PERIÓDICO TCHÊ QUÍMICA
ARTIGO DE REVISÃO

EFEITO DO USO DE GLP NO MOTOR DIESEL: UMA REVISÃO

EFFECT OF USING LPG OF DIESEL ENGINE: A REVIEW

تأثير استخدام غاز البترول المسال لمحرك الديزل : مراجعة

MOHSEN, Maysaa J.[1]; AL-DAWODY, Mohamed F.[2*]

[1,2]Department of Mechanical Engineering, University of Al-Qadisiyah, Al-Qadisiyah, Iraq

** Corresponding author*
e-mail: mohamed.aldawody@qu.edu.iq

Received 05 June 2022; received in revised form 13 July 2022; accepted 25 July 2022.

RESUMO

Introdução: O esgotamento dos recursos petrolíferos e as rígidas preocupações ambientais levaram os pesquisadores a se concentrarem na busca de fontes alternativas de energia para os combustíveis convencionais de petróleo. Essas questões exigem uma maior conscientização sobre o uso eficaz das reservas atuais e o uso de combustíveis alternativos. Uma das soluções para isso é o uso de combustíveis gasosos além do óleo diesel em motores a diesel, como hidrogênio, gás liquefeito de petróleo (GLP) e gás natural. Os motores bicombustíveis GLP são motores a diesel que foram modificados para usar GLP como combustível primário e diesel como combustível secundário. **Objetivo:** Este estudo teve como objetivo revisar o impacto da indução de GLP através do coletor de admissão e diretamente na câmara de combustão nos parâmetros de combustão, desempenho e emissão de motores diesel. **Métodos:** este estudo apresenta uma revisão sistemática da literatura em que artigos científicos foram utilizados como fontes bibliográficas. A seleção dos artigos foi realizada por meio de busca em diferentes bases de dados. Todos os artigos encontrados no ano de 2001 a 2021 foram inicialmente selecionados. Foram utilizadas as seguintes palavras-chave: diesel, gás liquefeito de petroleo, motores diesel a gás, tecnologias. Os termos foram pesquisados separadamente. A estratégia de busca utilizada nas bases de dados foi baseada na utilização dos seguintes descritores e palavras-chave: *("diesel" AND "liquefied petroleum gas") OR ("gas-powered diesel engines" AND "technologies")*. Como critério de exclusão, foram excluídos do trabalho todos os artigos que não abordavam o GLP como combustível gasoso no motor bicombustível. Após este levantamento, o número total de referências utilizadas neste estudo foi de 66 artigos. **Resultados e Discussão:** os resultados mostraram que as qualidades podem ser aprimoradas com o uso das técnicas e conceitos desenvolvidos. O motor e seus componentes, juntamente com o sistema de gás, foram testados em um ambiente de laboratório. Outros testes foram realizados com o uso de softwares de análise teórica como o diesel RK. A combustão pode ocorrer quando o gás é introduzido diretamente na câmara de combustão ou quando é introduzido indiretamente através do coletor de ar e misturado com ar. **Conclusões:** O uso de GLP no motor CI melhora a mistura e a combustão, reduz o consumo de combustível e melhora as características de emissão enquanto reduz os custos. Quando o GLP é colocado em um motor, o desempenho do motor melhora drasticamente. O GLP gasoso é injetado na câmara de combustão para criar uma mistura ar-GLP magra e uniforme. Como consequência desta mistura consistente, as emissões de NOx são drasticamente reduzidas. Aumentar a temperatura da carga de admissão melhora a eficiência térmica do freio e reduz as emissões de HC e CO.

Palavras-chave: *GLP, motor bicombustível GLP, combustíveis alternativos*

ABSTRACT

Background: The depletion of petroleum resources and strict environmental concerns have sparked researchers to focus on searching for alternative energy sources for conventional petroleum fuels. These issues call for increasing awareness of effectively using the present reserves and turning to the use of alternative fuels. One of the solutions to achieving this is using gaseous fuels in addition to diesel fuel in diesel engines, such as hydrogen, liquefied petroleum gas (LPG), and natural gas. LPG dual-fuel engines are diesel engines modified to use LPG as the primary fuel and diesel as the secondary fuel. **Aim:** This study aimed to review the impact of inducting LPG through the intake manifold and directly into the combustion chamber on the combustion, performance, and emission parameters of diesel engines. **Methods:** This study presents a systematic review of the literature in which scientific articles were used as bibliographic sources. The selection of articles was carried out through a search in different databases. All articles found from the year 2001 to 2021 were initially selected. The following keywords were used diesel, liquefied petroleum gas, gas-powered diesel engines, and technologies.

Terms were searched separately. The search strategy used to search the databases was based on the use of the following descriptors and keywords: ("diesel" AND "liquefied petroleum gas") OR ("gas-powered diesel engines" AND "technologies"). As an exclusion criterion, all articles that did not approach LPG as the gaseous fuel in the dual-fuel engine were excluded from the work. After this survey, the total number of references used in this study was 66 articles. **Results and Discussion**: the results have shown that the qualities can be improved by using the techniques and concepts that have been developed. The engine and its component elements and the gas system were put through their paces in a laboratory setting. Other tests were conducted using theoretical analysis software like diesel RK. Combustion may occur either when the gas is introduced directly into the combustion chamber or when it is introduced indirectly via the air manifold and mixed with air. **Conclusions:** Using LPG in the CI engine improves mixing and combustion, lowers fuel consumption, and enhances emission characteristics while lowering costs. When LPG is put into an engine, the engine's performance dramatically improves. Gaseous LPG is injected into the combustion chamber to create a lean, uniform air-LPG mixture. Due to this consistent mixture, NOx emissions are drastically reduced. Increasing the temperature of the intake charge improves the thermal brake efficiency and reduces emissions of HC and CO.

Keywords: *LPG, LPG dual-fuel engine, alternative fuels*

الخلاصة

الخلاصة: دفع استنفاد الموارد البترولية والمخاوف البيئية الصارمة الباحثين إلى التركيز على البحث عن مصادر طاقة بديلة للوقود البترولي التقليدي. وتدعو هذه الأمور إلى زيادة الوعي بالاستخدام الفعال للاحتياطيات الحالية والتحول إلى استخدام أنواع الوقود البديلة. أحد الحلول لتحقيق ذلك هو استخدام الوقود الغازي بالإضافة إلى وقود الديزل في محركات الديزل ، مثل الهيدروجين وغاز البترول المسال والغاز الطبيعي. محركات غاز البترول المسال ثنائية الوقود هي محركات **الهدف:** هدفت هذه الدراسة إلى مراجعة تأثير إدخال غاز البترول المسال من .ديزل تم تعديلها لاستخدام غاز البترول المسال كوقود أساسي وديزل كوقود ثانوي **الطريقة :** تقدم هذه .خلال مسار الهواء بطريقة غير مباشرة و طريقة مباشرة في غرفة الاحتراق على عوامل الاحتراق والأداء والانبعاثات لمحركات الديزل الدراسة مراجعة منهجية للبحوث السابقة التي استخدمت فيها المقالات العلمية كمصادر. تم اختيار المقالات من خلال البحث في قواعد بيانات مختلفة و اختيار جميع المقالات التي تم العثور عليها من عام 2001 إلى عام 2021 مبدئيًا كذلك تم استخدام الكلمات الرئيسية التالية: ديزل ، غاز البترول ؛ البترول المسال محركات الديزل التي تعمل بالغاز ، والتقنيات كما تم البحث عن المصطلحات بشكل منفصل. استندت استراتيجية هذا البحث المستخدمة للبحث في قواعد البيانات إلى استخدام الكلمات الوصفية والكلمات الرئيسية التالية: ("الديزل" و "الغاز البترول") أو ("محركات الديزل التي تعمل بالغاز والتقنيات الحديثة "). كمعيار للبحث في هذا المجال ، تم استبعاد جميع المقالات التي لم تتناول غاز البترول المسال كوقود غازي في المحرك ثنائي الوقود من العمل. بعد هذا المسح ، كان إجمالي عدد المصادر المستخدمة في هذه الدراسة 66 مصدر. **النتائج والمناقشة:** أظهرت النتائج أنه يمكن تحسين الخواص باستخدام التقنيات والمفاهيم التي تم تعديلها. تمت الدراسة بشكل عملي بوضع المحرك وأجزاءه ونظام الغاز في المختبر وكذلك إجراء دراسة نظرية باستخدام برنامج التحليل النظري(ديزل أر-كي) **الاستنتاجات:** استخدام غاز .ويحدث الاحتراق إما عند إدخال الغاز مباشرة إلى غرفة الاحتراق أو عند إدخاله بشكل غير مباشر عبر مسار الهواء وخلطه معه البترول المسال في محرك الاحتراق الداخلي يحسن من المزيج وعملية الاحتراق كذلك يقلل من استهلاك الوقود ويعزز خصائص الانبعاث مع خفض التكاليف. عندما يتم وضع غاز البترول المسال في المحرك يتحسن أداء المحرك بشكل كبير. يتم حقن غاز البترول المسال الغازي في غرفة الاحتراق لخلق خليط متجانس من الهواء وغاز البترول المسال. بسبب هذا المزيج المتجانس يتم تقليل انبعاثات أكاسيد النيتروجين بشكل كبير. تعمل زيادة درجة الحرارة على تحسين الكفاءة الحرارية وتقليل انبعاثات احادي أوكسيد الكاربون والهيدروكربونات .

