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Techno-Economic and Environmental Evaluation of Expansion Turbines for Gas Field Improvement (Case study)

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Abstract: Regarding the increased energy consumption of the processes at the operational units in the National Iranian Oil Company, the present study analyzed energy consumption at one of the gas refineries. In this refinery, which is the main supplier of Fajr Jam refinery for the national gas network, as well as an injection into the oil fields of the Iranian South oil company, the pressure of gas after passing through a Joule Thomson valvefrom120 to 70 barg reduced. This pressure drop results in the loss of gas temperature, as a result, temperature decrease to -15 °c. Due to the sudden drop in gas pressure, considerable energy, it will be lost. Replacing the Joule Thomson valve with an expansion turbine to use its recoverable energy was also studied. Based on the results from HYSYS software as well as the refinery's operational conditions, three solutions were discussed. These solutions include (1) using an expansion turbine for power generation, (2) using an expansion turbine to generate electricity and gas condensates, and (3) using an expansion turbine to produce condensates. Based on the technical and economic analysis of the solutions, as well as the results from environmental flow diagram (EFD), which is designed to compare the rates and the sources of the environmental pollutants, the second solution with an internal rate of return (IRR) of 74.53% and a payback period (PBP) of 1.3 years is regarded as the most suitable scenario. Results from EFD indicate that using the second scenario will decrease CO, CO2, and NOX by 57% in this refinery.

keywords: Flare Gas, Expansion Turbine, Economy, Simulation, Environmental Flow Diagram

1. Introduction

Many refineries around the world send a huge amount of gas to the atmosphere by flaring. One of the most attractive methods to improve energy efficiency in oil and gas refineries is flaring gas recovery. The increase in energy efficiency in refineries through gas recovery plans shows that gas recovery is the most attractive way to improve energy efficiency in refineries to reduce greenhouse gas emissions (Comodi, Renzi, and Rossi 2016). Simulation and environmental assessment of the system for the recovery of gases to the flare network stated that flare gases would be harmful to both the environment and the country's economic resources (Vatani 2014). Environmental and economic considerations have increased the use of flare gas systems. Flare gas recovery reduces noise and thermal radiation, as well as operation and maintenance costs. Flare gas recovery (FGR) is an important issue to reduce GHG emissions and environmental pollutants and to prevent hydrocarbon losses at refineries. Two general ways for flare gas recovery is used. The first method needs less possible further operations such as transporting flare gas via pipelines (PNG), flare gas injection into oil and gas reservoirs to capture and sequestration (CCS), and underground gas storage (UGS). In a case study in Nigeria, some researchers studied gas storage by injecting gas into reservoirs and using it at peak demand as one of the ways to prevent burning flare gases (Lawal et al. 2017). Three common ways to reduce flare gas are compression and transmission of gas to the practical point of view, flare gas conversion

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into electricity, and new methods such as a gas-to-liquid technology. In order to reduce gas supply and to implement such methods as GTL production in some of the gas refineries of southern Iran, gas is compressed and re-inject into pipelines, and power is generated using gas turbines (M R Rahimpour et al. 2012; Mohammad Reaza Rahimpour and Jokar 2012). In a recent study in a gas field in southern Iran, three main methods of FGR were designed by the use of an environmental flow diagram and other software to reduce energy consumption and to control environmental pollution. The scenarios were investigated with a technical and economic assessment. Pressurizing and injecting flare gas into oil wells, with an internal rate of return of 171% was the best method to reduce gas flare (Mousavi et al. 2020). Global warming is mainly driven by an increase in carbon dioxide and other greenhouse gases released into the atmosphere. Russia is one of the countries with the highest levels of flaring gas in the world. In a time of domestic and economic insecurity, as well as in Russia's primary export market in Europe, maintaining the status quo to ensure political stability is likely to be prioritized by the authorities at the expense of investments and structural reform which may be a premise to reach the APG utilization goal (Loe and Ladehaug 2012). Another method for power generation from flare gas is to burn the mixture of flare gas and conventional fuel and sending flare gas to an intermediate stage of a gas turbine (Heidari, Ataei, and Rahdar 2016). In recent years some researchers have studied methods to find the best way to reduce flare gas. MCDM is a method to compare options of flare gas recovery. Gas flare recovery via the MCDM method consists of pipeline usage, injection to oil fields, CHP, and liquid fuel production. When availability is the most important criterion, CHP usage is chosen (Bakhteeyar et al. 2014). Integration and use of waste and flared gases with FGN are effective ways to reduce GHG emissions and to conserve energy in refineries. An FGN was proposed for a refinery case study with the integration of flare gas streams (Tahouni, Gholami, and Panjeshahi 2016). A technical and economic evaluation of flare gas recovery in a refinery includes liquefaction, LPG production, and gas compression unit which were investigated by some researchers to select the best method for FGR systems (Hajizadeh et al. 2018). Three methods including GTL, GTG, and GTE were developed for flare gas recovery and, according to the results obtained in a case study, the production of electric power from flaring gases is one of the most economical methods (Zolfaghari, Pirouzfar, and Sakhaeinia 2017).

