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Economic Losses from Flaring Gases in Rumaila Oil Field

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Abstract

Flaring systems used in oil production systems have a significant impact on both the economy and the environment as they discharge large quantities of burned gases of elevated temperature to the atmosphere that have the potential to be used in some applications. This study aims to investigate the economic losses incurred due to the combustion of gases not utilized in the Rumaila oil field in Basrah, the southern region of Iraq. Additionally, the potential to use flare gases for power generation and water desalination was studied. The mathematical models established by the U.S. Environmental Protection Agency (EPA) were utilized in this study to estimate and calculate the expected losses and used MatLab Ver. R22 to get result. The result leads to expected annular economic losses to reach $ 347,735,700. Also, the flare gases can be used to produce electric power of 1175 MW per year, it can be used for producing desalinating water of 115,911,900 m^3 for thermal desalination and 173,867,850 m^3 for membrane desalination.

Keywords: Flaring systems, Rumaila oil field, Environmental Protection Agency (EPA), The annular economic losses.

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1. Introduction

The Rumaila oil field in southern Iraq is widely recognized as one of the largest and most productive oil fields in the Middle East. It is widely recognized as the country's primary source of oil production. The geographical territory spans 1,600 square kilometers, with a length of 80 kilometers and a width of 20 kilometers. In the fourth quarter of 2023, the field's crude oil production had surpassed 1.4 million barrels per day, with an average price of $76.28 per barrel. Due to this factor, the financial imports of this oil field are regarded as the most significant among Iraq's main oil fields [1].

Flare systems are essential safety components in oil and gas facilities, designed to combust excess or emergency gases to prevent the release of hazardous substances into the atmosphere.

Economic research on oil-flaring flares and their impact on the economy is crucial because of the significant financial losses affected by the Rumaila economy and the overall economy of Iraq. Preparing an economic study on oil-flaring systems and their economic effects is one of the most critical matters in the oil production field. This is because incendiary flares, which burn gases that cannot be fully utilized yet, are considered one of the most significant aspects of the economic and environmental damage in Rumaila and Basrah.

Flares used at remote locations, such as upstream oil and gas operations or landfills, are typically air-assisted or without air assistance. On top of that, the techniques didn't take into account the complexity of the design or the costs that are associated with the implementation of a utility safety flare that is designed to accommodate a variety of sources. The expenses that are incurred, particularly those that are associated with the installation, may differ significantly from the prices that are computed due to the specific conditions that exist at the location.

Speight [2], explained that the economic value of gases is based on quantifying their heat content or kinetic energy, directly correlating with their economic worth. Heat content is defined as the amount of energy that can be obtained from the combustion of gases per unit volume, usually measured in British Thermal Units (BTU).

Shayan et al. [3], they examined the environmental impact of properly disposing waste hydrocarbon gases in oil, gas, and petrochemical plants. Several approaches and protocols were developed to adapt flare stack gas-producing equipment to decrease or recover these gases. These approaches face challenges due to the lack of economic justification, systemic risks, and operational restrictions. The four flare gas recovery options were high-pressure steam, steam turbines, power and heat generation, and a combined cycle. These methods were simulated with Aspen HYSYS.

The last three methods generated 732,300; 435,000; and 1,442,000 kW from flaring gases. It conserved energy and reduced pollution. Economics was used to evaluate each method's logic and return. The investment return rates for high-pressure steam generation, steam turbines, electricity, cogeneration, and combined cycle were 18.66, 19.76, 25.79, and 31.97. These data demonstrate the combined cycle method's strong economic return.

Hamidzadeh et al. [4], examined all flare gas recovery technologies, including NGL (Natural Gas Liquid), pipeline injection, GTL, NGH, CNG, EOR, thermal power plant electricity production, and Multiple-Effect Distillation (MED) water generation. They suggested using MATLAB software to simulate flare gas recovery technologies with multi-value specifications to minimize economic costs and CO_2 pollution. They used 70% of dry gas from EOR (4% from the combined cycle power plant) and 80% from gas turbines to produce water. Construction of the proposed technology costs (411 million dollars) and yields 1.08 years.

