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## Use of LPG in SI engine- A review study

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### ABSTRACT

The depletion rate of conventional petroleum fuels is very fast. Gasoline is used as conventional fuel in the SI engine. Emissions from this fuel cause environmental pollution because it produces harmful emissions for the environment such as CO<sub>2</sub>, CO, HC, and NO<sub>x</sub>. Liquefied petroleum gas (LPG) has physical and chemical properties that make it a favorable fuel for IC engines. It can be used as a fuel alone or combined with gasoline with some minor engine modifications. The engine running on LPG showed improved performance - in terms of fuel economy, and overall efficiency compared to petrol. In addition, it is noted that LPG emissions are greatly lower than petrol. This work reviews the research conducted by previous researchers on LPG-powered SI engines under several working conditions.

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### 1. Introduction

Consumption of petroleum products has risen dramatically in the last decade due to the rise in car use and the rapid pace of technological and industrial growth worldwide. Gasoline is traditional fuel used in spark ignition engines Chung et al. [1]. Petrol is derived from crude oil, and its cost is increasing due to limited crude oil reserves. Furthermore, the limited reserves of fossil fuels would not be adequate to satisfy energy requirements in the close future, and the difficulty of fuel paucity will become very serious [2-3]. In addition, One of the most important interest around the world is the ecological issue due to vehicle emissions. Eco-friendly pollution and modification of energy sources arise from the necessity for substitute fuels for automobile uses Mistry et al. [4].

Alternative fuels are classified into industrial gasoline, alcohols, gaseous fuels and others[5-6]. Alternative fuels are promising in the future in the transportation sector, as shown in Fig. 1. It is expected that the use of conventional fuels in transportation will decrease by about 24% by 2050 compared to 2005, and the trend towards the use of alternative fuels, mainly due to reducing emissions, and also to improve the efficiency of the transportation system Fuels and Reports [9]. Gaseous fuels such as LPG have been used extensively around the world in SIE because it has less impact on global warming emissions than any other fossil fuel in addition to its distinct properties such as higher octane number, lesser polluting exhaust emission, greater calorific value and economic expenses. Several researchers have conducted a large number of educations on LPG as a fuel

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in the SIE and it has been described that the use of LPG has a important impact on emissions regulator and performance [7-8].

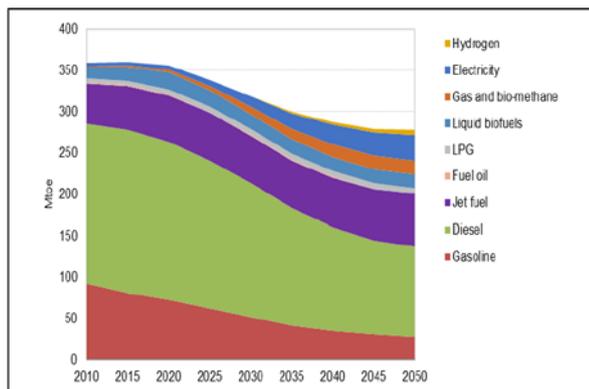


Figure 1. Total energy consumption in the transport sector [45]

## 2. Introduction to LPG

Liquefied petroleum gas (LPG), 55% of LPG is obtained from Natural gas refining, and the remaining 45% extraction from refining crude oil Taha et al. [10]. LPG is a gas consisting mainly of propane and butane, except that it could likewise contain various hydrocarbons such as propane, and n-butane in different amounts as presented in Table 1. It is only compressed 5 -20 bar and it works perfectly as an alternative fuel in SI engines Zhang [11]. It is odorless and for safety reasons, odorless has been added to detect undetected leaks that could lead to hazardous situations, because LPG is heavier than Air. One of the most important alternative fuels in SI engines is LPG because of several reasons, including the high octane number (110+) which enables the compression ratio (CR) to be as great as 15: 1, which is in the variety of 8: 1 to 9.5: 1 for petrol engines[10], the large global reserve of these gases, high heating value, and low emissions from burning in engines, in addition to their lower prices compared to gasoline Chaichan et al.[12]. LPG has a greater ignition temp. than petrol, which delays the self-ignition of fuel and thus avoids knocking Bisen et al. [13].