In recent years some companies have worked on shale oil and gas resources which contribute to increasing oil or gas recovery as well as CO_2 sequestration. There were some studies in the US on feasibility and efficiency of gas injection approaches, including gas flooding and huff-n-puff injection in shale oil/gas/condensate reservoirs, as well as experimental and simulation studies. In each section, one type of shale reservoir is discussed, in which the following aspects are covered: (1) experimental and simulation results for different gas injections; (2) different gas injection mechanisms; and (3) gas injection enhanced oil recovery (EOR) and enhanced gas recovery (EGR). Based on some experimental and simulation studies and some field tests, gas injection is seen as a potential method for EOR and EGR in shale reservoirs. The enhanced recovery factor differs for different experiments with different rock/fluid properties or models including different effects and shale complexities. Based on the simulation studies and successful field pilots, it is possible, through gas injection and huff-n-puff regimes, to capture CO_2 in shale gas reservoirs (Du and Nojabaei 2019). The potential of electricity generation from produced AG was studied and analyzed in a Tunisian oil company. Olga software was used to investigate the possibility of transporting AG into the same pipeline that carries oil and water. In order to investigate the process feasibility, technical, economic, and environmental assessment was performed (Fallah, Belghaieb, and Hajji 2019). Some researchers studied the feasibility of using a turbo expander instead of an expansion valve in a power plant station. They aimed to recover the energy of a gas pressure reducing station in a power plant gas turbine cycle in order to set a refrigeration cycle and to cool the inlet air of gas turbine compressors in a hybrid system of turbo expander (Golchoobian, Taheri, and Saedodin 2019).

This paper aims to study present conditions of a gas refinery and to simulate the process by HYSYS software to reduce energy consumption, to use turbo expander for the three scenarios, and to compare the energy destruction of the processes that may exist. The study attempts to see how much CO, CO_2, and NO_X are decreased in the field by the use of novel EFD, and analyzed three technical and economical methods in order to decrease and improve energy. EFD program was simultaneously used to observe water, soil, and air pollutants and to find a way to decrease them. Unlike other studies, the present study compared economic, technical, and environmental pollution impacts of the scenarios. So, the new EFD program was designed and a solution for all three main pollutions (soil, water, air) was found. To the best knowledge of the authors, all other studies have only focused on one of the pollutions.

2. Material and Method

The gas produced from the fields enters the gas refinery for processing. The refinery process includes finger type clusters to separate gas from liquid, two-phase and three-phase separators, six distillation units of gas with tri-ethylene glycol, a hydrocarbon dew point depression unit, a condensate stabilization unit, a storage tank, a station loading fluid, pig launcher, receiver systems, and condensate pumps as shown in Fig. 1.

The gas produced by the refinery is mainly based on the feed from two gas fields. As required, it can be injected into oil fields for recovery enhancement with a 42-inch 328-km-long pipeline to National Iranian South Oil Company or by 30-inch 26-km-long pipelines and 16-inch 25-km-long pipelines to the gas pipelines No.3 (IGATIII) and 2 (IGATII) for general consumption. Also, the produced condensate is transferred by 8-inch 153-km-long pipelines to Fajr Gas Refinery and from there to Taheri Port for export or by 8-inch 220-km-long pipeline or by tankers to Shiraz Refinery.

