CHEMICAL ENGINEERING TRANSACTIONS Volume 21, 2010
Editor J. J. Klemeš, H. L. Lam, P. S. Varbanov
 ISBN 978-88-95608-05-1 ISSN 1974-9791
DOI: 10.3303/CET1021021

Improving Energy Efficiency in Natural Gas Refineries, using Exergy Analysis

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Energy conservation is becoming increasingly important in energy intensive industries, including oil and gas refining and petrochemical plants. Economic pressures and rising fuel costs encourage more efficient use of energy within these industries so that operating costs can be reduced. Regulatory pressures are also forcing these plants to become more energy efficient so that CO_2 emissions can be reduced. Nowadays, various methods are applied to natural gas refineries in order to evaluate and reduce energy consumption and GHG emissions, and subsequently bring the operating cost down.
Exergy Analysis is considered to be one of conceptual methods in Process Integration and widely used for evaluation and improvement of energy systems. In this paper, a real life case study (South Pars Natural Gas Plant Phase 2 & 3) have been analyzed using exergy concept, then exergy loss as well as exergetic efficiency have been calculated for the major unit operations. Also, some modifications have been proposed in order to reduce energy consumption. Finally, the project economics have been studied and found to be cost effective.

1. Introduction

Nowadays, development of industries and significant needs of industrial processes to energy from one side and increasing the energy cost from the other side, result in necessity of paying high attention to energy consuming methods and developing an appropriate technique for evaluation. According to the existing statistics, Iran consumes about 9 percent of the oil products in the world while comprises just 1 percent of the world population. In other words, the energy intensity in Iran is amongst the top 5 countries in the world, based on the report published by the International Energy Agency. Because of the large amount of fossil fuels resources in Iran, energy has always been provided cheaper than the other countries which results in inefficient use of energy. Therefore, reviewing and retrofitting of huge energy intensive industries, such as oil and gas refineries is necessary. One of the most appropriate methods to improve energy efficiency is exergy analysis. Exergy Analysis is considered to be one of the

Please cite this article as: Panjeshahi M. H., Harati F. and Nouzari M. M., (2010), Improving energy efficiency in natural gas refineries, using exergy analysis, Chemical Engineering Transactions, 21, 121-126 DOI: 10.3303/CET1021021

conceptual methods in Process Integration and widely used for evaluation and improvement of energy systems.

2. Exergy and Exergy analysis review

In real processes energy is not destroyed, but rather transformed into other forms, less suitable for feeding and driving the processes. Hence, the quality of energy should be evaluated as well as its quantity (Dewulf et al., 2007). The concept of Exergy investigates the ability to perform useful work in a natural environment. Technically, exergy is defined using thermodynamics principles as the maximum amount of work, which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment. Unlike energy, exergy is consumed or destroyed, due to irreversibilities in any real process. Exergy of a system is usually divided to four parts: potential, kinetic, physical and chemical exergy (Rosen, 2008).
There are no clear agreements or rules about efficiency definitions, and authors often use different and sometimes unsuitable efficiency definitions for the same systems. This prevents a logical comparison of results at best, and wrong results at worst (Lior and Zhang, 2007). The exergy method is useful for improving the efficiency energy-resource use, as it quantifies the locations, types and magnitudes of wastes and losses. Therefore, exergy analysis identifies the margin available to design more efficient energy systems by reducing inefficiencies (Kanoglu et al., 2007). Exergy can be used to assess and improve energy systems, and can help to better understand the benefits of utilizing green energy by providing more useful and meaningful information than energy provides (Dincer et al., 2001).

3. Exergy analysis - Case Study

In this work, the exergy analysis of a case study of South Pars Gas Plant Phase 2 & 3, have been studied. This gas field is in the border line of the Iran and Qatar in the Persian Gulf water. Phases 2 and 3 of this gas field have been started working in 2002. The design capacity of this gas plant is 50 million cubic meter of treated gas, 80,000 barrels of gas condensates and 400 tons of sulphur.
For exergy analysis and calculating the waste work in a gas refinery, an appropriate method of exergy balance has been used in this study. For this analysis, all the units of the refinery have firstly been studied based on the process simulation and existing flow data and then, chosen volume controls in each unit has been studied which may consist of one equipment or some more.
For this purpose, the Eq. (1) has been used:

$$\sum_{\text{Streams}} EX_{in} + \sum (EX_Q)_{in} + \sum W_{in} = \sum_{\text{Streams}} EX_{out} + \sum (EX_Q)_{out} + \sum W_{out} + \sigma T_0 \tag{1}$$

$$\sum_{\text{Streams}} EX_{in} + \sum (EX_Q)_{in} + \sum W_{in} = \sum_{\text{Streams}} EX_{out} + \sum (EX_Q)_{out} + \sum W_{out} + \sigma T_0$$