.الكلمات الدالة *: الوقود البديل ,غاز البترول المسال, محركات الوقود المزدوج لغاز البترول المسال*

1. INTRODUCTION:

Increasing human populations throughout the globe have led to a growth in the use of mechanization and energy in various industries, including transportation, agriculture, electricity generation, and heavy industry. Compared to other engines of the same size, the diesel engine's excellent output and inexpensive cost make it very popular in these applications. In addition, alternative fuels are being studied in diesel engines to improve engine performance and eliminate harmful emissions (Rakopoulos *et al*., 2006; Corrêa and Arbilla, 2006).

The excessive use of fossil fuels depletes the reserves and increases environmental pollution. This increases awareness of the perfect use of present resources and slowly turns to environmentally friendly fuels (Lata *et al*., 2011; Mustafi *et al*., 2013). One of the solutions to achieving this is using gaseous fuels in addition to liquid diesel in compression ignition (CI) engines. The use of alternative gaseous fuels such as liquefied petroleum gas (LPG) and natural gas is a promising approach to reducing dependence on petroleum-based liquid fuels and carbon dioxide (CO_2) emissions and other pollutants from the diesel engine (Selim *et al*., 2009; Vasconcelos and Corrêa, 2008). Butane gas is a gas product of petroleum refining primarily consisting of butane, propane, propylene, and other light hydrocarbons (Raslavičius *et al*., 2014; Ashok *et al*., 2015; Goldsworthy *et al*., 2012).

The LPG has a high octane number and thus doesn't burn during the compression stroke, but when supplied with other fuel having a low auto-ignition temperature like a diesel, it burns easily (Cernat, 2016). The lower cetane number of LPG makes it difficult to use high percentages in the CI engine, mainly due to a high cyclic variation (Tira *et al*., 2012; Oguma *et al*., 2003; Negurescu *et al*., 2013). The engine uses conventional diesel and LPG fuel referred to as an LPG-Diesel dual-fuel engine. In this engine, LPG fuel is blended with air in the engine cylinders, either by direct mixing in the intake manifold with air (MI) or through injection directly into the cylinder (DI) (Badr *et al*., 1999).

The dual-fuel engine is essentially a modified diesel engine in which the LPG fuel, called a primary fuel, is inducted along with air. The primary gaseous fuel is pumped with intake air during a suction stroke but does not auto-ignite due to its high auto-ignition temperature. This fuel is the primary energy source that enters the engine. A small amount of diesel fuel, usually named a "pilot," is injected into a standard diesel engine at the near end of compression of the LPG-air mixture. The dual-fuel engines can easily be reverted back to diesel operation (Papagiannakis, 2010).

By converting diesel engines to operate on LPG, we can significantly decrease the diesel pollution problem while also improving greenhouse gas emissions (Kim *et al*., 2009;). However, dual-fuel engines have some pitfalls, such as poor utilization of LPG fuel at low and medium loads, resulting in poor engine performance (lower engine efficiency) and high CO and HC emissions. The poor part-load performance results from the incomplete combustion of LPG. This is due to low thermal efficiency and the high level of unburnt hydrocarbons in the exhaust (Papagiannakis, 2007).

This study aimed to see whether diesel engine combustion, performance, and emissions might be improved by introducing LPG into the combustion chamber via the intake manifold.

2. MATERIALS AND METHODS:

This study presents a systematic review of the literature in which scientific articles were used as bibliographic sources. Articles were searched in Scopus (ScienceDirect), Google Scholar and other sources as conferences, theses and dissertations, and other related files. The authors selected all articles found from the year 2001 to 2021. Articles only in English were selected. The following keywords were used: diesel, liquefied petroleum gas, gas-powered diesel engines, and technologies. The logical operators used in the search were AND, OR. In addition, the search used the terms individually and in combination, as follows: (“diesel” AND “liquefied petroleum gas”) OR (“gas-powered diesel engines” AND “technologies”). As an exclusion criterion, all articles that did not approached LPG as the gaseous fuel in the dual-fuel engine were excluded from the work.

RESULTS AND DISCUSSION

3.1. Results

Tables 1 and 2 show the results of the search in the different sources and databases as well as the number of papers excluded according to the criteria adopted. A total of 66 papers were considered in this study.

3.2. Discussions

3.2.1. Introduction to LPG

Among the available clean gaseous fuels are LPG and dimethyl-ether (DME). LPG is one of the most promising alternative fuels (Lee and Ryu, 2006). It is obtained from hydrocarbons produced through refining crude oil and from heavier components of natural gas (Saraf *et al*., 2009). It consists mainly of a mixture of two hydrocarbons; propane (C_3H_8), propene (C_3H_6), n-butane (C_4H_{10}), isobutene (methyl-propane), and variable proportions of other butanes. These are the leading constituent gases (mixtures of hydrocarbons) in various ratios depending on the production company and the season. The Iraqi LPG and diesel properties are presented in Table 3.

Compared with diesel fuel, LPG has a higher octane number, lower density, and higher auto-ignition temperature; hence it can't burn alone, and a small amount of diesel is required to initiate combustion. The dual-fuel engine employing LPG as a gaseous fuel was explored in this study. In this research, diesel engine emissions were reduced by utilizing liquefied petroleum gas (LPG) as a replacement for diesel. In addition, researchers wanted to see whether inducing LPG via the intake manifold and into the combustion chamber affects the combustion, performance, or emissions of diesel engines. In this article, diesel engine intake manifolds (MI) and direct injections (DI) have been studied by Chauhan (2011) and Negurescu *et al*. (2013). It is arranged from oldest data to newest.

3.2.2. LPG/diesel dual-fuel operation

The LPG is inducted into the engine's manifold, mixed with air, and then drawn into a cylinder; this mixture is subjected to higher pressure and temperature. Towards the end of the compression stage, the mixture is combusted by the injection of pilot diesel fuel (a small quantity), representing an ignition source (Ergenç and Koca, 2014), as shown in Figure 1.

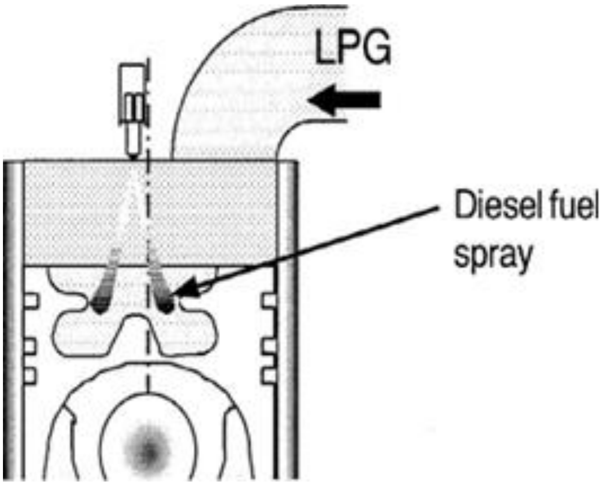

Figure 1. LPG/diesel dual engine (Lata *et al.*, 2011).

