International Journal of Advance Research in Science and Engineering
Volume No. 14, Issue No. 10, October 2025
www.ijarse.com
IJARSE
ISSN 2319 - 8354

"A Review on the Impact of Compressed Natural Gas (CNG) on Engine Performance, Emissions, and Tribological Behavior in Spark-Ignition Engines"

Saurabh S. Baviskar[1], Dr. Mahesh V. Rawlani[2]

Research Scholar, Mechanical Engineering Department SSBT's COET, Bambhori, Jalgaon (saurabhsbvaiskar@gmail.com)

Associate Professor, Mechanical Engineering Department SSBT's COET, Bambhori, Jalgaon (meshusir@gmail.com)

ABSTRACT

The transportation sector predominantly relies on conventional fossil fuels such as gasoline and diesel, which are primarily sourced from gulf countries, making India heavily dependent on imports. However, rising fuel costs, limited fossil fuel reserves, and increasing environmental concerns have driven global efforts toward sustainable and renewable energy solutions. Alternative fuels, including ethanol, methanol, and biodiesel, liquefied petroleum gas (LPG), and compressed natural gas (CNG), have emerged as promising substitutes to address energy crises and pollution problems. Among these, CNG has gained significant attention due to its abundance, lower cost, and cleaner combustion characteristics. Comprising mainly methane, CNG is stored under high pressure (200–248 bar) and offers substantial reductions in vehicle operating costs—up to 70% compared to conventional fuels. Its high octane rating (120–130) allows for higher compression ratios without abnormal combustion, resulting in improved thermal efficiency and lower emissions of CO, HC, and CO_2. However, CNG engines typically exhibit higher NOx emissions and a slight reduction in power output and volumetric efficiency relative to gasoline engines. One of the critical factors affecting engine performance is mechanical friction losses, which are influenced by parameters such as cylinder dimensions, engine speed, compression ratio, oil viscosity, and piston ring configuration. The piston ring–cylinder liner assembly contributes significantly to these losses, making tribological analysis crucial. Proper selection of lubricating oil and additives plays a key role in minimizing friction and improving overall engine efficiency. This study focuses on understanding the impact of CNG as an alternative fuel on engine performance, emission characteristics, and tribological behavior to optimize efficiency and sustainability in spark-ignition engines.

Keywords:- *CNG, fuel, performance characteristics, spark ignition engine ,efficiency etc.*

I. INTRODUCTION

Most vehicles today operate using conventional fossil fuels such as petrol (gasoline) and diesel. These fuels are obtained through refining processes after crude oil extraction, and a major portion of this crude oil is sourced from Gulf nations. India relies heavily on imports from these regions to meet its energy demands. [1] With the rapid depletion of fossil fuel reserves, rising international fuel prices, and increasing concerns about emissions, the global energy landscape is shifting toward sustainable solutions. Greater attention is now being given to improving energy efficiency and adopting renewable alternatives to conventional fuels. [2]

Due to the growing energy crisis and severe environmental issues, extensive research and development activities have focused on reducing fuel consumption and minimizing the release of harmful combustion by-products. Various liquid and gaseous fuels—such as ethanol, methanol, biodiesel, liquefied petroleum gas (LPG), and compressed natural gas (CNG)—are being explored as potential substitutes. Over the past two to three decades, stricter emission norms and fuel economy regulations have led to significant modifications in petrol engines to reduce their environmental impact. [3]

Among these alternatives, CNG has emerged as a clean, economical, and abundant energy source that supports cost-effective and efficient transportation. This has encouraged deeper studies into optimizing fuel–air mixing and combustion characteristics to achieve better engine power, higher fuel efficiency, and reduced harmful emissions. The growing interest in CNG is driven by its lower operating costs and cleaner exhaust, making it an attractive option to address issues of rising fuel prices and air pollution. [4]

CNG is produced by compressing natural gas—primarily composed of methane (CH_4)—to less than one percent of its original volume at atmospheric pressure. It is stored in strong cylindrical or spherical containers under high pressure, typically between 200 and 248 bar (2,900–3,600 psi). Due to these storage conditions, empty CNG cylinders themselves weigh around 68–70 kg, and a typical cylinder can hold 8–10 kg of fuel. Using CNG can reduce vehicle running costs by approximately 70% compared to conventional fuels. [5]

One of the notable advantages of CNG is its high research octane number, which ranges from 120 to 130. This allows engines to operate at higher compression ratios without knocking or detonation. Natural gas also has a higher ignition temperature than petrol or diesel, contributing to cleaner combustion. As a result, CNG has gained widespread use in spark-ignition (SI) engines globally, significantly lowering greenhouse gas emissions compared to other fossil fuels. [3,5]

Numerous studies have confirmed that CNG operation leads to lower emissions of carbon monoxide (CO), hydrocarbons (HC), and carbon dioxide (CO_2) compared to petrol engines. However, nitrogen oxides (NO_x) tend to be slightly higher for CNG at equivalent power output. Additionally, SI engines running on CNG often show reduced power and volumetric efficiency relative to petrol. One of the major factors influencing this performance drop is mechanical friction loss, which includes rubbing friction, pumping losses, and throttling losses.