- **Temperature and BTU:**
- **1 BTU:** Increases the water temperature by 1 degree Fahrenheit.
- **33.8 BTU:** Raises the water temperature by 1 degree Celsius [2].

- **Natural Gas and BTU:**
- **1 Cubic Foot of Natural Gas:** Contains 1031 BTU.
- **Heat Value Range:** The heat value of natural gas can vary between 500 and 1500 BTU, depending on the gas consumption or combustion rate [2].

The objective of the present research is to conduct an economic analysis of the combustion process of surplus gases in the Rumaila oil field located in southern Iraq to estimate the economic losses. Also, flare gas losses can be investigated and used for power generation and water desalination.

2. Rumaila oil field

The Rumaila oil field was developed in the 1950s and had a peak production of over 1.6 Mbps. A contract for technical services for Iraq's Rumaila Oil Field has been granted to BP and PetroChina. The contract started in 2009 for 20 years [5].

As illustrated in Fig. 1, the average oil production during 2023 arrived at approximately 756 mmscf/d and the average oil rate at approximately 1300 mstb/d. Also, as illustrated in Fig. 2, the average surplus arrived at approximately 140 mmscf/d and 95139 scfm [6].

These quantities counted from 14 Rumaila oil field plants and approximately 180 flares. Also, these quantities change depending on the oil produced and the gas rate sent to the Compressing plant.

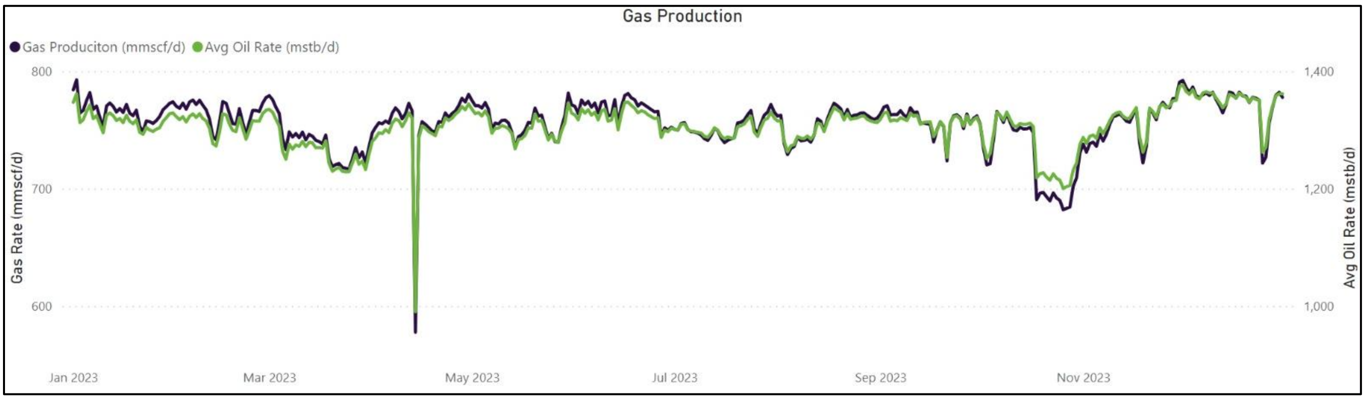


Fig. 1 Average of oil production in the Rumaila oil field through 2023 [7].

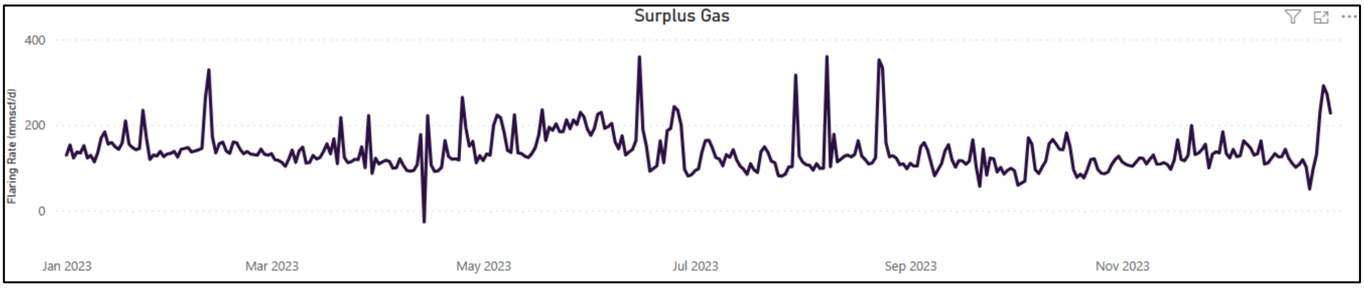


Fig. 2 Average of surplus gas in the Rumaila oil field through 2023 [7].