Total daily produced gas is 44.9 million cubic meter and gas consumption in furnaces is 29.9 thousand cubic meter per day and, in this situation, the quantity of flaring gas is about 173 thousand cubic meter per day.

In this refinery, energy loss occurs at expansion valves. The process to use this gas pressure reduction with different scenarios is simulated. The process of the refinery is simulated by HYSYS and Thermo Flow software in order to determine the best technology to reduce energy consumption. In addition, in this study, an environmental flow diagram (EFD) was employed based on an energy reference system (RES) and a process flow diagram (PFD) to monitor and reduce air, water, and soil pollution in the study area.

Assumptions made for all scenarios are from National Iranian Oil Company are as follow:

- The number of days taken into account is 330,
- Electricity sales are 0.067 $/ kWh,
- Electricity purchases are 0.036 $/ kWh,
- Condensate price is 120 $ / bbl.
- Flare gas price is 2$/ m^3,
- Atmospheric condition is 14.7 psig.

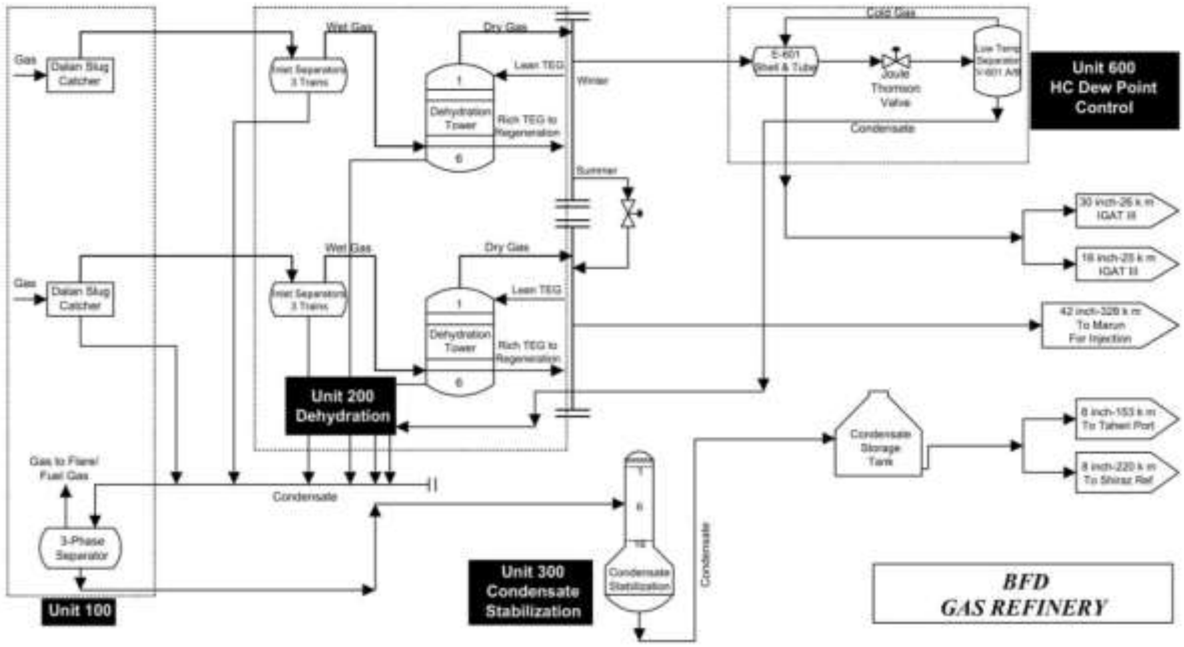

Figure 1. Gas refinery schematic

3. Results and Discussion

The operational process at the dew point adjustment unit is that the output gas from the dewatering unit enters the dew point unit (unit 600). In this section, the pressure of the gas, after passing through a Joule Thomson valve, reduces from 120 to 70 barg. This pressure drop results in a gas temperature reduction to -15 °c (the Joule-Thompson effect). In this case, heavier hydrocarbons turn to liquid and they come out of the gas phase. The resulting two-phase mixture in a separator turns into two phases of gas and condensate. Gas is split and the purity of methane reaches 92%. Due to the sudden drop in gas pressure, there is no 'considerable energy loss' but there will be exergy destruction. One of the suggested solutions is to use gas pressure energy and to install an expansion turbine instead of using a Joule Thomson valve, which makes it possible to define three distinct solutions. These Solutions include:

I- Using an expansion turbine for power generation

II- Using an expansion turbine to generate electricity and gas condensate

III- Using an expansion turbine to produce condensate

Each of these solutions is discussed below and related designs and economic calculation details are given.

