ADVANCED EXERGY ANALYSIS OF THE NATURAL GAS LIQUID RECOVERY PROCESS

by

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Energy quality in each country is one of the important indicators of economic development, Which affects the economic growth of that country. Exergy analysis, considering all flow properties including pressure, temperature, composition, is a powerful way to evaluate the energy consumption of equipment such as natural gas and liquefied gas plants. Inefficiency of a system can be defined by the conventional exergy analysis method, while, irreversible resources and real potentials for system improvement can only be identified by the advanced exergy analysis method. This analysis splits conventional exergy destruction into two exogenous and endogenous parts according to origin, and also unavoidable and avoidable parts according to the ability to remove and modifications. In this method, the exergy concept was separated by considering the ideal and avoidable condition assumptions. As a real case study, a natural gas liquid plant 800, from National Iranian South Oil Company located in southwest of Iran was considered to be investigated by conventional exergy analysis, advanced exergy analysis methods. The results of conventional exergy analysis illustrated that the highest amount of exergy destruction belonged to compressor and heat exchanger with 509.99 kW and 629.04 kW, respectively. However, in the case of heat exchanger, despite having the highest rate of exergy destruction, it is not considered in modification priorities due to its low avoidable exergy destruction value. Also, advanced exergy analysis suggested that the exergy destruction of the compressor and heat exchanger will be reduced by improving performance of these components.

Key words: *natural gas liquid plant, conventional exergy analysis, advanced exergy analysis, performance improvement*

Introduction

The amount of natural energy resources is decreasing, while human's need for energy has increased, especially for industries with high energy demand, such as oil, gas, and natural gas liquid (NGL) [1]. The rising global requirement for energy sources, especially in industries like oil and gas, leads to an increase in natural gas production. Natural gas is expected to supply 30% of the world's supply of fossil fuels by 2030 [2]. On the other hand, conventional sources

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of energy (coal, oil, and natural gas) have the largest negative impact on the environment and represent a real threat to the sustainability of economic flows [3]. Therefore, conducting studies to improve energy consumption patterns in these industries is a big step towards a more clean use of energy [4]. To solve this problem, many countries have sufficiently tried to control the rise in global temperature and prevent climate change. Due to limitations caused by the environmental effect of CO_2 emission, natural gas is applied as the cleanest fossil fuel, and its consumption is growing rapidly [5]. According to 2018 statistical report of BP World Energy Magazine, Iran, with 16.2% of the proven natural gas reserves, is ranked as the world's second nation with the highest natural gas reserves [6]. This shows a promising future for its natural gas and NGL recovery industries. In this regard, Iran's natural gas production has rapidly increased over the past two decades, from 0.9 Tcf in 1991 to 1127.7 Tcf in 2018 [6, 7].

It is worth mentioning that, energy consumption in each country is one of the important indicators of economic development. But, energy quality is more important than energy consumption, influencing the economic growth of that country. In designing a plant, the designer's main goal is to determine the optimal energy consumption state in relation environmental and operating conditions, which can be done through exergy analysis [8]. In this regard, many studies have been done on the evaluation of oil, gas, and chemical plants.

Song *et al.* [9] employed extended exergy analysis to investigate a typical cement production chain in China. Vilarinho *et al.* [10] appraised exergy and energy analysis for a pre-distillation unit (Un-0100) of an aromatics plant from a Portuguese refinery. Navarro *et al.* [11] evaluated the exergetic performance of Amine Treatment Refinery Unit in Colombia. Feyzi *et al.* [12] considered conventional exergy analysis (CEA) to assess the CO_2 removal process from syngas using methyl diethanolamine activated by piperazine (a-MDEA).

The NGL plant production is composed of heavy compositions like ethane, propane, and butane. The liquefied natural gas plant's production is mostly methane. The NGL is also extracted for petrochemical companies as their primary feed [13]. The NGL recovery is mostly among cryogenic processes in Iran, and the industrial propane cooling cycle is the main part of these plants. High energy consumption is the most important problem of NGL production technologies, especially in the refrigeration cycles [14]. Exergy analysis in such plants allows determining the most inefficient parts of a process where energy is wasted [7]. Raising the quality level of energy consumption is logical to improve the efficiency of these plants [13].

Many researchers performed the CEA method on NGL plants to evaluate improvement priorities [13]. In this regard, Mehrpooya *et al.* [15] considered CEA method in NGL1300, one of the biggest NGL recovery units in southern Iran. Jiang *et al.* [16] performed the CEA method on China's ethane recovery processes based on rich gas. Hu *et al.* [17] studied NGL plant equipment and found that air cooler contributed to the highest exergy destruction. Meanwhile, a new analysis method called as advanced exergy analysis (AEA) was employed in recent years to provide useful information for identifying system behavior [18]. Tsatsaronis [19] in a study, performed the AEA method for the first time. This method has been used for chemical and non-chemical industries.