These friction losses depend on several physical and geometric engine parameters such as bore size, stroke-to-bore ratio, number of cylinders, compression ratio, engine speed, applied load, oil viscosity, piston ring configuration, and cooling system design. Among these, the piston ring–cylinder liner assembly contributes the largest share of friction losses. Consequently, understanding the tribological behavior of components like the piston skirt, rings, and liner has been a major focus of research for many years. Recent work has involved analytical modeling, small-scale experiments, and full engine testing to reduce these losses.

Furthermore, the choice of lubricating oil and additives is critical in controlling engine friction. Proper lubrication reduces wear and mechanical losses, leading to improved performance and fuel efficiency in engines operating on CNG. [6]

II. PREVIOUS RESEARCH WORK

As per review of Literature, research scholars experimentally investigated the performance of S.I. engine, emission characteristics, fuel economy for petrol as well as alternative fuel like LPG and CNG. But there is no focus to find the effect of CNG on frictional power losses for enhancement of the performance of S.I. engine. So, more efforts are required on the development and analysis of the S.I. engine fueled by CNG fuels for frictional loss minimization. By minimizing the wear and thereby increasing the power output and volumetric efficiency. Also to reducing the frictional loss, study of the effect of the lubricants are essential and future Scenario for CNG vehicles Cost saving, longer life of the engine and less emission will attract the public for making use of CNG run vehicles.

Pundlik N. Patil et al. 2019[1] says after conducting the experiment test the volumetric efficiency for LPG fuel is always less than petrol fuel; frictional losses are also more for LPG fuel. Fuel consumption is at higher side in case of LPG than petrol as well as thermal efficiencies is also high with petrol. Among all the above, LPG fuel is having as better antiknock characteristics, high octane rating and cost effective and less emission pollutant.

Bhupendra Singh Chauhan et al. 2011[2] says observed the properties of Petrol, LPG and CNG Fuel. Engine tests were done in steady state part load and full load conditions for CNG, LPG and gasoline fuels and concluded that thermal efficiency is the measure of the efficiency and completeness of combustion of the fuel. As the brake power increases, there is considerable amount of increase in brake thermal efficiency for all fuel. Brake thermal efficiency of CNG during whole range is high, gasoline is low and LPG lies between the two. Thermal efficiency increases in CNG fuelled engine due to higher CNG calorific value. This is due to reduction in short-circuiting losses and increase in air-fuel ratio.

Table 1 Physico-chemical properties of fuels

Properties	Petrol	LPG	CNG
Chemical composition	C4toC10	C3toC4	CH4
Specific density at15^0 C(kg/litre)	0.73	0.54	0.14
Boiling point at 1 bar (^{0} C)	25 to 110	-50 to 0	-162
Lower heating value (MJ/kg)	43.5	46.1	47.7
Ignition temperature in air (^{0} C)	220	400	540
Lower ignition limit (vol % gas)	0.6	1.5	5
Upper ignition limit (vol % gas)	8	15	15
Stoichiometric air/fuel ratio (kg/kg gas)	14.8	15.5	17.2
Fuel octane rating RON	95	105	120
Fuel octane at 25^0 C(bar)	82	97	120

Pundlik N Patil et al. 2015[3] have mention that various consideration like performance variable, friction behaviour and emission characteristics of S.I engine that the power output and volumetric efficiency are decreasing with LPG but the brake thermal efficiency was found to be increased using LPG. The emission characteristics are also improved. Approximately 17 to 25% of fuel energy is wasted for maximum utilization in the form of frictional losses as direct losses like piston rings, main bearing, and cam shaft bearing etc. using

LPG fuel in S.I. Engine. These losses are excess than S.I. Engine fuel as petrol. So it very important to reduce frictional losses using both types of fuels and overcome wears of various parts and by applying proper lubrication optimum utilization of the fuel energy, which is otherwise going to be wasted must be utilized in such a way that it should not affect the engine performance adversely. Also the power output and volumetric efficiency of engine would be improved for LGP as a S.I. engine fuel.