Several articles were carried out on LPG-diesel dual-fuel engines, including modifications of one-cylinder (Murthy *et al.*, 2012; Kaleemuddin and Rao, 2009) and multi-cylinder (Ashok *et al.*, 2015; Jian *et al.*, 2001) diesel engines in which LPG is supplied in dual fuel mode through manifold induction (Murthy, 2012). It has been found that the performance, combustion, and emission characteristics of an LPG-diesel dual-engine depend on the LPG fuel supply system, engine type, and engine operating conditions.

LPG can be used in the gaseous phase, where it's fumigated and mixed with air in the intake manifold [Ciniviz, 2001.; Abd Alla, 2000). When the LPG is in the liquid phase, it blends with diesel fuel under high pressure (Cao *et al.*, 2004.; Ma *at el.*, 2007). The liquid LPG injection can be done using phase, either in an LPG-diesel mixture through a single injector or separately through a second injector (Boretti, 2017).

Diesel engines are characterized by high thermal efficiency and durability (Jothi *et al.*, 2008). However, the main issue that still exists is emissions, in particular from nitrogen oxides (NOx), smoke, and particulate matter (PM), causing environmental pollution (Sudhir *et al.*, 2003). A dual-fuel engine can be considered a solution to this problem due to its lower emissions. Presently, the use of LPG in diesel engines has attracted a lot of attention because of its lower emissions characteristics than diesel (Vijayabalan and Nagarajan, 2009). The next few paragraphs present different researchers' findings that recently worked in using LPG as fuel in the intake manifold (MI) in diesel engines.

Ciniviz (2001) studied a diesel engine that has been modified to run on dual fuel (diesel/LPG) with a 30% injection rate into the intake manifold. Compared to diesel mode, dual fuel operation increased engine power and torque by 5.8%, while NOx emissions were reduced by 5.9%. The dual-fuel operation improved engine power, torque, and specific fuel consumption. It showed, however, higher CO_2 emissions when using LPG because CO emissions did not convert CO to CO_2.

Sudhir *et al*. (2003) worked on a single-cylinder, four-stroke, water-cooled, naturally aspirated, and direct injection. The diesel engine was converted to dual-fuel engines (70% Butane and 30% Propane). This included modifications to the air intake system. This research was carried out in a load range setting where NOx levels were decreased by 40-60%. NOx increased by 38% at full load, but smoke decreased by 40-60%. Furthermore, the thermal efficiency improved after half-pregnancy operation, with a gain of up to 4% at full load compared to diesel operation.

Amarendar Rao *et al*. (2008) utilized a CI diesel engine that runs on LPG as the primary fuel and diesel as the pilot fuel in a dual fuel mode. Experiments were carried out at various load conditions. They demonstrated that by using dual-fuel, precious diesel might be conserved up to 80%, but only up to 45% due to significant engine vibrations. Furthermore, when the dual fuel system is turned on, the engines' brake power is raised by 15%, while the BSFC is reduced by 30% compared to the diesel fuel mode of operation. This may be due to better mixing of LPG and air and improved combustion efficiency.

Vijayabalan and Nagarajan (2009) tested the characteristics of an LPG diesel dual-fuel engine with a glow plug. By connecting the LPG line to the intake manifold with a flame trap, The study found that the thermal brake efficiency increased by 2% up to an 80% load state, but that there was no improvement in full load operation with the glow plug auxiliary dual fuel mode. However, carbon monoxide (CO), hydrocarbon (HC), and smoke emissions were reduced by 50%, 69%, and 9%, respectively, with a minor change in exhaust temperature with the glow plug compared to the mode of the non-glow plug.

Chauhan (2011) converted a diesel engine to run on dual fuel by adding LPG into the intake manifold. Changes in engine exhaust emission and performance were detected when the engine was operated with (40% and 70%) diesel and (60% and 30%) LPG fuel (by volume). LPG is combined with air and ignited by a little pilot mist of diesel fuel. Diesel is the primary fuel. According to the experiment's results, the thermal brake efficiency (BTE) improved by 3% in the dual-fuel. Especially at low load, when LPG was used, CO_2, CO, and H.C. emissions were reduced. The BSFC for a fueled engine with a mixture of LPG and diesel is lower than the BSFC for diesel fuel injection timings. The NOx emissions of the dual-fuel engine decrease over the whole load range.

Rao *et al*. (2011) replaced classical diesel with LPG to enhance combustion efficiency. LPG is used as a primary fuel and diesel as pilot fuel. The engine was run at a constant speed of 1500 rpm at a low engine load of 20% and a high engine load of 80%. The engine brake thermal efficiency (BTE) is 14.4% at 20% load on the diesel-fueled operation and 12.4% on a dual-fueled operation with 50% LPG energy, a loss of 13.8%. At both loads, the volumetric efficiency dropped as the LPG content increased. In terms of emissions, both NOx and smoke density decreased as the LPG content increased. At both loads, CO and H.C. emissions showed the opposite trend.

Lata *et al*. (2011) described the results of extensive experimental work on combustion characteristics using LPG and hydrogen (H_2) as secondary fuels. The diesel engine was adapted to run on dual fuel by connecting the LPG/hydrogen gas cylinder to the intake manifold with mass flow measurement flame traps, a one-way non-return valve, and a common flame arrestor. When a blend of LPG and hydrogen (40% LPG: hydrogen = 70:30) is utilized as secondary fuel, the results show an improvement in dual-fuel engine performance. For example, at 10% load condition, LPG with 30% substitution increases pressure by 1.37 bar/deg.CA, while LPG with 50% substitution decreases pressure by 0.47 bar/deg.CA at 80% load.

Kumaraswamy and Prasad (2012) used a CI engine to operate in dual fuel mode (diesel + LPG). On the engine's air intake side, an LPG carburetor is installed. Only pilot fuel was injected into the fuel injection system. Under the engine's flywheel is a constant speed meter with a microcontroller. A microprocessor will activate the relay attached to the control valve of the LPG line whenever the engine speed exceeds 1000 rpm. When the solenoid valve opens, LPG gas is forced into the diesel engine's air intake. When dual fuel was turned on, test results showed that the engine's brake power was enhanced by around 15%, but BSFC was 30% lower than diesel alone.

Goldsworthy (2012) tested a marine diesel engine on a test bench with regulated liquid fuel injection running under load and propane blended into the inlet air manifold at varied rates. The commercial propane fumigation system is installed on the test diesel engine and is controlled by a computer, enabling complete control over the rate of gas addition. Different degrees of propane replacement, up to 35% by energy, have been evaluated under various engine operating situations. Propane boosted early combustion rates and improved thermal efficiency considerably. In addition, increased propane replacement lowered NOx emissions.

Acharya and Jena (2013) developed a dual-fuel engine that uses biodiesel and gaseous fuel and investigated the performance and emission characteristics of the engine that uses LPG as a gaseous fuel. The engine involved in this experiment is a single-cylinder Kirloskar converted to turn on dual fuel by connecting a vaporizer between the LPG tunnel and the LPG tank in the intake manifold. BSFC and BTE were seen to improve for the CI engine with B10 and B20 when compared to diesel in the present study. CO and H.C. emissions increased in dual fuel mode; however, the KOME mixture had lower CO and H.C. emissions than diesel. In dual fuel, NOx emissions dropped, although NOx emissions increased as the percentage of KOME in the mixture increased.

Rosha (2014) investigated experimentally the characteristics of a dual-fuel engine (diesel-LPG) under various loads (0%, 20%, 40%, 60%, 80%, and 100%). The experimental engine was an air-cooled, single-cylinder, constant speed, direct injection diesel engine with a rated power output of 3.7 KW. Fumigating LPG before the input manifold has converted it for dual fuel use. Between the intake and exhaust pipes, a hot EGR system is fitted. As a conclusion of the pilot test, fuel consumption dropped by 8.75%, and BTE and BSFC improved by 28.9% and 29% in diesel–LPG–EGR, respectively, as well as CO_2 and NOx, compared to diesel fuel.