Acikkalp *et al.* [20] performed AEA method on milk processing facilities, and they found that the evaporator had the highest avoidable exergy destruction. In another study, results of performing AEA method on the Kalina cycle showed that the cycle had great potential for improvement by increasing the performance efficiency of condenser, turbine, and evaporator, respectively [21]. Acikalp *et al.* [22] considered AEA method for analyzing electricity generation plant in Turkey's Industrial Zone. Their results showed that the performance of gas turbine and combustion chamber should be improved to reduce their exergy destruction.

Furthermore, in the present study, the energy quality of NGL plant No. 800 from National Iranian South Oil Company (NISOC) with the production capacity of 120,000 NGL barrels per day located in Koreit Industrial Zone (Ahz. City, Khuz. Province, Iran) is investigated as a real case study using different methods. As a novelty, conventional and advanced exergy analyzes of NGL plant No. 800 is presented in this study to perform inefficient equipment and ways to improve their performance. These methods were used for a better understanding of the locations, causes, and improvement ways of inefficiencies in this typical, large-scale NGL recovery plant.

Process description

Figure 1 shows process flow diagram (PFD) for the current operating condition of the NGL plant.

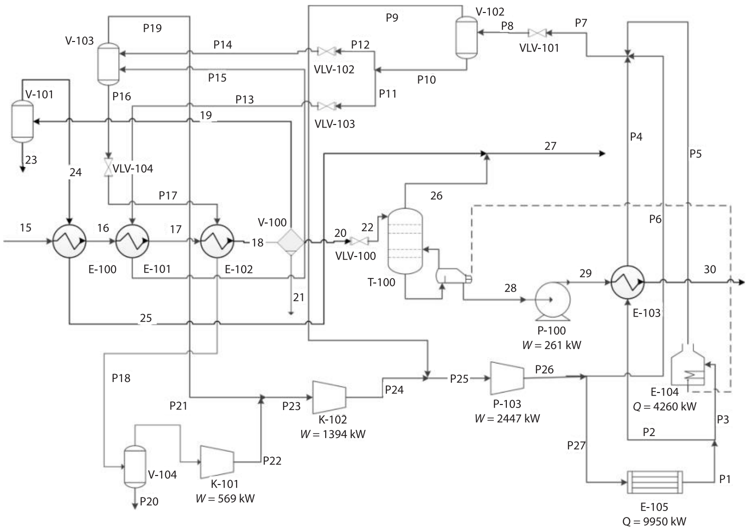

Figure 1. The PFD of NGL plant

According to the PFD, the NGL plant 800, located in industrial city of Ahvaz, has one input feed and two output productions including NGL and sales gas. The feed stream enters demethanizer column after cooling down to –23.3 °C by triple heat exchanger (E101, E102 in cryogenic cycle and in E100 refluxed feed stream). After extraction in demethanizer column, the sale gas and exchanged gas in heat exchanger (E-100) will be sent to pressure-boosting units. The NGL from bottom of the demethanizer column will be sent to petrochemical companies at 48 °C and 63 bar for other uses.

In this plant, propane cryogenic cycle completely separated from production process is used for procession and cooling of the NGL product. Its streams can be seen in fig. 1 marked with the letter P. This cycle is pressurized up to 23.84 bars by low pressure compressor (K-101), medium pressure compressor (K-102), and high pressure compressor (K-103). Economizer towers (V-102, V-103, and V-104) separate propane gas (to return to compression system) from liquid propane which continues heat exchanging in the cryogenic cycle. Inlet feed streams heat exchange with liquid propane by heat exchangers (E-101, E-102), and outlet product stream will be cooled down by (E-103). Processing is completed by the condenser (E-105) and cooler (E-104). Cooler provides the required heat for reboiler of the demethanizer column, and condenser cools down the pressurized propane to 65.55 °C.

Conventional exergy analysis

The exergy analysis method is a key issue for a better understanding the locations, causes, and magnitudes of process inefficiencies [7]. The CEA is a useful technique to evaluate the performance of chemical processes [23]. The main purpose of designer in designing a plant is to determine optimal state of energy consumption in relation the environmental and operating conditions of plant. The CEA determines the most inefficient equipment and shows where the energy is being wasted in operating condition conditions [24]. Therefore, it is important to determine ambient conditions for conducting exergy analysis. As a real-life case study, NGL plant 800 from NISOC with the production capacity of 120000 NGL barrels per day located in Koreit Industrial Zone (Ahvaz City, Khuzestan Province, Iran) was chosen. Average ambient conditions in Ahvaz City were assumed as: T_0 = 25 °C and P_0 = 101.325 kPa [25].

