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A Review on LPG as a Viable Fuel for SI Engines

Sanjeev Kumar V
M. Tech in IC Engines
ARAI Academy
Pune, India

Vikas Kumar
M. Tech in IC Engines
ARAI Academy
Pune, India

Aniruddh Kaulgi
M. Tech in IC Engines
ARAI Academy
Pune, India

Abstract – **In the recent years, the increase in toxic pollutants from automobiles, industries etc. due to burning of fossil fuels has shown hazardous impact on the environment like ozone depletion, acid rain etc. Humans also fall under this impact by breathing polluted air. Short term and long term effects on environment as well as on humans has put researchers and other experts in quest of alternate fuel. Among all fuels, Hydrogen and LPG fuel has shown promising results as better alternatives for sustainability. Combining the advantages of LPG with advantages of SI engine operation, an improved parameter can be observed. This paper puts front the research efforts carried on LPG fuel especially on SI engines. This review paper focuses primarily on the effects carried out in modifying LPG fuel along with the emission parameters, combustion characteristics, engine performance etc. on SI engine. The factors that hinders LPG as a viable fuel has also been discussed here. Apart from its good emission characteristics, it has also emerged out as an advantage in simplicity on production. It is concluded that advancements are still needed in making LPG as a viable alternate fuel through further research.**

Keywords – LPG (Liquefied Petroleum Gas), Blending,

1. INTRODUCTION

The global anthropogenic emissions from transportation amount to 21% of CO_2, 37% of NOx, 19% of VOC, 18% of CO and 14% of black carbon and all these are result of incomplete combustion of fossil fuel in vehicle etc.

LPG or Liquefied Petroleum gas referred to as propane or butane or a mixture of propane and butane. It is being manufactured from refining process of crude oil or natural gas as they emerge from ground. LPG also contains propylene and butylene in small concentration. A powerful odorant called ethanethiol is added in container that contains LPG to detect any leaks. It has higher octane rating of 105 to 112 compared to gasoline 91-97 which makes this fuel to use at higher compression ratio with reduced knocking characteristics. LPG burns will much lower carbon build up thus improving engine life. LPG can be liquefied at normal temperatures using a pressure of approximately (8.5 to 9.0) atmosphere. It is characterized by of being free of water and hydrogen sulphide and it is always under vapour pressure. LPG powered engines are well known for low emissions such as hydrocarbon (HC) emission reported as 40% lower, CO as 60% lower and CO2 as substantially reduced. Fuel consumption has been reduced in LPG compared to gasoline engine due to the high energy content of LPG. But power output can be seen slightly reduced due to poor volumetric efficiency of LPG fuel. However, by using Turbo charging or super charging over naturally aspirated engine can yield much better results. In a nutshell, LPG can become viable fuel with modifications in future.

2. REVIEW

A. Performance

Thirumal mamidi et al [1] used a single cylinder 4-stroke with a displacement of 256.66cc and CR of 4.67:1. The other specifications are forced air cooled with single overhead camshaft (SOHC). The objective behind this setup was to observe engine performance under different loads as well as its emission characteristics.

The mass of fuel consumption gradually increased w.r.t increase in BP (in kW). The maximum mass of fuel consumption recorded in LPG was 0.7523kg/hr @ 2.350kw and maximum mass of fuel consumption in petrol was 0.7787 kg/hr @2.350kW. This results shows that mass of fuel consumption increases in LPG fuel compared to gasoline fuel.

In Brake Specific Energy Consumption, LPG resulted with a minimum of 14.752MJ/ kw-hr @2.350kW whereas gasoline recorded 13.373MJ/kw-hr @2.350kw. This shows that gasoline recorded least values in BSEC values compared to LPG due to Gasoline's low calorific value (43MJ/Kg vs 46.1MJ/Kg).

In Brake thermal efficiency parameter, the value increases with respect to power. However, overall brake thermal efficiency increased when compression ratio was increased. But comparing gasoline with LPG, the gasoline showed better brake thermal efficiency when compared to that of LPG fuel.