3. Effective cost factors

Estimating the cost of a flare system for an oil plant involves considering various factors, such as the size and complexity of the facility, regulatory requirements, and specific design considerations [8], [9].

Some factors that can influence the cost of a flare system are explained in Fig. 3. The plant size and capacity can be defined. The scale of the oil plant, including its production capacity and the volume of gases to be handled, will significantly impact the cost, and the design and engineering of the complexity of the flare system's design and the engineering required for compliance with safety and environmental regulations will influence the costs [10].

Also, regulatory compliance adhering to local, state, and international standards is crucial. Compliance with environmental standards, safety codes, and emissions requirements will affect the design and cost.

Moreover, when referring to the flare types, they directly affect the cost (e.g., elevated, ground, enclosed flares) and make varying costs. The selection depends on plant layout, process conditions, and environmental considerations. Flare Gas Composition represents the composition of flared gases that influence the design and materials used in the flare system. Some gases may require more specialized equipment.

Monitoring and Control Systems: one of the advanced control systems for the flare system can add to the overall cost. These systems help optimize flare operations and ensure compliance.

Additionally, the site conditions differ from one location to another, where the location of the oil plant, environmental conditions, and site-specific factors can impact the design and cost of the flare system, and accessibility ease of access for construction and maintenance can affect costs. Remote or challenging locations may require additional resources, and the construction materials used in constructing the flare system, such as stainless steel, carbon steel, or special alloys, can influence costs.

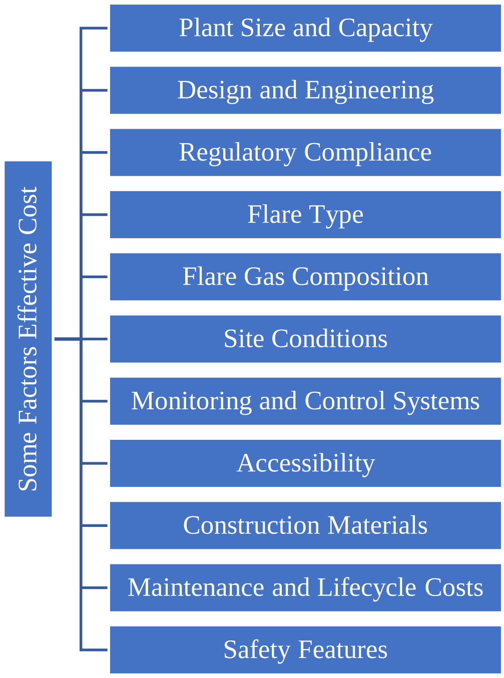


Fig. 3 Some factors that can influence the cost of a flare system [11].

Maintenance and lifecycle cost consideration of ongoing maintenance requirements and the expected lifecycle of the flare system is essential for cost estimation. The last factor is Safety Features; incorporating safety features and redundancy in the flare system design adds to the cost but is crucial for ensuring the reliability of the safety system.

Due to the complexity and site-specific nature of flare systems, it's recommended to involve engineering and design professionals to conduct a thorough analysis and provide a precise cost estimate based on the specific requirements of the oil plant. Engaging with experienced engineering firms or consultants with expertise in flare system design and oil and gas facilities can help ensure accurate cost projections.

4. Standard flare system components

Standard flare system components are frequently used to regulate emissions in emergencies, such as chemical plants and refinery process disruptions. Figure 4 refers to the main items of the standard flare system components. The necessary equipment for a flare depends on the type of flare (ground or elevated) and the method used to improve mixing at the flare tip (such as steam-assisted, air-assisted, pressure-assisted, or non-assisted). A standard flare system comprises several components:

1. A gas collection header and transport piping are needed to gather and transport gases from process units to the flare.
2. A knockout drum (condensate drum) to eliminate and store condensates and liquids carried along.
3. A seal or purge gas supply to prevent the occurrence of flashback.
4. A single or multiple burner unit and stack.
5. Gas pilots and an ignitor to ignite the mixture of waste gas and air.
6. Steam purge gas options include natural, fuel, inert, or nitrogen gas.