Table 1. Composition of Iraqi LPG

No.	Components	% vol.
1	methane	-
2	Ethane	0.03
3	Propane	20.13
4	Iso-Butane	19.35
5	n-butane	59.97
6	Total C4	79.32
7	Iso-pentane	0.50
8	n-pentene	0.02
9	Pentane and heavier	0.52

## 3. LPG in internal combustion engine

Vehicles running on liquefied petroleum gas (LPG) have been rapidly developed, as they are more economical and less polluting [14, 15]. Expected benefits of using LPG in SI are inexpensive and environmentally friendly. The SIE can be easily reformed to work on LPG [9]. Note in double fuel gas engines, gaseous fuel is introduced with air, and this mix of

air and gas is compacted as is the state in conventional engines Saraf et al. [16]. The LPG device runs under high pressure ratio. Thus, it has better thermal efficiency than a petrol engine due to its high octane rating Elnajjar et al. [17]. This means that it is possible to increase engine power output and fuel efficiency to what is possible with a petrol engine without producing a damaging phenomenon knocking . Also, given that LPG arrives the engine's combustion chambers as vapour, it does not remove the oil from cylinder sides or weak oil while the engine is cold. This helps to get a longer lifetime as well as reduce Engine maintenance costs. LPG is less hazardous than any other petroleum-based fuel and is expected to produce fewer emissions of carbon dioxide, nitrogen oxides, and May cause less ozone formation than gasoline engines Pundkar et al. [18] . Several scientists have studied with LPG as an substitute fuel for SI engines. A amount of proposals have been put forward by them to improves performance with this new fuel. A comparison of the physical properties and combustion characteristics of Iraqi LPG and traditional fuels(Iraqi gasoline) is shown in Table 2.

Table 2. Fuel properties at 25°C and 1 atm [19-20]

Property	Gasoline	LPG
Density, kg/m <sup>3</sup>	730	1.85/505
Flammability limits (Ø)	0.7-4	0.7-1.7
Auto Ignition Temperature in air, (K)	550	588
Lower heating value (MJ/kg)	44.79	46.22
Stoichiometric fuel/air mass ratio	0.068	0.064
Flame velocity (m/s)	0.37-0.43	0.48
Adiabatic flame temperature (K)	2580	2263

## 4. Literature review

In the recent period, the price of liquid fuel extracted from crude oil as well as the increasing concerns about environmental pollution emitted by cars have led to an increase in interest in alternative engine fuels [16]. Several researchers have studied the usage of LPG as an alternative fuel in the SIE. Experts and researchers conducted many experimental and theoretical investigations on the SIE supplied with LPG under dissimilar working conditions and standards and favourable results were obtained in terms of thermal efficiency, fuel cheap, as well as exhaust emissions. LPG combustion properties are higher to petrol in lean engines Jothi et al. [21]. Because of its effective combustion properties, LPG is commonly used in SIE but vehicles running on LPG fuels, in which fuel systems have been overridden from those of petrol engines, cannot realize a higher compression ratio and thus greater thermal efficiency where no Converted engines can take advantage of the high octane number of LPG [16]. LPG gas as a low carbon and high octane number fuel produces lower carbon dioxide (CO<sub>2</sub>) emission as compared to gasoline[22-23]. Ehsan M.d. et al. [24] Described working on 200 CC 1- cylinder, 4 stroke, SI coupled to generator with output power of 1.5 kW, 220V, 50Hz of electricity. The engine set's air inlet has been changed to use LPG. The load was applied to the motor as an electrical load. The test exhibited under the similar loading conditions, the fuel consumption of petrol was higher than that of LPG. In the absence of a load the flow of gasoline was 0.52 kg / hr and at a full load around 1kg / hr. Whereas in the situation of LPG from (0 to 400) watts the fuel consumed was 0.55 and 0.62 kg per hour respectively.The consumption of LPG fuel was 0.78 kg / hour ,at the maximum load of 1.3 kW.