Hakan Ozcan et al [2] works were based on LPG powered SI engine under variable stroke length and compression ratio. Considering engine performance, engine brake power increases with decreased bore to stroke (B/S) ratio. At a given speed, the volumetric efficiency increased with decreased B/S ratio, therefore more energy is converted to useful work. On the other hand, Brake specific fuel consumption (BSFC) also increased with decrease with B/S ratio but with unfavourable pollutants as exhaust gas temperature increased. Decrease in

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B/S ratio also resulted in poor mechanical efficiency because of the increased frictional losses. Though, B.P & volumetric efficiency were good, BSFC & η_{mech} needs improvement.

Syed YOUSUFUDDIN et al [3] also used single cylinder 4-stroke, air cooled engine. This engine used variable compression ratio SI engine which was fuelled with LPG at different compression ratios. This research motive was to show improvement in engine performance running on LPG fuel at various CR. It also focused on emission parameters such as CO and HC contents. The test rig enables the study of engine performance involving indicated power, brake power, thermal efficiency, volumetric efficiency, fuel consumption.

It is found that, as the brake power increases, there is considerable amount of increase in Brake thermal efficiency. On the other side, as the brake specific fuel consumption decreases as the load on the engine increases. LPG shows the increased specific fuel consumption trend than gasoline. Similarly, the volumetric efficiency with brake power at 2800 and 2500rpm at CR of 7:1 and 10:1 were taken. The result showed that LPG increased its volumetric efficiency with increase in compression ratio and speed. However, showed much ahead of LPG in terms of volumetric efficiency.

K. F. Mustafa et al [4] involved in finding the performance and emission characteristics of 60% propane and 40% butane composed LPG tested in a 183cc engine with compression ratio 6.3:1. A 5kw eddy current dynamometer and NDIR analyser was used for performance measurement and emission analysis respectively. In terms of engine performance aspect, it was observed that though LPG delivered good amount of Brake power, it was not consistent throughout its operation. Hence, LPG delivers its best only at a certain rpm bandwidth, in this case after 3000rpm, brake power started to decrease. It was observed that, addition of LPG does not yield any significant results. In fact, 5% LPG addition gave high brake power values when compared to 20% LPG addition. Hence, a better advanced ignition timing is required since LPG burns leaner than gasoline. In terms of BSFC, 10% and 20% LPG addition had similar and consistent declined values throughout for increasing rpms. Whereas, 5% LPG started at higher values of all close to gasoline value and slowly declined rpm gets increased and finally reached to values similar to 10% and 20% LPG addition. Thus, brake thermal efficiency would be higher for increasing operational speeds as the net heat release will get increased with increase in LPG blend. This may be due to the higher heating value of LPG when compared to gasoline. But, on the other hand, thermal efficiency is improved due to the fact that LPG has high H/C ratio when ensures that the engine gets enough oxygen for complete combustion of fuel. But high heating values also increases presence of NOx content which will be detailed below in emission parameters results.

B. Emission

Thirumal mamidi et al [5] used a single cylinder 4-stroke with a displacement of 256.66cc and CR of 4.67:1 and performed emission analysis. In emission analysis, LPG showed variation trend when operated at normal and high conditions. CO is produced generally when there is insufficient air in the combustion chamber. When the fuel does not burn completely it gets converted to CO. In the case of LPG, as the compression ratio increased, the speed as well as the CO content increases. In comparison with gasoline, LPG tends to produce low content of CO emissions in huge margin (0.11% vs 11.88%).

Similar trends are found for HC emissions. As increasing the CR, resulted in high HC emissions with increased BP. But overall HC emissions of LPG were less when compared to gasoline engine (230ppm vs 1829ppm).

CO_2 emissions performed substantially well for LPG. The level of CO_2 increased with increase in Brake power of the engine. However, overall CO_2 content of LPG were much lower than of gasoline engine (9.9% vs 18.8%).

