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Effect of Fuel Type and Engine Parameters on Performance and Emission Characteristics of a Spark Ignited Direct Injection Engine: A Review

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Abstract: *The stricter worldwide emission legislation and growing demand of efficient vehicles having lower specific fuel consumption with greatly improved power requires significant effort. An important factor to determine the Emission and Performance factor of an Engine is the Fuel Injection System. This has led to the improvement of this technology from the carburetor to the port Injection and finally to the direct injection engine. The Direct Injection Spark Ignition Engine has been tested with variety of fuels such as bio-diesel, blends of ethanol and gasoline, LPG, CNG etc. The study is based on the comparison of emissions such as NOx and CO as well as the performance parameters of the engine such as BSFC. The reviewer will also get information about the change in the engine performance and emission characteristics when important engine parameters. are varied. Recent research and development has shown that SI direct injection engines, coupled with optimal conditions can provide much better performance and emission characteristics than the conventional SI engines. This paper provides a comprehensive review of the technical optimality of a direct injection SI engine by suggesting optimum fuel type and engine parameters.*

Keywords: *Direct Injection Spark Ignited Engine; Spark-Ignition Engine; Engine emissions; performance.*

1. INTRODUCTION

The automotive industry is moving towards achieving higher fuel economy by developing engines having improved brake specific fuel consumption which can also comply with stringent emission standards.

The BSFC in a direct injection, compression ignition is higher than that of a port fuel injected spark ignited engine due to higher compression ratio and low throttle losses. The diesel engine on the other hand has a higher noise level, diminished start ability, low speed range, higher NOx and particulate emissions as compared to a Spark Ignited(SI) engine .

The most recent technologies combines the best features of both the SI and CI engine. The purpose of this design is to use the power of the gasoline engine combined with the efficient of the diesel engine. This can be achieved by using a direct- injection, 4-stroke SI engine that does throttle the inlet mixture. The fuel is injected in the same method as that seen in a CI engine but the mixture is ignited using a spark plug. These engines are called Direct Injection, stratified charge engine or a gasoline direct injection engine.

These engine have a multi fuel capacity and an enhanced tolerance for lower octane fuels. Initial work on the SIDI engine focused on this multi fuel capability of the engine[1,2].

The power output is changed by varying the amount of fuel injected in the cylinder. Since throttling is minimized, negative work is decreased. Since it uses a spark plug and a fuel injector, ultra lean operation may be achieved, hence increasing the BSFC. Furthermore higher volumetric efficiency can be achieved as compared to intake port injection which leads to increasing compression ratio and hence overall efficiency [3,4,5].

This paper reviews the effect of different fuels and engine parameters on the performance and emission characteristics of a SIDI engine.

2. EFFECT OF DIFFERENT TYPES OF FUELS

2.1 COMPRESSED NATURAL GAS

CNG has been used and investigated as a fuel in SI engine extensively mainly due to the fact that methane is one of the main components of CNG (90%). Secondly, CNG as compared to fresh air is not as dense thus during leakage the inherent ability of CNG to evaporate to the top of the air is an advantage. Third, because CNG is gaseous in nature the pre evaporation that is required for Gasoline is avoided. Hence problems related to Cold Staring in low temperature and high emission at rich air fuel mixture are avoided.

High octane number of CNG, approximately 120-130, allows higher compression ratio while preventing knocking. A complete combustion of CNG is seen due to its lower carbon and hydrogen ratio [7-12].

The results of various experiments dictated that CNG produced low performance compared to liquid fuel. When compared to liquid fuel the power of CNG was reduced by 18.5 %. The lower Volumetric efficiency of CNG was hailed as the reason for decreased power. The in cylinder pressure when running the engine with CNG was reduced by 25% at highest engine speed. The lower density of CNG also reduces the heat transfer rate. This helps in increasing the life of the engine.[13]

For CO and HC concentrations, Using CNG was beneficial at large throttle position while gasoline had better results at lower throttle position.[6]