Md.Sourove Akther Momin et al. 2016[4] said that the emission and performance, it's concluded that CNG represents a good fuel alternative for gasoline and therefore must be taken into consideration in the future for transport purpose. Apart from the fuel storage and delivery mechanism, CNG engine similar to LPG engines, and deliver similar performance and good in combustion characteristics than LPG vehicles.

Pravin T. Nitnaware et al. 2019[5] says objective of this works on the effect of port fuel injection pressure of CNG in 3-cylinder SI Engine at Wide Open throttle position using sequential port fuel injection system. All trials are performed on 4-stroke, 796 cc MPFI S.I engine at injection pressure of 2.0, 2.2, 2.4, 2.6, 2.8 bar for constant speed of 2500, 3000, 3500, 4000 & 4500 rpm.

Christina Ingo et al. 2024[6] mention that the experimental study was executed to investigate the performance of a SI-engine fueled with hydrogen-natural gas mixtures. The methane number and Wobbe index were calculated for each gas composition and compared to the requirements set by Euromot, which is a MN higher than 70.0 and a Wobbe index between 49.0 and 52.7 MJ/m3.

Mindaugas Melaika et al.2021[7] study found that the CNG fuel achieved a higher engine efficiency and lower indicated specific fuel consumption with the PFI and DI systems at most tested engine points due to the higher energy content of natural gas. The highest (8% to 10%) improvement in the engine efficiency compared to GDI was achieved with DI-CNG at 6 bar IMEP load and 2000–2500 rpm engine speed. This was due to an enhanced combustion process by the directly injected gas and higher turbulence in the cylinder.

Muhammad Imran Khan et al. 2015[8] study to found that Rising concerns about the harmful effects of emissions of diesel and gasoline have made CNG a very promising alternative fuel for the road transportation. The NGV sector has shown tremendous growth over the last 15 year in most of the gas producing countries to offer a product which has behind it a tried and tested technology which guarantees the environment protection, is inexpensive and affordable.

B.L. Salvi et al. 2013[9] says that the alternative fuels has been vitally important for quite some time. A variety of methods and technologies are currently available for the production of alternative fuels, which can be classified in different ways. Among the various technologies esterification and gas-to-liquid are the most useful. Biodiesel fuels are primarily the methyl/ethyl esters of fatty acids derived from a variety of vegetable oils and animal fats.

Zhe Zhao et al. 2022[10] study found that analyzes the impact of different CDIr and DIT on the combustion and emission characteristics of compressed natural gas-ethanol engine. The control group in this paper is set as 100% ethanol port injection (EPI), and the black dotted line is used to indicate the situation of CDIr = 0.

Akari San Win et al. 2021[11] study that in experimental investigations carried out on a single cylinder, four stroke air cooled SI engine to compare the performance results of this engine with the fuels of petrol and CNG. It can be concluded that the brake mean effective pressures increase as the loads increase, the break specific fuel consumptions decrease with the loads increase, and the thermal efficiency increase with the load increasing for the fuel using of petrol or CNG.

Musthafah Mohd. Tahir et al. 2015[12] said to found that in experiment study, compressed natural gas (CNG) produced low performance compared to liquid fuel. The power of CNG when compared to liquid fuel is reduced to about 18.5%. The main reason for the lack of power due to using CNG is because of the volumetric efficiency. CNG's volumetric efficiency is lower than liquid fuel, due to its physical properties which is gas. When the experiment result of pressure inside the cylinder is compared, the CNG have lower pressure than the liquid fuel at ignition stage. The pressure inside cylinder for liquid fuel at highest engine speed (4500 rpm) is nearly40 bar. However, for CNG at the same engine speed, the pressure inside engine cylinder is only 32 bar.

Akari San 2019[13] mention in study that on Comparative Analysis of a SI Engine using Petrol and CNG Fuel with and without Supercharger.

Chetan S. Mistry 2005[14] his case study on Comparative Assessment on performance of Multi cylinder Engine Using CNG, LPG and Petrol as a fuel and found that looking to the advantages of LPG and CNG fuel related efficiency and looking safety aspects.

H R Mistry et al. 2011[15] study that of tribological parameters on S I Engine, The performance parameters which reduce the efficiency of an I.C. engine are different mechanical losses, like direct friction losses, pumping loss, blow losses, valve throttling losses.