NOx showed opposite effect for LPG. NOx increased with respect to increasing Brake Power. But, the overall NOx emission throughout the cycle favoured gasoline when compared to LPG. Gasoline recorded low NOx when compared to LPG. (986ppm vs 961ppm).

The overall observations can be concluded safely by saying LPG has advantages over gasoline in emission characteristics. However, still LPG fuel needs some research on its engine performance aspect to perform well to compete against gasoline engines. In case of using LPG engines, the burning rate of fuel is increased, and thus, the combustion rate decreased. The cylinder pressure and temperature were high for LPG when compared to gasoline. LPG is free of lead and has very low sulphur content than gasoline.

Syed YOUSUFUDDIN et al [6] used single cylinder 4-stroke, air cooled engine. This engine used variable compression ratio SI engine which was fuelled with LPG at different compression ratios. The same team conducted emission tests for various compression ratios at different loads. It is found that CO and HC emissions were much lower on engine using LPG fuel than gasoline. The paper concluded by mentioning that, various injection techniques should be used in the case of LPG for obtaining better performance result. Although the emission seems to perform well on LPG engines, it still lacks some areas in terms of volumetric efficiency. LPG specific designed engines can overcome these hurdles.

K. F. Mustafa et al [7] took 60% of propane, 40% of propane and observed that CO levels were quite low for LPG blends. From Fig (a), However, when $\lambda>1$, all LPG blends started increasing and became equal to that of CO values of gasoline.

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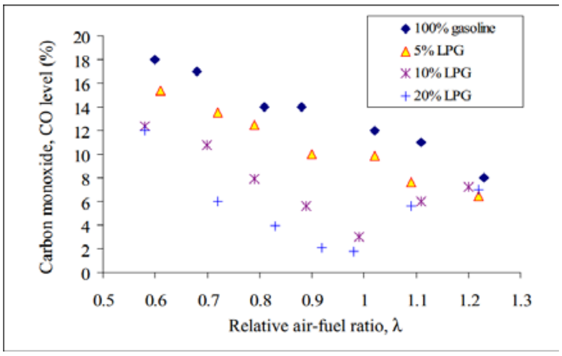

Fig (a)

Overall, 5% LPG showed some higher values than all LPG addition. 20% LPG addition had slightly less CO values than 10% LPG addition.

For CO_2, the values were fluctuating for all blends of LPG as per the fig (b)

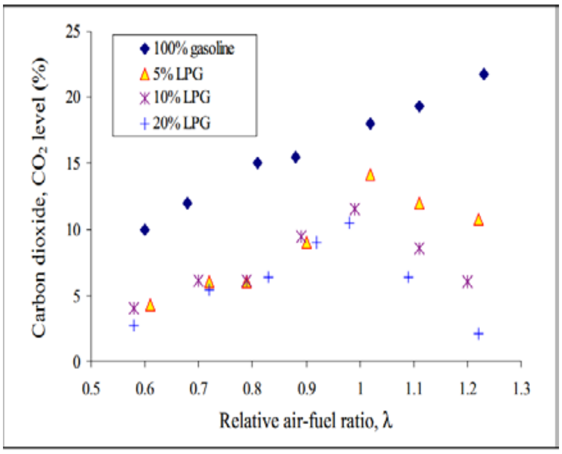

Fig (b)

But compared to gasoline, all LPG blends at all engine operated rpms were quite low. Overall, 20% LPG addition showed least CO_2 values of all. While the 5% addition showed high values among all LPG blends. For 10% addition, until λ=1, the results were similar with 20% addition but, λ>1, the values started deviating.