I. Using an Expansion Turbine for Power Generation (The First Scenario)

At first, gas enters the gas-gas heat exchanger with pressure about 104 barg and a temperature of 43°c. Then the temperature drops to about 3-4°c and then again, across the pressure breaker valve, pressure drops to 65 barg and temperature to -15°c. The first scenario is proposed on the basis that waste energy in Joule Thomson valve is recovered by replacing the valve by an expansion turbine generator. It is assumed that in this scenario the temperature of the exhaust gas from the expansion turbine is equal to the setpoint as used Joule Thomson valve (-15°c). Therefore, the amount of condensate production is constant. The equipment needed for this situation is shown in Figure 2.

The summary of the results obtained from the preliminary estimation of the production capacity is presented in Table 1.

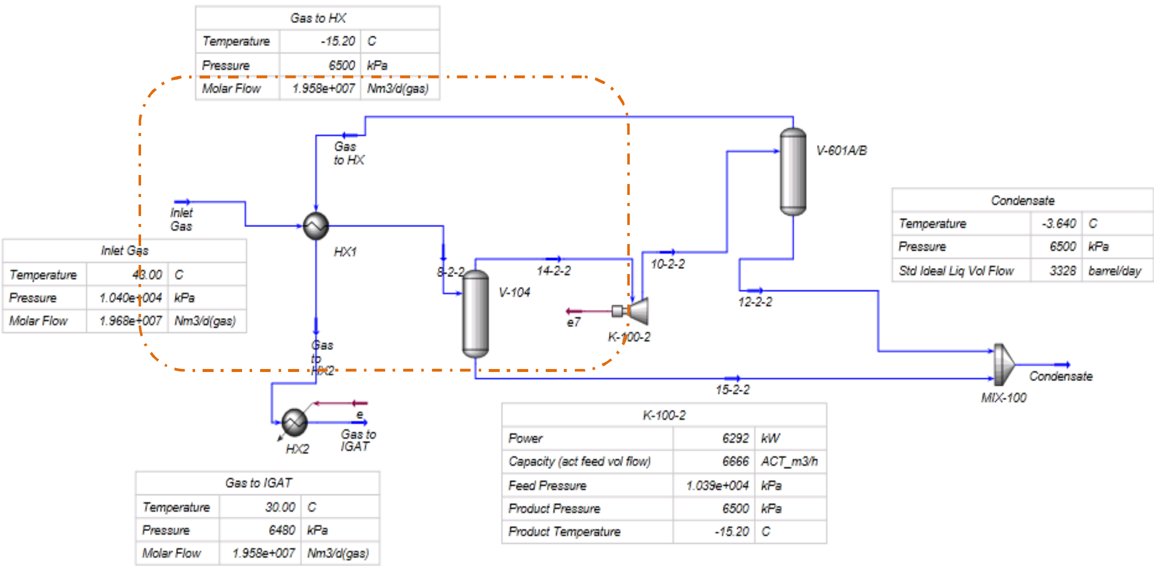

Figure 2. Process flow chart of replacing Joule Thomson valve by an exhaust turbine for power generation

Table 1. Design results for replacing Joule Thomson valve by an exhaust turbine for power generation

Design Specifications	
Output Power (kW)	5662.8
Electricity price ($ / kWh)	0.067

A summary of the results obtained from the economic calculations related to this solution is presented in Table 2.

As indicated by the economic calculations, the amount of return on investment for the proposed strategy is 14.87% and the payback period is 7.77 year. Therefore, based on the result of economic analysis, this solution is not economically feasible.

II. Expansion Turbine for Power Generation and Gas Condensate (The Second Scenario)

In the second scenario, gas energy is put into the dew point setting the unit to generate electricity and to increase the production of condensates by an expansion turbine generator system. In this scenario, it is assumed that the temperature of the gases entering the expansion turbine is equal to the temperature set as used in the Joule Thomson valve (3-4°c). Therefore, the temperature of the exhaust gas from the expansion turbine will be less than its predetermined temperature, which consequently increases the amount of gas condensate production. The amount of power generated in this scenario is less than that of the first scenario. The necessary equipment of the proposed flowchart is shown in Figure 3.