Choi et al.[25] estimated of combustion and emission characteristics of the LPG fed by SIE was presented with some simple modifications in standard SIE on LPG fuel with variable proportions of LPG ( 5%, 10%, 20%) with assistance of the PLC control. Engine velocity is fixed at 4000 rpm, and the relative (air-to-fuel) ratio ranges ( 0.8 to 1.3). The five gases analyzer was used to measure the exhaust gas components (CO<sub>2</sub>, CO, HC, and NO<sub>x</sub>). it was also observed that the maximum CO<sub>2</sub> emission at about  $\lambda=1$  and displays smaller fractions at rich and lean mixtures. Increase percentage of LPG in petrol increases the speed of combustion of the mixture significantly and thus reduces the combustion period and thus increases the maximum temperature inside the cylinder. At a high fuel-to-air ratio, The amount of measured nitrogen oxides was much higher, and UHC showed a noticeable decrease as the relative fuel air ratio exceeded stoichiometric.

Lee Hyung Ki et al. [26] investigated the combustion properties as well as the flame spread of LPG and petrol through a laser diffraction process and high-speed photographic technique in a fixed-size combustion chamber. The researcher showed that as the initial temperature increased and the primary pressure decreased, the flame spread velocity increased.

The equivalence ratio was quite specifically influenced by the flame velocity, combustion pressure and therefore the time of combustion of the fuel-air mixture. In addition, the comparison of the flame spread between LPG and petrol showed that for the lean mixture, the flame spread of LPG was faster than gasoline, whereas for the rich mixture, the flame speed of petrol was faster than that of LPG.

Mistry C. S. and Gandhi A. H [4] modified the unoriginal multi-cylinder water-cooled, vertical, SI engine to operate on LPG and gasoline as dual fuel. Morse test was performed for modified motor under changing loading conditions with changing speed. From the results of the Morse test, it was noticed that the frictional force in case of using gasoline was less compared to LPG. It had been noticed that in the case of gasoline the thermal efficiency of the brake and the indicated thermal efficiency is higher than that of LPG. Moreover, and the flame speed of LPG is less than that of gasoline, thus spark timing should be developed to get the best results Ignition condition for LPG.

Hakan B. and Orhan D.[7] developed a computer program to make numerical calculations for the semi-dimensional SIE to guess performance, cycle and exhaust emission of automobile engines in case of the use of LPG as a replacement fuel under changed engine speed and equivalence ratio of fuel and air, and the equations governing the study of the mathematical model consisted mainly of ordinary differential equations derived for temperature and cylinder pressure. The results of simulation comparison showed that SI engines using LPG fuel showed a significant improvement in the exhaust emission characteristics.

S. Murillo et al. [27] conducted an experimental study to determine the performance and measurement of the emission index of the Si engine liquefied petroleum gas. The results showed that with the use of LPG, the specific fuel consumption decreases CO and CO<sub>2</sub> emissions were much lower. Without noticeable loss of energy but noticeable NO<sub>x</sub> emissions It was high.

Radu B. et al.[28] investigative some knockdown characteristics by focusing on the development of a simple Arrhenius type correlation to the delay time of the strike was performed on a SIE for heavyweight vehicles using commercial LPG based on experimental data for the crank angle of the strike, pressure and simulation temperatures of un-burned gases. Temperatures were computed in addition to subtracting some of the auto-ignition characteristics of LPG in the engine, taking into account the heat release rates due to auto-ignition, and they were compared with former results of unmixed propane. Results showed a qualitative correlation

between the rate of heat release through the intensity of the blow and the self-ignition reactions.

Ristovski Z.D. et al.[29] studied carbon dioxide emissions and particulate matter at changed vehicle velocities (0 (passive), 40, 60, 80 and 100) km / hour . The study was conducted on five Ford Falcon Forte (ULP) passenger cars and six custom passenger cars running on liquefied petroleum gas. The results showed that in all operating methods, the particle number emission factor using LPG was lower compared to ULP. CMD in LPG condition was greater than unleaded petrol in all types excepting in no-load mode, where numerical analysis at 60 and 80 km / hr showed significant differences. In addition, the CO<sub>2</sub> emission factors for ULP were greater than that of LPG, and at 100 km / h a statistically significant difference was observed.