For NOx, from Fig (c), the dual fuel operated engine showed decreased content than engine with pure gasoline operated. This may be due to the fact that, intake charge temperature is reduced in case of LPG

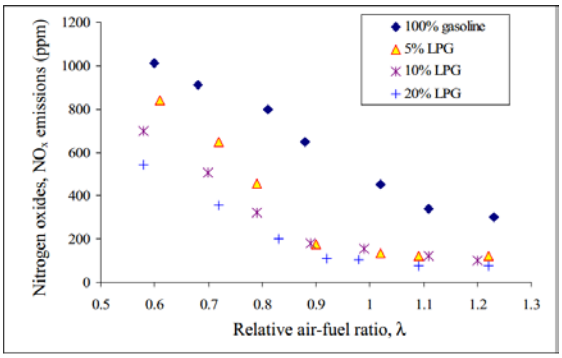

Fig (c)

dual mode operation. This, in turn reduces the overall operating temperatures that leads to NOx. In the graph, it can be seen that, all LPG blends performed adequately well throughout when compared to 100% gasoline.

In the case of unburned HC, LPG showed well ahead of pure gasoline values as per the graph attached in Fig (d),

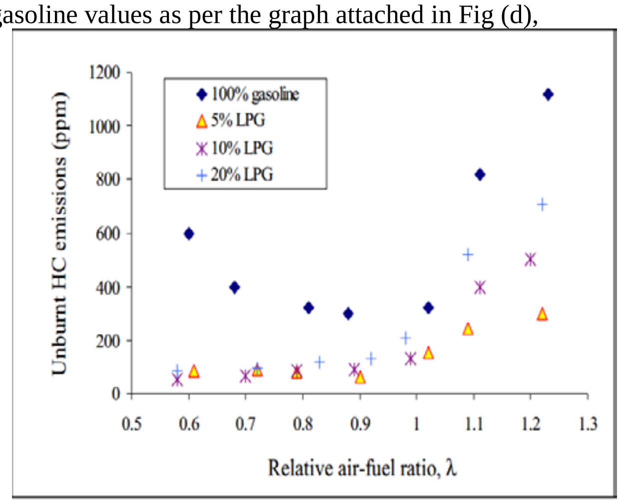

Fig (d)

Addition of LPG decreased HC emission content because of H/C ratio. Whereas, gasoline started increasing HC upon increased rpm due to less availability of oxygen for complete combustion.

The result of this experiment may be concluded that, LPG addition has positive effect on emission parameters whereas advanced ignition & optimization system is required for better operation of LPG in SI engines.

C. Special cases

Sulaiman et al [8] took some slight different approach in determining effectiveness of LPG. This experiment registered into three modes. First mode was engine with Unleaded Petrol (ULP), second mode was engine with LPG vaporizer (LPG V mode), and third one was engine with LPG capsule valve (LPG B mode). Test engine were analysed for wide-open throttle (WOT) at wide range of loads from 0% to 100%. Results from energy price perspective for three modes have been shown and discussed here. Currency used here is RM (Malaysian).

To determine the effective price of the fuel, data from SFC at 2600rpm were taken. All these data and price were recorded at the month of January 2011.

Fuel price/ litre for ULP RON 95 and LPG RM 1.90 & RM 1.06 respectively. To enable comparison with SFC, it was converted into RM/kg. Then the values became RM 2.53(ULP) and RM 1.90(LPG). Energy graph given below,

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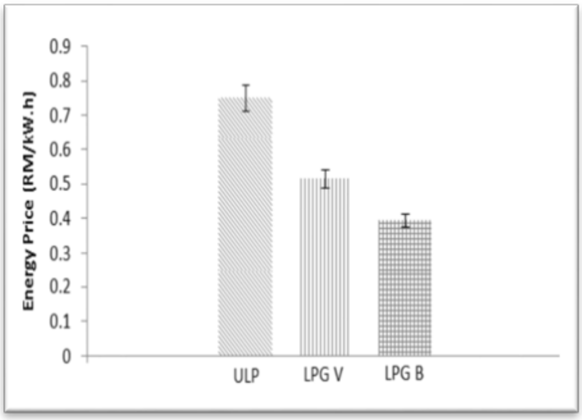

Fig (e)

From the fig (e), ULP recorded the high energy price than LPG V and LPG B by 31.38% and 47.40% respectively. Engine fuelled by LPG seems to be more efficient than ULP. Engine using ULP uses more fuel to generate same energy compared to LPG because of the energy content of LPG is much higher than that of gasoline. SFC also impacts proportionally in energy price.