Miqdam T Chaichan et al. 2016[16] study to aim examine that the possibilities of using two types of gaseous fuels in a laboratory engine to find the performance rest equivalence ratios, and be minimal value was at too lean ratios and the gasoline mechanical efficiency was greater than those of CNG and LPG. The LPG mechanical efficiency was higher than NG ones due to the gasoline higher bp for all tested compression ratios and equivalence ratios compared to the alternatives.

Quoc Dang Tran et al. 2022[17] study to mention that in experimental investigation the effect of piston bowl geometry on the performance of converted CNG engines has been investigated. Based on the experiment and calculation results, it is observed that the bowl depth and the position of the center bowl have strongly affected engine performance.

Pundlik N Patil et al. 2020[18] study to found that Due to lower volumetric efficiency, the brake power is also reduced and thereby the Mechanical efficiency are at lower side of LPG fuel by 5-7 %. Due to more fuel consumption, indicated and brake thermal efficiencies are also affected by LPG fuel, as both efficiencies become less for LPG and the frictional power losses are increased.

I.M.Yusri et al. 2018[19] said to mentioned the work on engine performance and exhaust emissions of alternative fuels using response surface and artificial neural network methods.

A. Bakar et al. 2015[20] said found that in the result showed that pressure inside cylinder for CNG is 20% less than gasoline. CNG fuel also produced 23% less heat transfer rate compared to gasoline. The results explained why CNG produced 18.5% lower power compared to liquid fuel (gasoline).So; some improvement needs to be done in order to use CNG as fuel.

Ibham Veza et al. 2022[21] said that ANN model can be beneficial especially when the system is too complicated, and it is too costly to model it using a simulation program. ANN has been successfully applied

International Journal of Advance Research in Science and Engineering
Volume No. 14, Issue No. 10, October 2025
www.ijarse.com
IJARSE
ISSN 2319 - 8354

and it now becomes an indispensable tool to rapidly predict engine performance, combustion and emission characteristics.

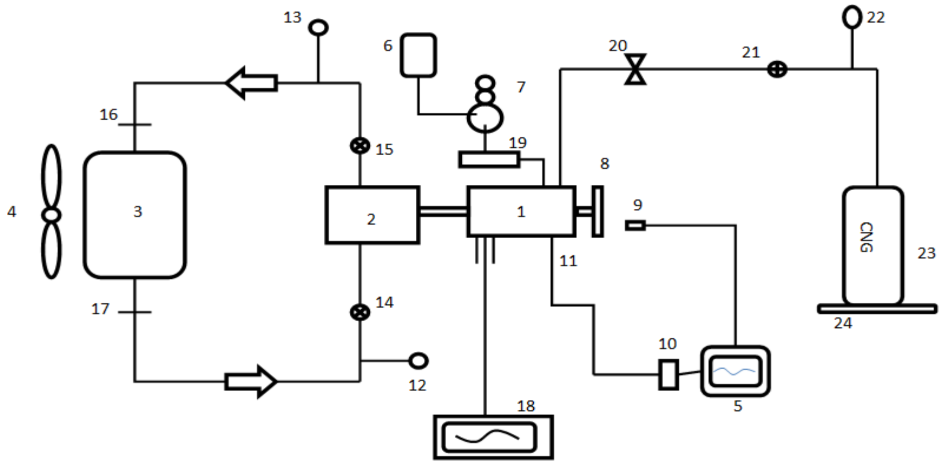
II. IDENTIFIED RESEARCH GAPS

Limited Tribological Investigations with Alternative Fuels

- Most studies ([1], [3], [15], [18]) mention that mechanical and frictional losses are higher for LPG/CNG compared to petrol, but **very few have systematically analyzed tribological parameters** (e.g., friction coefficient, wear patterns, lubricant behavior) under different operating conditions for CNG- and LPG-fueled SI engines.
- There is a lack of **experimental tribological data** linking frictional losses to engine performance with different lubricants.
- There is also limited work combining **performance, emission, and tribological analysis in a single experimental framework** for Gasoline and CNG engines.

IV. RESEARCH METHODOLOGY

This study focused on the performance of CNG when used in a single cylinder SI engine. The tested engine was equipped with CNG kit, which represent as the CNG system in the vehicle. The system was tested using a hydraulic dynamometer, which operates in two different fuel sources. The fuels are CNG and liquid fuel. The data from these two different types of fuel were compared and analysed. Fig. 1 shows the schematic diagram of the dynamometer with tested engine and the CNG kits.