2.2 LIQUEFIED PETROLEUM GAS

LPG is widely used as an alternative fuel for a variety of reasons. It has efficient combustion characteristics while maintaining low emissions Further more LPG can be liquefied at low pressures and low atmospheric temperatures, making it a favorable fuel. Finally Its higher octane number, auto ignition temperature, wider flammability limits and greater flame velocity make LPG a better spark-ignition engine fuel than gasoline [14-15]

LPG-DI, as compared to GDI, shows a decrease of 48%,99% and 74% in THC, NOx and PM concentrations for the FTP-75 while the NEDC results show a further decrease in these emission. The values in latter case are 55%, 99% and 92%. Carbon dioxide emission also decrease by 46% due to the low carbon fraction and low heating value of LPG fuel. The superior vaporization characteristics of LPG fuel produced less wall film and a more homogeneous mixture than the gasoline fuel, which resulted in a relatively lower accumulation mode particle concentration [16].

2.3 ETHANOL BLEND WITH GASOLINE

Ethanol (C2H5OH) obtained from renewable energy sources is an ecological fuel. It is colorless, transparent, volatile, neutral, oxygenated liquid hydrocarbon, flammable with a pungent odor and a sharp burning taste [17]. Ethanol is produced from various feed stocks such as sugar cane, sugarbeet, sorghum, grain, switch grass, sweet potatoes, cassava, sunflower, barley, fruit, molasses, stover, grain, wheat, corn, straw, cotton, and other biomass. Generally, ethanol or bioethanol is more reactive than hydro- carbon fuels, such as gasoline. It contains both hydroxyl radicals (polar fraction) and carbon chain (non-polar fraction); allowing it to easily dissolve in both non-polar (e.g. gasoline) and polar(e.g. water)substances [18]. Because of the biodegradable characteristics and regenerative properties of ethanol, it is widely used as an alternative fuel.

Due to the high octane number of Ethanol blended fuels, it can utilize a higher CR in SI engine. Thus increasing a higher percentage ethanol blend, a higher CR can be applied without increasing NOx emissions. Complete combustion for rich mixtures at high engine speeds and loads is achieved due to high flame speed of ethanol but NOx emissions subsequently increases when compared to gasoline engines. No significant change or a small decrease in NOx emission is observed at low engine load for ethanol. Pure ethanol fuel is not a valid source for engine cold-start. To easily start an engine in cold condition with lower HC, CO and NOx emission usage of ethanol blended gasoline fuel is used instead of gasoline. Hydrous ethanol blends can reduce NOx emissions the maximum when compared with gasoline and anhydrous ethanol blends due to the fact that the water content absorbs heat and lowers the peak in-cylinder temperature[19].

2.4 HYDROGEN

Hydrogen (H_2) is an attractive alternative energy carrier. It is being widely investigated as a fuel for passenger car. Hydrogen has an inherent capability of not producing air pollutants or greenhouse gases when used in fuel cells and subsequently it only produces NOx emission when burned in ICEs [20,21].

Hydrogen when compared to gasoline as a lower volumetric efficiency As liquid fuels have latent heat of vaporization, they produce a cooling effect on intake charge during vaporization. Hence, there is an increase in intake mixture density and in volumetric efficiency. Gaseous fuels on the other hand are vapor in ambient temperature have no such cooling effect. NOx formation takes place at high temperatures and hence the increase of BSNOx is caused by higher combustion temperature of hydrogen when compared to gasoline

When hydrogen is used as the fuel an average reduction in volumetric efficiency by 28% is seen. Also the power produced by hydrogen is less than that of gasoline by 19% . Since Hydrogen has a higher octane number than gasoline, engine compression ratio could be higher and therefore engine performance could be improved.

CO concentration in exhaust gases depends on air/fuel ratio and the Carbon to Hydrogen ratio of fuel. A rich mixture causes more CO in exhaust gases. The more the operating condition is close to the stoichiometric point, the less amount of CO is produced. It can be seen that no CO is produced in hydrogen combustion, as there is no atom of carbon in hydrogen's structure, but due to a lubricant oil leakage flow from outside to inside of the cylinder, a CO formation is anticipated when engine is operating with this fuel[22,23].