Ceviz M.A. and Yuksel F. [30] compared cyclical difference and emissions of LPG with petrol fuel fired under poor operating conditions. The testing was carried out on four (air,fuel) gasoline mixes and five mixtures values for LPG. It was observed that a rise in the relative ratio between air and fuel leads to an increase in the coefficient of variation in the composition. However, the higher flame speed of LPG combined with the good mixing of the gaseous fuel with the air leads to a decrease in the periodic variations, and the higher H / C ratio of LPG reduces engine emissions and thus LPG is a more convenience fuel in a light internal combustion engine comparable with petrol.

Arslan O. et al. [31] attempted an experimental investigation on a SI four-cylinder engine modified to operate with liquefied petroleum gas (LPG) to study engine characteristics under cold weather conditions. It is found that BSFC of LPG is higher than that of gasoline. While the carbon dioxide concentration was decreasing with increasing engine speed in both fuels, the decrease was higher for LPG, and the hydrocarbon emissions were great at 1000 rpm, and with the increase in speed the HC concentration decreased, In comparison with petrol, HC concentration for LPG was found to be poor at all speeds. Lower hydrocarbons emission of LPG is reported for all ranges of engine speed compared to gasoline. It has been found that CO emissions on unloading and loading are reduced at different engine speeds. Gumus M.[32] had been investigated the effect of difference in volumetric efficiency on the emission characteristics of the SI engine with the use of LPG in different proportions (25%, 50%, 75%, 100%), experiments conducted at constant speed of 3800 rpm and with different load (5, 30, 60 and 90) percent. Differences in brake thermal efficiency, air-to-fuel ratio, bsfc, and exhaust gases were examined. Significantly when using LPG, the volumetric efficiency is decreased. The air to fuel ratio decreases as the level of LPG usage increases. Bsfc and Bsec are reduced while preserving thermal efficiency. In terms of exhaust emissions, positive results were obtained at all levels of LPG consumption. When using 100 percent LPG for exhaust emissions, the best results are obtained.

Salhab Z. et. al. [33] studied of 4-stroke SI outboard engine powered by LPG. It is modified to run on alternative fuel and on gasoline. Two different operating methods have been developed with LPG; The first is by using the vacuum produced by the engine, which provides a stable mixture to the engine's carburetion, while the second method was implemented using fuel injection (LPG). The results showed that Low engine brake power, specific brake fuel consumption. The results show that with the use of injected LPG; The brake power, engine torque and specific fuel consumption of the brakes were lower compared to gasoline, while the vacuum system was higher excluding brake force. The emissions of CO, CO<sub>2</sub> and NO<sub>x</sub> were lowered in the LPG mode compared to the petrol mode while the HC emissions were High.

Shankar K. S, Mohanan P [34] studied the performance of four-cylinder petrol engine. The engine was modified to operate with LPG injection. The experimental study is conducted on variable motor speed adjustment at 5 °

BTDC then advance and delay timing to 6° BTDC, 4° and 3° BTDC respectively. The results showed lower thermal efficiency indicated at low engine speed and 5 degrees BTDC for LPG but beyond 3,500 rpm higher efficiency for LPG detected compared to gasoline. Reduced CO<sub>2</sub> and HC emissions with LPG. While there was an increase in nitrogen oxide emissions of LPG at 4,500 rpm. When the ignition timing is brought up to 6° BTDC, the efficiency is high at low engine speed and when delayed to 4° and 3° BTDC results in an increased specified power consumption. emissions of 6° BTDC, HC and CO are found to be lower for LPG. Delayed time of ignition caused incomplete combustion and consequently high CO emission at 6° BTDC and lower at 3° and 4° BTDC.