Vighnesha Nayak et al [9] involved in finding the combustion characteristics of SI engine by using LPG in a dual fuel mode. Gasoline along with LPG is used as dual fuel in ratios 25%, 50%, 75% and 100% at various rpm conditions. This team handled based on Cycle by Cycle (CBC) variation analysis on SI engine. It is found that CBC occurs more frequently with lean fuelling and EGR, resulting in large misfires, thus resulting in poor output. CBC variation known to limit the operating conditions. Thus, CBC elimination will yield 10% increased output for the same fuel consumption. CBC variation not only hinders engine performance but also increases emission contents which is a big concern for current trend. This variation can be easily traced by measuring cylinder pressure and its variation of 30% from cycle to cycle. Historically, it is the cylinder pressure that has taken into account. Thus, pressure related parameters are used to measure the fluctuation intensity.

The experiment carried out on a four cylinder 4-s engine Maruti Suzuki Engine with all adequate data acquisition system like P-θ, P-V diagrams as well as the interfacing airflow, fuel flow, temperature & load measurements etc. Following are the results obtained, IMEP and COV, P-θ, Net heat release, Mean Gas temperature. LPG is injected through solenoid injectors with ECU's process.

IMEP is calculated generally by indicated power divided by swept volume. The team used some special software to compute the IMEP where values were taken from 100 consecutive cycles by knowing the engine configuration. This software calculated mean IMEP also the maximum IMEP. In order to find the Coefficient Of cycle Variation (or COV), mean and maximum IMEP values of 100 cycles were taken and a formula were computed by this group,

$$COV_{IMEP} = \frac{\sigma IMEP}{\mu IMEP}$$

The standard deviation is given by

$$\sigma = \sqrt{\frac{\sum_1^n (IMEP_i - \mu_{IMEP})^2}{(n-1)}}$$

Where n= Number of combustion cycles.

From the observations, effect of COV affected the engine performance in two ways. Firstly, since optimum spark timing were designed for average cycle, any changes in cycle variation will result in either advanced or retard timing, hence losses in power and efficiency. Secondly, extreme COVs put limit on engine operation. Hence, the COV variations must be strictly controlled.

P-θ curve analysis for gasoline at full load and similar setup with LPG in all ratios were performed. It is found that, as the rpm and speed gets increased, the LPG started to show increased output in peak pressures at all ratios compared to similarly operated gasoline fuel. This indicates that LPG fuel will take an advantage on better combustion characteristics than gasoline. On the other side, at lower speeds, LPG does not show any noticeable peak pressure difference. Cycle to cycle variation for IMEP curve was less than P-θ curve analysis. Overall, the gasoline showed higher COV variations than that of LPG ratios. Heat release rate and Mean gas temperature of LPG increased with increase in LPG content than gasoline.
Thus, this paper clearly signifies how cyclic changes like P-θ, IMEP etc. will affect the engine performance overall.

Barıs Erkus et al [10] is the paper that did comparative study analysis of specially designed gas phase operated liquefied petroleum injection system on a carburettor SI engine were performed. The objective of the study was to determine the effectiveness of the LPG on specially designed injection system and compare it with the existing carburettor system results. The result came out with increased output, lower fuel consumption and lower exhaust contents for their LPG injection system.

The results for 25% throttle discussed here and it is seen that LPG injection system shown promising results. In the terms of Brake power, LPG injection scored higher in number than the carburetion system. The average values of Torque, volumetric efficiency and Brake power were higher than that of carburetion system. LPG injection system were 49.81% and 67.51% higher B.P than that of gasoline and LPG carburetion respectively. In volumetric efficiency, it was 39.67% and 61.46% higher than gasoline and LPG carburetion respectively. Since there is an increase in Torque throughout the range, power output also was higher throughout its range. For all increasing rpms, power and volumetric efficiency resulted better.