According to eq. (1), the total exergy of the system for material stream is split into four parts, namely kinetic, $\dot{E}x_{\mathrm{ke}}$, potential, $\dot{E}x_{\mathrm{po}}$, physical, $\dot{E}x_{\mathrm{ph}}$, and chemical, and $\dot{E}x_{\mathrm{ch}}$, exergies [26]. The potential and kinetic exergies are neglected [27]:

$$\dot{E}x = \dot{E}x_{\mathrm{po}} + \dot{E}x_{\mathrm{ke}} + \dot{E}x_{\mathrm{ph}} + \dot{E}x_{\mathrm{ch}} \tag{1}$$

So, the material stream exergy rate is defined as the sum of chemical and physical parts [28, 29]:

$$\dot{E}x = \dot{E}x_{\mathrm{ph}} + \dot{E}x_{\mathrm{ch}} \tag{2}$$

Physical and chemical exergy are defined [27, 30]:

$$\dot{E}x_{\mathrm{ph}} = \dot{m} \times \left[\left(h - h_0 \right) - T_0 \times \left(S - S_0 \right) \right] \tag{3}$$

$$\dot{E}x_{\mathrm{ch}} = \sum_{i=1}^{N} y_i \times e_i^0 + G - \sum_{i=1}^{N} y_i \times G_i \tag{4}$$

where 0 is the subscription refers to an ambient condition in previous equations, T_0, h_0, s_0, and $\dot{m}$ [kmols^{-1}] are the reference ambient temperature, specific enthalpy, specific entropy, and molar flow rate, respectively, in eq. (3). The term y_i is the mole fraction of stream components, e_i^0 and G_i are the standard chemical exergy and Gibbs free energy for chemical exergy, respectively, in eq. (4) [27]. The method of calculating the total exergy of streams is detailed in fig. 2.

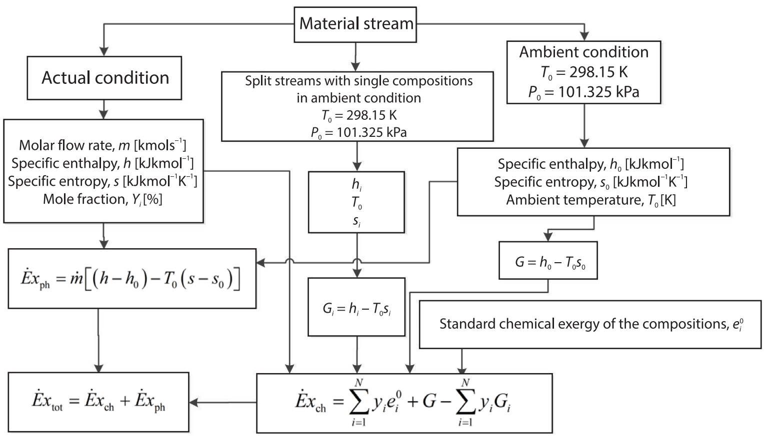

Figure 2. Flowchart of the material stream's total exergy calculation

After obtaining these parameters, exergy destruction and exergy efficiency are two main parameters of process which are required to be defined in exergy analysis [31]. These essential parameters are investigated and discussed for the *kth* component of the process components:

$$\dot{E}x_D = \dot{E}x_F - \dot{E}x_P \tag{5}$$

$$\varepsilon = \frac{\dot{E}x_P}{\dot{E}x_F} = 1 - \frac{\dot{E}x_D}{\dot{E}x_F} \tag{6}$$

where P, D, and F are is product, destruction, and fuel in these equations, respectively. According to the fuel-product methodology, tab. 1 presents exergy calculation formulas in the main component of the NGL plant. For the exergy efficiency of expansion valve,the thermal component results from the temperature difference between the stream and the environment. The pressure component is resulted from the pressure difference between the stream and the environment at environment temperature.

Table 2 shows the exergy rate of NGL plant's streams. The results of CEA method performed on NGL plant are shown in tab. 3. The highest exergy destruction rate belonged to compressors K103 and heat exchanger E-101 with 509.99 and 629 kW, respectively. Exergy destruction percentage of other equipment was at the least level to be considered for improvement.