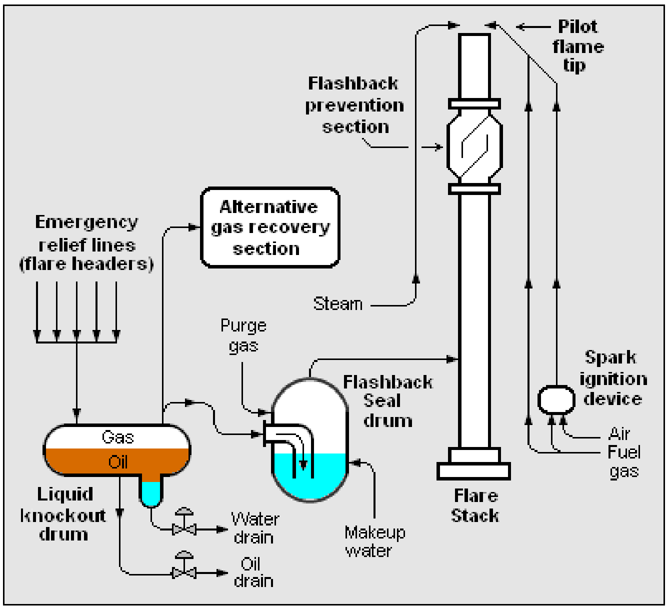


Fig. 4 Standard flare system components.

5. Analysis of the flare system

In analyzing the costs associated with the flare system, two critical factors are the system's design life and the actual operating hours under the required conditions [12]. These aspects are significant in their own right; they would not be noteworthy without each other. Another critical component must be considered is the anticipated maintenance cost required throughout the operation. On top of that, the projected number of operators per hour is another essential aspect that needs to be considered [13].

When attempting to generate a close estimate of the cost of the flare system, it is necessary to consider the cost of several components. This is done to achieve the desired result. These components consist of several different things, such as the composition factor, the flow factor of the compressor, the emission of volatile organic compounds (VOC) per hour, and a few more. Alternatively, we focus merely on the flare system case to determine the total cost without considering other factors.