1	Engine	7	Fuel burret	13	Pressure gauges	19	Fuel pump
2	Hydraulic pump	8	Crank angle disc	14	Control valve	20	Flow rate gauges
3	Hydraulic tank	9	Crank angle decoder	15	Control valve	21	Pressure regulator
4	Cooling fan	10	Amplifier	16	Thermocouple	22	Pressure gauges
5	Combustion analyse	11	Pressure sensor	17	Thermocouple	23	CNG tank
6	Fuel tank	12	Pressure gauges	18	Gas analyzer	24	Weight scale

Fig. 1. Schematic diagram of experimental setup.

The fix variable during this experiment is backpressure from the hydraulic pump. The back pressure is only applied about 50% of certain engine speed in revolution per minute (rpm). When 100% back pressure applies to

the engine, it will cause the engine to stop and it indicates that the pressure is too high. Manipulated variable is the engine speed (rpm). For the overall average heat transfer from the gas to the cylinder coolant, convection
type heat transfer equations are used.

$$Q/A = h\,(T\,gas - Tcool)$$

where Q is overall heat transfer (W/m2), A is reference cylinder area (m2), Tgas is effective gas temperature typically 800°C, Tcool is coolant temperature typically 80°C, h: heat transfer coefficient (W/m2 K) The different engine speed will represent the performance of the tested engine with different types of fuel where in this case is liquid fuel (gasoline) and natural gas. Table 3 shows the tested engine specification that was used in this study. The result of this experiment indicates the performance of CNG in SI engine compared to the liquid fuel.

Table 3. Engine Specification.

Item	Specification
Bore x stroke (mm)	67 x52
Piston displacement	183 cm3
Power (max/ rpm)	2.6 kW/3,600 rpm
Type	Single cylinder
Stroke	4-stroke
Connecting rod length	91 mm

V Results and discussion

From the experiments conducted, the data for CNG in SI engine were analysed. Then the data were compared with the liquid fuel data. The experiment results focus on the power, cylinder pressure, and volumetric efficiency. The experiment was conducted by applying the pressure from the hydraulic pump to the tested engine. Table 4 shows the pressure indicated from pressure gauge of the hydraulic pump.

Table 4. Experimental data.

Engine Speed (rpm)	Liquid Fuel Pressure (bar)	CNG Pressure (bar)
2,000	6	2
2,500	9	4
3,000	8	5
3,600	10	6
4,000	12	8

From the results shown in Fig. 2, the performance of liquid fuel is higher than CNG. During at low engine speed, such as 2,000 rpm, the liquid fuel shows higher power output compare with the CNG. This behavior is almost the same until at the end of engine speed which 4,000 rpm. Based on the engine specification in Table 4, the maximum power for this tested engine is 2.6 kW at 3,600 rpm. Therefore, from Fig. 2, in this experiment liquid fuel as power source at 3,600 rpm give the power output about 2.7 kW.

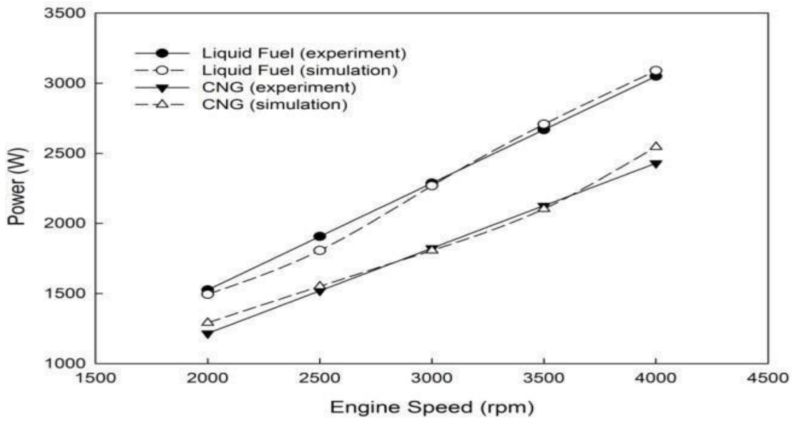


Fig. 2. Performance of tested engine with different types of fuel.

When CNG were used as a power source, the power output for this test engine at 3600 rpm is only 2.2 kW. This power drop by CNG engine is 18.5 %. Simulation model also have been done in order to validate the result for the power. In Fig. 2 shows the dash line which indicated the simulation result. The simulation was run based on the engine parameter. The simulation result also shows the same behavior where the power created by CNG is lower than liquid fuel. The lower power for CNG is due to several factors. One of the main factors is volumetric efficiency. The volumetric efficiency of CNG is lower than liquid fuel[2]. Figure 3 shows the volumetric efficiency for liquid fuel and CNG. According to the figure, the volumetric efficiency for this test engine is high when liquid fuel was used as the power source. However, when CNG was applied to this engine, it results low volumetric efficiency compare to liquid fuel. The lower volumetric efficiency is due to CNG physical properties, which is gas. During intake, CNG which consist of methane as the main particle does not produce a cooling effect during this condition. This result is due to the CNG is in the gas phase and it is vapour at ambient temperature.