Table 1. Exergy calculation formulas in the main component of the NGL plant

Component	Exergy destruction	Exergy efficiency
Compressor [32, 33]	$\dot{E}x_D = \sum(\dot{m}\times e)_{\text{in}} + W - \sum(\dot{m}\times e)_{\text{out}}$	$\varepsilon = \dfrac{\sum(\dot{m}\times e)_{\text{in}} - \sum(\dot{m}\times e)_{\text{out}}}{W}$
Heat exchanger [5]	$\dot{E}x_D = \left[\sum(\dot{m}\times e)\right]_{\text{in},(\text{hot})} + \left[\sum(\dot{m}\times e)\right]_{1,(\text{cold})} - -\left[\sum(\dot{m}\times e)\right]_{\text{out},(\text{hot})} - \left[\sum(\dot{m}\times e)\right]_{2,(\text{cold})}$	$\varepsilon = \dfrac{\left[\sum(\dot{m}\times e)\right]_{\text{in},(\text{hot})} - \left[\sum(\dot{m}\times e)\right]_{\text{out},(\text{hot})}}{\left[\sum(\dot{m}\times e)\right]_{2,(\text{cold})} - \left[\sum(\dot{m}\times e)\right]_{1,(\text{cold})}}$
Column/TEE/ MIX [34, 35]	$\dot{E}x_D = \sum(\dot{m}\times e)_{in} - \sum(\dot{m}\times e)_{\text{out}}$	$\varepsilon = \dfrac{\sum(\dot{m}\times e)_{\text{out}}}{\sum(\dot{m}\times e)_{in}}$
Cooler [14, 31]	$\dot{E}x_D = \sum(\dot{m}\times e)_{\text{in}} + Q\times\left(1-\dfrac{T}{T_0}\right) - \sum(\dot{m}\times e)_{\text{out}}$	$\varepsilon = \dfrac{Q\times\left(1-\dfrac{T}{T_0}\right)}{\sum(\dot{m}\times e)_{\text{in}} - \sum(\dot{m}\times e)_{\text{out}}}$
Pumps [33, 35]	$\dot{E}x_D = \sum(\dot{m}\times e)_{\text{in}} + W - \sum(\dot{m}\times e)_{\text{out}}$	$\varepsilon = \dfrac{\sum(\dot{m}\times e)_{\text{in}} - \sum(\dot{m}\times e)_{\text{out}}}{W}$
Expansion valves [36]	$\dot{E}x_D = \sum(\dot{m}\times e)_{\text{in}} - \sum(\dot{m}\times e)_{\text{out}}$	$\varepsilon = \dfrac{e_{\text{out}}^{\Delta T} - e_{\text{in}}^{\Delta T}}{e_{in}^{\Delta P} - e_{\text{out}}^{\Delta P}},\ e^{\Delta T} = \left[-\int_T^{T_0}\dfrac{T-T_0}{T}\text{d}h\right]$ $e^{\Delta P} = T_0\times(S_0 - S_{\text{in}}) - (h_0 - h_{\text{in}})$

Table 2. Summarized conventional exergy for process and cryogenic cycle

Stream No.	Total exergy [kW]	Stream number	Total exergy [kW]	Stream number	Total exergy [kW]
15 (feed stream)	1843368	30 (NGL product)	1135324	P14	604790.6
16	1843255	P1	1654493	P15	991526.2
17	1843375	P2	325384.7	P16	510359.4
18	1843867	P3	1329108	P17	510315.8
19	593789.2	P4	325344.7	P18	509466.5
20	1250520	P5	1328887	P19	1085958
21	35.9	P6	0	P20	0
22	1250510	P7	1654204	P21	509466.5
23	20.4	P8	1654096	P22	509882.5
24	593761.6	P9	56916.9	P23	1595835
25	593591.3	P10	1597180	P24	1596884
26	115149.2	P11	992345.6	P25	1653800
27 (sale gas)	708671.4	P12	604834	P26	1655737
28	1135105	P13	992274.5	P27	1655737
29	1135297				

Table 3. Conventional exergy results of main equipment

Component ID	P100	K101	K102	K103	E100	E101	E102	E103	E104	E105	T100
Exergy destruction [kW]	69.2	152.8	345.5	510	283.2	629	357.5	13.2	420.7	228.4	455.4
Exergy efficiency [%]	73.5	73.1	75.2	79.2	66.3	15.9	57.9	66.9	90.3	84.5	80

Advanced exergy analysis

The inefficiency of a system can be defined by CEA method. While irreversible resources and real potentials for system improvement can only be identified by AEA method. It is possible to better identify values of exergy destruction and ways to improve it by splitting the concept of exergy. This is possible only using AEA method [37]. This analysis splits conventional exergy destruction into two exogenous and endogenous parts according to origin, and also into unavoidable and avoidable parts according to the ability to remove and modify.

The endogenous exergy destruction is based on reversibility rates occurring within the k^{th} component when all other components operate without irreversibility rates (ideally).

