



ISSN: 1813-162X (Print); 2312-7589 (Online)

Tikrit Journal of Engineering Sciences

available online at: <http://www.tj-es.com>

TJES
Tikrit Journal of
Engineering Sciences

Utilizing LPG as an Additive to Enhance the Properties of Iraqi Diesel Oil

Davan Abdulqadir Ali *, Fakhri Hamadullah Ibraheem

Chemical Engineering Department/Faculty of Engineering/Koya University /Erbil, Iraq.

Keywords:

Diesel Oil; Gas Recovery; LPG, Dual Fuel;
Flash Point; Cetane Number; Cetane Index

ARTICLE INFO

Article history:

Received 07 Mar. 2023
Accepted 27 Mar. 2023
Available online 27 Apr. 2023

©2023 COLLEGE OF ENGINEERING, TIKRIT UNIVERSITY. THIS IS AN OPEN ACCESS ARTICLE UNDER THE CC BY LICENSE

<http://creativecommons.org/licenses/by/4.0/>



Citation: Ali DA, Ibraheem FH. Utilizing LPG as an Additive to Enhance the Properties of Iraqi Diesel Oil. *Tikrit Journal of Engineering Sciences* 2023; 30(2): 10-20.

<http://doi.org/10.25130/tjes.30.2.2>

*Corresponding author:



Davan Abdulqadir Ali

Chemical Engineering Department, Faculty of Engineering, Koya University, Erbil, Iraq.

Abstract: For environmental and economic purposes, it is necessary to search for methods that reduce gas emission by flare from the oil refineries. It causes environmental pollution and warmup. All laboratory tests have been completed at Koya University, with the contribution of the Institute of Technology in Koya, to check some readings and verify their accuracy. Increasing the absorptivity of the gases by heavy oil will have expected to improve oil burning characteristics. This research aims to determine the best operating conditions that leads for higher absorption. In this research the diesel oil is considered as a heavy cut and LPG as a light gas. A lab scale unit was installed for that purpose. The amount of changes in oil weight before and after atomizing was determines as well as, the properties of the diesel oil like flash point, cetane number, and diesel index. The effect of a wide range of atomizing time (10, 20, 30, 40, 50, 60, and 90) minutes at different temperatures (0, 10, 20, 30, 40, and 50) °C was considered. The data is discussed and graphically analyzed. The optimum operating conditions is achieved by, 9 liters/minute gas Atomizing flowrate of LPG for one liter of diesel oil, atomizing Temperature is 30 °C, atomizing Time is 30 minutes' minimum till 60 minutes' maximum. The produced Diesel Flash Point is 55 °C, and the amount of gas absorption is 24 gm per 850 gm of diesel oil which represent 2.8 % of diesel weight and 5% of LPG gas flowrate.

استخدام غاز البترول المسال كمادة مضافة لتعزيز خصائص زيت الديزل العراقي

دافان عبدالقادر علي، فخري حمدالله أبراهيم
قسم الهندسة الكيماوية / كلية الهندسة / جامعة كوية.

الخلاصة

لأغراض بيئية واقتصادية من الضروري البحث عن الطرق التي تقلل من انبعاث الغازات الهيدروكربونات التي تحرق في مداخن المصافي النفطية مما تسبب ارتفاع تراكيز الملوثات وزيادة درجات الحرارة المسببة لظاهرة الاحتباس الحراري. من المتوقع أن تؤدي زيادة امتصاص هذه الغازات من قبل الوقود الثقيل الى تحسين كفاءة احتراقه. حيث يهدف هذا البحث إلى تحديد أفضل الظروف التشغيلية التي تؤدي إلى تحقيق أعلى امتصاص للغازات مقبول نوعياً. لقد أجريت التجارب على زيت الديزل باعتباره من المقاطع الثقيلة وغاز البترول المسال كغاز خفيف. لقد تم بناء منظومة مختبرية لهذا الغرض. تم تثبيت معدل جريان الغاز على الحدود التي لا تسبب اضطراب للسائل. جرى احتساب مقدار الزيادة في وزن الديزل بعد التدفق كمعيار لكمية الغازات الممتصة ومن خلال إجراء فحوصات نقطة الوميض ورقم السيتان ومعامل السيتان للنماذج قبل وبعد التدفق والمقارنة بينها تم الوقوف على أحسن ظروف تشغيلية. الدراسة شملت الدرجات الحرارية (٥٠، ٤٠، ٣٠، ٢٠، ١٠، ٥) م وتحت زمن تدفق متغير (١٠، ٢٠، ٣٠، ٤٠، ٥٠، ٦٠، ٩٠) دقيقة. تمت مناقشة النتائج وتحليلها بيانياً. لقد أتضح بان أحسن ظروف تشغيلية قد تم الحصول عليها من خلال تثبيت معدل جريان تدفق الغاز ٩ لتر / دقيقة خلال لتر واحد من زيت الديزل ودرجة حرارة زيت الديزل ٣٠ م وقت تدفق الغاز المستمر ٣٠ دقيقة كحد أدنى. لقد كانت مواصفة وقود الديزل الناتج هي نقطة وميض ٥٥ م وهي تتسجم مع المواصفة القياسية العراقية وبلغت الكمية الممتصة من الغاز السائل ٢٤ غرام لكل ٨٥٠ غرام من زيت الديزل والتي تمثل ٢,٨٪ من وزن الديزل و٥٪ من وزن الغاز الكلي المتدفق خلال التجربة.

الكلمات الدالة: زيت الديزل، إعادة تدوير الغازات، مزيج وقود الديزل والغاز، نقطة الوميض، رقم السيتان، مؤشر السيتان.

1. INTRODUCTION

The energy crisis and environmental pollution are two issues that are now affecting the world. Energy has the priority for economic growth of any country and is vital to the sustenance of modern economy. The major sources of energy in the world are fossil fuels (petroleum oil, coal, and natural gas) and renewable energy (hydro, wind, solar, geothermal, marine energy, and combustible wastes). Crude oil is the most important and abundantly available energy source. The world is witnessing an annual increase in crude oil consumption rates. Natural and associated gas has been the energy source with highest rates of growth in recent years [1]. The burning of light hydrocarbon gases via a refineries flare produces carbon dioxide CO₂, which is accumulated in the atmosphere. CO₂ is one of the greenhouse gases that is slowly accumulated in the atmosphere, and it is believed this will raise the temperature of the planet, causing dramatic climate changes. Therefore, searching for methods to reduce CO₂ emission is a crucial point. Petroleum refineries are very important in our live. Most transportation vehicles are fueled by its products like gasoline and diesel oil. Crude oil quality is getting heavier worldwide. Existing refineries, which are designed to handle normal crudes are being modified to handle heavy crude [2]. Despite global efforts to find clean energy sources, the need for petroleum fuels still exists and is expanding annually. The combustion of Hydrocarbon gases HCG releases pollutant gases into the atmosphere, like CO₂, CO, H₂S, NO_x and Mass Particulate (MP) [3, 4]. Typical constituents of flared gas are listed in Table 1. Both flare safety design and emission control are important parameters for environmental regulations.