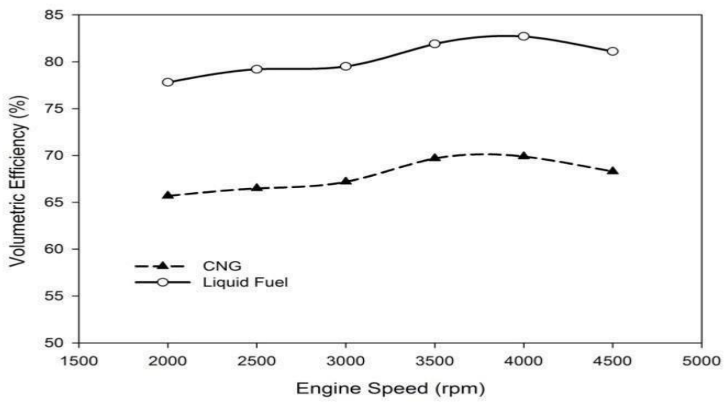


Fig. 3. Result of volumetric efficiency for both fuel.

Therefore, without cooling effect, it becomes low in volumetric efficiency compare to the gasoline fuel. Fig. 3 also showed that the highest peak in volumetric efficiency for each type of fuel is at 3,600 rpm. This indicates that the highest is also achieved when the maximum power of the engine, referring to the engine specification in Table 3, also state that the maximum power obtained at 3,600 rpm. Therefore, from this experiment, the highest peak of volumetric efficiency will be obtained at maximum power output of the engine. Other than the volumetric efficiency effect, the pressure inside cylinder also gives the different result between liquid fuel and CNG. The pressure inside the cylinder which also observed at all the stages of the engine, but the main focus is

the ignition stage. According to previous studies, when the engine used CNG as a power source, during ignition stage the pressure inside the cylinder is lower than liquid fuel.

Based from the experiment in this study, compressed natural gas (CNG) produced low performance compared to liquid fuel. The power of CNG when compared to liquid fuel is reduced to about 18.5 %. The main reason for the lack of power when using CNG is because of the volumetric efficiency. CNG's volumetric efficiency is lower than liquid fuel, due to its physical properties which is gas. When the experiment result of pressure inside the cylinder is compared, the CNG have lower pressure than the liquid fuel at ignition stage. The pressure inside cylinder for liquid fuel at highest engine speed (4500 rpm) is nearly40 bar. However, for CNG at the same engine speed, the pressure inside engine cylinder is only 32 bar. The lower pressure obtained by CNG is due to the low density of CNG itself compared to liquid fuel. The density is also resulting the low heat generated by CNG. The low heat generated is based on the temperature during combustion.

VI. CONCLUSION

Extensive review has been accomplished to identify and compare different fuels properties of Gasoline, LPG and CNG. Also reviewed various performance conducted by various authors and compared frictional power loss in S. I. Engine using different fuels like LPG,CNG etc.

From the literature review we are concluding properties of fuel and identified the compressed natural gas (CNG) is the best alternative fuel for SI engine, it is good emission effects, less fuel cost and many other benefits can also be achieved by SI engine with the using of CNG fuel.

Table 1 Physico-chemical properties of fuels

Properties	CNG	Petrol	LPG	Reference by
Chemical composition	CH_4	C4toC10	C3toC4	Bhupendra Singh Chauhan et al.
Specific density at15^0 C(kg/litre)	0.14	0.73	0.54	
Boiling point at 1 bar (^{0} C)	-162	25 to 110	-50 to 0	
Lower heating value (MJ/kg)	47.7	43.5	46.1	
Ignition temperature in air (^{0} C)	540	220	400	
Lower ignition limit (vol % gas)	5	0.6	1.5	
Upper ignition limit (vol % gas)	15	8	15	

Stoichiometric air/fuel ratio (kg/kg gas)	17.2	14.8	15.5	2011[2]
Fuel octane rating RON	120	95	105	
Fuel octane at 25^0 C(bar)	120	82	97	
Properties	**CNG**	**Gasoline**		Pravin T. Nitnaware et al. 2019[5]
Octane/Cetane No	120-130	85-95	-	
Molar Mass (Kg/mol)	17.3	109	-	

Stoichiometric (A/F) Mass	17.2	14.7	-	
L.H.V (MJ/kg)	47.5	43.5	-	
Combustion Energy	24.6	42.7	-	
Flame Propagation Speed(m/s)	0.41	0.5	-	
Adiabatic Flame Temp C	1890	2150	-	
Auto Ignition Temp	540	258	-	
Wobble Index (MJ/m3)	51-58	-	-	

1. The review of various research paper found that the physical properties and chemical properties of Gasoline, LPG and CNG fuel.