According to the definitions of exogenous and endogenous exergy destruction, exergy destruction of the k^{th} component can be formulized:

$$\dot{E}_{D,k} = \dot{E}_{D,k}^{EN} + \dot{E}_{D,k}^{EX} \tag{7}$$

where $\dot{E}_{D,k}^{EN}$ is the endogenous exergy destruction and can be calculated by engineering methods. The main principle of this method is calculation of the endogenous exergy destruction of k^{th} component, $\dot{E}_{D,k}^{EN}$, through a schematic in fig. 3, which is based:

$$\dot{E}_{D,\text{tot}} = \dot{E}_{F,\text{tot}} - \dot{E}_{P,\text{tot}} \tag{8}$$

This equation can be re-written:

$$\dot{E}_{D,\text{tot}} = \dot{E}_{D,k} + \dot{E}_{D,\text{others}} \tag{9}$$

where the target device is kth component. Exergy destruction of system's remaining components is named as $\dot{E}_{D,\text{others}}$. The $\dot{E}_{D,k}^{EN}$ parameter of the k^{th} component can be calculated when the other components do not have any exergy destruction, $\dot{E}_{D,\text{others}} = 0$. In fact, the intersection of this diagram with the vertical axis shows the endogenous exergy destruction value of a component k.

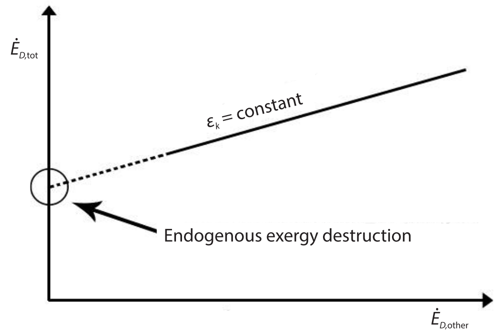

Figure 3. Plot obtained from the engineering approach to calculate endogenous exergy destruction [39]

In this method, since $\dot{E}_{D,k}^{EN}$ of the component depends on the component's exergy efficiency, the exergy efficiency of component k should be constant, whilst exergy destruction varies in other components, and the graph should have a straight line and not a curve [38].

Table 4 shows assumptions of real, ideal, and unavoid able conditions to calculate $\dot{E}_{D,k}^{EN}$ and $\dot{E}_{D,k}^{EX}$ for the main equipment. Ideal operation conditions should be in accordance with the assumptions ($\dot{E}x_D$ = minimum or $\dot{E}x_D = 0$). Whilst, simulation of unavoidable operating conditions depends on the manufacturer's experience and knowledge. It should be noted that the technical and economic constraints (manufacturing methods, production costs, and material characteristics) prevent the achievement of ideal equipment conditions [32]. In this study, computationsof the advanced and conventional exergy and simulations of all the needed basic conditions and the system assumptions were carried out in Aspen HYSYS, Microsoft Excel, and MATLAB software.

Table 4. The real, ideal, and unavoidable assumptions for calculating endogenous and unavoidable exergy destruction [40]

Components, k	Real conditions	Ideal conditions		Unavoidable conditions
Pump	$\eta_{\text{iso}} = 75\%$	$\eta_{\text{iso}} = 100\%$		$\eta_{\text{iso}} = 90\%$
Compressor	$\eta_{\text{iso}} = 75\%$	$\eta_{\text{iso}} = 100\%$		$\eta_{\text{iso}} = 90\%$
Heat exchanger	$\Delta T_{\min}$ = real ΔP = real	$\Delta T_{\min}$ = 0 K ΔP = 0 kPa	E-100	$\Delta T_{\min}$ = 4.26 °C
				Tube side ΔP = 34.47 kPa Shell side ΔP = 103.42 kPa
			E-101	$\Delta T_{\min}$ = 2.22 °C
				Tube side ΔP = 34.47 kPa Shell side ΔP = 0 kPa
			E-102	$\Delta T_{\min}$ = 3.11 °C
				Tube side ΔP = 34.47 kPa Shell side ΔP = 0 kPa
			E-103	$\Delta T_{\min}$ = 2.22 °C
				Tube side ΔP = 34.47 kPa Shell side ΔP = 0 kPa

The following equation calculates exogenous exergy destruction by measuring endogenous exergy destruction value:

$$\dot{E}_{D,k}^{EX} = \dot{E}x_{D,k} - \dot{E}_{D,k}^{EN} \tag{10}$$

Based on the possibility of eliminating the irreversibility of equipment and achieving a realistic measure of improvement potential, the total exergy destruction of equipment k is split into two parts, unavoidable and avoidable. The exergy destruction rate which is not reducible due to technical constraints, such as material quality, production methods, and design parameters, is considered unavoidable $\dot{E}_{D,k}^{UN}$ part of the exergy destruction and $\dot{E}_{D,k}^{AV}$ is avoidable exergy destruction which can be avoided. These definitions are formalized:

$$\dot{E}_{D,k}^{UN} = \dot{E}_{P,k}\left(\frac{\dot{E}_{D,k}}{\dot{E}_{P,k}}\right)^{UN} \tag{11}$$

$$\dot{E}_{D,k}^{AV} = \dot{E}_{D,k} - \dot{E}_{D,k}^{UN} \tag{12}$$

These splitting are combined to provide a better understanding of their effect on the system and options for the improvement of the overall system efficiency, consequently, we will be able to determine which part of the inefficiencies caused by interactions between components, and which part can be prevented by improving plants̉ technology [41, 42]. Therefore, exergy destruction is divided into four main groups including:
– avoidable-endogenous exergy destructions,
– unavoidable-endogenous exergy destructions,
– avoidable-exogenous exergy destructions, and
– unavoidable-exogenous exergy destructions.