Table 1 Typical Constituents of Flared Gases [2]

Component	Mol. %	Heat of combustion (kJ / mol.)
C1	52.1 – 72.8	-890.36
C2	14.3 – 21.3	-1559.9
C3	6.3 – 13.8	-2220.0
i C4	1.1 – 2.8	-2865.8
n C4	1.7 – 4.6	-2878.5
i C5	0.4 – 1.1	-3529.2
n C5	0.5 – 1.3	-3536.1
C6	0	-4194.8

The flares in the oil projects are to achieve a safe operation process through the leakage of gases to the incinerators. Legislations and laws set strict controls to limit the release of polluting gases. Therefore, a balance must be struck between operation and environmental requirements[5]. The systems can be used for, extensive venting during start-up or shutdown, venting of excess process gas, handling emergency releases from safety valves, blowdown and venting systems. There are many causes of emergency relief and may include fire, blocked outlets, utility failures (steam, electricity, instrument air, cooling medium etc.) abnormal heat input, chemical reaction and so on. Several authors have published research about flare gas recovery FGR and upgrading of petroleum products. It concentrated on two methods as follows [6].

1. Gas to Liquid (GTL) system. Flare gases can be converted into normally liquid products by indirect liquefaction. Industrial GTL facilities are normally classified in terms of the syngas conversion technology that is employed by methanol synthesis and fischer-tropsch synthesis [7, 8]

2. Direct burning of light hydrocarbons like LPG with the normal diesel (Dual fuel) in the modified internal combustion engine.

The Fischer-Tropsch process [9], which was discovered in 1923 by German scientists, has been used for a long time for gas to liquid technology. Two main technologies are used to produce synthetic petroleum products. It is an indirect conversion via syngas and a direct conversion from gas using partial oxidation [10]. The GTL process produces very high quality fuel such as diesel oil. 18 billion tons of CO₂ released in 2008 came from the production of oil and gas [11]. It will be of utmost importance to lessen the amount of carbon dioxide and methane released into the atmosphere. The reuse of the flare gases by Flare Gas Recovery System (FGRS) will reduce the amount of purged gases which increases the environmental and economic considerations and minimize the amount of gases being burned [12, 13]. There is a range of methods to reduce and recover flaring by collection, compression, and injection/reinjection of gases into oil fields to enhanced oil recovery; or into wet gas fields for maximal recovery of liquids; or into the refinery pipelines [14-16]. A literature survey mainly focused on injecting LPG with the diesel into the internal combustion engine, but this needs to modify the machine fuel feed nozzle. Qi et al. [17] propose the use of a gaseous fuel as a partial supplement for liquid diesel fuel. The high auto-ignition temperature of LPG is a serious advantage since the compression ratio of conventional diesel engines can be maintained. The researcher described an experimental investigation conducted on a single cylinder diesel engine, which has been properly modified to operate under LPG–Diesel blended fuel at various blended rates (0%, 10%, 20%, 30%, 40%). Comparative results are given for various engine speeds and loads revealing its effect on engine performance and exhaust emissions. Cao et al. [18] Studied a mixed liquefied petroleum gas (LPG) and diesel are both injected into engines between 180 and 260-bar pressure by a common injector. The researchers studied the comparison of the LPG and diesel fuels in the engines. Aydin et al. [19] investigated the impact of diesel/LPG dual fuel's in diesel engine, The four different ratios of LPG are used, where the mixture ratio of fuel is 0% (Pure diesel), 30%, 50%, and 70% of LPG with diesel and it is shown that CO and HC are reduced. Saleh [4] investigated the effect of LPG composition variation on emission and engine performance characteristics. In this research a simple atomizing of light hydrocarbons like LPG across a diesel oil (Atomizing Process) at different temperature and time is conducted. The amount of absorbed gas by diesel oil and its effect on upgrading the diesel properties was determined. Analyzing of

data by graphing the relations between the operation parameter is done to achieve the optimum operating conditions for higher gas absorption.

2. EXPERIMENTAL PROGRAM

2.1.Apparatus and Procedures

The Laboratories scale unit is designed for implementation of the experiments as shown in Fig.1 The experimental unit includes preparing an LPG gas bottle with suitable pressure and connected with a flow control valve. The gas is transferred by a plastic tube to a calibrated rotameter YOKOGAWA, where the amount of gas flowing is manually controlled via a valve placed before the flowmeter. Then the gas is transferred by an open-end plastic tube to a laboratory standard bottle of 2 liters' capacity in order to get efficient atomizing of LPG through one liter of diesel without splashing. The tube opening end is positioned at the bottom of the bottle, where the gas stream atomizes from the bottom up through the diesel fuel. The diesel bottle is held inside a water bath model (Koehler K33053) that covers most of the bottle's volume to control the diesel temperature accurately during the experiments. The process of controlling the temperature of the water bath is carried out automatically through thermal heaters; bath ice water is used to keep its temperature low, like 0 C. The water bath temperature is confirmed by using an externally calibrated portable thermometer. A weighing balance model Ming Heng Digital reading is used to determine the changes in the diesel weight which refers to the primary absorption of LPG gas. The diesel oil flash point, cetane number and cetane index are tested before and after atomizing by Closed Pinsky Martens tester model APM-7 and Kohler Tester Analyzer K88600 respectively.

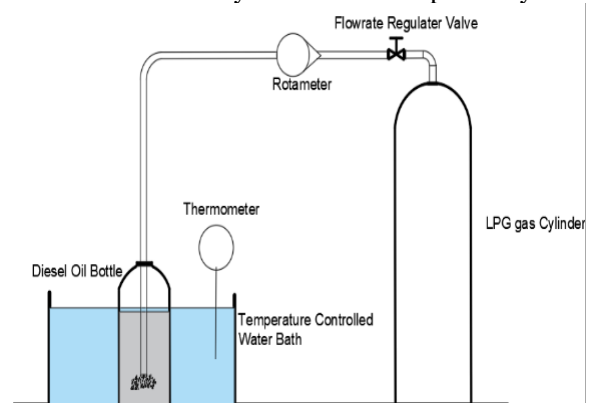


Fig. 1 The Laboratory Scale Unit for Experimental Work.