Hwang I G. et al. [35] compared the combustion phenomena as well as the emission characteristics of nanoparticles from the spark ignition engine by direct wall-directed injection (DI) of liquefied petroleum gas (LPG) and benzene. The Gasoline Direct Injection (GDI) fuel supply system has been modified for the liquid-type LPG injection fuel supply system. To confirm the clean combustion properties of the LPG DI engine, emissions and concentrations of nanoparticles for an LPG-powered engine were compared with those of the petrol engine. The results showed that the emissions of nanoparticles and exhaust of the LPG DI engine were significantly lower than those of the GDI engine. Combustion performance at full LPG loading was similar to that of gasoline fuel.

Masi Massimo [36] took into their considerations the following factors: brake performance comparison for a SI 4-stroke , five-cylinder engine feeding with LPG in addition to petrol. The engine is converted by the

**Table 3:** Summary of researchers' contributions of LPG

Researcher name	Experimental Fuels	Results Summary
[23] Dr. Md. Ehsan2001	Gasoline and LPG which consists of Propane 85% min. Propylene 5% max. Butane and heavier HC 2.5% max Sulphur 120 ppm max	Better mixing and combustion, lower fuel consumption and improved emission characteristics. The power output decreased. More economical than gasoline
[24] G. Choi 2002	LPG was approximately mixture of 95% butane and 5% propane using fuel LPG 100% propane	The power output of LPG system with liquid-phase is approximately 17% higher than that of vapor -phase Mixer. CR is increased, power output is decreased & maximum cylinder pressure decreased
[25] K.H. Lee 2002	LPG and gasoline	The maximum flame propagation speed appeared at the stoichiometric equivalence ratio condition ( $\phi=1.0$ ) for LPG, but at equivalence ratio of 1.1 for gasoline, the flame speed of LPG is faster than that of gasoline at the range of lean or stoichiometric equivalence ratios. However at the range of rich equivalence ratio conditions, the speed of flame propagation for the gasoline was superior to that of LPG.
[4] C.S. Mistry 2004	Dual fuel mode LPG and petrol	Brake thermal and indicated thermal efficiencies were higher for petrol .Fuel consumption was higher in the case of LPG. Friction power was higher in the case of LPG.
[7] Hakan B. 2005	LPG is considered to consist of only propane.	Decrements of about 3–4% in engine power output and volumetric efficiency computed for the LPG fueled engine are lower than those for gasoline. LPG increases the specific fuel consumption of the engine.
[26] S. Murillo 2005	Gasoline and LPG	Reduction in power outboard engine, fuel consumption and pollutant emission
[27] Radu B 2005	Commercial LPG, (83-87 ) % propane, (9-15) % alkenes,	It was proved that reactions leading to auto ignition in the case of LPG proceed via chemical kinetics with cool flames. A qualitative correlation between the rate of heat release by auto ignition reactions and knock intensity is apparent.
[28] Z. Ristovski 2005	ULP and LPG	LPG was found to be the cleaner fuel with respect to both particle and carbon dioxide emissions