Mohan Kumar and Azad (2014) employed a dual-fuel diesel engine that had been converted to operate with LPG. A 3.7 KW, 1500 rpm diesel engine produced by Kirloskar. The engine was modified to run on two fuels by adding LPG toward the intake manifold. The engine emissions and performance tests were carried out in different concentrations of diesel and LPG, up to 100% diesel. The experiment's results found that in a mix of 30% LPG and 70% diesel, thermal brake efficiency (BTE) and brake-specific fuel consumption (BSFC) improved by 30% at full load. The fuel consumption cost would have been around 22% less than the maximum load cost of 100% diesel. At full load, you can also cut smoking and NOx emissions by 33% and 28%, respectively.

Ergenç and Koca (2014) investigated the use of LPG in diesel engines. They fitted the LPG injector into the intake manifold. Three LPG ratios (10, 20, and 25%) were taken. With a 25% LPG ratio, the maximum improvement in engine power and specific fuel consumption was obtained. Furthermore, exhaust emissions, such as H.C. and NOx, dropped as the proportion of LPG increased, whereas CO_2 and CO emissions increased.

According to Tiwari and Sinha (2014), the diesel engine is connected to work on dual fuel (diesel-LPG). Diesel has been used as a primary fuel, while LPG is used as a secondary fuel. At varied concentration levels, LPG-air mixes were employed in the air intake manifold, whereas diesel injection by injector at the finish of the compression stroke was left unchanged. The smoke in this experiment was reduced by around 30% at all loads. As a result of the LPG injection, NOx emissions have decreased, and fuel consumption has been reduced at all loads. When LPG is introduced, the knock also decreases at larger loads for this engine; LPG injection should be less than 0.5 L/h, as lowering exhaust temperature lowers the structure of the NOx undesirable emission component.

Hari Prasad *et al*. (2014) conducted experiments by feeding biodiesel and LPG mixtures into a diesel engine. The engine has been appropriately converted to work on dual fuel, with LPG and diesel combined as the ignition source. The mechanical loading is directly connected to the test device, which has been changed to work in dual fuel mode. The rubber hose with the control valve connects the LPG cylinder to the inlet manifold. TME and LPG blends with diesel have a lower brake thermal efficiency (BTE) than diesel, and the loss in BTE is not proportionate to the rise in TME content in the fuel. This change is due to the TME's superior lubricating characteristics over diesel. When TME is injected as fuel with LPG, there are differences in brake thermal efficiency with the load. Changes in LPG flow rate (1.5 LPM, 2 LPM) increase brake thermal efficiency. Faster LPG flow rates and LPG flame speeds may result in optimal fuel combustion.

Nugroho *et al*. (2018) used a diesel engine with liquid LPG as a supplementary fuel. The dual fuel method was utilized to reduce fuel consumption in a diesel engine. Different LPG concentrations (35%, 45%, and 75%) and various speeds (1500, 1800, 2100, and 2700 rpm) are used. The indirect injection method was adopted. The study's main conclusion is an increase in brake-specific fuel consumption (BSFC); the greatest BSFC enhancement is seen when the LPG concentration is 45% LPG and 65% LPG when compared to pure diesel operation.

Tira *et al*. (2015), a single-cylinder dual fuel CI engine has been developed to reduce diesel engine emissions (soot and NOx) while also enabling the use of other non-conventional fuels in transportation. The liquid fuel employed in this research was ultra-low sulfur diesel (ULSD), gas to liquid (GTL), and rapeseed methyl ester (RME). Bottled gaseous fuels (i.e., H_2, LPG, and CO.) were employed to simulate LPG- reformed gas. The emissions analysis and combustion studies were carried out at two different engine loads. At 1500 rpm, the engine pressure is 3.5 bar (IMEP). LPG was injected into the engine manifold with varying concentrations of (0.2%, 0.5%, and 1%). Thermal, chemical, and dilution factors all play a role in the soot characteristics of the LPG – reformed gas. The particle matter (PM) and smoke levels were improved in the case of (0.2% and 0.5%) LPG additions, while there was no significant decrease in the case of 1% LPG addition. The H_2 introduced can be increased to provide a better balance of soot and NOx.

Rimkus *et al*. (2016) tested at 2000 rpm under 60 N.M with five different LPG/diesel mixtures. Diesel injection begins at (0°-24°) crankshaft rotation and continues until the top dead center (TDC) is reached at (2°). The LPG was fed into the engine cylinder using air from the intake manifold. The BSFC was lowest at a blend of diesel and 60% LPG, while peak engine efficiency was obtained at 40% LPG. Diesel use raises NOx and CO_2 levels in the exhaust and smoke while lowering HC and CO levels.

Sendilvelan and Sundarraj (2016) conducted experiments on dual-fuel diesel engines using diesel as the primary fuel and LPG as the secondary fuel by delivering the venture at the input manifold to contribute to enhanced performance under varied load circumstances. Different LPG flow rates (300, 500, and 800 g/h) were evaluated for this study. Engine performance with diesel as the sole fuel was compared to the results. Diesel consumption is reduced significantly with increasing load, whereas H.C. and C.O. emissions are slightly more significant at lower loads. In addition, the modified design reduces NOx and smoke density, with an LPG flow rate of 0.3 kg/h shown to be suitable for all conditions.

According to the Ambarita *et al*. (2017) study, a single-cylinder diesel engine was evaluated in two modes: one using diesel fuel and the other using LPG. LPG is made of the following additives: 30% propane and 70% butane. An intake manifold injects the mixture into the engine, allowing it to run on LPG fuel. The manufacturing capacity is similar to the diesel engine only. LPG fuel has 21.43% less engine efficiency than diesel. The LPG fuel consumption was 17.53% higher than diesel fuel consumption in comparison to diesel; LPG has a lower carbon concentration in the cylinder head. The reason for this carbon deposition is that a diesel engine running on LPG is cleaner, can run longer, and requires less maintenance than a diesel engine.

Nutu *et al*. (2017) utilized a turbocharged diesel engine running on 40% load and 1750 rpm, with an energy substitution ratio of diesel fuel and LPG, that varied from 0.5 to 1. (0 – 25%). Using a substitution ratio of xc = 25 resulted in a 20% reduction in the energy consumption of the brakes, and NOx emissions decreased by 25% when LPG was present in the combustion chamber. In addition, the burring rate of distributed mixes decreased, resulting in lower smoke emissions.

Giang and Son (2017) showed the results of an experimental investigation into a fuel control system installed on a diesel Toyota 3C-TE to evaluate the technical characteristics and emissions when the engine is running on dual fuel LPG-diesel with varied LPG ratios. The LPG fuel delivery controller and suitable injection modifications are required to ensure that the amount of LPG used conforms with engine operating standards. According to the data, the engine working on dual fuel diesel-LPG achieved a maximum moment of 98.5 percent and 85% full power. In addition, the amount of smoke produced decreases in all modes while HC and CO emissions are higher. NOx emissions have dropped by around 6.7%.

Abdul and Qadir (2017) analyzed the use of various percentages of Iraqi LPG (10% to 25%) with different percentages of Iraqi gas-oil fuel while keeping the thermal load constant to show the possibility of lowering pollutant emissions. The Rota-meter regulates the gas–oil mass flow rate, which also provides the rest of the thermal load to obtain a specific temperature by combining LPG and gas–oil and air mass flow. As the equivalency ratio went up, CO, soot, and UHC went up by 3%. On the other hand, CO_2 and NOx levels went down by 2.5% because the oxygen ratio in the blend went down. This caused incomplete combustion.

Yuvaraj (2018) experimented with a CI engine that ran on diesel and LPG. The LPG is fed into the intake manifold at a rate of 0.25 kg/h. As a result, carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), oxygen (O_2), and nitric oxide (NO) emissions were reduced. In addition, brake thermal efficiency improved by more than 3% in the diesel and LPG modes with increased load. Dual-fuel usage was at 0.78 kg/kwh, whereas diesel consumption was at 0.8 kg/kwh.