The equations for calculating physical and chemical exergies are shown by Eq.s (2) to (5):

$$EX_i^{PH} = (H_i - H_i^0) - T_0(S_i - S_i^0) \tag{2}$$

$$\Delta EX_{PH} = \left(\sum_{Streams} EX_{in}^{PH} - \sum_{Streams} EX_{out}^{PH} \right) + \left(\sum W_{in} - \sum W_{out} \right) \tag{3}$$

$$\Delta EX_{OR} = \sum_{Streams} G_{in} - \sum_{Streams} G_{out} = \sum_{Streams} \sum_{Components} (n_k g_k)_{in} - \sum_{Streams} \sum_{Components} (n_k g_k)_{out} \tag{4}$$

$$\Delta EX_{OC} = \sum_{Streams} \left(n_{in} \overline{R} T_0 \sum_{Components} (x_k Ln x_k) \right) - \sum_{Streams} \left(n_{out} \overline{R} T_0 \sum_{Components} (x_k Ln x_k) \right) \tag{5}$$

Finally, the exergy loss in each control volume is calculated by Eq.(6):

$$\sigma T_0 = \Delta EX_{PH} + \Delta EX_{OR} + \Delta EX_{OC} \tag{6}$$

$$\Delta EX_{PH} = \left(\sum_{Streams} EX_{in}^{PH} - \sum_{Streams} EX_{out}^{PH} \right) + \left(\sum W_{in} - \sum W_{out} \right))$$

To evaluate the exergy efficiency, two approaches have been studied here: (1) Stream-wise approach (Eq. 7) and (2) Sink-source model approach, which is more accurate in cases, if could be calculated (Eq. 8):

$$\eta_{Ex} = \frac{\sum_{Streams} EX_{out}^{PH} + \sum W_{in}}{\sum_{Streams} EX_{in}^{PH} + \sum W_{out} + \Delta EX_{OR} + \Delta EX_{OC}} \tag{7}$$

$$\eta_{Ex} = \frac{\Delta EX_{Sink}}{\Delta EX_{Source}} \tag{8}$$

The major units which have been analyzed in our study are: Primary Separation (100), Sweetening (101), Glycol Recovery (102), Condensate Stabilization (103), Dehydration and Mercury Removal (104), Dew Point Control and Mercaptan Removal (105), Propane (107), Sulphur Recovery (108), Sour Water Treatment (109), Liquid Gas Treatment (114), Gas Pressure Compression (106), Power Production (120), Steam Production (121), Air Centrifugal Compressors (123).

Besides of the whole units calculations, different equipments in each unit such as slugcatcher, drums, absorption and recovery columns, heat exchangers, pumps, compressors, filters, gas turbines, air coolers, boilers, deaerators, incinerators and etc. have been analyzed separately or with some other equipments as control volumes.

Detailed exergy analysis of all units and their control volumes have not been reported here, due to the large amount of calculations. However, according to the obtained results, the most exergy losses in this case study are in Amine Recovery Column, Absorption Column, Air Coolers, Recovery Column Reboilers, Glycol Flash Drums, Incinerator of Sulphur Recovery Unit, Boilers and finally Gas Turbines of Power Production Unit (120) and Gas Turbines of Gas Pressure Compression Unit (106). Because of the significant exergy loss in the gas turbines of unit 120, one of their exergy calculations based on the mole balance, calculated the exergy of reaction and exergy of inlet and outlet streams is shown in Table 1.

4. Suggestion for Efficiency Improvement of Units 106 & 120 Gas Turbines

Approximately, more than 60 percent of fuel is consumed in gas turbines and boilers of a gas plant. Pre-heating the inlet combustion air by hot emissions is an efficient method for improving the efficiency of process. The common fuel saving with this method is between 8 to 18 percent. Also, applying the modern incinerators and perfect maintenance of the system would result in energy saving as well as emission reductions. Since the gas plant needs a high pressure steam, another efficient method for exergy loss reduction in these equipments, is converting the boiler feed water to a high pressure steam by using high temperature gases emitted from the turbines. This approach has been proposed for gas turbines of units 120 and 106 in this paper.

Table 1: Exergy efficiency calculation for the gas turbine of unit 120

Item No.	120-GT-101 A				
Service	Generator Gas Turbine				
Ex(in)	Ex(FG(1))	405.744	kJ/kg	1704.125	kW
Ex(OR)				-176596.9	kW
W(out)				41370	kW
Ex(out)	Ex (Flue Gas)		kJ/kg	37658.3	kW
σT0	Ex(in)-Ex(OR)-ExQ(out)-Ex(out)-W(out)			99272.69	kW
η_{EX}	(W / Ex(In))*100			23.20234	%

For each equipment, some suggestions have been proposed to improve the efficiency and reduce exergy loss. The suggestion for gas turbines of Gas Pressure Compression Unit (106) and Power Production Unit (120) are discussed more in next part owing to their importance.

