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# NATURAL GAS AS AN ALTERNATIVE FUEL OF DIESEL FOR GENERATION POWER PLANTS

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## Abstract
This study aims to explore the possibility of using flared natural gas as a cheaper and more eco-friendly alternative to diesel fuel at the Tobruk gas power station, since it is readily available from oil and gas fields in Libya. The utilization of gas flare of two gas fields namely Faregh and El Ragouba gas fields have been highlighted. The physical and chemical properties of natural gas and diesel from Faregh and El Ragouba gas fields will be evaluated to assess their suitability for power generation. Data on daily gas flaring volumes is analyzed to evaluate the potential for energy recovery, while the economic feasibility of using flared natural gas as an alternative to diesel is assessed and Faregh and El Ragouba gas fielded. The total gas being flared in the two fields are approximately 6.350 and 0.18 MMSCF/D respectively. The daily output from flare natural gas of Faregh and El Ragouba gas fields gives a significant values of power generation comparing with diesel fuel. Also, the total energy from flare natural gas per day for both gas fields regarded as reliable values as alternative fuel. The calculating heating values of flare natural gas for Faregh and El Ragouba gas fields are 7329.15 Btu/scf and 1248.94 Btu/scf respectively. These values indicate that they fall within the required specifications for the heating value of natural gas fuel used in power plant turbines. Additionally, the Wobbe Index values are consistent with the typical range specified in the literature on natural gas turbine specifications.

**Keywords**: *Diesel, natural gas, flare gas, diesel power plants, diesel engine, power generation.*

**الملخص**
تهدف هذه الدراسة إلى استكشاف إمكانية استخدام الغاز الطبيعي المحروق باعتباره مصدر للطاقة أرخص وصديق للبيئة كوقود بديل لوقود الديزل في محطة طبرق لتوليد القوى، نظراً لتوفره في كلٍ من حقول النفط والغاز في ليبيا. وتتناول الدراسة أيضاً أهمية تسليط الضوء على إمكانية استخدام الغاز المحروق في كلٍ من حقلي الفارغ والراقوبة، حيث تم تقييم كل من الخواص الفيزيائية والكيمائية للغاز الطبيعي بالحقلين بهدف معرفة مدى ملائمتهما لتوليد القوى. لقد تم تحليل الحجوم اليومية المحروقة من الغاز بهدف تقييم القدرة الإنتاجية من الطاقة الناتجة والجدوى الاقتصادية من استخدام الغاز الطبيعي المحروق كمصدر طاقة بديل للديزل في الحقلين. حيث كان الحجم الكلي لحرق الغاز في الحقلين حوالي 6.350 و 0.18 مليون قدم مكعب قياسي لكل يوم لحقلي الفارغ والراقوبة على التوالي. وكان الناتج اليومي من الطاقة التي يتم إنتاجها من الغاز الطبيعي في الحقلين ذات قيم معتبرة وذلك مقارنةً مع وقود الديزل. ومن جهة أخرى تُعد الطاقة الكلية من الغاز المحروق اليومي لكلا الحقلين قيم موثوقة كوقود بديل. وقد أسفرت حسابات القيم الحراريةً للغاز المحروق في حقلي الفارغ والراقوبة 7329.15 و 1248.94 وحدة حرارة بريطانية على التوالي. حيث تشير هذه القيم إلى أنها تندرج ضمن المواصفات المتطلبة للقيم الحرارية

للغاز الطبيعي المستخدم في توربينات محطات توليد القوى، بالإضافة إلى قيم مؤشر ووبي والتي تتوافق مع المدى النموذجي في الأدبيات المنشورة المحددة لمواصفات الغاز الطبيعي المستخدم في التوربينات.

الكلمات الدالة : الديزل، الغاز الطبيعي، الغاز المحروق، محطات قوى الديزل، توربينات الديزل، توليد القوى.

## 1. Introduction

Diesel turbines have wide applications in power generation because of their intrinsic fuel efficiency, robustness, and fuel flexibility. However, because most diesel engines use fossil fuels, especially diesel or heavy fuel oil, they are linked to serious environmental pollution. As a result, many nations forbid diesel power plants because of their high cost of electricity and stringent environmental regulations (Kabeyi and Olanrewaju, 2021). Because of this, manufacturers are now compelled to search for alternative fuels that are more cost-effective, less harmful to the environment, and more efficient. Converting traditional CI engines to dual-fuel (DF) operations is one of the most drastic choices available. With a few exceptions, such as installing a gas mixing and injection system on the fuel intake and lowering the compression ratio, the conversion does not require a whole new engine design. (Kabeyi and Olanrewaju, 2021, 2022; Srinivasan et al., 2019).

Power plants are capable of using a variety of gaseous fuels. Natural gas, oil-associated gas extracted during oil production, chemicals produced in blast furnaces and coke ovens during metallurgical processes, synthetic gases from solid fuel gasification, biogas, biomethane, and so on are examples of gaseous power plant fuels. In terms of primary energy, natural gas is the most prevalent gaseous fuel.(MKabeyi 2012). Natural gas is made up of a variety of gaseous carbohydrates, with methane ($CH_4$) serving as its primary ingredient (Kumar and Majid, 2020). Diesel fuel, which is sadly non-renewable and polluting, is the primary fuel used by diesel engine prime movers in transportation, industry, and diesel power plants (Arefin et al., 2020). As a result, alternative fuel is required to lower pollution and power plant costs from diesel engines (Niemi, 1997). In addition to emitting $SO_x$ and $NO_X$, diesel power plants also produce sulphuric acid through chemical interactions with atmospheric moisture (Barasa, 2020). Fuel made of natural gas can help accomplish this decrease.

However, as the globe deals with global warming due to the increase in carbon dioxide and greenhouse gas concentrations in the atmosphere, gas flaring has become a significant problem. Therefore, global trends are shifting in favour of minimising gas flaring on exploration and production facilities in order to reduce $CO_2$ emissions. This work is significant for the same reason. The gas flaring operations on the Faregh and El Ragouba gas fields will be the subject of the case study chosen for this investigation.