2.2.Experimental Procedure

The experimental work includes manually opening the gas valve to a specific limit to achieve a constant flow rate of 9 liters per minute, which is controlled manually. The atomizing of gas is monitored at different intervals according to the experimental designs.

Each run takes time from one hour to three hours to achieve stability temperature. Some experiments have been repeated two times to ensure the efficiency of the work and the accuracy of the results. The materials that are used in this research are:

1. LPG according to the Iraqi standard specification Appendix A [20].
2. Local market diesel oil according to the Iraqi standard specification Appendix B [21].

More than 50 runs with more than 400 laboratory tests were conducted to achieve optimum absorption conditions.

2.3. Experimental Sets

The absorptivity of LPG by diesel oil is affected by three parameters which are gas flowrate, atomizing temperature and time. Increasing the absorption efficiency will enhance the burning properties of heavy diesel oil due to increase volatile content. The gas flowrate can't increase more than a certain limit to avoid liquid disturbances and splashes. Therefore, the research is carried out under a case study of a high possible flowrate and kept it constant at 9 liters per minute. This research focuses on the optimum atomizing temperature and time for a higher absorption amount LPG by diesel oil. The experimental work covers the ranges of temperatures 0, 10, 20, 30, 40, and 50 °C at different range of time 10, 20, 30, 40, 50, and 90 minutes. Each run is done at a constant temperature with a variable atomizing time. The difference in the oil density at 60 °F is expected to be insignificant, considering the weight of the absorbed gas is essential to indicate the efficiency of the experimental work. The effect of gas atomizing on diesel Sulphur content is not considered. According to the Iraqi standard specification, diesel oil sulfur content is 1% for grade A and 2.5% for grade B. Several samples of local diesel were laboratory tested to determine their sulfur content. It was found that its content ranged from 0.65-0.9 wt. % in most of them. Since the average weight of the absorbed gases in these experiments is low, its effect on the total sulfur content is minimal. It remains within the limits of the standard specification. The study did not take into consideration the impact of absorbed gases on the diesel mineral content because we believe that their effect will not be noticeable, especially with the low weight of the absorbed gas, in addition to that the Iraqi standard did not focus on the mineral content in diesel standard sheet. The effect of absorbed gas on diesel asphalt and ash content is predicted to be very low or have no effect for two reasons: its content is very low in the gas because it is heavy cuts, and second the amount of absorbed gas by diesel is low.

3. RESULTS AND DISCUSSIONS:

3.1. Results of Diesel Oil Weight Difference ($\Delta wt.$)

The rate of increase diesel oil weight after atomizing ($\Delta wt.$) is determined with respect to a different atomizing temperature and time, Table 2. The average ($\Delta wt.$) for each range of temperature is estimated to get clear idea about its profile, Table 3. Similarly, it is estimated for each range of atomizing time, Table 4. The average ($\Delta wt.$) is drawn against atomizing temperature and time Figs. 2 and 3.

Table 2 Rate of Changes of Diesel Oil Weight with Increasing Atomizing Time at A Different Temperature.

Exp. No.	Diesel Temp. °C	Atomizing Time. minutes	$\Delta Wt.$ gm
1	0	10	43
2	0	20	47
3	0	30	71
4	0	40	74
5	0	50	82
6	0	60	87
7	0	90	107
8	10	10	49
9	10	20	52
10	10	30	24
11	10	40	28
12	10	50	74
13	10	60	81
14	10	90	117
15	20	10	4.4
16	20	20	8.4
17	20	30	12
18	20	40	18.5
19	20	50	21.7
20	20	60	23.2
21	20	90	37
22	30	10	5
23	30	20	6
24	30	30	18
25	30	40	23
26	30	50	18
27	30	60	24
28	30	90	25
29	30	120	31
30	40	10	8.9
31	40	20	15.1
32	40	30	18.2
33	40	40	22.3
34	40	50	23.2
35	40	60	18.3
36	40	90	23
37	50	10	6.8
38	50	20	16.4
39	50	30	14.1
40	50	40	12.3
41	50	50	15
42	50	60	17.3
43	50	90	12.9

Table 2 Average Increase in Weight of Samples with Respect to the Temperature.

Temp °C	Δ Wt. Average
0	73
10	68
20	18
30	18
44	19
50	14

Table 3 Average Increase in Weight of Samples with Respect to the Atomizing Time.

Time in minutes	Δ Wt. average
10	17
20	21
30	28
40	31
50	34
60	37
90	43

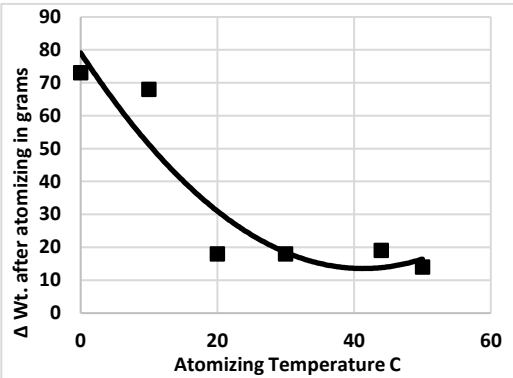


Fig. 2. The Effect of Atomizing Temperature on the Absorption Weight of LPG.

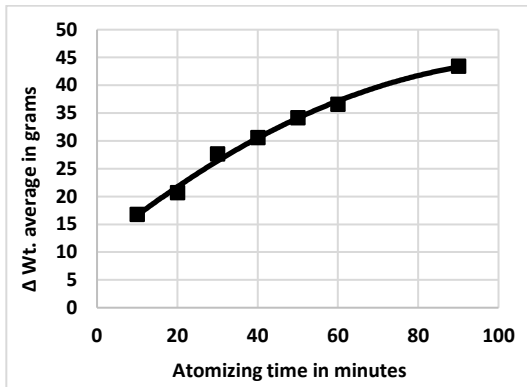


Fig. 3. The Effect of Atomizing Time on the Absorption Weight of LPG.

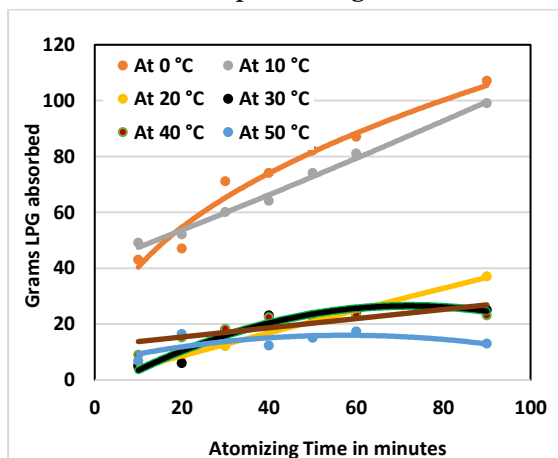


Fig. 4 The Changes in (Δwt.) with Increasing Atomizing Time at Different Temperatures.