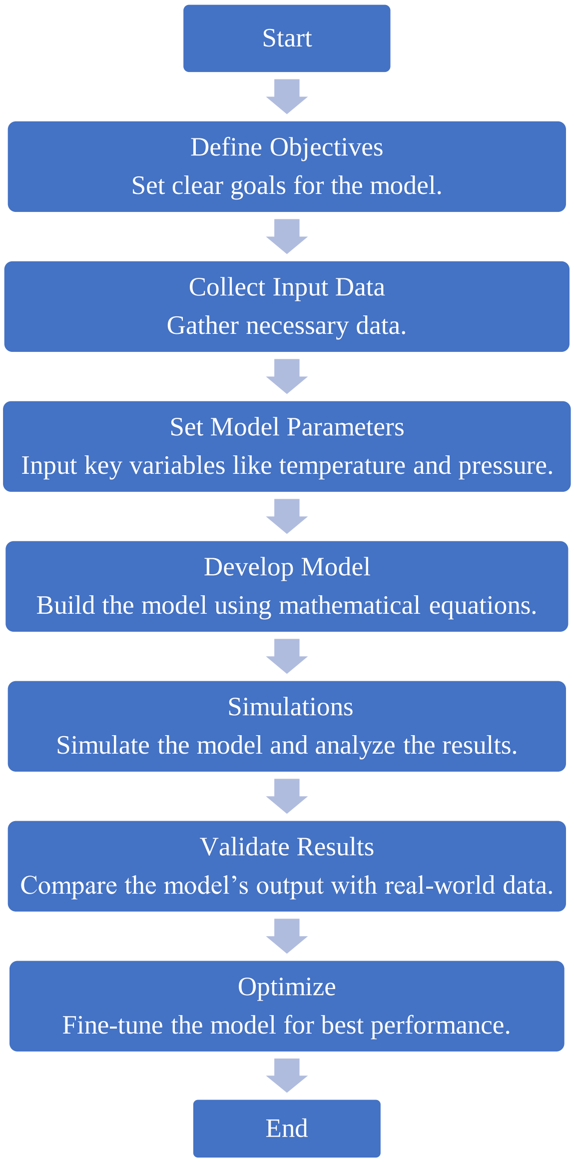
6. Design parameter

To accurately calculate the cost of a flare, it is crucial to have a thorough understanding of the specific design criteria that triggered the inquiry [14]. This knowledge is essential for completing the calculations. Here are a few examples of these personality criteria:

- Gas flowrate.
- Flare tip diameter.
- Height of flare stack.
- Knock-out drum diameter.
- Knock-out drum height.
- Waste gas net heat content.
- Average molecular weight of the waste gas steam.
- Pressure at the waste gas assembly point.

- Temperature.
- Liquid & vapor density.
- Length pipe.

7. Methodology flow chart



8. Economic model

The calculation of economic losses will be utilized in this study using the Environmental Protection Agency (EPA) Model. And used Matlab Ver. R22 to apply this model.

It is necessary to establish the design specifications and compute the initial and recurring costs for elevated flares that employ steam assistance concurrently to initiate the computation.

These kinds of flares are commonly utilized in industrial environments worldwide. Furthermore, the process was specifically designed to generate cost estimates for the research. This section provides a means to calculate the Total Annual Cost (TAC) and Total Capital Investment (TCI). Flares manage waste streams that exhibit continuous, batch, and variable flows and use English units for all equations.

8.1. Total Capital Investment (TCI)

The formula (1) can be utilized to determine the Total Capital Investment (TCI).

$$TCI = 1.89B + C + X + Y \quad (1)$$

Where the cost B (the summation of Instrumentation Costs, Taxes, Freight, and Equipment Costs) is given by:

$$B = I + T_s + F + E \quad (2)$$

Where I (Costs of All instrumentation costs) and given by:

$$I = 0.1\ E \quad (3)$$

Also, the Taxes (Ts) can be given by:

$$T_s = 0.3\ E \quad (4)$$

The item (F) represents the cost of summation of costs of freight equipment and all tools to the site it can get by:

$$F = 0.05\ E \quad (5)$$

Also, the last item (E) represents the cost of equipment and is given by:

$$E = C_f + C_k + C_u + C_{me} + C_p \quad (6)$$

The C_f (Cost of Flare) and C_k (Knock-out Drum Cost) are assumed from:

$$C_f = 1.25(93.6 + 10.97D + 0.899H)^2 \quad (7)$$

$$C_k = 20.5 \times 1.25\left(d \times t\ (h + 0.812d)\right)^{0.737} \quad (8)$$

While the C_{me} (Monitoring Equipment Costs) was taken as the default value where it = 5115 \$, and because the diameter of flare is greater than 1 and smaller than 24, the C_p (Vent Stream Transport Piping Cost) is given by:

$$C_p = 183 \times \frac{L}{100} \times D^{1.21} \quad (9)$$

The C_u (Utility costs) is different from one site to another; therefore, it can be taken as equal to zero as lowercase.

The Contingency Cost (C) formula can be given by:

$$C = CF\ (DC + IC) \quad (10)$$

Where two formulas can give the total direct costs (DC), the second is considered the easy and the faster formula because it is related to the Total Purchased Equipment Costs (B) that are already calculated.

The first considers the general formula:

$$DC = B + (0.57B) + X + Y \quad (11)$$

The second consideration was multi-trial and experimental, and the relation between the total indirect costs (IC) and the total purchased equipment costs (B) was approximately 32%.

$$IC = 0.32\ B \quad (12)$$

8.2. Total Annual Cost (TAC)

An essential concept in economics is calculating the average of gains or losses for years. In this part, the overall annual expenditure associated with the flaring of gases will be computed.