Aydin (2018) used four fuels to drive a diesel engine, including D100, LPG30, LPG50, and LPG70. The electronic control unit was employed, and position control data was used to regulate the timing and duration of LPG fuel injection. The engine was tested under various loads (500, 750, 1000, 1250, and 1500 watts). At a base of mass, the LPG injection rates are 30%, 50%, and 70%. The engine was running at 3000 rpm at all times. When employing the LPG-70 BSFC decreases, the best fuel efficiency was obtained by 8%. The effective efficiency rises to 1.75%, whereas NOx levels rise by 6%. This condition occurred because LPG fuel had a greater combustion reaction and temperature than D-100 when combustion processes were at their best, resulting in a 20% and 30% reduction in H.C. and C.O. emissions, respectively. It is eventually reduced by adding LPG to the fuel mixture.

Nemoianu et al. (2018) fuelled diesel engines with diesel and LPG using the diesel gas method. The LPG injectors are controlled electronically by a unique device ECU linked to the main engine ECU and computer, with the injectors attached to the inlet manifold. According to this study, LPG fueling reduces H.C. emissions by 63%, NOx emissions by 42%, CO_2 emissions by 35%, and soot emissions by 30%.

For Ngang and Abbe (2018), the emission and performance characteristics of a diesel engine converted to operate in a dual fuel mode (diesel-LPG) are explored in this study. Some changes were made utilizing a stage diesel conversion kit. The stage system allows LPG to be delivered into the engine's intake manifold from the gas cylinder through the vaporizer, ensuring that the LPG is entered in vaporized form. Under comparable experimental conditions, the engine was utilized to study emissions and the performance of a retrofitted engine. The performance of a diesel–LPG engine at low load and half load is low. However, the engine's power output is more than that of a diesel engine when running at high and full load. In general, greater engine speed equals higher cylinder pressure maximum and vice-versa. By increasing the LPG mass fraction from 50% to 60% in each operating system, engine performance (power, torque, and efficiency) will be improved, while H.C. and NOx emissions will be reduced.

Dittrich *et al*. (2018) performed experimental research on a fuel control system installed on a Cummins diesel engine to evaluate technical characteristics and emissions when it runs on dual fuel (liquid LPG–diesel) at various LPG flow rates. Manifold injection (MI) is used. The results suggest that the engine, which works on a dual fuel diesel–LPG engine, has an alternative LPG fuel ratio of 60% is available.

Sinaga (2019) experimented with studying the performance and cost of operating a small diesel engine using B20 biodiesel fuel and B20-LPG dual fuel. The converter kit was used to adjust gas pressure and vaporize gas. In general, the performance of dual-fuel engines was found to be higher than that of single-fuel engines. Compared to a single-fuel engine, this represents a maximum BSFC reduction of 20% and a maximum power boost of 12%. In addition, BTE increased by roughly 9% in dual fuel mode.

Al-kaabi and Balla (2020) conducted an experiment in which D-100 and D-50 were used to test the engine. Diesel was replaced with LPG in varying quantities at injection flow rates of 100% and 50%. Each load condition was tested at different speeds (0%, 25%, 50%, 75%, and 100%) (1000, 1500, and 2000 rpm). The LPG system's electronic control unit (ECU) regulates the time and amount of LPG that enters the intake manifold and mixes with the air before entering the combustion chamber. When the engine is in dual fuel mode and running at 1000 rpm, BSFC is more effective. The quality of the fuel has improved by 9.81%. At different speeds of 1000, 1500, and 2000 rpm, the lowest hourly operating cost per liter of duel fuel was 14.45%, 15%, and 15.31% compared to pure diesel fuel.

Santhoshkumar *et al*. (2021) transformed hazardous waste oil (WEO) into a suitable hydrocarbon fuel for energy conversion. In a typical diesel engine that was converted into a dual-fuel engine, LPG and pyrolysis fuel were added. The port for LPG injection was installed on the suction manifold. The experiment was conducted at a constant speed of 1500 rpm using a CI engine with a power of 3.7 KW at different conditions of load and three different mixes with energy sharing of LPG (20%, 30%, and 40%) and PWEO (80%, 70%, and 60%). The findings stated that using 40% of the LPG's energy lowered smoke and NO by 46.30% and 233 ppm, respectively. However, due to incomplete combustion, thermal brake efficiency was reduced by 3.25%.

Procházka (2021) experimented with detecting knocks in a gas dual-fuel engine converted from a Cummins diesel CI engine. The Solaris (diesel–LPG) system controls dual-fuel engine operation. The combination of liquid LPG fuel, consisting of nearly 52% propane (C_3H_8) and 48% butane (C_4H_{10}), is employed for dual fuel engine experiments. To minimize the flow cross-section in the engine inlet manifold, the engine contains an injector with an LPG heated exhaust nozzle. Despite the maximum pressure in the combustion chamber, LPG fuel may substitute roughly 60% of diesel at medium loads with the same performance parameters as dual fuel and diesel engines. In addition, the use of LPG reduces CO_2 emissions and fuel consumption significantly.

Prasath and Ramesh (2018) modified a traditional moderate-speed stationary CI engine to run on LPG as the primary fuel and diesel as the secondary fuel. The LPG is introduced into the intake manifold with air. The diesel was injected according to the engine's injection timing at 23o BTDC. LPG manifold induction is termed "MI." The thermal efficiency of the LPG (DI) system at 80 percent load was reduced by 6.7 percent due to the release of most heat BTDC. At full load, they were similar. However, LPG (DI) had a higher volumetric efficiency (1.7%) than (MI) at 100% load, resulting in less smoke with LPG (DI) than with (MI). Due to the division of a gas mixture of air, LPG (DI) has higher H.C. levels than LPG (MI) at any energy ratio.

3.2.3. directly injecting LPG into the combustion chamber of a diesel engine (CI).

Luft and Michalczewski (2002) created a dual-fuel system that uses LPG as a primary fuel and diesel as a pilot fuel to initiate combustion. The test was done at a 16:1 pressure ratio. At 20° BTDC, the optimal operation of the dual-fuel engine was observed. The pilot fuel (diesel) contributed 30% of the total fuel for a full load. The volume of ignition diesel and injection timing considerably affect the maximum torque, overall efficiency, and emissions. Compared to standard fuelling, it was observed that the combustion process in this form of dual fuel produces lower peak pressure and a lower pressure rise rating without knocking.

Cao *et al*. (2004) conducted a comparative study on diesel and LPG in a diesel engine. The combination of liquid LPG and diesel fuel was delivered to a high-pressure pump. The conventional injection injects the LPG–diesel fuel mixture into the cylinder at a pressure of 180 to 260 bar. Tests were conducted using 100% diesel, 10% LPG, and 30% LPG ratios. This analysis aimed to see if the engine torque and power stayed the same in different fuel ratios when the speed was kept fixed at about 1800 rpm. Improved CO, NOx, and smoke emissions were obtained with 30% LPG. On the other hand, using 100%, diesel fuel resulted in lower H.C. emissions.

Helin *et al*. (2006) presented an analytical and experimental investigation into the spray and combustion properties of LPG, diesel, and blends of 30% and 50% LPG. A high-pressure constant volume container with high-speed imaging and numerical methods of spray characteristics using the KIVA–3V code is used. The spray time of LPG was shorter, and the spray angle of LPG was lower than that of diesel fuel. In addition, as the atmospheric pressure rises, spray penetration decreases. The numerical findings and experimental data agreed very well. However, when using the imaging equipment at fast speeds with limited sensitivity, there was a difference between experimental and projected results at the late injection point.

Qi *et al*. (2007) examined the emissions and performance of a diesel engine that operates on pure diesel and LPG mixed fuels based on (0 %, 10%, 20%, 30%, 40%). Using a high-pressure pump and injector, it was converted to work on dual fuel. The mixed fuel was injected straight into the liquid phase, forcing the use of a pressurized nitrogen tank to maintain the liquid LPG. According to the experiment, this study aimed to achieve low cylinder peak pressure results in blended fuel operation. Compared with diesel operation, when LPG mass is greater than 20%, the maximum heat release rate is shallow, the combustion time is increased, and NOx content is lowered.