Data from gas fields was collected for this investigation and its potential for recovery was assessed. On an average daily basis, the total gas being flared in the Faregh and El Ragouba gas fields is around 6.350 and 0.18 MMscf/d, respectively. This may be seen as a significant waste of unrealised energy that could have been put towards the production of electricity. This study looks into and assesses the energy potential of gas flaring activities on these sites as a diesel fuel substitute for the power plant in question.

## 2. Study Methodology

The methodology of the research on using natural gas as an alternative fuel for diesel in turbines at the Tobruk power plant involves the following steps:

1- A comprehensive review of existing literature on compressed natural gas (CNG) utilization in power plants will be conducted.
2-Data regarding the use of CNG in power plants, both locally and globally, will be collected from a variety of sources, including scientific journals, and online databases.
3-The study provides an overview of the physical and chemical properties of both natural gas and diesel from both field, comparing their characteristics to assess suitability for power generation.
4-The research focuses specifically on the gas flaring operations at the Faregh and El Ragouba gas fields. Data on the amount of gas being flared daily was collected and analyzed to evaluate its potential for energy recovery.
5-The economic benefits and environmental advantages of using flared natural gas as an alternative to diesel will be evaluated
6-The potential for generating electricity from the recovered flared gas is modeled and analyzed to compare its effectiveness against traditional diesel fuel.

## 3. Tobruk Power Plant Description

### 3.1. Gaseous Fuels Specification

The characteristics of the fuel gas that may be utilized with conventional equipment are described by the fuel data given in Table 1.

Table 1. Fuel gas requirements

| Property | | Requirement |
|---|---|---|
| Wobbe Index ($WI_{ref}$) | Range | 36 – 53 MJ/$m^3$ |
| Fluctuations | Max | ± 10 % with<br>max. gradient 0.5%/s |
| Lower Heating Value (LHV) | Approx. Range | 35 - 50 MJ/kg |
| Fluctuations | Max | ± 10 % |
| Gas pressure | Max | 36 bar abs |
| | Min | Project specific |
| Gas temperature | Min | °C and<br>20 K above dew point of hydrocarbons or water |
| Gas temperature after efficiency heater | Max | 150 °C |
| Composition | | |
| Higher Hydrocarbons (C2+) | | ≥ 0 % vol. |
| Fluctuations | Max | 22 % vol. |
| | Range | 5 - 14 %vol. |
| | Max | ± 0.25 % vol./s abs |
| Hydrogen (H2) | Max | 5 % vol. |
| Higher Hydrocarbons + Hydrogen (C2+ + H2) | Max | 22 % vol. |
| Carbon Monoxide (CO) | Max | 250 ppmv |
| Hydrogen Sulphide (H2S) | Max | 50 ppmv (76 mg/$Nm^3$) |
| | 1st limit | If SCR catalyst installed:<br>< 50 mg/Nm3<br>(<35 ppmv as H2S) |

| | | |
|---|---|---|
| Total Sulphur (S) | 2nd limit | Standard equipment or CO catalyst installed: < 72 mg/Nm3 (<50 ppmv as H2S) |
| | 3rd limit | >200 mg/Nm3 (>140 ppmv as H2S) |
| | Max limit | 7’200 mg/Nm3= 7.2g/Nm$^3$ (5’000 ppmv = 0.5% H2S) |
| Contamination / Trace elements | | |
| Lube oil content | Max | 0.5 ppm wt. |
| Total dust content | Max | 20 ppm wt. |
| particles sizes dm ≤ 5 µm | Max | 19.9 ppm wt. |
| 5 µm < dm ≤ 10 µm | Max | 0.1 ppm wt. |
| dm > 10 µm | Max | 0 ppm wt. |
| Sodium + Potassium (Na + K) | Max | 0.5 ppm wt. |
| Calcium + Magnesium (Ca + Mg) | Max | 2.0 ppm wt. |
| Vanadium (V) | Max | 0.5 ppm wt. |
| Lead + Zinc (Pb + Zn) | Max | 0.5 ppm wt. |
| Nickel (Ni) | Max | 1.0 ppm wt. |
| Total heavy metals (V + Ni +Pb +Zn) | Max | 2.0 ppm wt. |

Source: The information herein is referred to the General Electric Company

### 3.2. Liquid Fuels Specification

The attributes of liquid fuels that may be utilised with standard equipment without additional precautions are described by the fuel data given in Table 2. These fuels are often diesel oils or fuels known as type No. 2 GT. The information in Table 2 pertains to the "Interface Point to Gas Turbine".

Table 2. Liquid fuel requirements

| Property | | Requirement |
|---|---|---|
| Physical properties | | |
| Kinematic viscosity at 40°C | Max | 10 mm2/s |
| | Min | 1.5 mm2/s |
| Density at 15°C | | ---- |
| Pour Point or Cloud Point or Cold Filter Plugging Point | | --- |
| Fuel oil temperature | Max | 45 °C |
| | Min | 10 K above Pour Point |
| Flash Point (Pensky-Martens) | Min | 56°C |
| Distillation: Initial boiling point | Min | 170°C |
| 90% vol. recovered | Max | 365 C |
| Carbon residue (Micro method) of 10% dist. Residue | Max | 0.15 % |
| Calorific value (heating value) | | ---- |
| Composition | | |
| Elementary composition | | ---- |

| | | |
|---|---|---|
| (C), (H), (N) | | |
| Aromatics | Max | 30 % vol. |
| Ash | Max | 50 ppm wt. (0.005 % wt.) |
| Purity | | |
| Water | Max | 200 ppm wt. (0.02 % wt.) |
| Sediment (Filterable dirt) | Max | 100 ppm wt. (0.01 % wt.) |
| Particle size | Max | 35 $\mu$m |
| Trace elements | | |
| Sodium + Potassium (Na + K) | Max | 0.5 ppm wt. |
| Calcium + Magnesium (Ca +Mg) | Max | 2.0 ppm wt. |
| Vanadium (V) | Max | 0.5 ppm wt. |
| Lead + Zinc (Pb + Zn) | Max | 0.5 ppm wt. |
| Nickel (Ni) | Max | 1.0 ppm wt. |
| Total heavy metals (V + Pb + Zn + Ni) | Max | 1.0 ppm wt. |