A summary of the results obtained from the preliminary estimation of the production capacity and gas condensate produced is presented in Table 3.

Table 2. Economic results of the first solution

Economic Analysis	
Total Equipment Cost (MM$)	3.50
Zero Time Total Capital Investment (MM$)	9.73
NPV (MM$)	9.06
IRR (%)	14.87
PBP (year)	7.77

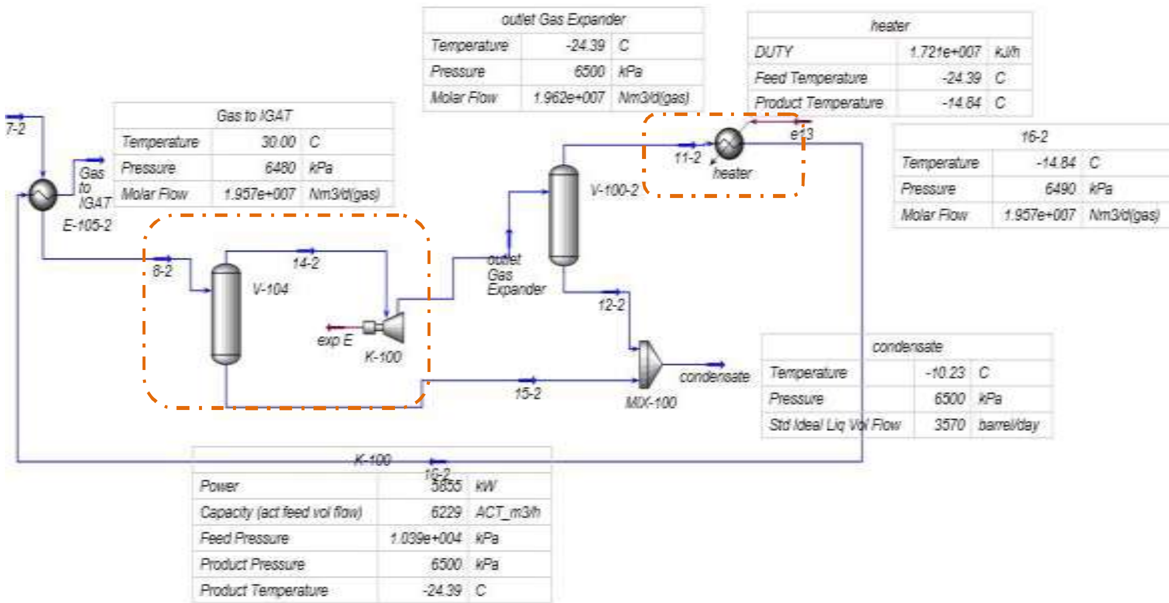

Figure 3. Process flow chart of replacing Joule Thomson valve by an expansion turbine for generating electricity and condensate

Table 3. Estimated power generation for the second solution

Design Specifications	
Output Power(kW)	5270
Increase in Condensate (bbl. / year)	79860
Reduced Gas (Nm^3 / year)	3502860
Electricity price ($ / kWh)	0.067
Condensate Price ($ / bbl.)	120
Gas Price ($ / m^3)	0.2

Table 4 shows the economic calculations for this solution.

The internal rate of return is 74.53% and the payback period is 1.3 year which shows the economic justification of this project.

III- Expansion Turbine in the Production of Gas Condensates (The Third Scenario)

As mentioned, the exhaust gas pressure from the dew point adjustment unit is 65 barg. If the Joule Thomson valve of the unit is replaced by an expansion turbine, it can reduce gas pressure to a value less than the current value (35 barg). Then it increases gas pressure by using an axial compressor with an expansion turbine to an adjusted value.

The necessary equipment of the proposed flowchart is shown in Fig. 4.

Table 5 shows a summary of the design and equipment costs proposed for the third solution.

Table 6 shows a summary of economic calculations for the third solution.