Jothi *et al*. (2008) studied the influence of exhaust gas recirculation (EGR) on an HCCI. A single-cylinder, 4-stroke, DI diesel engine. In HCCI mode, the engine has been changed to produce 3.7 KW at 1500 rpm. For optimum ignition, diethyl ether (DEE) was introduced as LPG with a low cetane number (cetane number<3). The EGR process improved the thermal break efficiency by around 2.5% under part-load conditions. Still, it was greatly decreased to approximately 68.6% at full load compared to the original case without EGR.

According to Saleh (2008), this investigation fed the LPG with varying propane and butane concentrations to an EGR diesel engine. According to the LPG content, higher propane ratios resulted in lower CO emissions, whereas higher butane content resulted in lower NOx emissions. According to the experiment, EGR influences emissions and engine performance in part loads, which was carried out with dual fuel at 1500rpm. Used LPG contains (30% butane+70% propane) with 40% diesel replacement in the dual fuel under two loads (10% and 25% of full loads) with varying EGR ratios (0–20%) depending on the fuel supplied from the second portion. Compared to diesel engines, SO_2 and NOx emissions through LPG and diesel blends are reduced by around (27%, 70% at maximum load, and 35%, 50% at 25% load). At maximum load, CO_2 emissions climbed by 15.7 % or roughly 100 % at a load of 25 %. Better NOx and C.O. emissions were measured within the EGR range (5–15%). SO_2 emissions decreased by 2%, while CO2 emissions increased by 0.4%.

Ayhan *et al*. (2011) studied the impact of LPG on performance and emissions. On a mass basis, the LPG quantity was injected into the cylinder at 5,10,15, and 25% for typical engine fuel consumption. The evaluation was done at (1200, 1400, 1600, 1800, 2000, and 2200) rpm. With a mixture of 25% LPG in the regular diesel fuel, a maximum torque of 65.2 Nm was recorded at 1600 rpm in dual-fuel operation. Between 1400 and 1800 rpm, 15% LPG produced the lowest fuel consumption and the highest brake efficiency. The best rate of injection was identified at 5% LPG and 1600 rpm. Under these conditions, NOx, SFC, and smoke emissions were reduced by 9, 27.6%, and 20%, respectively. Furthermore, with 25% of the LPG injection rate, the largest increase in volumetric efficiency is obtained.

Murthy *et al*. (2012) experimented with different LPG flow rates and engine loads. The LPG from the pipe enters the engine through a rubber hosepipe regulated by a valve. This research indicated that the lowest NOx emission was obtained when the LPG flow rate was between 0.4 and 0.6 kg/h and the engine was operating at 75% load. There is a reasonable agreement between the expected and actual results, with a difference of 13.7%.

Elnajjar *et al*. (2013) investigated the effect of LPG fuel with varying concentrations of propane and butane volume ratios of 100%, (70-30%), (55-45%), (25-75%), and 100%) on the performance of the dual CI engine. The testing was carried out with a single-cylinder Ricardo E6 engine that had been modified. Engine characteristics, according to experimental data, have a significant effect on engine performance. The various LPG fuel formulations did not affect engine efficiency. However, they did have a direct impact on the generation of combustion noise.

Boretti (2017) investigated a numerical study of the dual-fuel diesel–LPG engine operation with two main injectors for every cylinder. The analytical results are proposed for a 1600 cc high-speed direct-injection turbocharged diesel engine fed by diesel and LPG over a wide range of speeds and loads. Introducing a second direct injector for each cylinder modifies the engine to take a direct injection of LPG fuel. The study aims to find the pilot/per diesel fuel energy required to run a diesel engine like combustion with LPG main injection. The results showed that it is possible to obtain diesel-like fuel conversion torque, efficiency, and power output while replacing the bulk of diesel power with more environmentally friendly LPG up to 95% on medium-high loads. This change helped to reduce pollution and improve the mix of energy sources used to make fuels for transportation.

Two volume ratios combining diesel and LPG (20/80 and 35/65) were prepared and used by Ianniello *et al*. (2020). Proper experimental tests were conducted on the direct injection (light-duty single-cylinder diesel engine) to evaluate its effects on emissions and combustion performance. It's important to remember that petroleum gas is an LPG liquid at a pressure greater than 5 bar at room temperature. The results of this research demonstrate excellent NOx-smoke trade-off improvements, with smoke decreases of upwards of 95% while maintaining the same NOx and efficiency levels. This will increase unburned emissions slightly to acceptable limits. Improvements in indicated specific fuel consumption (ISFC) have been found in various conditions (1–3%). CO_2 levels drop proportionately to the mixing ratio.

4. CONCLUSIONS:

1- Using LPG in the CI engine reduces costs while quickly maintaining the system's capacity to switch back to conventional fuel.

2- The engine's usage of LPG led to an improvement in mixing and combustion, reduced fuel consumption, and improved emission characteristics.

3- There is a significant improvement in the engine performance when LPG is injected into the engine.

4- The LPG is introduced into the combustion chamber as a gas, resulting in a homogeneous lean mixture of air and LPG. NOx emissions are reduced significantly as a result of this uniform combination.

5- The usage of LPG allows operating with a high compression ratio below the knocking limit, enhancing overall efficiency.

6- LPG-fueled engines have higher cylinder pressure and temperature than traditional fuelled engines.

7- The ignition delay decreases with diesel and dual-fuel operations when the intake temperature increases.

8- A higher intake charge temperature enhances brake thermal efficiency while lowering HC and CO emissions.

5. DECLARATIONS

5.1. Study Limitations

This study is limited to the period of the search (2001-2021) as well the descriptors used and the inclusion and exclusion criteria adopted. Other studies can be found and considered when using different search criteria.

5.2. Data availability statement (DAS)

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

5.3. Funding source

No funding was received to assist with the preparation of this manuscript.