It is shown from Fig. 2, there is no significant changes in (Δ wt.) above 30 °C because we're getting close to saturation for diesel with LPG gas. The amount of absorbed gas increases with atomizing time. As it is known, the rate of mass transfer depends on the concentration difference between the two media. Therefore, the rate of LPG gas absorption depends on its content in the diesel oil. In the beginning the content of light hydrocarbons in diesel is very low. The diesel content of gas will increase by time, and this leads to reduce its absorption rate gradually. Therefore, a significant decrease in the amount of absorbed gases is observed experimentally after an hour of gas atomizing Fig. 3. Fig.4 shows clearly that at lower atomizing temperature 0 and 10 °C a higher absorption rate is achieved and increased by increasing atomizing time, but it is very important to looking at other diesel properties like flash point because it will have affected by increasing volatile content. The process of absorption of gases by liquids is affected by several factors, including temperature, pressure and interfacial area between gas and liquid. The pressure of the system in our study is constant under normal pressure as well as the atomizing shape of gas. The higher the temperature, the more gas molecules gain kinetic energy. This kinetic energy pushes the gas molecules to spread in the solution and thus increase the dissolved amount, but within certain limits, because the increase in temperature above a specific limit can give the gases higher kinetic energy, which pushes them to escape from the solution and thus lower the rates of gas absorption. Therefore, it was crucial to know the range of temperatures that achieve the best absorption before we enter the high degrees of heat that lead to the re-evaporation of gas from liquid. The figure shows a significant increase in the solubility rates of gas in diesel at low temperatures of 0 and 10 °C. Increasing the absorbed quantities of LPG gas by diesel is beneficial to some extent because it directly affects the flash point and other combustion specifications, such as cetane number and diesel index, which are listed in the Iraqi standard specification. Accordingly, we must monitor the best temperature that achieves a balanced amount of gas absorption so that it leads to the production of diesel fuel that conforms to standard specifications and with ideal combustion specifications. The optimum amount of absorbed gases is achieved at 30 °C, as shown in the figure, and for a flow period of approximately 60 minutes. The atomizing at a range of temperature between 20 °C till 50 °C shows lower rate of (Δ wt.) with a smooth uniform shape. The flash point (FP) change with respect to the atomizing temperature and time. The FP value for each sample is tested before and after atomizing,

Table 5. The Iraqi standard specifies the ignition point value of diesel fuel 54 °C minimum. The direct reading of FP after atomizing gives unstable values. Therefore, it is stored at room temperature in open cap bottles for several days and two months then record the stable reading of FP. Fig.5, shows the profiles of the FP changes with different cases of atomizing temperature and time.

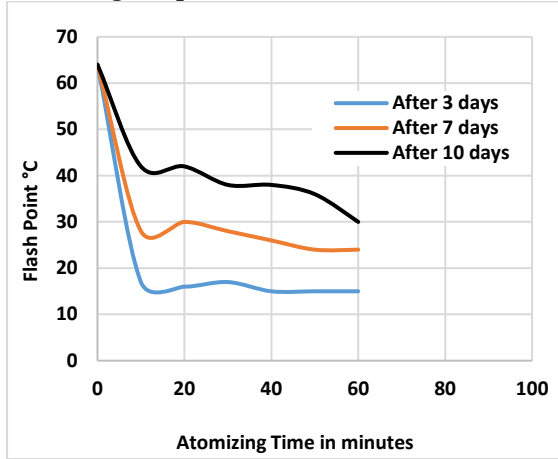


Fig. 5 Flash Point at 0 °C at Different Atomizing Time.

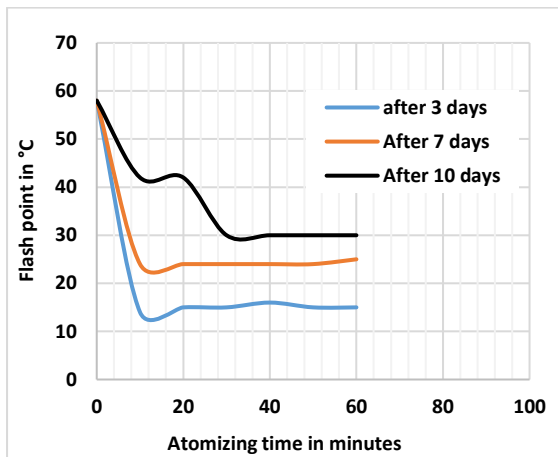


Fig. 6 Flash Point at 10 °C at Different Atomizing Time.

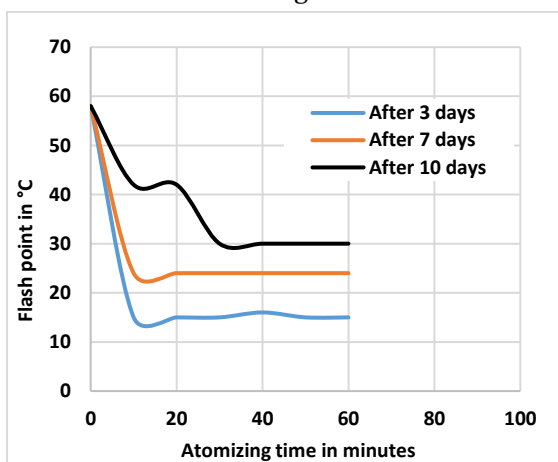


Fig. 7 Flash Point at 20 °C at Different Atomizing Time.

Table 4 The Change of FP Value with Increasing Atomizing Time at a Different Temperature.