BSFC is a function of spark timing, heating value of fuel, A/F ratio, speed and engine load. As the engine speed rises the BSFC rises as well due to more working cycles in a specific period of time at large engine speeds. Due to high heating value and high stoichiometric air/fuel ratio, the engine has the lowest BSFC when fueled by hydrogen.

3. EFFECT OF ENGINE PARAMETERS ON EMISSION AND PERFORMANCE CHARACTERISTICS

3.1 PISTON HEAD GEOMETRY

A comparison of brake specific fuel consumption, HC emissions, CO_2 emissions and NOx emissions is studied when the piston heads having no cavity with piston heads having cylindrical, conical and spherical cavities are compared. It is observed that the BSFC decreased with piston cavities, however CO_2 and NO_x emissions increased as expected. Ranking the piston cavities according to various performance parameters, the following qualitative results were obtained (Table 1).

From the above data, we can see that there are no clear-cut winners. The spherical and conical profiles prove to be the best in terms of bsfc, but they lose out in terms of emissions. However, we attain our objective of experimentally verifying that different pistons head geometries significantly affect the bsfc.[24]

TABLE 1: Effect of piston geometry on BSFC and Emissions[24]

Rank	Bsfc	Emissions			
		CO	HC	CO2	NOX
1	Spherical	Conical	Conical	No cavity	No cavity
2	Conical	Spherical	Spherical	Cylindrical	Cylindrical
3	Cylindrical	Cylindrical	Cylindrical	Spherical	Conical
4	No Cavity	No Cavity	No Cavity	Conical	Spherical

3.2 INJECTION STRATEGY

Double injection strategy increased the turbulent intensity inside the cylinder without losing mixture homogeneity. Using a first injection at the middle of the intake stroke and a second injection early in the compression stroke for improved combustion and mixture characteristics. The effects of increased turbulent intensity with affordable decreases in the level of mixture homogeneity were investigated.

In the case of the improved double injection, the mixture homogeneity was slightly decreased; however, the vapor fuel fraction in the cylinder was higher than that for the single injection case with early injection timing. The equivalence ratio at spark plug gap of the double injection case was higher than that of the single injection case. Due to the retarded injection timing of the double injection case, the counterclockwise tumble motion which dominates the in-cylinder mixture flow for the compression stroke was strengthened.

From the combustion analysis, an increased flame propagation speed was observed for the double injection case. However, an overly-rich zone was formed at the intake port side. Although faster combustion is expected due to increased turbulent intensity from using a double injection strategy, higher emissions are expected due to the locally overly-rich zone.

4. CONCLUSIONS

It was seen from the review paper that the possibility of using various fuel still exits when using direct injection in a spark ignited engine. CNG, LPG, Ethanol blends and Hydrogen were fuels that were studied in this review paper. In all cases an improvement of emissions and performance characteristics was seen.

In engine parameters two cases were studied. One was changing the piston head geometry and the other was the injection strategy. In the first case we studied four different techniques to vary the piston head geometry and a comparison study was undertaken between them. It was shown that a best option is not present. The options either improved emission parameters or the performance characteristics. Hence depending on the need of the situation a different geometry can be used.

The next part of the paper studied about the injection strategy. We have reviewed the double injection strategy, which when compared with the single injection strategy showed extensive improvements.

REFERENCES

[1] Mitchell, E.; Alperstein, M.; Cobb, J.M.; Faist, C.H. A stratified charge multifuel military engine—a progress report. SAE Technical Paper No. 720051, 1972.

[2] Lewis, J.M. UPS multifuel stratified charge engine development program—field test. SAE Technical Paper, 1986, No. 860067.

[3] Zhao, F.; Lai, M.C.; Harrington, D.L. Automotive spark-ignited direct-injection gasoline engines. Progress in Energy and Combustion Science 25, 1999, 437–562

[4] Farrell, J.; Weissman, W.; Johnston, R.; Nishimura, J. et al. Fuel Effects on SIDI Efficiency and Emissions. SAE Technical Paper 2003-01-3186, 2003.

[5] Spicher, U.; Kölmel, A.; Kubach, H.; Töpfer, G. Combustion in Spark Ignition Engines with Direct Injection. SAE Technical Paper 2000-01-0649, 2000.