The results for 50% throttle discussed here. Below 3500rpm the power output was same for LPG injection and carburetion systems. But after 3500rpm, the LPG injection values scored ahead of all carburetion systems. As with the 25% throttle, 50% throttle also shows that Brake power was higher than carburetion throughout its range. The average values of torque for LPG injection system were higher. The average volumetric efficiency 7.51% and 18.96% higher in comparing

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with the gasoline & LPG carburetion system respectively. In terms of power, 10.83% and 16.43% higher when compared to gasoline and LPG carburetion system respectively. BSFC were lower in LPG injection especially in reviving at lower rpms. CO and HC emissions were also quite acceptable for concerns. Only NOx were higher due to peak pressure and temperature of LPG fuel's combustion properties.

Overall, this LPG proto injection system achieved good results than conventional gasoline and LPG carburetion. Positive effect on engine output parameters like higher volumetric efficiency, brake power was quite significant. But all these advantages held up well for 25% throttle whereas the 50% throttle advantages were subtle. On the other side, lower emissions proved that this proto is a one of viable options for SI.

Hakan O¨ zcan et al [11] involves in different approach by injecting water into LPG fuel operated SI engine. This experiment involves in finding the right water to fuel ratio by mass and analysing the relative output parameters. The experiment carried out on a four cylinder, 4-stroke SI engine. All data were taken at constant throttle position but at various speed. Results for thermal balance of LPG fuel and water injection has been discussed here. A good thermally balanced engine should possess low heat rejection for water cooling, exhaust loss and unaccounted losses with much useful work done inside engine. It was observed that, ratio of increase in water injection content, the greater is the brake power and useful work done. This is because, overall heat loss to water cooling system might have reduced and in turn reduces the intake mixture temperature which then performs better than normally operated SI engine fuel.
Comparing with pure LPG reaction, water injected engine performed quite well in average heat loss to the cooling system. This is significant because more the heat loss more the power loss and less efficiency obtained. For addition of 0.5 water to fuel mass ratio, there was a 13.5% heat loss to cooling system where as 15% heat losses occurred to cooling system in case of pure LPG mode operation. Even exhaust gas temperature was 23% whereas 26% for pure LPG mode. However, at higher rpms the engine has less time for complete combustion and suffers from heat transfer loss, at lower rpms due to lack of turbulence, the heat loss occurs. This puts to a conclusion that, though heat losses were reduced, optimum water to fuel mass injection ratio needs to be precisely controlled.

M. Loganathan et al [12] involved in quite different approach compare to other works. This experiment was based on study on manifold injection of LPG in 2 stroke SI engines. The experiment carried out on a 145cc two stroke with specially designed electronic circuit for optimized air fuel ratio control. The entire results were taken on 3000rev/min with various throttle positions. Both gasoline and LPG were injected at different pulse width. For normal throttle, 0.28Mpa for gasoline and 0.15Mpa for LPG was maintained. At low throttle (10%), both gasoline and LPG injection pressure were maintained at 0.1Mpa.

The injection duration for corresponding peak pressure and ηB_{th} has been attached graphically here,

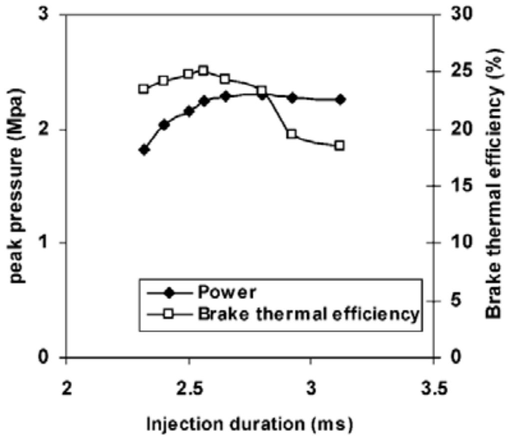

Fig (f)