Exp. No.	Diesel Temp. °C	Time in minute	FP before atomizing in °C	FP after several days from atomizing at open bottle			
				3 days	7 days	10 days	60 days
1	0	10	64	17	28	42	>70
2	0	20	64	16	30	42	>70
3	0	30	64	17	28	38	>70
4	0	40	64	15	26	38	>70
5	0	50	64	15	24	36	>70
6	0	60	64	15	24	30	>70
7	0	90	64	15	24	32	70
8	10	10	58	14	24	42	70
9	10	20	58	15	24	42	68
10	10	30	58	15	24	30	68
11	10	40	58	16	24	30	67
12	10	50	58	15	24	30	67
13	10	60	58	15	25	30	67
14	10	90	58	15	24	30	66
15	20	10	58	15	24	42	>70
16	20	20	58	15	24	42	>70
17	20	30	58	15	24	30	>70
18	20	40	58	16	24	30	70
19	20	50	58	15	24	30	70
20	20	60	58	15	24	30	70
21	20	90	58	16	24	30	68
22	30	10	62	19	48	58	>70
23	30	20	62	18	48	58	>70
24	30	30	62	18	46	57	>70
25	30	40	62	18	44	56	>70
26	30	50	62	18	44	56	>70
27	30	60	62	18	44	55	>70
28	30	90	62	18	42	55	69
30	40	10	62	26	51	59	>70
31	40	20	62	26	50	58	>70
32	40	30	62	24	48	57	>70
33	40	40	62	24	46	57	>70
34	40	50	62	24	45	56	>70
35	40	60	62	22	44	56	>70
36	40	90	62	22	42	55	>70
37	50	10	62	27	53	60	>70
38	50	20	62	26	52	59	>70
39	50	30	62	26	50	59	>70
40	50	40	62	24	49	58	>70
41	50	50	62	24	48	57	>70
42	50	60	62	23	46	56	>70
43	50	90	62	23	45	56	>70

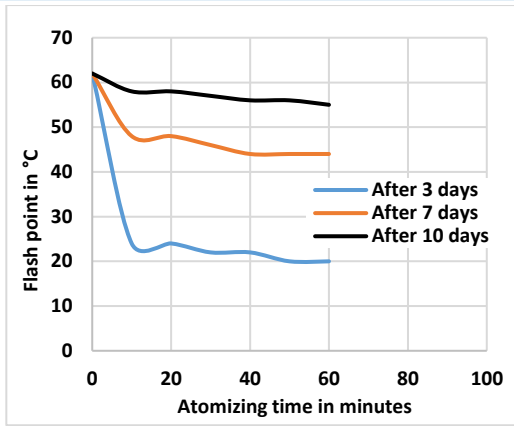


Fig. 8 Flash Point at 30 °C at Different Atomizing Time.

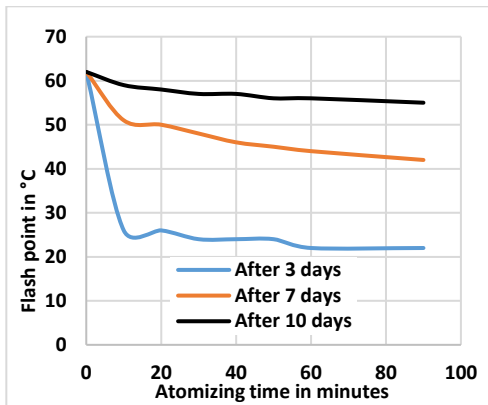


Fig. 9 Flash Point at 40 °C at Different Atomizing Time.

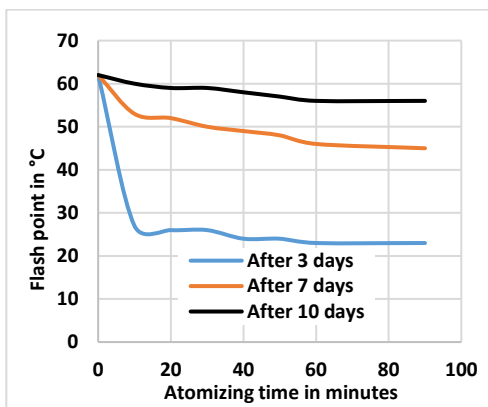


Fig. 10 Flash Point at 50 °C at Different Atomizing Time.

Fig. 5-10, shows the ability of diesel fuel for fast burning depends on its content of light cuts. The increase in fuel temperature leads to the released gas and early combustion when examining the flash point. The early combustion of diesel at low temperatures is undesirable due to the technical problems it causes in the regularity of the movement of internal combustion engines. And since the Iraqi standard specified the flash point at 54 °C minimum. Therefore, when examining the samples' flash points, monitoring the lowest temperature that achieves the required flash point was necessary. In order to get accurate and actual readings of FP, the samples must be

in a stable state by expelling the over-saturation gas by leaving the diesel in open cap bottles for several days. The curves shown in the figure indicate that the lowest temperature of the atomizing of LPG in the diesel that gives the required flash point is 30 °C. The higher the temperature, the better stability of the readings, while the lower one gives diesel out of standard specifications. The stable FP is achieved after 10 days storing. As has been mentioned before the FP should be above 54 °C according to Iraqi Standard Specification which can be achieved after 10 days storing under 30 °C atomizing temperature minimum. Therefore, any storing lower than 10 days is rejected.

3.2.The Effect of Atomizing Process on Diesel Cetane Number (CN)

The value of diesel oil CN is 50 minimum (grade 1) for fast diesel engine and 40 minimum (grade 2) for slow motion engine according to Iraqi Standard Specification no. 1099. Higher CN better burning characterization fuel. The upgrading of CN is expressed by Δ CN which represent the difference between CN of the sample after two months from experiment (stable diesel properties) and before atomizing. The CN for each sample is tested before and after atomizing Table 6. The CN is tested after 2 months storing in order to get a stable accurate value The average (Δ CN) for each range of temperature at different atomizing time is estimated in order to get clear idea about its profile shape, Table 7. Similarly, it is estimated for each range of atomizing time, Table 8. The average (Δ CN) is drawn against atomizing temperature and time Figs. 11, 12.

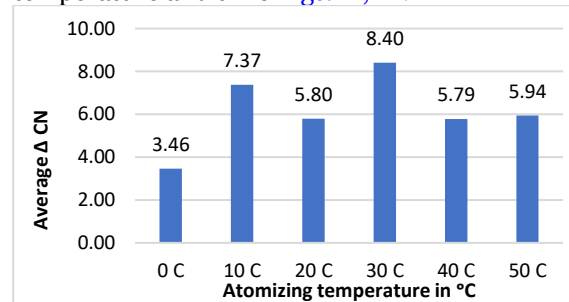


Fig. 11 The Average Δ CN Profile with Respect to Atomizing Temperature.

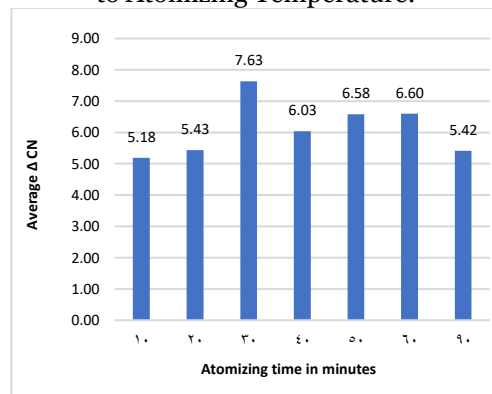


Fig. 12 The Average Δ CN Profile with Respect to Atomizing Time.