[29] M. Ceviz 2006	Gasoline and LPG	Relative air–fuel ratio increases. CO emissions decreases, and there is no serious change over the lean burn operating condition. CO <sub>2</sub> emission decreased with lower C number of fuel (LPG) and leaner mixture
[30] O. Arslan 2010	Leaded gasoline C <sub>3</sub> H <sub>18</sub> LPG (30% C <sub>3</sub> H <sub>8</sub> +,70% C <sub>4</sub> H <sub>10</sub> )	Without mixer CO & CO <sub>2</sub> emission has been reduced with mixer the specific fuel consumption increases. As a result of this increasing, the emissions t are relatively higher in comparison of the gasoline usage
[31] M. Gumus 2011	gasoline and LPG fuel is composed of (50% C <sub>3</sub> H <sub>8</sub> and 50% C <sub>4</sub> H <sub>10</sub> )	The volumetric effi. was shown a decrease depending on the LPG usage. A/F decreases with the increase in LPG usage level and the minimum A/F value was obtained at 100% LPG usage. With the use of mixture containing 25% LPG, BSFC and BSEC decreased while the BTE was maintained. Best results in terms of exhaust emissions were achieved at using 100% LPG.
[32] Z. Salhab 2011	Gasoline and LPG	It was concluded that using LPG instead of conventional gasoline results in reduced engine brake power, pollutant emissions and specific brake fuel consumption, with energy loss (7%).
[33] K. Shankar 2011	Gasoline and LPG	The advanced ignition timing when using LPG has resulted in reduced emissions of CO and HC. But it shows an increase in NO <sub>x</sub> emissions. and gives better thermal efficiency
[34] I. Hwang 2012	Gasoline and LPG of ( n-butane 46.4 % i-butane 29.9 % and propane 23% )	The particle emission levels of the LPG DI engine were lower than those of the GDI engine by one order of magnitude. The engine-out HC emission levels decreased, but the NO <sub>x</sub> concentration increased
[35] M. Masi 2012	gasoline and dual-fuel operation petrol and LPG	Performance deterioration in LPG operation due to deterioration in Volumetric efficiency and insufficient fuel delivery.
[36] B. Erkuş 2013	Gasoline and LPG	Engine has higher power outputs. Less fuel consumption. Lower exhaust emissions.
[37] M. Sulaiman 2013	Unleaded petrol and LPG ( 40 % propane and 60 % butane)	Slight power output reduction, due to the lower volumetric efficiencies and unaltered ignition timing of the engine. LPG consume less fuel. LPG has better energy price as compared to the conventional fuel, which is ULP
[38] C.Çinar 2016	Dual fuel (Gasoline and LPG)	Torque and power decreased and BSFC increased when the engine was converted to LPG. HC and CO emissions decrease were observed with LPG fuel while NO <sub>x</sub> emissions increased. Improvements on the engine performance results
[40] P. Bielaczyc 2016	Gasoline , LPG and CNG	In CNG fuelled vehicle CO and HC emissions were increased in while NO <sub>x</sub> emissions lower in comparison to petrol. In case of LPG fuelled vehicles HC emissions were similar to petrol and CO lower but NO <sub>x</sub> higher, However, the CO <sub>2</sub> emissions were decreased for both LPG and CNG operated vehicle
[41] A. Suyabodha 2017	Gasoline 95 Stoichiometric ratio 14.7 :1, Phase of injection liquid O.N 80-95 LPG Stoichiometric ratio 15.6:1, Phase of injection vapour, O.N 106-111	The energy consumption rate of LPG was less than using Gasoline95 under constant speed test although the vehicle consumed LPG slightly higher than Gasoline95. The engine power was generated more than LPG under full throttle position.
[42] M.M. Tukiman 2018	LPG (60% C <sub>4</sub> H <sub>10</sub> + 40% C <sub>3</sub> H <sub>8</sub> )	The LPG liquid phase was improved BT and BP compared with gasoline fuel. Variation of exhaust emission from CO has significantly reduced & Emission exhaust HC emitted from LPG is higher than gasoline as the engine speed increased. The concentrations of NO <sub>x</sub> emission for LPG are higher compared to gasoline. BSFC improvement when using LPG at low speed engine
[43] N. Mustafa 2019	Petrol and LPG	Engine torque and BMEP as compared with ULP and BSFC significantly improved. average NO <sub>x</sub> , HC and CO emissions were higher for liquid LPG as compared with the ULP.
[44] M. Usman 2020	Petrol and LPG (Propane 95 ,% Butane 5%)	Reduced maximum speed, torque and power. LPG produced lower HC ,CO ,CO <sub>2</sub> and NO <sub>x</sub> emissions comparison to petrol, lower. Flash point and ash contents decreased for petrol whereas the same for LPG.

standard third-generation kit to dual fuel operation. The kit is an injection system. The fuel is electronically multi-port and serial delivers LPG in the

gaseous state to the upstream intake holes of the gasoline injector. The results showed that the engine brake force was more in the petrol mode for

the same test conditions. In addition, the operating performance of LPG decreased due to lack of LPG feeding in the combustor.