$$TAC = DAC + IAC - RC \tag{13}$$

1. Direct Annual Costs (DAC)

The Direct Annual Costs (DAC) can be given by:

$$DAC = C_{OL} + C_M + C_{AE} + C_{PU} + C_{PI} + C_{AF} + C_{AS} - C_{RE} \tag{14}$$

Where, the C_{OL} (Operating Labor Costs) can be found as below form:

$$C_{OL} = \left(\frac{Operator\ hours}{Year} \times Labor\ rate\right) + Supervisor \tag{15}$$

$Supervisor = 15\%\ of\ Operator.$

Other items can be found below equations:

$$C_M = N_m \times Labor\ rate \times \frac{Operator\ hours}{8\ \frac{hours}{shift}} \tag{16}$$

$$C_{AE} = E_C\ C_E \tag{17}$$

$$C_{PU} = C_{NG}\ P_u \tag{18}$$

$$C_{PI} = C_{NG}\ P_i \tag{19}$$

$$C_{AF} = C_{NG}\ A_f \tag{20}$$

$$C_{AS} = C_S\ S_t \tag{21}$$

$$C_{RE} = C_{NG}\ N_o \tag{22}$$

2. Indirect Annual Costs (IAC)

The cost of the Indirect Annual (IAC) can be given by:

$$IAC = OH + AC + PT + IS + CR \tag{23}$$

Where Overhead (*OH*) = 60% of the sum of the operator, supervisor, maintenance labor plus maintenance materials.

- Administrative Charges (*AC*) = 2% of *TCI*
- Property Taxes (*PT*) = 1% of *TCI*
- Insurance (*IS*) = 1% of *TCI*
- Capital Recovery (*CR*) = *CE* × *TCI*

9. Model parameters settings

It is better to include a detailed table of model parameters settings that outlines the specific values and configurations used in the calculations. Table 1 ensures clarity and transparency, allowing others to understand and replicate the results accurately.

Table 1. Model parameters settings.

Parameters	Calculated value	Units
Flare tip diameter (*D*)	6	inch
Height of flare stack (*H*)	30	ft
Waste gas flow rate	527	scfm
Waste gas net heat	316	Btu/scf
Average molecular weight	821.472	lbs/lb-mol
Pressure at waste gas collection point	12	psig
Liquid density	54.31	lb/ft3
Vapor density	0.0845	lb/cubic feet
Temperature	154.4	°F
Number of operating hours	8640	hours/year
Fraction of heat radiated	0.3	-
Pressure at knockout drum	5	psig
Pressure at the flare tip	2.5	bar
Estimated equipment life	25	Years

10. Input data of economic model

In addition to the factors that were discussed previously, the local part must take into consideration the expense of flaring gasses as well as the impact that they have on the economy. As shown in Table 2, the general input of the Rumaila field is the average value for both the multiple plants located in the field and for a single flare individually.

Table 2. Rumaila field input values.

Items	Value	Units
Waste gas flow rate	527	scfm (at 154.4 °F and 1 atm)
Waste gas net heat content	3351	Btu/scf
Average molecular weight of the waste gas stream (MW)	821.5	lbs/lb-mol
Pressure at waste gas collection point	12	psig
Liquid density (ρ_l)	51.31	lb/cubic feet
Vapor density (ρ_v)	0.085	lb/cubic feet
Temperature (*T*)	154.4	°F
Pressure at knockout drum (P_k)	5	psig
Pressure at the flare tip (P_t)	1	psig
Number of operating hours	8640	hours/year (360 days)
Estimated equipment life (*n*)	25	Years

The waste gas flow rate taken from the average of surplus gas as the operation condition in the Rumaila oil field from 1/1/2023 to 31/12/2023 for one flare and Fig 2. refer to the average of surplus gas in the Rumaila oil field through 2023. Other items depended on the operation condition in the field.

Additionally, the prices of the various expenses are considered, and it is sometimes referred to as a direct cost, while other times, it is considered an indirect cost, as shown in Table 3.

Table 3. Default values of price.

Data element	Default value	Ref.
Natural gas price ($/Mscf)	$4.14	[15]
Operator labor rate ($/hour)	$29.63	[16]
Maintenance labor rate ($/hour)	$25.12	[17]
Steam ($/1,000 lb.)	$7.70	[18]
Electricity ($/kW-hr)	$0.0688	[19]

11. Results and discussion

Based on the input data in Tables 1 and 2, the economic losses predicted by the *EPA* economic model are given in Tables 4 and 5.