Table 5 The Change of Cetane Number (CN) Value with Different Atomizing Temperatures and Time.

Exp. No.	Diesel Temp. °C	Time in minutes	CN before atomizing	CN after 2 months atomizing	Δ CN
1	0	10	42.9	46.1	3.2
2	0	20	42.9	45.5	2.6
3	0	30	42.9	48.2	5.3
4	0	40	42.9	45.9	3
5	0	50	42.9	45.1	2.2
6	0	60	42.9	47.3	4.4
7	0	90	42.9	46.4	3.5
8	10	10	40	46	6
9	10	20	40	45.9	5.9
10	10	30	40	49.4	9.4
11	10	40	40	47.5	7.5
12	10	50	40	47.9	7.9
13	10	60	40	47.9	7.9
14	10	90	40	47	7
15	20	10	40	44.8	4.8
16	20	20	40	44.9	4.9
17	20	30	40	47.3	7.3
18	20	40	40	44.6	4.6
19	20	50	40	46.9	6.9
20	20	60	40	47	7
21	20	90	40	45.1	5.1
22	30	10	40	47.7	7.7
23	30	20	40	48.8	8.8
24	30	30	40	50	10
25	30	40	40	48.7	8.7
26	30	50	40	48.5	8.5
27	30	60	40	48.7	8.7
28	30	90	40	46.4	6.4
29	30	120	40	45.9	5.9
30	40	10	40	46.1	6.1
31	40	20	40	45.6	5.6
32	40	30	40	47	7
33	40	40	40	47	7
34	40	50	40	45.1	5.1
35	40	60	40	43.8	3.8
36	40	90	40	43.5	3.5
37	50	10	40	44.3	4.3
38	50	20	40	48.2	8.2
39	50	30	40	45.4	5.4
40	50	40	40	47	7
41	50	50	40	46.5	6.5
42	50	60	40	46.7	6.7
43	50	90	42.9	46.1	3.2

Table 6 Average Increase of Δ CN with Respect to Atomizing Temperature.

Temp °C	Δ CN
0	3.46
10	7.37
20	5.80
30	8.40
44	5.79
50	5.94

Table 7 Average Increase in Δ CN with Respect to the Atomizing Time in Minutes.

Time in minutes	Δ CN
10	5.18
20	5.43
30	7.63
40	6.03
50	6.58
60	6.60
90	5.42

Fig. 13 shows the profiles of the whole CN changes with different cases of atomizing temperature and time. CN can be directly related to ignition delay, and its estimation is of practical significance. A higher CN of fuel means a lower auto-ignition temperature, which refers to a shorter ignition delay time. It is shown from the figure the samples that have higher gas content have higher CN values. The

higher increase of CN is achieved at 30 °C. Adding gas to diesel fuel affects its properties, including density, calorific value (CV), and cetane number (CN). The CV of diesel should be according to the engine load. The higher CV is, the higher resistance to load. Therefore, the best quality of diesel oil is achieved by looking at CN and CV together. The Iraqi standard specified the calorific value for diesel oil at 43.96 MJ/kg as a minimum, while it is 45.5 MJ/kg for LPG. Since there is not much difference in CV, mixing diesel with gas has no negative impact on the CV. Fig. 12 shows the higher stable CN value is achieved at atomizing temperature 30 °C, while Fig. 13 shows the higher value at 30 – 60 minutes atomizing time. The average upgrade of CN is about 8 units.

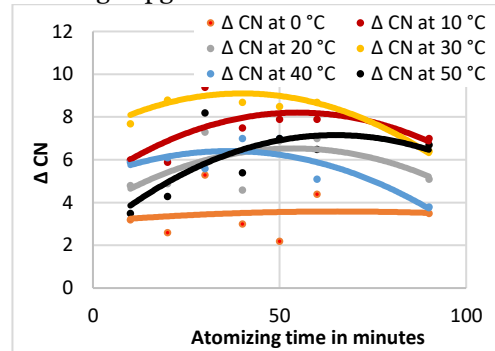


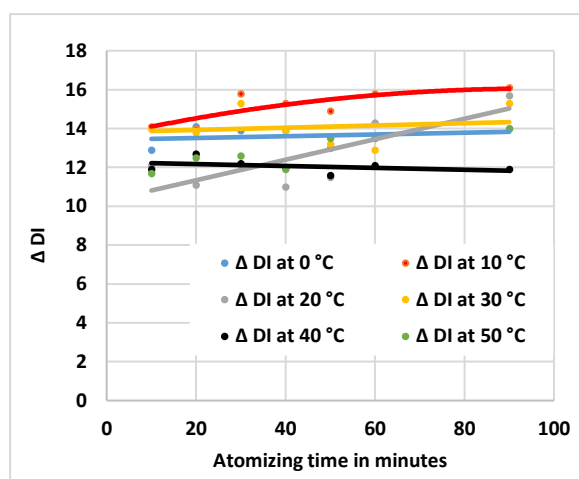
Fig. 13 The Upgrading Profile of Cetane Number with Different Atomizing Time and Temperature.

3.3. The Effect of Atomizing Process on Diesel Index (DI)

The diesel index is a figure which denotes the quality of a diesel fuel, based upon its density and volatility. The value of diesel oil CI is 55 minimum (grade 1) for fast diesel engine and 50 minimum (grade 2) for slow motion engine according to Iraqi Standard Specification no. 1099. The upgrading of DI is expressed by Δ DI which represent the difference between DI of the sample after two months from experiment (stable diesel properties) and before atomizing. The DI for each sample is tested as shown in Table 9. Diesel Index is just the same as Cetane Number. Both denote the Ignition properties of a Diesel Fuel. The Cetane number is calculated based on the percentage of Cetane (Hexadecane) in a combustible mixture having properties the same as that of the Diesel Fuel tested. And Diesel Index is calculated based on the fuel's density and distillation range. The increase in both Diesel Index and Cetane Number indicates good quality fuel. It is shown that there is uniform upgrading of DI with time by about 13 units over the normal diesel value, but there are no significant changes of DI with increasing atomizing temperature. Δ DI is drawn with respect to the atomizing temperature and time as shown in Fig. 14.

Table 8 The Profile of Diesel Index (DI) Changes at Different Temperatures and Atomizing Time.