Erkus B. et al.[37] reported the impact of multi-phase LPG injection system on the performance of SI engine was investigated. Experiments were conducted at engine speeds of 2000–4000 rpm. A stable throttle position of (25-50) percent of the fully open position were performed experiments. To compare the performance of mixing systems and different fuels, LPG with gasoline and carbon LPG. The results showed a higher brake force achieved for LPG injection system compared to gasoline and LPG carbonate. The volumetric efficiency also presented a perfection in the LPG injection system compared to the carbonization systems at each throttle position. Both modes of throttle have lower BSFC with the LPG injection system except 2500 rpm it raised by 25percent.

Sulaiman M.Y. et al. [38] analyzed engine speed and torque under WOT (wide open throttle) of an SI LPG powered SI engine with a global dynamometer. Tests were conducted with an air-cooled four-stroke spark-ignition engine. The test was conducted in three modes. The first mode is ULP fuel system, the second is LPG evaporator (LPG V) and the third is the LPG capsule valve (LPG B). The results showed that the SFC and the energy produced from Mode II LPG V and Mode III LPG B are lower than that of ULP.

Çinar C. et al. [39] performed a comparative study of the performance and emissions of the SI engine powered by LPG and unleaded gasoline. The engine was modified to run on LPG. The results showed a decrease in engine torque and power and an increase in BSFC when the engine was running Converted to LPG fuel and a 7mm valve lift. Additionally, improvements to CO and HC emissions were observed with LPG fuels while emissions of nitrogen oxides rise. Also, improvements are on engine performance results depending on the increased quantity of mixture taken in A cylinder with LPG .

Chaichan M. T. et al.[12] conducted a practical study using 2-types of gaseous fuel (NG, LPG) with single cylinder SI-engine with compression ratio variable, velocity and spark timing. Ricardo E6 / USA then comparing its performance with gasoline engine. Results It appears that a greater useful compression ratio for gasoline, LPG and natural gas are (8/1), (10.5/1) and (13/1) respectively. The findings showed that when using NG, spark timing was more advanced than other fuels, due to decreased flame spread in the combustion chamber. The findings showed that the consumption of fuel was determined on a mass basis for LPG, which was lower than gasoline and higher than natural gas. It was also found that the temperature of the exhaust gas of LPG is lower than gasoline and more expensive than natural gas.

Bielaczyc Piotr et al. [40] tested two SI vehicles. The vehicles were adapted by the manufacturers of binary fuels Gasoline and gaseous fuels. The first vehicle works with (liquefied petroleum gas and gasoline) and the other works with (compressed natural gas and benzene). The emissions of THC, NO<sub>x</sub> , CO and CO<sub>2</sub> were analyzed. using special additional equipment installed on the existing gasoline refueling system. Cars in this test feature multi-point gas injection systems. The objective of the work is an analysis of the effect of gaseous fuels on exhaust emissions on the emissions comparison of gasoline-powered vehicles. The researcher noticed that emissions of carbon dioxide and THC increased in CNG fuel vehicles while emissions of nitrogen oxides were lower compared to gasoline. In vehicles running on LPG fuel, CO emissions were much lower than gasoline and THC emissions were similar to gasoline but nitrogen oxides emissions were higher compared to gasoline, however, CO<sub>2</sub> emissions were reduced for both LPG and compressed natural gas vehicles.

Suyabodha A.[41] considered the use of LPG and Gasoline 95 as substitute fuel in petrol engines in continuous and fast driving conditions. The results

of the study showed that the best fuel consumption at an average speed of 100 km / h. The difference in energy consumption is due to LPG properties which is compared to gasoline 95 has a higher flame intensity. The injection of LPG resulted in a successful preparation of the mixture. Hence, the pressure in the combustion chamber increased, resulting in greater output power than the 95th gasoline under partial load conditions.

Tukiman M. M. et al.[42] studied and investigated of the performance and emissions of the petrol engine when LPG substitutes gasoline in addition to determining the effect of the LPG system in the liquid state. The engine was modified by adding a multi-port injection system (MPI) to deliver fuel to the engine in addition to installing a near-intake valve with a sequential injection system Liquid LPG (LSI) without affecting the gasoline injector.