Source: The information herein is referred to the General Electric Company

## 4. Comparing Natural Gas to Diesel Based

### 4.1. Equivalent Energy

Diesel litre equivalent (DLE), or the quantity of natural gas required to have the same energy content as one litre of diesel, is the unit of measurement that we must use in order to comprehend and compare natural gas and diesel. There are common units of measurement for natural gas.

3 shows the equivalent energy in diesel litre equivalent (DLE) for each of these units:

### 4.2. Energy Content

The energy content of a certain amount of diesel must be taken into account in order to calculate the amount of natural gas required to equal that energy in British thermal unit (BTU) as indicated in Table 3.

Table 3. A comparison between diesel and natural gas

| Natural gas | Diesel Litre Equivalent | Energy content |
|---|---|---|
| 1 GJ | 27.7 litres of diesel | 947,950 BTU |
| 1 kg | 1.462 litres of diesel | 50,020 BTU |
| 1 $m^3$ | 1.032 litres of diesel | 35,300 BTU |
| 1 $ft^3$ | 0.0292 litres of diesel | 1,000 BTU |
| | 1 litre of diesel | 34,210 BTU |

### 4.3. Energy Efficiency

The efficiency of natural gas and diesel engines of similar capacity may differ. Fuel savings estimates ought to take this possible variation into account.

## 5. Utilizing Flare Gas for Power Generation

The use of natural gas combustion to generate electricity has grown in popularity over the past several decades. Pollutant and greenhouse gas emissions are often higher from coal and oil. The process of shifting the energy matrix towards sustainable and renewable sources may be aided and complemented by natural gas. The power generation from flare gas is shown in Figure 1.

## 6. Results and Discussion

The fuel consumption of several natural gas engine types was calculated in comparison to engines that run on diesel. Three things need to be taken into account when comparing the fuel consumption of a natural gas engine to that of a diesel engine:

1. Engine technologies energy efficiency.
2. The various fuels corresponding thermal values.
3. The use guidelines.

Based on the gas consumption and flaring data that was available, this study was carried out on two small gas fields: Faregh and El Ragouba.

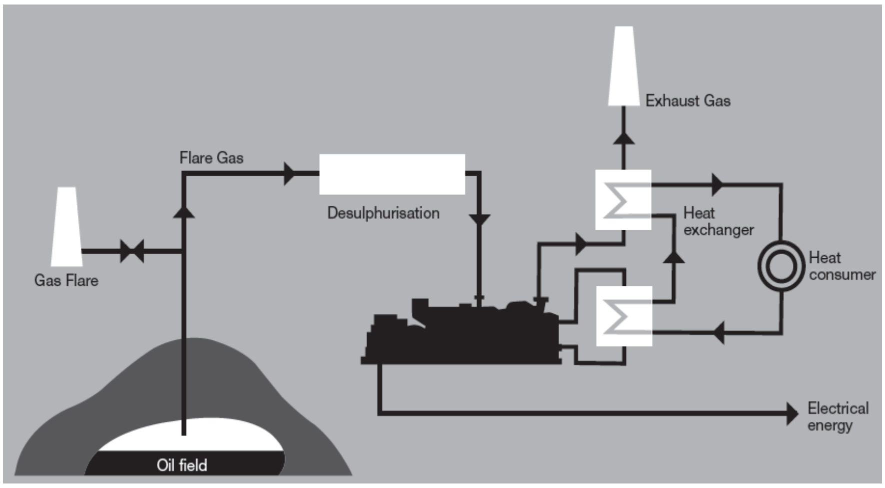


Fig. 1 Generator set producing heat and electricity from flare gas

### 6.1. Gas Consumptions and Flaring at Faregh Gas Field

The Faregh gas field, which consists of Faregh fields I and II, in the Al Wahat region of southern Libya, is the subject of this case study. The research shows the data that is currently accessible, which was gathered from the field and is related to gas flaring volumes. Six,350 of the 63.097 million standard cubic feet of gas produced per day were flared. Table4 and Figure 2 show the Faregh fields (I & II) daily gas output (Waha Oil Company, 2022).

Table 4. Gas consumptions and flaring at Faregh gas field

| Description | Faregh field (MMSCFD) | | Total | |
|---|---|---|---|---|
| | Faregh I | Faregh II | (MMSCFD) | MMCMD |
| Gas produced | 62.527 | 0.570 | 63.097 | 1.79 |
| Fuel gas consumed | 0.227 | 0.120 | 0.347 | 0.0098 |
| Gas to condensate | 0.000 | 0.000 | 0.000 | 0.000 |
| Gas injection | Nil | Nil | Nil | Nil |
| Gas sales | 56.400 | 0.000 | 56.400 | 1.60 |
| Controllable flared | 5.900 | 0.450 | --- | --- |
| Noncontrollable flared | --- | --- | --- | --- |
| Total flare (daily) | 5.900 | 0.450 | 6.350 | 0.18 |
| Annual total flare | 70.8 | 5.40 | 76.20 | 2.16 |
| MMSCFD = Million standard cubic feet per day<br>MMCMD = Million cubic meter per day<br>1 cubic meter = 35.3145 $ft^3$ (cubic feet) | | | | |

