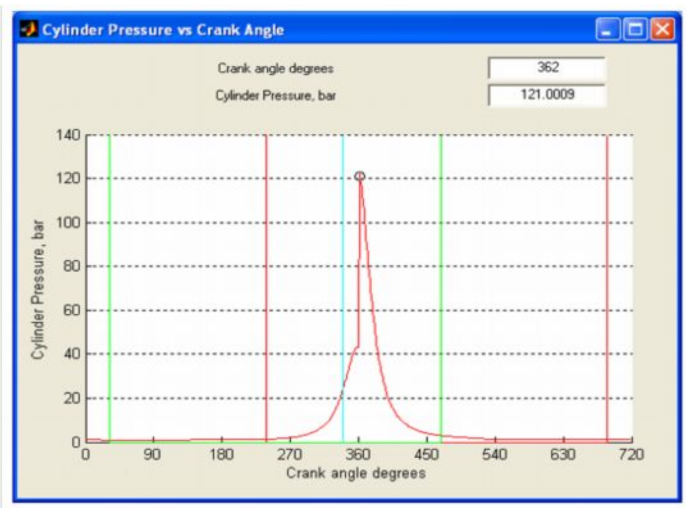

Figure 5. In-cylinder gas pressure plot for one cycle in hydrogen direct injection mode [22]

Antunes et al[22] tested a diesel engine with hydrogen in direct injection mode. Their results showed that the use of hydrogen in direct injection mode gave a higher power to weight ratio when compared to conventional diesel-fueled operation, with the peak power being approximately 14% higher. The use of inlet air heating was required for the hydrogen-fueled engine to ensure satisfactory combustion, and a large increase in the peak in-cylinder gas pressure was observed which is shown in **Figure 5.** A significant efficiency advantage was found when using hydrogen as opposed to diesel fuel, with the hydrogen-fueled engine achieving a fuel efficiency of approximately 43% compared to 28% in conventional, diesel-fueled mode.

Conclusions

The present review of hydrogen combustion in diesel engine draws the following results.

- Hydrogen can be used in an unmodified diesel engine as a fuel.
- Using hydrogen in dual fuel mode increases Brake thermal efficiency and reduces BSFC.
- NO_X emission gets increased because of high in-cylinder temperature.
- Smoke emission gets decreased even at part load operation.

Induction of higher percentage of hydrogen is not advisable as it will create high in-cylinder temperature and may induce large thermal stresses in the cylinder material. This may be due to its instantaneous combustion.

References

1. Sierens R.and Rosseel E., Backfire mechanism in a carburetted hydrogen fuelled engine, Proceedings of the Twelfth World Hydrogen Energy Conference, 1998, Buenos Aires, 537-546.
2. Vandenborre H.andSierens R., Greenbus: a hydrogen fuelled city bus, International Journal of Hydrogen Energy, 1996, 21, 6, 521-524.
3. Rosseel E.and Sierens R., Knock detection in a hydrogen engine, 1997, SAE Technical Paper No. 970039.
4. Mathur H.B.and Das L.M., Performance characteristics of a hydrogen fuelled SI engine using timed manifold injection, International Journal of Hydrogen Energy, 1991, 16, 2, 115-127.
5. Billings R., Hatch S.andDivacky R., Conversion and testing of hydrogen-powered post office vehicle, International Journal of Hydrogen Energy, 1983, 8, 11-12, 943-948.
6. Ding L.J., Qing L.Y.and Shen D.T., Improvement on the combustion of a hydrogen fuelled engine, International Journal of Hydrogen Energy, 1986, 11, 10, 661-668.
7. Varde K.S. and Frame G.A., A study of combustion and engine performance using electronic hydrogen fuel injection, International Journal of Hydrogen Energy, 1984, 9, 4, 327-332.
8. Heywood J.B., Internal combustion engine fundamentals, 1988, McGraw-Hill, New York.
9. Overend E., Hydrogen combustion engines. Ph.D. thesis, 1999, University of Edinburgh.
10. Varde K.S.and Frame G.A., Development of a high- pressure hydrogen injection for SI engine and results of engine behaviour, International Journal of Hydrogen Energy, 1985, 10, 11, 743-748.
11. Ikegami M., Miwa K.andShioji M., A study of hydrogen fuelled compression ignition engines, International Journal of Hydrogen Energy, 1982, 7, 4, 341-353.
12. Furuhama S., Hydrogen engine systems for land vehicles, International Journal of Hydrogen Energy, 1989, 14, 12, 907-913.
13. Jorach R., Enderle C.and Decker R., Development of a low-NO_X truck hydrogen engine with high specific power output, International Journal of Hydrogen Energy, 1997, 22, 4, 423-427.
14. Homan H.S., DeBoer P.C.T.and McLean W.J., The effect of fuel injection on NOx emissions and undesirable combustion for hydrogen - fuelled piston engines, International Journal of Hydrogen Energy, 1983, 8, 2, 131-146.
15. Mathur H.B.and Das L.M., Performance characteristics of a hydrogen fuelled SI engine using timed manifold injection, International Journal of Hydrogen Energy, 1991, 16, 2, 115-127.
16. Wong J., Compression ignition of hydrogen in a direct injection diesel engine modified to operate as a low-heat-rejection engine, International Journal of Hydrogen Energy, 1990, 15, 7, 507-514.

17. Hedrick J.and Winsor R., Advanced hydrogen utilisation technology demonstration, NREL, 1994, Technical Paper No. DE9401181.
18. Yi H.S., Lee S.J.and Kim E.S., Performance evaluation and emission characteristics of in-cylinder injection type hydrogen fuelled engine, International Journal of Hydrogen Energy, 1996, 21, 7, 617-624.
19. Glasson N.D.and Green R.K., Performance of a spark- ignition engine fuelled with hydrogen using a high pressure injector, International Journal of Hydrogen Energy, 1994, 19, 11, 917-923.
20. Varde K.S.and Frame G.A., Hydrogen aspiration in a direct injection type diesel engine-its effects on smoke and other engine performance parameters, International Journal of Hydrogen Energy, 1983, 8, 7, 549-555.
21. Saravanan N., Nagarajan G., Dhanasekaran C.and Kalaiselvan K.M., Experimental investigation of hydrogen port fuel injection in DI diesel engine, International Journal of Hydrogen Energy, 2007, 32, 16, 4071-4080.
22. AntunesJ.M.G.,MikalsenR. and Roskilly A.P., An experimental study of a direct injection compression ignition hydrogen engine,International Journal of Hydrogen Energy, 2009, 34, 15, 6516-6522.

*****