There are four and three gas turbines in unit 120 and 106, respectively, therefore, four heat exchangers for unit 120 and three heat exchangers for unit 106 have been considered. Outlet emissions from unit 120 with 551°C and from unit 106 with 538°C and boiler feed water with 130°C enter to heat exchangers of each unit. By reducing the emissions temperature to 200°C , a high pressure steam by 385°C could be produced. By simulating these heat exchangers with Hysys software, considering this fact that only three turbines of unit 120 and two turbines of unit 106 work simultaneously, 242,070 kg/hr and 108,040 kg/hr high pressure steam will be produced in units 120 and 106, respectively, which means 1,8759,192 kJ/hr and 11,505,348 kJ/hr energy saving for producing this amount of steam by a boiler. Applying these improvements, exergy efficiency of a gas turbine of unit 120 and 106 are increased from 23% to 37% and 26% to 46%, respectively. In addition, their thermal efficiency improved about 14%.

The calculations for modified gas turbine of unit 120 are shown in Table 2. It should be noted that the calculations for gas turbine of unit 106 are the same as unit 120.

5. Economic survey

The average natural gas sales price in the September and October of 2009 in Iran was 4 $/MMBTU. Based on the heat energy saving calculated for each unit in previous part and according to the 92 percent efficiency of boilers, 20, 390, 426 and 12,505,813 kJ/hr heat value of inlet fuel to the boilers would be reduced. Hence, by avoiding fuel consumption in boilers for providing this amount of produced high pressure steam in these modified units and based on the 8000 working hours per year and above mentioned natural gas price, about 618,418 $ and 379,288 $ would be saved yearly in units 120 and 106, respectively.

Table 2: Exergy efficiency calculation for the modified gas turbine of unit 120

Item No.	120-GT-101 A MODIFIED				
Service	Generator Gas Turbine				
Ex(in)	Ex (BFW)	72.5	kJ/kg	1624.725	kW
	Ex(FG(1))	405.744	kJ/kg	1704.125	kW
Ex(OR)				-176596.9	kW
Ex (Out)	Ex (HP Steam)	1193.34	kJ/kg	26742.75	kW
ExQ(out)		0	kJ/kg	0	kW
W(out)				41370	kW
Ex(out)	Ex (Flue Gas)		kJ/kg	6252.4	kW
σT_0	Ex(in)-Ex(OR)-ExQ(out)-Ex(out)-W(out)			105560.6	kW

For calculating fixed capital investment needed for equipments procurement, engineering, construction and start up the heat exchangers of these two units, the output diagrams of Aspen Icarus Software has been applied. The costs have been up to dated with the help of Marshall & Swift Equipment Cost Index. The total capital cost and payback period are shown in Tables 3 and 4, respectively.

Table 3: Total capital cost

No.	Unit	No. of Heat Exchangers	Equipments Procurement Cost ($)	Fixed Capital Cost ($)	Total Capital Cost ($)
1	120	4	373,824	1,495,296	1,759,171
2	106	3	280,368	1,121,472	1,319,378
3	total	7	654,192	2,616,768	3,078,550

Table 4: Payback period

No.	Unit	Total Capital Cost ($)	Saving ($/year)	Payback (year)
1	120	1,759,171	618,419	2.84
2	106	1,319,378	379,288	3.4
3	total	3,078,550	997,707	3

Therefore, this modification can save energy by 997,700 $/year, while the required investment will be paid back in about 3 years.

6. Conclusion

In this paper, first a brief description of exergy and its meanings and usages has been reviewed. As a case study for exergy analysis, Phase 2 & 3 of South Pars Gas Plants in the Persian gulf were chosen and major unit operations such as Primary Separation, Sweetening, Glycol Recovery, Condensate Stabilization, Dehydration and Mercury Removal, Dew Point Control and Mercaptan Removal, Propane, Sulphur Recovery, Sour Water Treatment, Liquid Gas Treatment, Gas Pressure Compression, Power Production, Steam Production, Air Centrifugal Compressors and also their related equipment analyzed, in order to identify energy consumption bottlenecks. The exergy loss calculation for the gas turbine in Power Production Unit proposed as a sample.

According to the obtained results, most exergy losses occurs in Amine Recovery Column, Absorption Column, Air Coolers, Recovery Column Reboilers, Glycol Flash Drums, Incinerator in Sulphur Recovery Unit, Boilers and finally Gas Turbines in Power Production Unit (120) and Gas Turbines in Gas Pressure Compression Unit (106).

Some suggestions to improve these units have been proposed and because of the high exergy loss in gas turbines of units 120 & 106, they have technically and economically been studied with more details.

It has also been shown that high-pressure steam can be raised using turbine exhaust heat. This modification can save energy by 997,700 $/year, while the required investment will be paid back in about 3 years.

Nomenclature

Ex_{in}: Inlet Exergy (kW)
Ex_{OC}: Exergy of Composition (kW)
Ex_{OR}: Chemical Exergy (kW)
Ex_{out}: Outlet Exergy (kW)
Ex^{PH}: Physical Exergy (kW)
H: Enthalpy (kW)
N: Number of Moles (kmole/sec)
R: Gas Constant, (Kj/kmol°C)
S: Entropy (kW /°C)
T_0: Ambient Temperature (°C)
W: Work (kW)
W_{in}: Provided Work (kW)
W_{out}: Produced Work (kW)
η_{EX}: Exergetic Efficiency
σT_0: Work Lost (kW)

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