Therefore, exergy destruction is divided into four main groups, including:
– avoidable-endogenous exergy destructions,
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– avoidable-exogenous exergy destructions, and
– unavoidable-exogenous exergy destructions.

$$\dot{E}_D = \dot{E}_D^{UN,EN} + \dot{E}_D^{UN,EX} + \dot{E}_D^{AV,EN} + \dot{E}_D^{AV,EX} \tag{13}$$

The $\dot{E}_{D,k}^{UN,EN}$ is the unreduced part of exergy destruction due to technical and economic constraints of the *kth* component, and is formulized [42]:

$$\dot{E}_{D,k}^{UN,EN} = \dot{E}_{P,k}^{EN}\left(\frac{\dot{E}_{D,k}}{\dot{E}_{P,k}}\right)^{UN} \tag{14}$$

Figure 4 shows the results of measuring endogenous advanced exergy of rotating and heat exchanging equipment. The diagrams in this figure show the linear relation between $\dot{E}_{D,\mathrm{tot}}$ and $\dot{E}_{D,\mathrm{others}}$. Linear equations intersection with the vertical axis shows the endogenous exergy destruction.

Similarly, the unavoidable exergy of equipment k, which is unreduced because of economic and technical limitations of other components of the process is called as $\dot{E}_{D,k}^{UN,EX}$ which can be formulized [32]:

$$\dot{E}_D^{UN,EX} = \dot{E}_D^{UN} - \dot{E}_D^{UN,EN} \tag{15}$$

The avoidable exergy destruction that will be reduced by improving the performance of k component is called as avoidable endogenous exergy destruction:

$$\dot{E}_D^{AV,EN} = \dot{E}_D^{EN} - \dot{E}_D^{UN,EN} \tag{16}$$

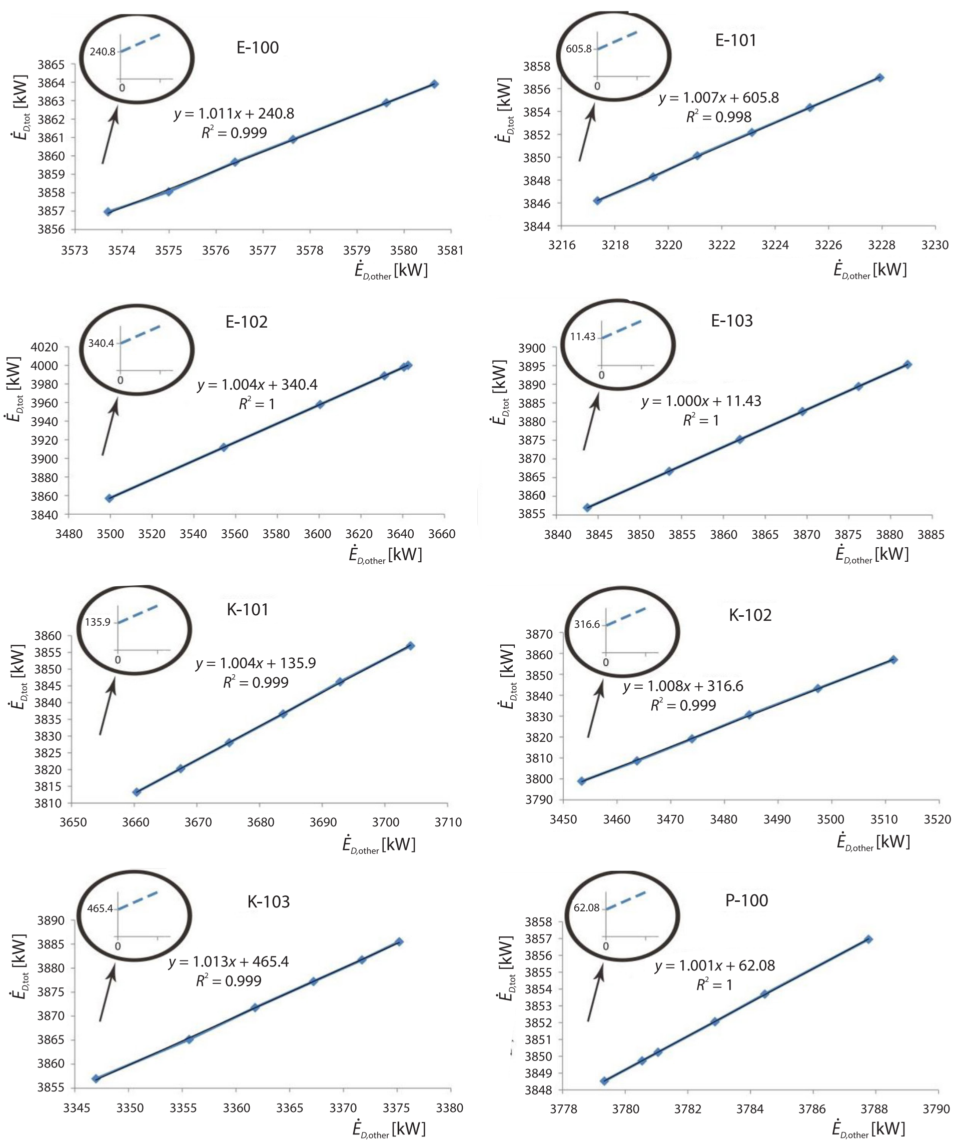

Figure 4. Calculation of the endogenous exergy destruction for main equipments

Similarly, reducible part of avoidable exergy destruction by improving the efficiency of other process components is called $\dot{E}_{D,k}^{UN,EX}$:

$$\dot{E}_D^{AV,EX} = \dot{E}_D^{AV} - \dot{E}_D^{AV,EN} \tag{17}$$

Finally, the results of AEA method applied for the main equipment of NGL 800 plant can be detailed in tab. 6.

In AEA, modified exergy efficiency can be calculated according to eq. (18):

$$\varepsilon_{\text{modified},k} = \frac{\dot{E}x_{P,k}}{\dot{E}x_{F,k} - \dot{E}x_{D,k}^{UN} - \dot{E}x_{D,k}^{AV,EX}} \tag{18}$$

This parameter is the real and modifiable exergy efficiency of the k^{th} component [43]. The results of this exergetic efficiency on the main equipment can be seen in tab. 5.

Table 5. Exergetic parameters results of the main equipment

	K-101	K-102	K-103	P-100	E-100	E-101	E-102	E-103
ε_{conv}	73.13	75.21	79.16	73.49	66.31	15.93	57.91	66.88
$\varepsilon_{modified}$	82.99	83.93	84.97	84.54	29.79	9.96	79.57	98.53

According to this tab. 5, for equipment which, the efficiency of exergy destruction in the conventional analysis is less than the efficiency in the advanced study, efficiency can be improved up to a greater value which is its real value. For example, the ε for K-103 can be improved up to 84.97%, denoted by $\varepsilon_{modified}$.

Table 6. Detailed results of the AEA for main equipment

Conventional exergy destruction [kW]		Advanced exergy destruction [kW]							
	$\dot{E}x_D$	$\dot{E}x_D^{UN}$	$\dot{E}x_D^{AV}$	$\dot{E}x_D^{EN}$	$\dot{E}x_D^{EX}$	$\dot{E}x_D^{AV,EX}$	$\dot{E}x_D^{AV,EN}$	$\dot{E}x_D^{UN,EX}$	$\dot{E}x_D^{UN,EN}$
Heat exchangers									
E-100	283.25	198.84	84.42	240.83	42.42	10.01	74.4	32.41	166.43
E-101	629.04	532.91	96.13	605.84	23.2	15.21	80.92	7.99	524.92
E-102	357.46	214.12	143.34	340.41	17.05	17.05	126.29	0	214.12
E-103	13.23	11.03	2.2	11.43	1.8	1.8	0.4	0	11.03
Rotary machines									
K-101	152.85	51.46	101.39	135.93	16.92	16.12	85.27	0.8	50.66
K-102	345.48	115.9	229.58	316.64	28.84	28.84	200.74	0	115.9
K-103	509.99	171.18	338.81	465.41	44.58	44.41	294.4	0.17	171.01
P-100	69.19	28.11	41.08	62.08	7.11	6	35.08	1.11	27

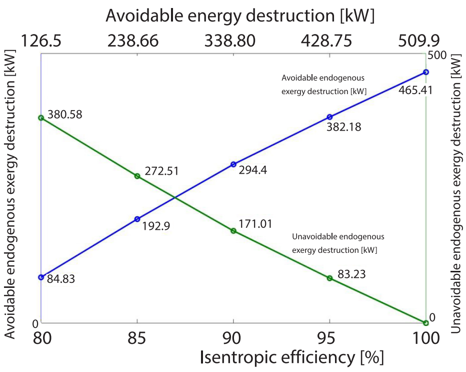

Figure 5. Effect of isotropic efficiency on the exergy destruction within the compressor (K-103)

Among the compressors, the highest exergy destruction belonged to K-103, with 509.99 kW (endogenous exergy of 465.41 kW). In this regard, for analyzing equipment improvement and reducing energy destruction, technical limitations were considered again. Figure 5 displays change in the compressor's isentropic efficiency with endogenous exergy destruction. In this regard and after calculating endogenous exergy destruction, the unavoidable assumption (isentropic efficiency as 75%) was variated. This variation is due to improving the compressor's performance. According to the second x-axis, the available exergy destruction will be increased.