The performance result showed with LPG increased efficiency, power and decreased BSFC. The exhaust emission of CO, HC and NO<sub>x</sub> increased compared to gasoline.

Mustaffa N. et al.[43] studied the combustion, performance and emissions characteristics of a four-stroke spark ignition engine using LPG as an alternative fuel and compare the results with unleaded gasoline (ULP). The experiments were conducted at a constant speed of 3000 r.p.m at various load conditions. The results of the combustion analysis showed that LPG had a higher pressure inside the cylinder and a higher pressure rate compared to ULP. The heat release rate (ROHR) of LPG had increased before ULP. The results showed that brake effective pressure (BMEP) and torque were higher for LPG compared to ULP. And that Brake Specific Fuel Consumption (BSFC) for LPG injection is lower as compared to ULP. Meanwhile, emissions of carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>) and hydrocarbon (HC) for LPG recorded higher.

Usman Muhammad and Hayat Nasir [44] studied the performance and emissions in addition to the deterioration of lubricant oil for 125 cc motorcycle engines running on liquefied petroleum gas and gasoline. The result showed a deterioration of the lubricant oil when operating the motorcycle for both types of fuels. Also, the brake force, torque and maximum speed of the LPG-powered motorcycle were lower compared With gasoline and lower emissions from LPG compared to gasoline.

Mohammed H.A. and Abdulhaleem S.M.[46] studied the effect of adding LPG fuel in different proportions with naphtha or gasoline on engine performance and pollutant emissions. Experiments were conducted on the spark ignition engine under different load conditions, constant CR (6: 1) and different mixing ratios (10-25)%. The results showed that mixing LPG improves the thermal efficiency of the brakes and the specific fuel consumption of the brakes and reduces carbon monoxide, carbon dioxide and nitrogen oxides, but it increases the concentration of hydrocarbons.

Mustafa K. F. and Gitano-Briggs H.W.[47] performed an experimental study to measure exhaust emissions from a four-stroke spark ignition engine modified to run with both LPG and gasoline. Experiments were done at different mixing ratios (5%, 10% and 20%) at a constant speed of 4000 rpm. It has been found that by increasing the proportion of LPG in gasoline, the level of carbon dioxide (CO<sub>2</sub>) reaches a peak at a relative air fuel ratio of 1.0, and that carbon monoxide (CO) shows a sharp decrease with the increase in the relative proportion of air fuel. The unburned hydrocarbons (UHC) also show a marked decrease as the relative air-fuel ratio exceeds the stoichiometric measures and nitrogen oxides (NO<sub>x</sub>) show an increasing trend as the air-to-fuel relative ratio increases.

## 5. Summary

This paper offers a review of the researchers' works conducted on the use of petrol engines powered by LPG. It has been found that the most effective

way to eliminate the problem of fossil fuel scarcity and exhaust emissions is the dual fuel process. The performance, combustion and emission characteristics of engines running on LPG fuel as an alternative fuel to gasoline reviewed extensively. Studies have indicated that performance, combustion and emission properties can be improved by improving compression ratio, ignition timing, engine speed, loading status, test fuel supply, injection timing, and inlet manifold condition. Based on current study the next conclusions are summarized below:

1. The use of LPG in the SI system can be exchanged instantly from LPG to petrol fuel and no much cost is required.
2. Feeding SI engine with LPG improved combustion characteristics, reduced emissions and fuel consumption.
3. Since the entry of LPG into the combustion chamber in the gaseous state, this causes air and LPG to form a homogeneous mixture of fats. It significantly reduces NOx emissions.
4. Fuel consumption for braking is lower for LPG-using engine compared to conventional fuel under same loading conditions.
5. LPG has a high calorific value, which leads to the increase of the fuel burning rate and the shortening of the combustion time, thus the fuel consumption specified for the brakes is reduced.
6. LPG can be used with higher compression ratios and lower thumping level, thus enhancing engine efficiency.
7. LPG engines have higher cylinder temperature and pressure compared to conventional fuels.

#### Authors' contribution

All authors contributed equally to the preparation of this article.

#### Declaration of competing interest

The authors declare no conflicts of interest.

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