Table 4. Economic calculation of the second solution

Economic analysis	
Total Equipment Cost (MM$)	2.46
Zero Time Capital Investment (MM$)	6.85
NPV (MM$)	72.02
IRR (%)	74.53
PBP (year)	1.30

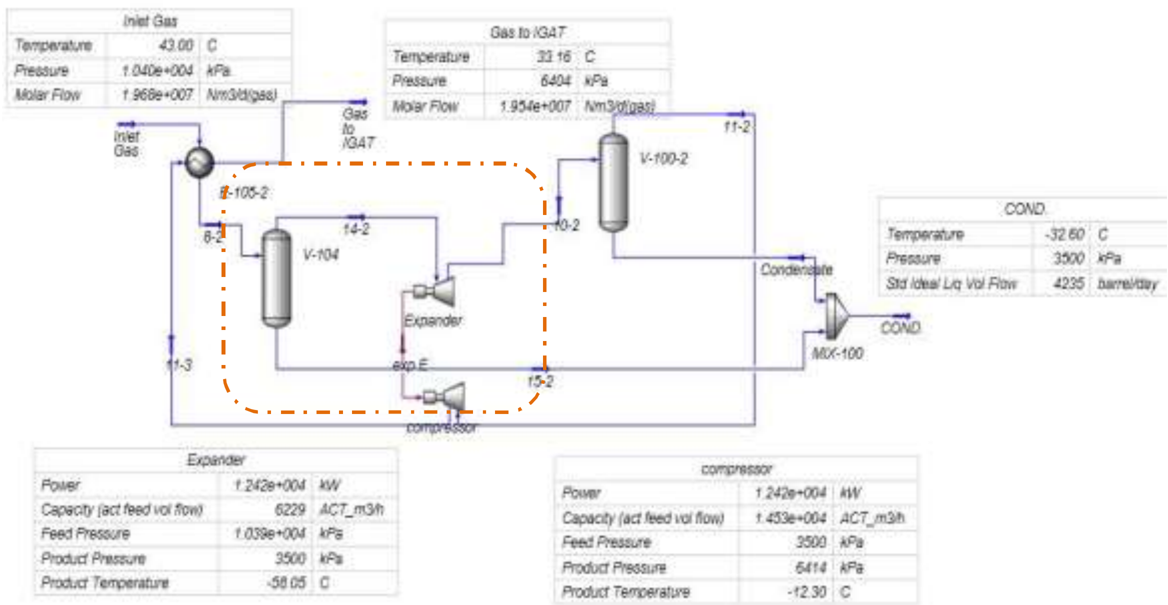

Figure 4. Process flow chart of replacing Joule Thomson valve by expansion turbine for generating condensate

Table 5. Design results and equipment cost of the third solution

Design Specifications	
Increase in Condensate (bbl. / year)	149655
Reduced Gas (Nm^3 / year)	5,606,397
Condensate Price ($ / bbl.)	120
Gas Price ($ / m^3)	0.2

Table 6. Summary of economic calculations for the third solution

Total Equipment Cost (MM$)	8.73
Zero Time Capital Investment (MM$)	24.29
NPV (MM$)	98.85
IRR (%)	62.19
PBP (year)	1.60

This is also a solution with a payback period of 1.60 years and an internal rate of return of 62.19%. Therefore, it is economically feasible.

Since the produced electricity is not suitable to enter the main network, the differences between the payback period (PBP) and the internal rate of return (IRR) in the second and the third scenarios are insignificant. Also, considering that the volume of gas condensate produced in the third scenario is almost twice the second scenario, therefore, the third scenario is economically more desirable than the other two scenarios.

Exergy Analysis

For exergy analysis of this study, the base case with J-T valve and three other cases were simulated and analyzed, and the streams of each case were examined. In this study, in order to change the composition of the streams in the process, the chemical exergy of all the streams was examined along with their physical exergy.

The exergy destruction of the 4 cases and exergetic efficiency of these cases are shown in Table 7.

By definition, exergy destruction is an input exergy minus output exergy.

As indicated by the calculations in all cases, the exergy destruction of the process was reduced. In the third case, to eliminate power generation, the exergy destruction of the process is higher than the other two cases. The first case has the lowest exergy destruction.