Exp. No.	Diesel Temp. °C	Time in minutes	DI before atomizing	DI after 2 months atomizing in open bottle	Δ DI
1	0	10	46.1	59	12.9
2	0	20	46.1	60.2	14.1
3	0	30	46.1	60	13.9
4	0	40	46.1	60	13.9
5	0	50	46.1	59.1	13
6	0	60	46.1	59.6	13.5
7	0	90	46.1	60.1	14
8	10	10	46.2	60.3	14.1
9	10	20	46.2	60.2	14
10	10	30	45.2	61	15.8
11	10	40	45.2	60.5	15.3
12	10	50	45.2	60.1	14.9
13	10	60	45.2	61	15.8
14	10	90	45.2	61.3	16.1
15	20	10	48.5	60.6	12.1
16	20	20	48.5	59.6	11.1
17	20	30	48.4	60.5	12.1
18	20	40	48.4	59.4	11
19	20	50	48.5	58.2	9.7
20	20	60	43.9	58.2	14.3
21	20	90	43.9	59.6	15.7
22	30	10	45	61.4	16.4
23	30	20	53.8	60.8	7
24	30	30	55	61.3	6.3
25	30	40	53.7	60.9	7.2
26	30	50	53.5	61.2	7.7
27	30	60	53.7	59.9	6.2
28	30	90	51.4	59.4	8
29	30	120	45	56.9	11.9
30	40	10	45	57.7	12.7
31	40	20	45	57.2	12.2
32	40	30	45	57	12
33	40	40	45	56.6	11.6
34	40	50	45	57.1	12.1
35	40	60	45	56.9	11.9
36	40	90	45	56.7	11.7
37	50	10	45	57.5	12.5
38	50	20	45	57.6	12.6
39	50	30	45	56.9	11.9
40	50	40	45	58.5	13.5
41	50	50	45	58.5	13.5
42	50	60	45	59	14
43	50	90	46.1	59	12.9

**Fig. 14** The Upgrading Profile of Diesel Index with Atomizing Temperature and Atomizing Time.

3.4. Estimation of Gas Absorption Amount

It is shown that optimum operation condition of atomizing LPG in the diesel oil is 30 °C and at atomizing range time 30 – 60 minutes. From

Tables (3, 4), the average amount of absorbed LPG gas is = $(18 + 30) / 2 = 24$ grams. The average specific gravity of Iraqi diesel oil is 0.85. Therefore, the absorption amount of LPG gas which represent 2.8 % of diesel weight. The amount of flowing gas = flowrate of gas × gas specific gravity × atomizing time which is 30 Minutes, the average density of LPG = 1.9 gm/liter. The amount of flowing gas = 9 (liters / min.) × 1.9 (gm/liter) × 30 minutes = 513 gm. The material balance shows that the amount of released gas from bottle during 30 minutes = $513 - 24 = 489$ gm, which represent 95 % of whole gas amount. And absorption is occurred for 5 % only of the atomized gas. The gas absorption percent can be increased on site if the gas pipelines go throw several tanks in series in addition to reducing the bubbles size of the atomizing LPG gas by installing fine dispersion gas distributor.

3.5. The Importance of this Research is in the Following Points

1. It is a new simple gas recovery system for petroleum refineries while investigating heavy petroleum cuts like diesel oil to absorb released light hydrocarbon gases and enhance its burning characterization.
2. Reducing environmentally polluting emissions from conventional crude oil refineries stack due to decrease the burning amount of light hydrocarbon gases by the amount absorbed by heavy diesel oil. Therefore, the research will contribute to reducing global warming up.
3. Can apply the research results on the refinery projects. It provides easy operating conditions of temperature, pressure, and gas flow rate to achieve the highest gas absorptivity by diesel oil. It is done by atomizing the gas under the diesel oil in its storage tanks.
4. No need to make any modifications to the internal combustion engine.

4. CONCLUSIONS

1. The amount of absorbed gas by diesel oil increases with increasing atomizing time. A significant increase in the solubility rates of gas in diesel at low temperatures of 0 and 10 °C, but it has a bad effect on flash point. Increasing the absorbed quantities of LPG gas by diesel is beneficial to some extent because it directly affects the flash point and other combustion specifications, such as cetane number and diesel index. The optimum amount of absorbed gases is achieved at 30 °C.
2. The FP of Iraqi diesel oil should be 54 °C minimum. The FP test for the samples that are prepared at a temperature of 0 – 20 °C is lower than the standard limit. The best practical result is 55 C and is achieved at 30 °C. The higher the temperature, the better stability of the readings, while the

lower one gives diesel out of standard specifications.

- The CN value is affected by higher gas content. The higher increase of CN is achieved at an atomizing temperature of 30 °C for 30 - 60 minutes.
- The increasing gas content in diesel affects other properties like calorific value (CV), which refers to the ability of the fuel to derive a heavy engine load. Since there is not much difference in CV, mixing diesel with gas has no negative impact.
- DI is just the same as CN. Both denote the Ignition properties of a Diesel Fuel. Diesel Index is calculated based on the fuel's density and distillation range. The increase in both DI and CN indicates good quality fuel. The upgrading of DI with time is about 13 units over the standard diesel value.

5. RECOMMENDATIONS FOR FUTURE WORK

- Apply the dual fuel (diesel oil + LPG) on the internal combustion engine and determine its operating performance.
- Develop the absorption process of HCG by using of mixers, packing materials and reduce gas bubble size.
- Determining the effect of gas pressure on absorption rate of HCG.
- Repeat the same procedure steps on refinery residue and investigate its effect on fuel properties.

NOMENCLATURE

CO	Carbon monoxide
CO ₂	Carbon dioxide
H ₂ S	Hydrogen sulfide
NO _x	Nitrogen oxide
HC	Hydrocarbon
MP	Mass Particulate
LPG	Liquefied Petroleum Gas
FP	Flash point
DI	Diesel Index
CN	Cetane number
FGRS	Flare Gas Recovery System
GTL	Gas to Liquid
Δ Wt.:	The increase in weight of diesel oil after atomizing by LPG

ACKNOWLEDGMENTS

The authors expressed their deep thanks and grateful to Prof. Assistant Dr. Mohammad Haseeb Zanganna for helpful discussions. The authors are highly appreciating the helpful support by Drs. Heaven Emad and Mr. Rebwar Krmang head of chemical engineering department. Special thanks to Koya University – Faculty of Engineering – Petroleum Test Lab for providing access to the diesel oil testing lab and the support provided by Mr. Sameer Ameer Saber. We also thank Koya Technical Institute for some testing support.