2. The methods adopted by various researchers for analyze the performance of S.I.Engine at considering the various parameters by using Gasoline, LPG and CNG fuel and identified performing testing method for S.I.Engine.

3. The research gap identified gives opportunity to investigation of the effects of CNG on frictional power loss for Performance Enhancement of S. I. Engine and compare with other fuel.

REFERENCES

[1] Pundlik N. Patil, Dheeraj S. Dehmukh, Vilas S. Patil, ―Analysis of the effect of LPG on the Performance and Frictional Power Loss for SI Engine‖, International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-8, Issue-9S3, pp.1406- 1409, July 2019, DOI: 10.35940/ijitee.I3300.0789S319.

[2] Bhupendra Singh Chauhan, Haeng Muk Cho, ―The Performance and Emissions Analysis of a Multi Cylinder Spark Ignition Engine with Gasoline LPG & CNG‖, Journal of the Korean Institute of Gas, KIGAS Vol. 15, No. 4, pp.33-38, August, 2011, DOI:10.7842/kigas.2011.15.4.033.

[3] Pundlik Nivrutti Patil, Dr. Dheeraj Sheshrao Deshmukh, ―Effect of Liquefied Petroleum Gas as a Fuel on Spark Ignition Engine Performance: A Critical Review‖, International Journal Of Science, Spirituality, Business And Technology (IJSSBT), Vol. 4, No. 1, ISSN (Print)2277—7261,pp.50- 55,Nov.2015 from:https://www.researchgate.net/publication/346194589.

[4] Md.Sourove Akther Momin* , Mihir Dutta, Md.Sahid Hassan, Md.Golam Kader, Shovon Md. Iftakher

[5] ―Study of Liquefied Petroleum Gas and Compressed Natural Gas Vehicles And It's Future Aspects‖,

International Conference on Mechanical, Industrial and Energy Engineering, Khulna, Bangladesh. pp.26-27 December, 2016, from: https://www.researchgate.net/publication/341450385.

[6] Pravin T. Nitnaware, Nakul N. Bhange, Premendra J. Bansod, Manoj D. Hambarde, Sanjay R. Deodas,

[7] ―Effects of CNG Injection Pressure on Performance, Emission and Combustion Characteristics of Multi-cylinder SI Engine,‖ International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-8 Issue-3, pp.2383-2387 September 2019, DOI: 10.35940/ijrte.C4662.098319.

[8] Christina Ingo, Jessica Tuuf, Margareta Bjorklund-Sankiaho, ―Experimental study of the performance of a SI-engine fueled with hydrogen-natural gas mixtures‖, International Journal of Hydrogen Energy, Elsevier Publication, Volume 63, pp.1036-1043,18 April 2024, DOI: https://doi.org/10.1016/j.ijhydene.2024.03.252.

[9] Mindaugas Melaika, Gilles Herbillon, Petter Dahlander, ―Spark ignition engine performance, standard emissions and particulates using GDI, PFI-CNG and DI-CNG systems‖, Published by Elsevier, Fuel Volume 293,PP.1-18,1 June 2021, 120454, DOI:https://doi.org/10.1016/j.fuel.2021.120454.

[10] Muhammad Imran Khan, Tabassum Yasmin, Abdul Shakoor, ―Technical overview of compressed natural gas (CNG) as a transportation fuel‖, Elsevier Publication, Renewable and Sustainable Energy Reviews Volume 51, November 2015, pp.785-797, DOI: https://doi.org/10.1016/j.rser.2015.06.053.

[11] B.L. Salvi, K.A. Subramanian, N.L, Panwar, ―Alternative fuels for transportation vehicles: A technical review‖, Elsevier Publication, Renewable and Sustainable Energy Reviews Volume 25, September 2013, pp.404-419, DOI: https://doi.org/10.1016/j.rser.2013.04.017

[12] Zhe Zhao, Yan Huang, Xiumin Yu, Zezhou Guo, Longlong Yu, Shuxuan Meng, Decheng Li ―Experimental study on combustion and emission of an SI engine with natural gas/ethanol combined injection‖, Published by Elsevier, Fuel, Volume 318, 15 June 2022, 123476, DOI: https://doi.org/10.1016/j.fuel.2022.123476.