IV. Environmental Monitoring Using Environmental Flow Diagram (EFD)

In order to analyze the environmental situation and to monitor and decrease air, water, and soil pollution in this operational area, an environmental flow diagram (EFD) was designed based on a reference energy system (RES) and a process flow diagram (PFD). Using this diagram, the sources and impacts of the potential environmental pollution are identified. The environmental impacts information associated with these sources and pollutants are also shown in the following figure. In the environmental flow diagram, all units are located at different levels of energy, and pollutants are divided according to the pollutant receiving area (air, water, and soil).

The environmental flow diagram of the area shows the sources of pollutants (air, soil, and water) and different levels of energy which makes it possible to manage and reduce each pollutant (Figure 5).

Table 7. Summary of exergy calculation of the scenarios

Case	Feed	Product	Exergy Destruction (kw)
Base case	Ex of inlet gas	Ex gas to IGAT+ Ex condensate	12135
Case 1	Ex of inlet gas	Ex gas to IGAT+ Ex condensate + power generated	3886
Case 2	Ex of inlet gas	Ex gas to IGAT+ Ex condensate + power generated	3942
Case 3	Ex of inlet gas	Ex gas to IGAT+ Ex condensate	6550

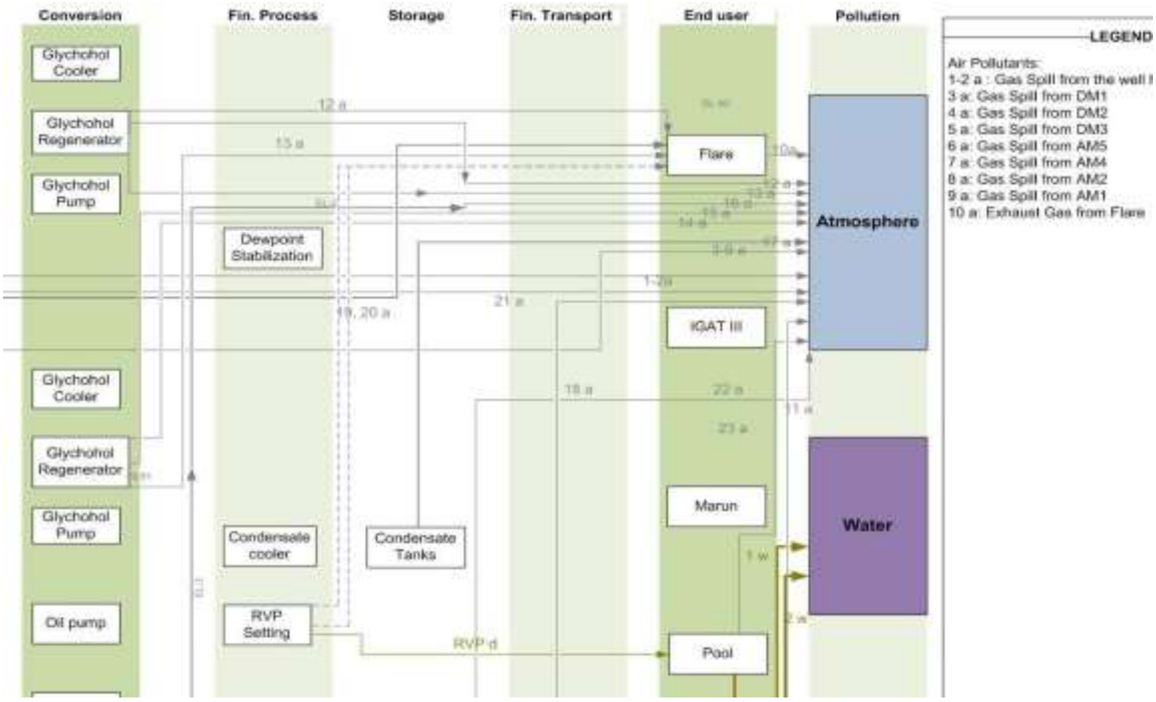

Figure 5. Environmental Flow Diagram (EFD)

There are sources and potentials of water, soil, and air pollution in this refinery. One of the most important environmental pollutants is flue gas in the region. There are 22 flues, which have the potential to pollute the air and the environment. In addition to their discharge into the atmosphere, the wastewater is also discharged without refining or after a slight degradation. Pollution of the soil floor of the evaporation pond and the burn pit are among other sources of pollution in the area. Table 8 shows the number of air pollutants.