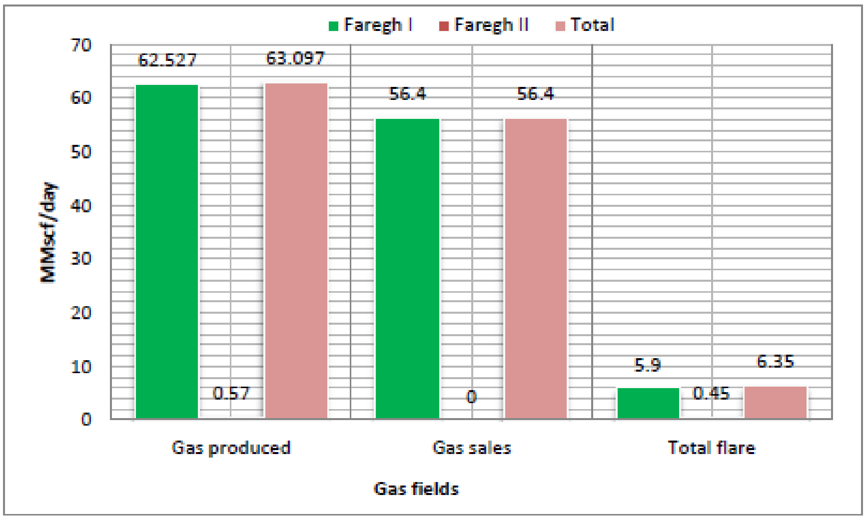


Fig. 2 Faregh gas field production and flaring rates

### 6.2. Gas Consumptions and Flaring at El Ragouba Gas Field

The average yearly gas usage at El Ragouba gas field, comprising the quantity of gas flare, lifting gas, fuel gas, and powering gas, is shown in Table 5 (Sirte oil company, 2022). Figure 3 compares the gas fields under investigation for flaring rate.

Table 5. Annual gas consumptions and flaring at El Ragouba gas field

| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel | 2.00 | 0.20 | 0.10 | 0.10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 1.0 | 1.20 |
| Flare | 13.0 | 11.0 | 0.48 | 0.22 | 0.0 | 0.0 | 0.0 | 0.0 | 0.66 | 12.0 | 14.0 | 13.0 |
| Powering | 0.20 | 0.20 | 0.20 | 0.01 | 0.0 | 0.0 | 0.0 | 0.0 | 0.20 | 0.20 | 0.20 | 0.20 |
| Lifting | 1.10 | 4.80 | 0.13 | 0.13 | 0.0 | 0.0 | 0.0 | 0.0 | 1.18 | 6.90 | 10.0 | 9.60 |
| Total flare/year | 64.36 MMSCF<br>1.82 MMCM | | | | | | | | | | | |
| Average total flare/day | 0.18 MMSCF<br>0.0050 MMCM | | | | | | | | | | | |
| Units | MMSCF = Million standard cubic feet<br>MMCM = Million cubic meter | | | | | | | | | | | |

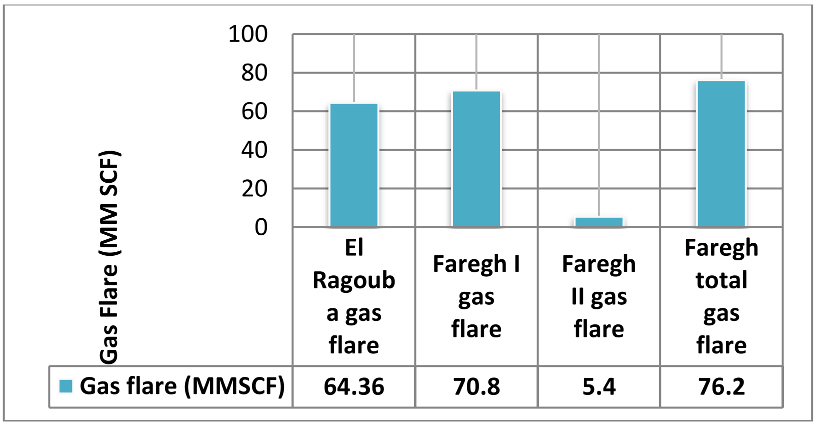


Fig. 3 Flare gas comparison of the investigated fields

### 6.3. Output Power Calculations

The plant output can be calculated as following based on the provided plant data:

- The plant consumed 50 $m^3$ of diesel fuel per hour
- The produced electricity output from 50 $m^3$ diesel fuel = 168 Mw = 168,000 Kw
- Then, the daily output = 168 Mw * 24 hours = 4,032 Mw = 4,032,000 Kw

### 6.4. Energy Calculations for Diesel Fuel

- 1 litre of diesel = 34,210 BTU
- 1 $m^3$ of diesel = 34,210 * 1000 =34,210,000 BTU
- Total energy produced per hour = 50 * 34,210,000 = 1.7 * $10^9$ BTU
- Total energy produced per day = 24 * (1.7 * $10^9$) = 4.105 * $10^{10}$ BTU

### 7.5. Output Power Calculations for Natural Gas

- 1 cubic metre of natural gas =1.032 litres of diesel or,
- 1 litre of diesel = 0.969 cubic metres of natural gas
- Hence, 1 $m^3$ of diesel = 1,032 cubic metre of natural gas
- The required natural gas as alternative fuel of diesel is:
  1,032 cubic metre of natural gas * 50 = 51,600 $m^3$ natural gas/hour
- Required natural gas per day = 51,600 * 24 = 1,238,400 $m^3$
- Hence, 1 kilowatt–hour (kWh) = 3412 Btu
- Then, the daily output from natural gas = 4.37 * $10^{10}$ BTU/3412 Btu = 12812286.05 kWh = 12812.286 Mw = 12.812 GW

### 6.6. Energy Calculations for Natural Gas

- 1 $m^3$ of natural gas = 35,300 BTU
- The total energy required from natural gas per day = 35,300 * 1,238,400 = 4.37 * $10^{10}$ BTU