The cost of total capital investment (*TCI*) in Table 3 and Fig. 5 was established without site preparation (*X*) and buildings (*Y*) because sites have different operating conditions and sizes and also without utility costs (*CU*).

The total annual cost (*TAC*) is for one flare in the Rumaila oil field. Therefore, to find the total annual cost of the Rumaila oil field, we need to know the number of flares in the Rumaila field and multiply it by the single cost.

Table 4. Total capital investment.

Total Capital Investment (TCI)	Equ.	Cost (1 flare)
Equipment costs	3	$203,517
Flare (*CF*)	4	$149,396
Knock-out drum (*CK*)	5	$1,749
Total purchased equipment costs (*B*)	2	$240,151
Direct installation costs (*DC*)	10	$136,886
Total indirect costs (*IC*)	11	$76,848
Contingency cost (*C*)	9	$45,388
Total capital investment (*TCI*)	1	$499,273

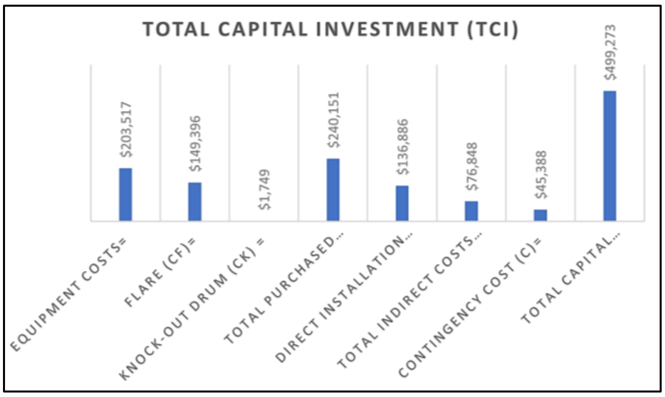


Fig. 5 Total capital investment.

Finally, the total capital investigation for one flare in the Rumaila oilfield can be obtained in Table 4.

Table 5. Total annual cost.

Total Capital Investment (TCI)	Equ.	Cost for single flare
Direct Annual Costs (*DAC*)	13	$1,845,540
Indirect Annual Costs (*IAC*)	14	$86,325
Total Annual Cost (*TAC*)	12	$1,931,865

In 2023, the Rumaila oil field had approximately 180 flares distributed on the 14 plants. Thus, the total annual cost (*TAC*) for flaring waste gases is approximately $ 347,735,700.

11.1. Using economic losses for power generation

This section will explain the opportunity to use the economic losses for power generation.

According to the cost of electricity generation given by the Ministry of Electricity (Iraq) in 2022, the cost of generation of 1 MW is (34.35 USD/MWh), as given in Fig. 6 [20], [21]. The annual economic loss cost of ($347,735,700) can be used for electricity power generation of (1171.679 MWy).

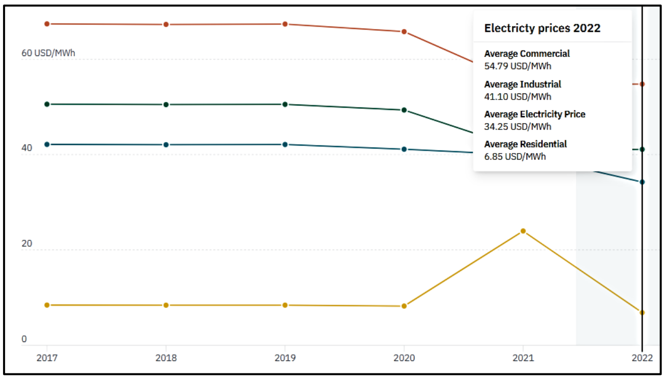


Fig. 6 Cost (MW) in Iraq in 2022.

11.2. Using economic losses for water desalination

Two primary categories can be used to classify water desalination: thermal techniques and membrane processes. There are several distinct methods included in each of these categories. The cost of producing 1 m^3 of distilled water by using thermal desalination ranges from $0.70 to $3.00 per m^3 [22], and the cost for membrane techniques is between $0.50 and $2.00 per m^3 [23]. The economic loss cost of ($347,735,700) can be used for producing desalinating water of 115,911,900 m^3 per year for thermal desalination and 173,867,850 m^3 per year for membrane desalination.