As can be seen, increasing compressors̉ efficiency increased the $\dot{E}_D^{AV,EN}$ and decreased the

$\dot{E}_D^{UN,EN}$. Also, the avoidable exergy destruction (second x-axis) will be increased. Showing that more attention shall be focused on improving the compressor's efficiency to reduce exergy destruction.

Also in according to the results of tab. 6, E-102 exchanger has a better improvement potential than other exchangers. In this regard, and technical limitations were considered again to analyze equipment improvement and reduce energy destruction. Figure 6 shows the heat exchangers' endogenous exergy destruction variation with $\Delta T_{\min}$. In this regard and after calculating endogenous exergy destruction, the unavoidable assumption was variated. This variation is due to improving the heat exchanger's performance. According to the second x-axis, the available exergy destruction

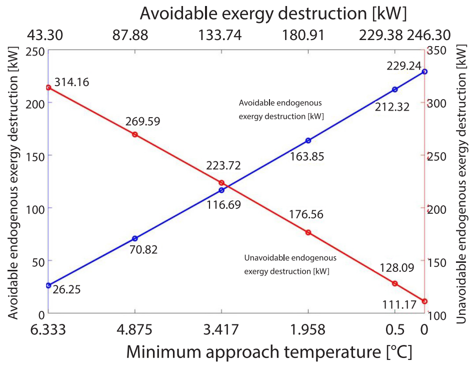

Figure 6. Effect of $\Delta T_{\min}$ on the exergy destruction within the heat exchanger (E-102)

As can be seen, decreasing $\Delta T_{\min}$ value, increased the $\dot{E}_D^{AV,EN}$ and decreased $\dot{E}_D^{UN,EN}$. Also, the avoidable exergy destruction (second x-axis) will be increased. Showing that more attention shall be focused on improving the heat exchanger's efficiency to reduce exergy destruction.

Conclusions

In the current study, the results of applying two practical ways of exergy analysis, including CEA, AEA, and methods were presented. These methods were used to better understand locations and causes of inefficiencies and ways for their improvement in a typical, large-scale NGL recovery plant located in the southwest of Iran. Summary of exergy analyses performed for this plant and real potentials for improvement are given in the following.

The results of CEA illustrated that the highest amount of exergy destruction belonged to compressors (K-103) and heat exchanger (E-101) with 509.99 and 629.04 kW, respectively, showing that more attention shall be focused on improving these equipment to reduce exergy destruction.

For having a better understanding about exergy destruction of the main equipment, the AEA method was performed. Exergy destruction of the compressor (K-103) and heat exchanger (E-102) will be reduced by improving performance of these components. However, despite of having the highest rate of exergy destruction in the case of (E-101) heat exchanger, it is not considered in modification priorities due to its low measured value.

Nomenclature

$\dot{E}x$ – exergy destruction, [kW]
$\dot{E}$ – exergy destruction, [kW])
e – exergy destruction rate, [Jkmol^{-1}]
h – specific enthalpy, [kJkmol^{-1}]
P – pressure, [kPa]
ΔP – pressure drop, [kPa]
$\dot{m}$ – molar flow rate, [kmols-1]
Q – heat load, [kW]
S – specific entropy, [kJkmol^{-1}K^{-1}]
T – temperature, [K]
ΔT – temperature diffrence, [°C]
$\Delta T_{\min}$ – minimum approach temperature, [°C]
W – work, [kW]

Greek letters

ε – exergy efficiency, [%]
$\varepsilon_{\mathrm{conv}}$ – conventional exergy efficiency, [%]
$\varepsilon_{\mathrm{modified}}$ – modified exergy efficiency, [%]
η_{iso} – isotropic efficiency, [%]

Subscripts

ch – chemical

D – destruction
F – fuel
in – inlet
ke – kinetic
out – outlet
P – product
ph – physical
po – potential
0 – ambient condition
min – minimum

Superscript

EX – exogenous
EN – endogenous
AV – avoidable
UN – unavoidable

Acronyms

AEA – advanced exergy analysis
CEA – conventional exergy analysis
E – heat exchanger/ cooler/ heater
K – compressor
LNG – luquefied natural gas
MIX – mixer
TEE – branching device
Tcf – trillion cubic feet
V – separators and flash drum
VLV – throttle valve
NGL – natural gas liquid
PFD – process flow diagram

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