[6] Putrasari, Y.; Praptijanto, A.; Nur, A.; Wahono, B.; Santoso, W. Evaluation of Performance and Emission of SI Engine Fuelled with CNG at Low and High Load Condition. Energy Procedia, 2015, Volume 68, Pages 147-156.

[7] Rante, P.; Sodre, J.R. Evaluating carbon emissions reduction by use of natural gas as engine fuel. Journal of Natural Gas Science and Engineering, 2009, vol. 1, pp. 216–220.

[8] Ben, L. et al., Quantitative imaging of equivalence ratios in a natural gas SI. Exp Fluids, 2007, vol. 43, pp. 77–88.

[9] Diéguez, P.M. et al. Experimental study of the performance and emission characteristics of an adapted commercial four-cylinder spark ignition engine running on hydrogen–methane mixtures. Applied Energy, 2014, vol. 113, pp. 1068–1076..

[10] Liu, Y. et al. An experimental study on the effects of impingement-walls on the spray and combustion characteristics of SIDI CNG. Journal of Mechanical Science and Technology, 2012, vol. 26, pp. 2239-2246.

[11] Xu, J. et al. Experimental study of a single-cylinder engine fueled with natural gas–hydrogen mixtures. International journal of hydrogen energy, 2010, vol. 35, pp. 2909-2914.

[12] Kakaee, A.H. et al. The influence of fuel composition on the combustion and emission characteristics of natural gas fueled engines. Renewable and Sustainable Energy Reviews, 2014, vol. 38, pp. 64-78.

[13] Tahira, M.M. et al. Performance analysis of a spark ignition engine using compressed natural gas (CNG) as fuel.

[14] Hansub, S.; Kangyoon, L.; Namhoon, C.; Myoungho, S. A study on the injection characteristics of a liquid-phase liquefied petroleum gas injector for air–fuel ratio control. PI Mech Eng DJ Aut, 2005, 219:1037–46.

[15] Loganathan, M.; Ramesh, A. Study on manifold injection of LPG in two stroke SI engine. J Energ Inst 2007, 80:3168–74.

[16] Myung, C.; Choi, K.; Kim, J.; Lim, Y.; Lee, J.; Park, S. Comparative study of regulated and unregulated toxic emissions characteristics from a spark ignition direct injection light-duty vehicle fueled with gasoline and liquid phase LPG (liquefied petroleum gas). Energy, 2012, Volume 44, Issue 1, Pages 189-196.

[17] Ganguly, A.; Chatterjee, P.K.; Dey, A. Studies on ethanol production from water hyacinth—A review. Renewable and Sustainable Energy Reviews, 2012, 16(1):966–72.

[18] Costa, R.C.; Sodré, J.R. Hydrous ethanol vs. gasoline–ethanol blend: engine performance andemissions.Fuel, 2010, 89(2):287–93.

[19] Masum, B.M.; Masjuki, H.H.; Kalam, M.A.; Rizwanul, I.M. et al. Effect of ethanol–gasoline blend on NOx emission in SI engine. Renewable and Sustainable Energy Reviews, Volume 24, 2013, Pages 209-222.

[20] Verhelst, S.; Sierens, R.; Verstraeten, S. Development of a simulation code for hydrogen fuelled SI engines. 2006, ASME paper, ICES2006-1317.

[21] Schoenung, M. Hydrogen vehicle fueling alternatives: an analysis developed for the international energy agency. SAE World Congress, 2001-01-2528, 2001.

[22] Heywood, J.B. Internal combustion engines fundamentals. New York: McGraw-Hill, 1988.

[23] Ferguson, C.R.; Kirkpatrick, A.T. Internal combustion engines: applied thermo science. 2nd ed. John Wiley and Sons, Inc., 2001.

[24] Mani, K.; Jain, V. Development of mechanical gasoline direct injection (gdi) engines for 4 stroke two wheelers.

[25] Kim, T.; Song, J.; Park, S. Effects of turbulence enhancement on combustion process using a double injection strategy in direct-injection spark-ignition (DISI) gasoline engines. International Journal of Heat and Fluid Flow, Volume 56, 2015, Pages 124-136.