12. Conclusions

This study aimed to analyze the economic losses caused by flaring gases in the Rumaila oil field. Flaring gas, which is the result of the flaring system and is an amendatory component of the oil production facility in the Rumaila oil field, is responsible for the economic losses and the harsh environment that are caused by their major pollution. The Environmental Protection Agency (EPA) Model was utilized in this investigation to estimate the annular cost of flaring systems.

Upon analysis, it was discovered that the overall annular cost was $1,931,865 per flare, and the overall annular cost for the Rumaila oil field was approximately $347,735,700. It is strongly suggested and requested that the applicable investment be utilized to make use of those flared gases (treated gases) in industry, such as in the operation of power plants, water desalination facilities, produced gas re-injection in oil fields, and so on.

Therefor the proposed investment may contribute to the achievement of the zero-flaring stage, which is the stage in which no economic losses or environmental damage are observed. Additionally, it is recommended that the viability of investment activities be investigated because some regions are considered useless, and as a result, the costs of investment are higher than the costs of flaring itself.

The cost of MW of average electricity price per day will reach 295,920 USD/MW in 2022 using the previous cost and paragraphs 10 and 11. Also, obtaining 1175 megawatts per year, or 0.14 megawatts per hour from that or obtaining (381,080 m^3) per day of water desalination. These are examples of an investment in the cost of flaring waste gas in the Rumaila oil field.

Additionally, this cost in other fields can be invested, such as the potential utilization of these costs in a variety of projects, such as the generation of electricity, the operation of desalination facilities, the transmission of these gases to gas compression stations, and the conversion of these gases into liquefied gas after the removal of industrial impurities.

Nomenclate

symbol	Definition
AC	Administrative Charges Cost.
A_f	Total Auxiliary Fuel Consumption.
B	The summation of Instrumentation Costs, Taxes, Freight, and the Equipment Costs.
C	Contingency Cost.
C_{AE}	Annual Electricity Cost.
C_{AF}	Annual Auxiliary Fuel Cost.
C_{AS}	Annual Steam Cost.
C_e	Cost of Electricity.
CE	Cost Effective.
C_f	Cost of Flare.
CF	Contingency Factor.
C_K	Knock-out Drum Cost.
C_M	Maintenance Costs.
C_{me}	Monitoring Equipment Costs.
C_{NG}	Cost of Natural Gas.
C_{OL}	Operating Labor Costs.
C_P	Vent Stream Transport Piping Cost.
C_{PI}	Annual Pilot Gas Cost.
C_{PU}	Annual Purge Gas Cost.
CR	Capital Recovery Cost.
C_{RE}	Annual NG Offset from recovered flare gas.
C_S	Cost of Steam.
C_U	Utility costs.
D	Flare Tip diameter.
d	Knock-out drum diameter.
DAC	Direct Annual Costs.
DC	Total Direct Costs.
E	Equipment Costs.
E_C	Total Electricity Consumption.
F	Summation of costs of freight equipment and all tools to the site.
H	Flare height.
h	Knock-out drum height.
I	Costs of All instrumentation costs.
IC	Total Indirect Costs.
IS	Insurance Cost.
N_m	Expected Number of Maintenance Labor Hours per Shift.
N_o	Natural gas offset.
OH	Overhead Cost.
Pi	Total Pilot Gas Consumption.
P_t	Pressure at the Flare Tip.
PT	Property Taxes Cost.
P_u	Total Purge Gas Consumption.
RC	Recovery Credits.
S_t	Total Steam Required.
T	Temperature.
T_s	Taxes.
TAC	Total Annual Cost.
TCI	Total Capital Investment.
X	Cost of site preparation.
Y	Cost of building construction.
ρ_l	Liquid Density.
ρ_v	Vapor Density.
mmscf/d	Million standard cubic feet per day.
mstb/d	Thousand Stock Tank Barrels per day.
scfm	Standard cubic feet per minute.
BTU	British thermal unit.

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