5.4. Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

5.5. Open Access

6. REFERENCES:

1. Rakopoulos, C.D., Antonopoulos, K.A., Rakopoulos, D.C., Hountalas, D.T. and Giakoumis, E.G., 2006. Comparative performance and emissions study of a direct injection diesel engine using blends of diesel fuel with vegetable oils or bio-diesels of various origins. *Energy conversion and management*, 47(18-19), pp.3272-3287.
2. Corrêa, S. M., Arbilla, G. (2006). Emissões de Formaldeído e Acetaldeído de Misturas Biodiesel/Diesel. *Periódico Tchê Química*. Vol.3, N.6. pp. 54-68. 10.52571/PTQ.v3.n06.2006.AGOSTO/7_ pgs_54_68.pdf
3. Lata, D.B., Misra, A. and Medhekar, S., 2011. Investigations on the combustion parameters of a dual fuel diesel engine with hydrogen and LPG as secondary fuels. *International journal of hydrogen energy*, 36(21), pp.13808-13819.
4. Mustafi, N.N., Raine, R.R. and Verhelst, S., 2013. Combustion and emissions characteristics of a dual fuel engine operated on alternative gaseous fuels. *Fuel*, *109*, pp.669-678.
5. Selim, M.Y., Al-Omari, S.B. and Al-Aseery, A.A., 2009. *Effects of steam injection to dual-fuel engine on performance, noise, and exhaust emission* (No. 2009-01-1831). SAE Technical Paper.
6. Raslavičius, L., Keršys, A., Mockus, S., Keršienė, N. and Starevičius, M., 2014. Liquefied petroleum gas (LPG) as a medium-term option in the transition to sustainable fuels and transport. *Renewable and Sustainable Energy Reviews*, *32*, pp.513-525.
7. Ashok, B., Ashok, S.D. and Kumar, C.R., 2015. LPG diesel dual-fuel engine–A critical review. *Alexandria Engineering Journal*, *54*(2), pp.105-126.
8. Goldsworthy, L., 2012. Combustion behavior of a heavy-duty common rail marine Diesel engine fumigated with Propane. *Experimental Thermal and Fluid Science*, *42*, pp.93-106.
9. Cernat, A., Pana, C., Negurescu, N. and Nutu, C., 2016. The influence of LPG fuelling on diesel engine cycle variability. *Procedia Technology*, *22*, pp.746-753.
10. Tira, H.S., Herreros, J.M., Tsolakis, A. and Wyszynski, M.L., 2012. Characteristics of LPG-diesel dual-fuelled engine operated with rapeseed methyl ester and gas-to-liquid diesel fuels. *Energy*, *47*(1), pp.620-629.
11. Oguma, M., Goto, S., Sugiyama, K., Kajiwara, M., Mori, M., Konno, M. and Yano, T., 2003. *Spray characteristics of LPG direct injection diesel engine* (No. 2003-01-0764). SAE Technical Paper.
12. Negurescu, N., Pana, C. and Cernat, A., 2013. Theoretical and experimental investigations on the LPG fuelled diesel engine. In *Proceedings of the FISITA 2012 World Automotive Congress* (pp. 37-49). Springer, Berlin, Heidelberg.
13. Badr, O., Karim, G.A. and Liu, B., 1999. An examination of the flame spread limits in a dual-fuel engine. *Applied Thermal Engineering*, *19*(10), pp.1071-1080.
14. Papagiannakis, R.G., Rakopoulos, C.D., Hountalas, D.T. and Rakopoulos, D.C., 2010. Emission characteristics of high speed, dual fuel, compression ignition engine operating in a wide range of natural gas/diesel fuel proportions. *Fuel*, *89*(7), pp.1397-1406.
15. Kim, Y.J., Kim, K.B. and Lee, K.H., 2009. *The spray characteristics of a liquid phase LPG port injection type injector for a remodeled diesel engine* (No. 2009-01-1879). SAE Technical Paper.
16. Papagiannakis, R.G., Hountalas, D.T. and Rakopoulos, C.D., 2007. Theoretical study of the effects of pilot fuel quantity and its injection timing on the performance and emissions of a dual fuel diesel engine. *Energy Conversion and Management*, *48*(11), pp.2951-2961.
17. Lee, K. and Ryu, J., 2005. An experimental study of the flame propagation and

combustion characteristics of LPG fuel. *Fuel*, *84*(9), pp.1116-1127.

18. Saraf, R.R., Thipse, S.S. and Saxena, P.K., 2009. Comparative emission analysis of gasoline/LPG automotive bi-fuel engine. *International Journal of Civil and Environmental Engineering*, *1*(4), pp.199-202.

19. Rimkus, A., Melaika, M. and Matijošius, J., 2017. Efficient and ecological indicators of CI engine fuelled with different diesel and LPG mixtures. *Procedia Engineering*, *187*, pp.504-512.

20. Ergenç, A.T. and Koca, D.Ö., 2014. PLC controlled single-cylinder diesel-LPG engine. *Fuel*, *130*, pp.273-278.

21. Murthy, K., Madhwesh, N. and ShrinivasaRao, B.R., 2012. Influence of injection timing on the performance of dual-fuel compression ignition engine with exhaust gas recirculation. *Int. J. Eng. Res. Dev*, *1*(11), pp.37-42.

22. Kaleemuddin, S. and Rao, G.A., 2009. *Study on Single Cylinder Engine for Performance and Exhaust Emission with Diesel, Bio-Diesel, LPG, and CNG* (No. 2009-32-0048). SAE Technical Paper.

23. Jian, D., Xiaohong, G., Gesheng, L. and Xintang, Z., 2001. *Study on diesel-LPG dual-fuel engines* (No. 2001-01-3679). SAE Technical Paper.

24. Ciniviz, M., 2001. *Dizel motorlarında dizel yakıtı ve LPG kullanımının performans ve emisyona etkisi* (Master's thesis, Fen Bilimleri Enstitüsü).

25. Abd Alla, G.H., Soliman, H.A., Badr, O.A. and Abd Rabbo, E.M., 2000. Effect of pilot fuel quantity on the performance of a dual-fuel engine. *Energy Conversion and Management*, *41*(6), pp.559-572.

26. Cao, J., Bian, Y.Z., Qi, D.H., Cheng, Q. and Wu, T., 2004. Comparative investigation of diesel and mixed liquefied petroleum gas/diesel injection engines. *Proceedings of the institution of mechanical engineers, part d: journal of automobile engineering*, *218*(5), pp.557-565.

27. Ma, Z., Huang, Z., Li, C., Wang, X. and Miao, H., 2007. Effects of fuel injection timing on combustion and emission characteristics of a diesel engine fueled with diesel-propane blends. *Energy & fuels*, *21*(3), pp.1504-1510.

28. Boretti, A., 2017. Numerical study of the substitutional diesel fuel energy in a dual fuel diesel-LPG engine with two direct injectors per cylinder. *Fuel Processing Technology*, *161*, pp.41-51.

29. Jothi, N.M., Nagarajan, G. and Renganarayanan, S., 2008. LPG fueled diesel engine using diethyl ether with exhaust gas recirculation. *International Journal of Thermal Sciences*, *47*(4), pp.450-457.

30. Sudhir, C.V., Desai, V., Kumar, S.Y. and Mohanan, P., 2003. *Performance and emission studies on the effect of injection timing and diesel replacement on a 4-S LPG-Diesel Dual-Fuel Engine* (No. 2003-01-3087). SAE Technical Paper.

31. Vijayabalan, P. and Nagarajan, G., 2009. Performance, emission, and combustion of LPG diesel dual-fuel engine using glow plug. *JJMIE*, *2*, pp.105-110.

32. Rao, G., Raju, A.S.R., Rao, C.M. and Rajulu, K.G., 2008. Experimental investigation of a single-cylinder, four-stroke diesel engine operating on the dual-fuel mode (LPG+ Diesel). *International Journal of Scientific Computing*, *2*(2), pp.145-152.

33. Chauhan, M.T., 2011. Exhaust analysis and performance of a single-cylinder diesel engine run on dual fuels mode. *Journal of Engineering*, *17*(4), pp.873-885.

34. Rao, G.A., Raju, A.V.S., Rao, C.M. and Rajulu, K.G., 2011. Effect of LPG content on the performance and emissions of a diesel-LPG Dual-Fuel Engine. *Bangladesh Journal of Scientific and Industrial Research*, *46*(2), pp.195-200.

35. Kumaraswamy, A. and Prasad, B.D., 2012. Implementation of an Automatic Dual Fuel Injection system in a CI Engine. *International Journal of Engineering Research and Applications*, *2*(6), pp.1685-1689.

36. Acharya, S.K. and Jena, S.P., 2013. Performance and emission analysis of a CI engine in dual mode with LPG and Karanja oil methyl ester. *International Scholarly Research Notices*, *2013*.

37. Rosha, P., Bharj, R.S. and Gill, K.J., 2014. Performance and emission characteristics of Diesel+ LPG dual-fuel engine with exhaust gas recirculation. *International*

Journal of Science, Engineering and Technology Research (IJSETR), *3*(10), pp.2570-2574.