### 6.7. Energy Calculations from Flare Natural Gas

**Faregh Gas Field**

The total flare of natural gas daily from Faregh gas field = 0.18 MMCM

- The total energy from flare natural gas per day = 35,300 * 0.18 * $10^6$ = 6.35 * $10^9$ BTU

**El Ragouba Gas Field**

The total flare of natural gas daily from El Ragouba gas field = 0.0050 MMCM

- The total energy from flare natural gas per day = 35,300 * 0.0050 * $10^6$ = 1.76 * $10^8$ BTU

### 6.8. Output Power Calculations from Flare Natural Gas

**Faregh Gas Field**

- The daily output from flare natural gas = 6.35 * $10^9$ BTU/3412 Btu = 1861078.55 kWh = 1861.08 Mw = 1.861 GW

**El Ragouba Gas Field**

- The daily output from flare natural gas = 1.76 * $10^8$ BTU/3412 Btu = 51582.65 kWh = 51.58 Mw

Then from the previous it obviously that the daily output from natural gas fuel (12.812 Gw) exceeds the daily output from diesel fuel (4,032 Mw).

On the other hand, the daily output from flare natural gas are 1.861 GW and 51.58 Mw of Faregh and El Ragouba Gas Fields respectively. While the total energy from flare natural gas

per day for both gas fields are $6.35 * 10^9$ BTU and $1.76 * 10^8$ BTU respectively. These findings revealed that the natural gas could be utilized as an alternative fuel of diesel particularly flared gas which is a waste source of energy.
However, Table 6 summarizes the previous obtained findings for natural gas and diesel fuels as well as flare natural gases at investigated oil fields.

Table 6. Output and energy calculations for energy fuels

| Parameter | Unit | Results |
|---|---|---|
| **Diesel Fuel** | | |
| Daily output from diesel fuel | GW | 4.032 |
| Total energy produced per day from diesel | BTU | $4.105 * 10^{10}$ |
| **Natural Gas** | | |
| Daily output from natural gas | GW | 12.812 |
| Total energy required from natural gas per day | BTU | $4.37 * 10^{10}$ |
| **Energy calculations from flare natural gas** | | |
| **Faregh Gas Field** | | |
| Total energy from flare natural gas per day from Faregh Gas Field | BTU | $6.35 * 10^9$ |
| Daily output from flare natural gas | GW | 1.861 |
| **El Ragouba Gas Field** | | |
| Total energy from flare natural gas per day from El Ragouba Gas Field | BTU | $1.76 * 10^8$ |
| Daily output from flare natural gas | GW | 0.052 |

Figure 4 shows the output for the different types fuels and its obviously that the amount of daily output from natural gas fuel exceeds three times (12.812 Giga watt) the output obtained from diesel fuel (4.032 Giga watt). Also, Figure 5 gives the total energy from fuels whereas the amount of energy from natural gas is highest ($4.37 * 10^{10}$ BTU).

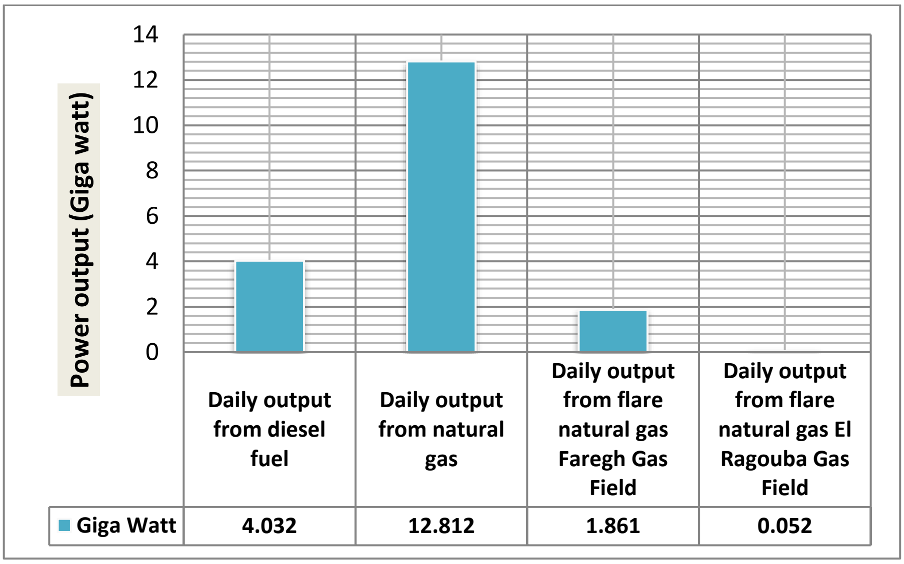


Fig. 4 Power output of different fuels

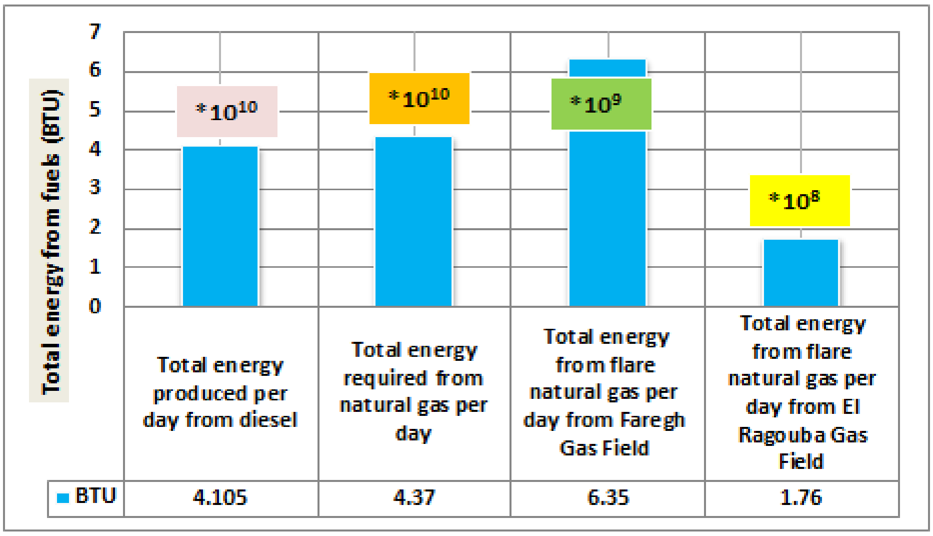


Fig. 5 Total energy from fuels

## 7. Fuels Characterizations

Fuel specifications impact on the engines performance, so these specifications have been taken into account for the assessment of fuel type as following:

### 7.1. Diesel Fuel Characterizations and Specifications

The characterizations and specifications of diesel fuel for power generation of the plant under consideration are listed in Tables 7 and 8. These characterizations and specifications of diesel fuel are coinciding with the parameters of power plant design according to the fluid requirement which presented in Tables 1 and 2.

**7. Table Results analysis of diesel fuel characterizations**

| No. | Analysis method | Characterizations | Results | Units |
|---|---|---|---|---|
| 1 | ASTM D1298 | Specific gravity @15.6/15.6 ℃ | 0.8133 | --- |
| 2 | ASTM D1298 | Gravity (API) @ 60°F | 42.5 | --- |
| 3 | ASTM D1298 | Density @15℃ | 0.8129 | Kg/l |
| 4 | ASTM D445 | Kinematic viscosity @40℃ | 3.00 | Cst |
| 5 | ASTM D86 | Distillation recovery @250℃ | 44.0 | Vol.% |
| 6 | ASTM D86 | Distillation recovery @350℃ | 98.0 | Vol.% |
| 7 | ASTM D86 | Boiling point @95% recovery | 341.0 | ℃ |
| 8 | ASTM D93 | Flash point | 65.0 | ℃ |
| 9 | ASTM D2500 | Cloud point | 3.0 | ℃ |
| 10 | ASTM D97 | Pour point | -3.0 | ℃ |
| 11 | ASTM D5453 | Total sulphur | 0.050 | Wt.% |
| 12 | ASTM D189 | Conradson carbon residue @ 10% | 0.0099 | Wt.% |
| 13 | ASTM D482 | Ash content | 0.0097 | Wt.% |
| 14 | ASTM D974 | Total acid number | 0.005 | mg KOH/g |
| 15 | ASTM D4737 | Cetane index | 60.0 | --- |
| 16 | ASTM D4868 | Gross calorific value | 11015 | Kcal/Kg |
| 17 | ASTM 1500 | ASTM Color | < 0.5 | --- |

Table 8. Results analysis of diesel fuel specifications

| No. | Parameters | Method | specifications | Lower value | Max. value | Average | Units |
|---|---|---|---|---|---|---|---|
| 1 | Specific gravity @15.6/15.6 °C | ASTM D1298 | As report | 0.8141 | 0.8168 | 0.8159 | ---- |
| 2 | Distillation recovery @250°C | ASTM D86 | 65, max. | 32.2 | 38 | 34.8 | Vol.% |
| 3 | Distillation recovery @350°C | ASTM D86 | 85, min. | 90.8 | 97.0 | 95.4 | Vol.% |
| 4 | Boiling point @95% recovery | ASTM D86 | As report | 344 | 348 | 345.9 | °C |
| 5 | Flash point | ASTM D93 | 60, min. | 70.0 | 75.0 | 72.8 | °C |
| 6 | Pour point (summer) | ASTM D97 | 3.0 max. | 0 | 3 | 1.20 | °C |
| 7 | Pour point (winter) | ASTM D97 | 0, max. | - | - | - | °C |
| 8 | Cloud point (summer) | ASTM D2500 | 9, max. | 4 | 6 | 5.00 | °C |
| 9 | Cloud point (winter) | ASTM D2500 | 6, max. | - | - | - | °C |
| 10 | Kinematic viscosity @40°C | ASTM D445 | 2.0-5.0 | 2.70 | 2.94 | 2.87 | cst |
| 11 | Total sulphur | ASTM D5453 | 0.10, max. | 0.051 | 0.056 | 0.05 | Wt.% |
| 12 | Total sulphur | ASTM D974 | 0.10, max. | 0.046 | 0.051 | 0.048 | mgKOH/g |
| 13 | Conradson carbon residue @ 10% | ASTM D189 | 0.15, max. | 0.0097 | 0.0120 | 0.0102 | Wt.% |
| 14 | Conradson carbon residue @ 10% | ASTM D482 | 0.01, max. | 0.0006 | 0.0007 | 0.00062 | Wt.% |
| 15 | Cetane index | ASTM D976 | 50, min. | 61.0 | 62.7 | 62.0 | - |
| 16 | Gross calorific value | ASTM D4868 | 10,600 min. | 11004 | 11010 | 11006 | Kcal/kg |

## 7.2. Natural Gases Fuel Characterizations and Specifications

### 7.2.1. Faregh Gas Field

**1. Natural Gas Chemical Composition**

The hydrocarbon composition of natural gas of Faregh gas field is presented in Table 9.

**2. Natural Gas Critical Properties**

On the other hand, the pseudocritical properties and other characterization parameters such as compressibility factor z and gas specific gravity $\gamma_g$ are calculated in given in Table 9.