APPENDIX A

Iraqi Standard Specification of Commercial Liquefied Petroleum Gases LPG

Type of test	General, Physical and Chemical analysis	
No. and Date of standard specification	Iraqi Standard Specification IQS / 1045 – 1988, UDC: 665.723.662 + DANA Gas Specifications	
General Requirements: It is a light hydrocarbon. It is gas at normal temperature and pressure and converted to liquid at high pressure. It should be free from water and solid impurities. It is a mixture of liquefied propane and butane.		
Chemical Test		
No	Test details	Standard Specifications
1	The pH of water that is used for wash the gas	7 – 7.5
2	Content of Sulphur compounds mg/m ³ maximum	343
3	Content of Mercaptane mg/m ³ maximum	110
4	Content of Carbonyl Sulfide mg/m ³ maximum	20
5	Methane content volume % maximum	0 % (Should be free from methane)
6	Ethane content volume % maximum	0.5 in summer 0.6 in winter
7	Propane content volume %	30 – 40 in summer 40 – 60 in winter
8	(Isobutane + Normal Butane) content volume %	60 – 70 in summer 40 – 60 in winter
9	(Pentene + Isopenten) content volume % maximum	2 % for summer and winter
10	Heavier than Pentane, volume content maximum	2 %
Physical Test		
11	Specific gravity at 15.6 °C	0.551 – 0.558 in summer 0.534 – 0.551 in winter
12	Calorific value of Gas in 15.6 °C in Kcal /m ³ IN Mj/kg	27420 – 28250 45.5
13	Calorific value of Liquid in 15.6 °C in Kcal /m ³	11880 - 11912
14	Vapor pressure at 37.8 °C in kilopascal maximum	800 in summer 1000 in winter
15	Volatility (it is the temperature in centigrade at which 95 % evaporated maximum	2.2

APPENDIX B

Iraqi Standard Specification of Gasoil and Diesel Fuel

Grade A: For fast engine

Grade B: For slow engine

Type of test	General, Physical and Chemical analysis	
No. and Date of standard specification	Iraqi Standard Specification IQS / 1099 – 1986, UDC: 662.753.323	
General Requirements: The fuel should be free from any impurities, suspended materials and organic acids. Grade A should be free from any distillation residue.		
Chemical Test		
No	Test details	Standard Specifications
1	Sulfur content mass % maximum	1.0 for grade A 2.5 for grade B
2	Remaining Carbon mass % from 10% residue maximum limit (Rasputin method)	0.2 for grade A 1.5 for grade B
Physical Test		
3	Flash point (Closed pensky-martiense) minimum Grade A Grade B	54 °C 54 °C
4	Kinematic viscosity max. in centistoke at: 40 °C 50 °C	5.5 for grade A and 18 – 12 for grade B at summer and winter respectively 5 for grade A and 12 – 8 for grade B at summer and winter respectively
5	Pouring point maximum	-9 °C for grade A 10 – 0 °C for grade B for summer and winter respectively
6	Diesel Index minimum for: Grade A: Grade B:	55 min. for grade A 50 min. for grade B
7	Cetane Number for: Grade A: Grade B:	50 min. for grade A 40 min. for grade B
8	Remaining Ash minimum mass % Grade A Grade B	0.01 0.1
9	Water and precipitated volume percent maximum for: Grade A: Grade B:	0.05 0.5

REFERENCES

- [1] OPEC. OPEC launches 2022 edition of the World Oil Outlook at ADIPEC. OPEC: UAE; 2022: pp. 411-474.
- [2] Emam EA. **Gas Flaring in Industry: An Overview.** *Petroleum and Coal* 2015; **57**(5):532-555.
- [3] Hadi A-GY. Optimal Chosen for use Gas Flaring. Master Thesis - POLITECNICO DI TORINO; 2021.
- [4] Saleh HE. **Effect of Variation in LPG Composition on Emissions and Performance in a Dual Fuel Diesel Engine.** *Fuel* 2008; **87**(13-14): 3031-3039.
- [5] Almeida ELF. Creating Opportunities for Gas-to-Liquids Projects Through Market Organization. *Petroleum Conference Brazil*; 2003.
- [6] Keshav T, Basu S. **Gas-to-Liquid Technologies: India's Perspective.** *Fuel Processing Technology* 2007; **88**(5): 493-500.
- [7] Devold H. **Oil and Gas Production Handbook: An Introduction to Oil and Gas Production:** Lulu.com; 2013.
- [8] Fahim MA, ALSahhaf TA, Elkilani A. **Fundamentals of Petroleum Refining.** Kuwait: Elsevier B.V.; 2010.
- [9] Ghadyanlou F, Vatani A. **Flare-Gas Recovery Methods for Olefin Plants.** *Chemical Engineering* 2015; **122**(5):66-75.
- [10] Sangsaraki ME, Anajafi E. Design Criteria and Simulation of Flare Gas Recovery System. In: *International Conference on Chemical, Food and Environment Engineering (ICCFEE'15)* Dubai (UAE). 2015. p. 35-39.
- [11] Abuhesa MB. Investigation Into Gas Flaring Reduction in The Oil and Gas Industry. University of Salford, Manchester, UK: SRG; 2010.
- [12] Abdelbagi MNF, AbdelhalimFaiz IA, Mohammad AAMA, Hajahmed UA. Diesel Production Using Gas to liquid Technology. Sudan University of Science and Technology: Sudan; 2018.
- [13] El Shamy AA, Zayed AM. **Gas to Liquids Technology: A Futuristic View.** *TESCE* 2004; **30**(2):89-111.
- [14] Glebova O. Gas to Liquids: Historical Development and Future Prospects. Oxford Institute for Energy Studies: UK; 2013.
- [15] Rahimpour MR, Jokara SM. **Feasibility of Flare Gas Reformation to Practical Energy in Farashband Gas Refinery: No Gas Flaring.** *Journal of Hazards Materials* 2012; **209**:204-217.
- [16] Barati A, Pirozfar V. **Flare Gas Review in Oil and Gas Industry.** *Journal of Biochemical Technology* 2019;(Special Issue 2):71-89.
- [17] Qi DH, Chen, H., Geng, L.M. and Bian, Y.Z.H. **Experimental Studies on the Combustion Characteristics and Performance of a Direct Injection Engine Fueled with Biodiesel/Diesel Blends.** *Journal of Sustainable Bioenergy Systems* 2010; **9**(3): 2985-2992.
- [18] Cao JM, Bian YZ, Qi DH, Cheng Q, Wu T. **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* 2004; **218**(5) :557-565.
- [19] Aydin M, Irgin A, Çelik MB. **The Impact of Diesel/LPG Dual Fuel on Performance and Emissions in a Single Cylinder Diesel Generator.** *Applied Sciences* 2018; **8**(5):825-836.
- [20] Oil M. Liquefied Petroleum Gases. Baghdad 1988: 1-5.
- [21] Oil M. Petroleum products gas oil and diesel fuel for diesel engine. Iraq 2018 : 1-8.