It was found that 2.5ms [From Fig (f)] was the best timing to achieve the good efficiency. Richer mixture induces higher pulse width and hence the highest power output. Anything less than 2.5ms of pulse width led to increase in levels of HC. At rich mixtures, excess fuel along with short circuiting causes high HC emissions and at low operating conditions, due to lack of oxygen, CO emission occurs and it is clearly shown in the attached graph for HC & CO

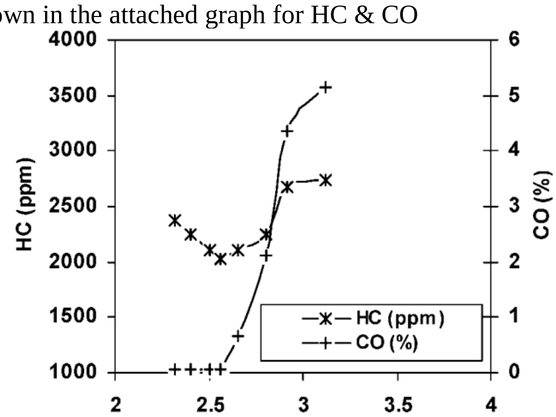

Fig (g)

From Fig (g), Even CO and HC performed well less than 2.5ms pulse width. The deviation happened after 2.5ms of pulse width.

For NO, the results are discussed based on the obtained graph,

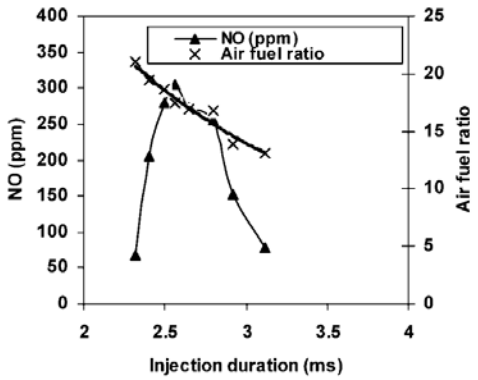

Fig (h)

It is evident that, from fig (h), NO is maximum where the A/F ratio of maximum thermal efficiency is present. The operation takes place on lean mixture. It was proved that there was significant difference in changing the injection timing i.e. pulse width difference.

Taking into exhaust gas temperature account, with both the fuels the engine can operate much leaner than stoichiometric. But, LPG showed higher exhaust temperature than gasoline. Primary reasons might be LPG injected as gas as well as highly operated engine temperatures due to LPG fuel.

From these different results obtained on two stroke engine, shows that effect of injection pulse width timing on engine performance and emission content is significant. Also, ηB_{th} were higher for LPG (25%) than gasoline (23%). Coefficient of variation of IMEP and peak pressure for LPG were much lower than gasoline which is a very advantageous factor. But, NOx and HC emissions has to controlled even better.

3. CONCLUSION

From all these references, some of the notable traces of evidence are increased brake thermal efficiency, decreased Coefficient of variation in terms of BMEP and peak pressure. In terms of engine output, overall Brake power was quite improved in LPG. But, the trend showed that only by increasing the engine speed the LPG takes significant step ahead of conventional engines. In a low operated engine, LPG inadequately performed due to its own characteristics. Being a gaseous fuel, right amount of injection and advanced ignition directly affects the engine output. Volumetric efficiency was less when compared to gasoline engine. Hence, twice the volume of fuel is required to achieve the power output similar to gasoline. Overall leaner operating advantages of LPG gives good combustion characteristics. In emission parameters, depending upon the operating conditions, HC and CO were much better than gasoline in SI engines. Due to LPG property, higher operating temperatures lead to NOx content but it can be reduced effectively. Overall, by accounting the advantages coupled along with disadvantages to be overcome, LPG is a viable option but still improvements needed to become a strong alternate fuel. Cost of fuel may reduce once socio-economics factors favours LPG fuel.

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