Table 9. Chemical composition and critical properties of Faregh gas field

| Components | Mol. fraction $y_i$ | Critical press. $p_{ci}$ (psi) | Critical temp. $T_{ci}$ (˚R) | Mol. weight $M_i$ | $y_i p_{ci}$ | $y_i T_{ci}$ | $y_i M_i$ |
|---|---|---|---|---|---|---|---|
| $CH_4$ | 0.679 | 673.1 | 343.0 | 16.043 | 457.04 | 232.90 | 10.89 |
| $C_2H_6$ | 0.116 | 708.3 | 549.6 | 30.070 | 82.16 | 63.75 | 3.49 |
| $C_3H_8$ | 0.085 | 617.4 | 665.6 | 44.097 | 52.48 | 56.58 | 3.75 |
| $C_4H_{10}$ | 0.015 | 550.7 | 765.3 | 58.123 | 8.26 | 11.48 | 0.87 |
| $C_5H_{12}$ | 0.005 | 489.0 | 845.6 | 72.150 | 2.45 | 4.23 | 0.36 |
| $C_6H_{14}$ | 0.0004 | 439.7 | 914.2 | 86.177 | 0.18 | 0.37 | 0.034 |
| $C_7H_{16}^+$ | - | - | - | - | - | - | - |
| $CO_2$ | 0.047 | 1071.1 | 547.6 | 44.010 | 50.34 | 25.74 | 2.09 |
| $N_2$ | 0.019 | 187.5 | 227.2 | 28.013 | 3.56 | 4.32 | 0.53 |
| $H_2S$ | 0.013 | 493.1 | 672.4 | 34.08 | 6.41 | 8.74 | 0.44 |
| $\sum$ | 0.979 | | | | $p_{pc}$ = 662.88 | $T_{pc}$ = 408.11 | $Mw$ = 22.45 |
| Specific gravity | | | $\gamma_g = Mw/29 = 22.45/29 = 0.77$ | | | | |
| Pseudoreduced pressure ($p_{pr}$) | | | $p_{pr} = \frac{p}{p_{pc}} = \frac{2200}{662.88} = 3.32$ | | | | |
| Pseudoreduced temp. ($T_{pr}$) | | | $T_{pr} = \frac{T+460}{T_{pc}} = \frac{575}{408.11} = 1.41$ | | | | |
| Compressibility factor (z) | | | 0.72 | | | | |

### 7.2.2. El Ragouba Gas Field

**1. Natural Gas Chemical Composition**

Table 10 presents the chemical composition of the utilized natural gas fuel for El Ragouba gas field.

**2. Natural Gas Critical Properties**

On the other hand, the natural gas pseudocritical and pseudoreduced properties were calculated to estimate gas mixture specific gravity (SG), molecular weight (Mw) and compressibility factor (z) as shown in Table 10.

## 8. Natural Gas Fuel Qulaity Inducators

According to the previous data which recorded for both two gas fields in Tables 11 and 12, the quality indicators of these gases have been estimated.

### 8.1. Heating Value Types

1. Higher heating value (HHV): HV with latent heat included. Appears to be low efficiency.
2. Lower heating value (LHV): LV with latent heat excluded. Appears to be high efficiency.
3. Gross heating value = High heating value (HHV).
4. Net heating value = Low heating value (LHV).

Table 10. Chemical composition of gas fuel El Ragouba gas field

| Components | Mol. fraction $y_i$ | Critical press. $p_{ci}$ (psi) | Critical temp. $T_{ci}$ (˚R) | Mol. weight $M_i$ | $y_i p_{ci}$ | $y_i T_{ci}$ | $y_i M_i$ |
|---|---|---|---|---|---|---|---|
| $CH_4$ | 0.761 | 673.1 | 343.0 | 16.043 | 512.30 | 261.02 | 12.21 |
| $C_2H_6$ | 0.109 | 708.3 | 549.6 | 30.070 | 77.21 | 59.91 | 3.28 |
| $C_3H_8$ | 0.050 | 617.4 | 665.6 | 44.097 | 30.87 | 33.28 | 2.21 |
| $C_4H_{10}$ | 0.010 | 550.7 | 765.3 | 58.123 | 5.51 | 7.65 | 5.18 |
| $C_5H_{12}$ | 0.025 | 489.0 | 845.6 | 72.150 | 12.23 | 21.14 | 1.80 |
| $C_6H_{14}$ | 0.004 | 439.7 | 914.2 | 86.177 | 1.76 | 3.66 | 0.345 |
| $CO_2$ | 0.019 | 1071.1 | 547.6 | 44.010 | 20.35 | 10.40 | 0.836 |
| $N_2$ | 0.0015 | 187.5 | 227.2 | 28.013 | 0.281 | 0.341 | 0.042 |
| $H_2S$ | 0.020 | 493.1 | 672.4 | 34.08 | 98.62 | 13.45 | 0.682 |
| ∑ | 1.000 | | | | $p_{pc}$= 759.13 | $T_{pc}$= 410.85 | $Mw$ = 26.59 |
| Specific gravity | | | $SG = Mw/29$ = 26.59/29 = 0.92 | | | | |
| Pseudoreduced pressure ($p_{pr}$) | | | $p_{pr}=\frac{p}{p_{pc}}=\frac{1500}{759.13}=1.98$ | | | | |
| Pseudoreduced temp. ($T_{pr}$) | | | $T_{pr}=\frac{T+460}{T_{pc}}=\frac{570}{410.85}=1.39$ | | | | |
| Compressibility factor (z) | | | 0.87 | | | | |

## 8.2. Calculation Gross Heating Value of Natural Gases

The gross heating values and Wobbe Index of natural gas fuel were calculated and presented in Tables 11 and 12.

The calculating heating values of natural gas for Faregh and El Ragouba gas fields gas fuel is 7329.15 *Btu/scf* and 1248.94 *Btu/scf* respectively. These values demonstrate that are within the range of required and specifications of natural gas fuel heating value for engines of power plants. In General, these index parameters quality are relay on the chemical composition of the natural gas utilized in engines for power plants.

## 8.3. Wobbe Index of Natural Gases

The calculated Wobbe Index for natural gas fuel has been carried out and presented in Tables 11 and 12. The Wobbe Index of a gas fuel with a specific gravity is 0.77 is 8352.34 heating value for Faregh gas field and 1302.11 of specific gravity 0.92 for El Ragouba gas field.