[13] Akari San Win, Sandar Aung, ―Performance Analysis of a Single Cylinder SI Engine using Compressed Natural Gas (CNG)‖, International Journal of Trend in Scientific Research and Development (IJTSRD) Volume 6 Issue 1,pp. 237-248, November-December 2021 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470.

[14] Musthafah Mohd. Tahir , M.S.Ali , M.A.Salim, Rosil A. Bakar, A.M.Fudhail, M.Z.Hassan, Abdul Muhaimin M.S., ―Performance analysis of a spark ignition engine using compressed natural gas (CNG) as fuel‖, Published by Elsevier, 2nd International Conference on Sustainable Energy Engineering and Application, ICSEEA 2014. Energy Procedia 68 (2015) pp.355 – 362. DOI: 10.1016/j.egypro.2015.03.266.

[15] Akari San Win, ―Comparative Analysis of a SI Engine using Petrol and CNG Fuel with and without Supercharger Review Study‖, International Journal of Science and Engineering Applications Volume 8–Issue 08, pp.371-375, 2019, ISSN:-2319–7560, Available from: www.ijsea.com.

[16] Chetan S. Mistry, ―Comparative Assessment on performance of Multi cylinder Engine Using CNG, LPG and Petrol as a fuel‖, SAE International April 11-14, 2005, from: https://www.jstor.org/stable/44682422.

[17] H R Mistry, D V Bhatt, ―Tribological Parameters On Si Engine – A Case Study‖, International Journal of Advances in Engineering & Technology,.©ijaet issn: 2231-196. Vol. 1,Issue 3,pp.111-117, July 2011,

From: https://scholar.google.co.in/scholar?q=%E2%80%9CTr

[18] Miqdam T Chaichan, Jaafar Ali Kadhum, Khalid Sadiq Riza, ―Spark Ignition Engine Performance When Fueled with NG, LPG and Gasolin‖, Saudi Journal of Engineering and Technology ISSN 2415- 6272 (Print), Scholars Middle East Publishers ISSN 2415-6264, pp.105-116, DOI: 10.21276/sjeat.2016.1.3.7.

[19] Quoc Dang Trana, Tam Thanh Trana, and Vinh Nguyen Duy, ―An experimental investigation on performance of converted CNG engine byvarying piston bowl geometry: A case study‖, journal of the

[20] air & waste management association, vol. 72, no. 4, pp.361–369, 2022, DOI: 10.1080/10962247.2022.2028689.

[21] Pundlik N. Patil, Dr. Dheeraj S. Deshmukh, Dr. Vilas Patil, Dr. Manish S.Deshmukh, ―Investigation of the Effect of LPG on the Performance and Frictional Power Loss for Multi Cylinder SI Engine‖, IJIRAE, ISSN: 2349-2163, Issue 09,Vol.7, pp. 354-360, 2020, DOI:https://doi.org/10.26562/

[22] ijirae.2020.v0709.003.

[23] I.M. Yusri, A.P.P. Abdul Majeed, R. Mamat, M.F. Ghazali, Omar I. Awad, W.H. Azmi,― A review on the application of response surface method and artificial neural network in engine performance and exhaust emissions characteristics in alternative fuel‖, Published by Elsevier, Renewable and Sustainable Energy Reviews, Volume 90, pp.665-686, July 2018, DOI: https://doi.org/10.1016/j.rser.2018.03.095.

[24] Musthafah Mohd. Tahir, M.S. Ali, M.A. Salim, RosliA. Bakar, A.M. Fudhail, M.Z. Hass n, M.S. Abdul Muhaimin, ―:Performance Analysis of A Spark Ignition Engine Using Compressed Natural Gas (CNG) as Fuel‖, Published by Elsevier, Energy Procedia Volume 68, pp.355-362, April 2015, DOI:https://doi.org/10.1016/j.egypro.2015.03.266.

[25] Ibham Veza, Asif Afzal, M.A. Mujtaba, Anh Tuan Hoang, Dhinesh Balasubramanian, Manigandan Sekar, et al., ―Review of artificial neural networks for gasoline, diesel and homogeneous charge compression ignition engine‖ Published by Elsevier, Alexandria Engineering Journal, Volume 61, Issue 11, pp. 8363-8391, November 2022, DOI: https://doi.org/10.1016/j.aej.2022.01.072.