Greenhouse Gases and Air Pollutants Reduction and Control

The major sources of air release in this refinery are flares, combustion equipment, and burn pit and dehumidification unit. Decreasing energy consumption in combustion equipment as well as reducing the amount of burned gases in the flame will reduce the greenhouse gas produced from these sources.

Impact of Energy Efficiency Optimization on the Number of Pollutants in the Refinery

By increasing the efficiency of the combustion equipment used in the RVP unit and the dehydration unit, the amount of energy needed in the area can be reduced. Obviously, by reducing energy consumption, pollutants such as carbon monoxide and carbon dioxide will also decrease. The only exception is the increase in NOx of boilers in the dehumidifying unit. NOx increases due to increased flame temperature in incomplete combustion mode. Complete combustion of the flame will increase the temperature, and more NOx will be produced.

Using a compressor to pressurize the gas and send it to the pipeline in order to produce the electricity and steam for the process can decrease gas pollutants as shown in Table 9.

We can see the impact of energy efficiency by using the optimization process as illustrated in Table 10.

4. Conclusion

If an expansion turbine is used for power generation, there will be an investment of 9.7 million dollars, a net present value of 9.06 million dollars, and a payback period of 7.7 year over a 10-year period.

If an expansion turbine is used for the simultaneous production of electrical energy and gas condensate, there will be an investment of 6.9 million dollars, and the payback period and net present value are respectively equal to 1.3 years and 72 million dollars over a 10-year period.

If the expansion turbine is only used to increase the production of gas condensate, the investment will be 24.3 million dollars. In this case, it is estimated that the net present value will be 98.9 million dollars (with 10 years of operation) and the payback period will be 1.6 years as shown in Table 11.

In the third case, to eliminate power generation, the exergy destruction of the process is higher than the other two cases. The first case has the lowest exergy destruction.

Table 8. GHG emissions of CO2 and air pollutants (ton per year)

Pollutant	Boiler	Dehydration	Flare	Burn pit
CO_2	8589.87	11464.6	84510.55	2298.26
CO	101.99	12.96	245.51	162.5
NOx	2.71	4.42	45.12	-

Table 9. Amount of environmental pollutant emissions (ton per year)

Pollutant	Boiler	Dehydration	Flare	Burn pit
CO_2	0	0	36466.79	2298.26
CO	0	0	105.34	162.5
NOx	0	0	19.36	-

Table 10. Comparing emission variations in different parts of the region

Pollutant	Boiler	Dehydration	Flare	Burn pit
CO_2	-100%	-100%	-56.85%	0%
CO	-100%	-100%	-57.09%	0%
NOx	-100%	-100%	-57.09%	0%

Table 11. Summary of the scenarios' economic calculations

	First scenario	Second scenario	Third scenario
Zero Time Capital Investment (MM$)	9.73	6.85	24.29
NPV (MM$)	9.06	72.02	98.85
IRR (%)	14.87	74.53	62.19
PBP (year)	7.77	1.30	1.60

In the air pollution section, some of the pollutants from the source gases are above the environmental standard. The sources are the outlet of combustion chimneys in different units and leakage in transmission units.

The use of a gas compressor to collect and send the gases into pipelines reduces flare pollutants about 57%.

Abbreviations and Symbols

Abb.	Description
EFD	Environmental Flow Diagram
PFD	Process Flow Diagram
RES	Reference Energy System
FGR	Flare Gas Recovery
GHG	Greenhouse Gas
UGS	Underground Gas Storage
GTL	Gas To Liquid
APG	Associated Petroleum Gas
MCDM	Multiple Criteria Decision Making
GTG	Gas Turbine Generator
kW	kilowatt
M^3	Cubic meter
barg	Gauge pressure
exp	expander
CO_2	Carbon Dioxide
Abb.	Description
GTE	Gas To Ethylene
IRR	Internal Rate of Return
LPG	Liquefy Petroleum Gas
CHP	Combined Heat and Power
NPV	Net Present Value
PBP	Pay Back Period
RVP	Reid vapor Pressure
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
ROR	Rate Of Return
$	Us dollar
bbl	barrel
E	exchanger
V	vessel
CO	Carbon Monoxide

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