However, these values of Wobbe Index of these specific gravities are ranging within the typical range mentioned in the literature survey of Wobbe index of natural gas engines specifications.

Table 11. Quality indicators for Faregh gas field

| Components | Mole fraction $y_i$ | Gross heating value (Btu/scf) $L_{ci}$ | $y_i L_{ci}$ | Compressibility factor (z) Standard conditions | |
|---|---|---|---|---|---|
| | | | | $z_i$ | $y_i\sqrt{1-z_i}$ |
| $CH_4$ | 0.679 | 1009.7 | 6796.59 | 0.9980 | 0.0304 |
| $C_2H_6$ | 0.116 | 1768.8 | 205.18 | 0.9919 | 0.0104 |
| $C_3H_8$ | 0.085 | 2517.5 | 213.99 | 0.9825 | 0.0112 |

| | | | | | |
|---|---|---|---|---|---|
| $C_4H_{10}$ | 0.015 | 3262.1 | 48.93 | 0.00354 | 0.0150 |
| $C_5H_{12}$ | 0.005 | 4009.6 | 20.05 | 0.00065 | 0.0050 |
| $C_6H_{14}$ | 0.0004 | 4756.2 | 1.90 | 0.00081 | 0.0004 |
| $C_7H_{16}^+$ | ---- | ---- | ---- | 0.00081 | ---- |
| $CO_2$ | 0.047 | 0.0 | ---- | 0.9943 | 0.0035 |
| $N_2$ | 0.019 | 0.0 | ---- | 0.9997 | 0.0003 |
| $H_2S$ | 0.013 | 0.0 | ---- | ---- | ---- |
| $\sum$ | 0.979 | | 7286.64 Btu/scf | | 0.0762 |
| Gross heating value for ideal gas and compressibility factor at standard conditions | | | z = 1- $(\sum_i y_i\sqrt{1-z_i}\,)^2$ = 1- $(0.0762)^2$ = 0.9942 | | |
| Gross heating value as real gas (GHV) | | | $L_c = \frac{L_{c\,ideal}}{z} = \frac{7286.64\ BTU/scf}{0.9942}$=7329.15 *Btu/scf* | | |
| Wobbe Index | | | $WI = \frac{HHV}{\sqrt{SG}} = \frac{7329.15}{\sqrt{0.77}} = 8352.34$ | | |

Table 12. Quality indicators for El Ragouba gas field

| Components | Mole fraction $y_i$ | Gross heating value (Btu/scf) $L_{ci}$ | $y_i L_{ci}$ | Compressibility factor (z) Standard conditions | |
|---|---|---|---|---|---|
| | | | | $z_i$ | $y_i\sqrt{1-z_i}$ |
| $CH_4$ | 0.761 | 1009.7 | 768.38 | 0.9980 | 0.0340 |
| $C_2H_6$ | 0.109 | 1768.8 | 192.80 | 0.9919 | 0.0098 |
| $C_3H_8$ | 0.050 | 2517.5 | 125.88 | 0.9825 | 0.0066 |
| $C_4H_{10}$ | 0.010 | 3262.1 | 32.62 | 0.00354 | 0.0099 |
| $C_5H_{12}$ | 0.025 | 4009.6 | 100.24 | 0.00065 | 0.0250 |
| $C_6H_{14}$ | 0.004 | 4756.2 | 19.03 | 0.00081 | 0.0040 |
| $CO_2$ | 0.019 | 0.0 | 00.0 | 0.9943 | 0.0001 |
| $N_2$ | 0.0015 | 0.0 | 00.0 | 0.9997 | 0.00004 |
| $H_2S$ | 0.020 | 0.0 | 00.0 | - | -- |
| $\sum$ | 1.000 | | 1238.95 Btu/scf | | 0.08944 |
| Gross heating value for ideal gas and compressibility factor at standard conditions | | | z = 1- $(\sum_i y_i\sqrt{1-z_i}\,)^2$ = 1- $(0.08944)^2$ = 0.9920 | | |
| Gross heating value as real gas (GHV) | | | $L_c = \frac{L_{c\,ideal}}{z} = \frac{1238.95\ BTU/scf}{0.9920}$=1248.94 *Btu/scf* | | |
| Wobbe Index | | | $WI = \frac{HHV}{\sqrt{SG}} = \frac{1248.94}{\sqrt{0.92}} = 1302.11$ | | |

## 9. Conclusion

In light of this study the following conclusions can be drawn:

1. The power output and thermal efficiency of engines are strongly influenced by fuel type.

2. The natural gas fuel can be replace the diesel fuel which exceeds the daily output from diesel fuel in power plants.
3. The daily output from flare natural gas of Faregh and El Ragouba gas fields gives a significant values of power generation comparing with diesel fuel.
4. Also, the total energy from flare natural gas per day for both gas fields regarded as reliable values as alternative fuel.
5. Natural gas can be utilized as an alternative fuel of diesel particularly flared gas which is a waste source of energy.
6. Natural gas fuel quality relay on the indicators of heating values (HHV, LHV), and Wobbe index (WI).
7. The calculating heating values of flare natural gas for Faregh and El Ragouba gas fields gas fuel are 7329.15 *Btu/scf* and 1248.94 *Btu/scf* respectively. These values demonstrate that are within the range of required and specifications of natural gas fuel for heating value for turbines of power plants.
8. In General, these index parameters quality are relay on the chemical composition of the natural gas utilized in turbines for power plants.
9. Wobbe Index of a gas fuel with a specific gravity is 0.77 is 8352.34 heating value for Faregh gas field and 1302.11 of specific gravity 0.92 for El Ragouba gas field.
10. However, these values of Wobbe Index of these specific gravities are ranging within the typical range mentioned in the literature survey of Wobbe index of natural gas turbines specifications.
11. Natural gas fuel regards as clean source energy comparing with diesel fuel due to the low emissions of greenhouse gases (GHG) and environmental pollution.

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