38. Mohan Kumar, K., and Azad, D., 2014. An experimental investigation of performance and emissions of LPG as dual fuel in diesel engine generator. *International J. of Engineering Research and Applications*, *4*(11), pp.41-53.
39. Tiwari, D.R. and Sinha, G.P., 2014. Performance and emission study of LPG diesel dual-fuel engine. *International Journal of Engineering and Advanced Technology (IJEAT), ISSN*, pp.2249-8958.
40. Hari Prasad, T., Rao, P.M. and Reddy, R.M., 2014. Comparison of Performance of Diesel and LPG Blends in Dual Fuel Engine with Tallow Methyl Ester (TME) as a Fuel. In *Applied Mechanics and Materials* (Vol. 592, pp. 1869-1874). Trans Tech Publications Ltd.
41. Nugroho, A., Sinaga, N. and Haryanto, I., 2018, September. Performance of a compression ignition engine four strokes four cylinders on dual fuel (diesel–LPG). In *AIP Conference Proceedings* (Vol. 2014, No. 1, p. 020166). AIP Publishing LLC.
42. Tira, H.S., Herreros, J.M., Tsolakis, A. and Wyszynski, M.L., 2014. Influence of the addition of LPG-reformate and H_2 on an engine dually fuelled with LPG–diesel,–RME, and–GTL Fuels. *Fuel*, *118*, pp.73-82.
43. Rimkus, A., Berioza, M., Melaika, M., Juknelevičius, R. and Bogdanovičius, Z., 2016. Improvement of the compression-ignition engine indicators using dual fuel (diesel and liquefied petroleum gas). *Procedia Engineering*, *134*, pp.30-39.
44. Sendilvelan, S. and Sundarraj, C., 2016. Performance and emission study on a dual fuel engine with the modified gas inlet. *International Journal of Heat and Technology*, *34*(3), pp.545-550.
45. Ambarita, H., Setyawan, E.Y., Ginting, S. and Naibaho, W., 2017, September. Performance of a small compression ignition engine fuelled by liquified petroleum gas. In *IOP Conference Series: Materials Science and Engineering* (Vol. 237, No. 1, p. 012011). IOP Publishing.
46. Nutu, N.C., Pana, C., Negurescu, N., Cernat, A. and Mirica, I., 2017, October. LPG as a Fuel for Diesel Engines-Experimental Investigations. In *IOP Conference Series: Materials Science and Engineering* (Vol. 252, No. 1, p. 012079). IOP Publishing.
47. Giang, N.V.L. and Son, H.P., 2017, July. Experimental research on the fuel control system of an internal combustion engine using dual-fuel LPG-Diesel. In *2017 International Conference on System Science and Engineering (ICSSE)* (pp. 365-370). IEEE.
48. Abdul, A.K.M. and Qadir, S.O., 2017. The Effect of Iraqi Liquefied Petroleum Gas (LPG) Addition to a Liquid Hydrocarbon Fuels on Emission of an Industrial Furnace Burner. *Al-Nahrain Journal for Engineering Sciences*, *20*(5), pp.1240-1247.
49. Yuvaraj, M., SenthamilSelvan, M., Louis, S.W. and Kayalvizhi, V., 2018. Performance and emission characteristics of a diesel-LPG duel fuel in a greeves engine. *Journal of Automation and Automobile Engineering*, *3*(3), pp.18-24.
50. Aydin, M., Irgin, A. and Çelik, M.B., 2018. The impact of diesel/LPG dual fuel on performance and emissions in a single-cylinder diesel generator. *Applied Sciences*, *8*(5), p.825.
51. Nemoianu, L., Pana, C., Negurescu, N., Cernat, A., Fuiorescu, D. and Nutu, C., 2018, November. On LPG use at diesel engine: pollutant emissions level and cycle variability aspects. In *IOP Conference Series: Materials Science and Engineering* (Vol. 444, No. 7, p. 072002). IOP Publishing.
52. Ngang, E.A. and Abbe, C.V.N., 2018. Experimental and numerical analysis of the performance of a diesel engine retrofitted to use LPG as secondary fuel. *Applied Thermal Engineering*, *136*, pp.462-474.
53. Dittrich, A., Beroun, S. and Zvolsky, T., 2018. Diesel gas dual engine with liquid LPG injection into the intake manifold. *Engineering for Rural Development*, pp.1978-1983.
54. Sinaga, N., Mel, M. and Purba, D., 2019, August. Comparative study of the performance and economic value of a small engine fueled with B20 and B20-LPG as an effort to reduce the operating cost of

diesel engines in remote areas. In *IOP Conference Series: Materials Science and Engineering* (Vol. 598, No. 1, p. 012032). IOP Publishing.

55. Al-kaabi, M.M. and Balla, H.H., 2020, November. Study the consumption and cost of using LPG in diesel engines. In IOP *Conference Series: Materials Science and Engineering* (Vol. 928, No. 2, p. 022020). IOP Publishing.
56. Santhoshkumar, A., Hussain, A.Z. and Ramanathan, A., 2021. An experimental investigation of the effect of liquified petroleum gas addition on a dual fuel diesel engine fuelled with pyrolysis waste engine oil. *Materials Today: Proceedings*, *46*, pp.9800-9808.
57. Procházka, R., Dittrich, A., Zvolský, T. and Phu, D.N., 2021. The Knocking in the Gas Dual-fuel Engine with Liquid LPG Injection into the Intake Manifold. *International Journal of Mechanical Engineering and Robotics Research*, *10*(12).
58. Prasath K, A., and Ramesh, A., 2018. A low-pressure direct gas injection system for a four-stroke LPG: Diesel dual-fuel engine. *International Journal of Green Energy*, *15*(4), pp.223-231.
59. Luft, S. and Michalczewski, A., 2002. *Analysis of chosen parameters of a dual fuel CI engine fuelled with propane-butane gas as the main fuel* (No. 2002-01-2234). SAE Technical Paper.
60. Helin, X., Yusheng, Z. and Huiya, Z., 2006. *Experimental and numerical study on the characteristics of liquid phase LPG and diesel fuel sprays* (No. 2006-32-0076). SAE Technical Paper.
61. Qi, D.H., Bian, Y.Z., Ma, Z.Y., Zhang, C.H. and Liu, S.Q., 2007. Combustion and exhaust emission characteristics of a compression ignition engine using liquefied petroleum gas–diesel blended fuel. *Energy Conversion and Management*, *48*(2), pp.500-509.
62. Saleh, H.E., 2008. Effect of variation in LPG composition on emissions and performance in a dual fuel diesel engine. *Fuel*, *87*(13-14), pp.3031-3039.
63. Ayhan, V., Parlak, A., Cesur, I., Boru, B. and Kolip, A., 2011. Performance and exhaust emission characteristics of a diesel engine running with LPG. *International Journal of Physical Sciences*, *6*(8), pp.1905-1914.
64. Elnajjar, E., Selim, M.Y. and Hamdan, M.O., 2013. Experimental study of dual-fuel engine performance using variable LPG composition and engine parameters. *Energy Conversion and Management*, *76*, pp.32-42.
65. Ianniello, R., Di Blasio, G., Marialto, R., Beatrice, C. and Cardone, M., 2020. Assessment of Direct Injected Liquefied Petroleum Gas-Diesel Blends for Ultra-Low Soot Combustion Engine Application. *Applied Sciences*, *10*(14), p.4949.
66. Vasconcelos, A. P., Corrêa, S. M. Compostos de Enxofre em Misturas Diesel e Biodiesel (2008). *Periódico Tchê Química*. Vol.5, N.10, pp. 51-57. DOI: 10.52571/PTQ.v5.n10.2008.AGOSTO/7_pgs_51_57.pdf.

Table 1. *Search results*

Term	Source	Results	Exclusions
diesel	Scopus	125.644	125.641
	Google Scholar	26.900	26.899
	Other*	22.300	22.298
liquefied petroleum gas	Scopus	21.144	21.142
	Google Scholar	5.240	5.238
	Other*	32.300	32.296
gas-powered diesel engines	Scopus	37.897	37.892
	Google Scholar	87	85
	Other*	75.600	75.599

* Conferences, theses and dissertations, and other related files

Table 2. *Combined search results*

Term	Database	Results	Exclusions
"diesel" AND "liquefied petroleum gas"	Scopus	8.249	8.243
	Google Scholar	2.240	2.235
	Others*	67.000	66.975
"gas-powered diesel engines" AND "technologies"	Scopus	4	0
	Google Scholar	3	0
	Others*	5	0

* Conferences, theses and dissertations, and other related files

Table 3: *Properties of diesel and LPG*

Property	Iraq diesel	Iraq LPG
Chemical formula	$C_{13.775}H_{24.7}$	$C_{3.624}H_{9.248}$
Density (kg/m^3)	830	2.137
Lower heating value (MK/Kg)	45.83	46.22
Moluceular mass	190	52.916
Stoichiometric A/F ratio (kg/kg)	14.545	15.654

Reference: Rimkus, Melaika, and Matijošius (2017).