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Abstract
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Advanced exergy analysis of the oil and gas processing Plant on a North Sea Platform

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Abstract:

The objective of this work is to extend previous research by considering realistic improvement potential and mutual effects of components of the oil and gas processing plant on a North Sea oil platform. For this purpose, advanced exergy analysis (developed by Tsatsaronis and co-workers) is applied on such a platform. The study focuses on components and sub-systems highlighted with high exergy destruction through conventional exergy analysis in previous research. The true improvement potential is revealed by splitting the exergy destruction of components into avoidable and unavoidable parts. Results show that compressors have the highest energy saving potential. System-wise, the recompression train has the highest avoidable exergy destruction due to high recirculation rate around the compressors. It is also concluded that the overall system has a 4% improvement potential in exergy efficiency when all main components are operated at unavoidable conditions. Splitting the exergy destruction into endogenous and exogenous parts reveals the mutual interdependencies of the system components. It is shown that the proportion of exogenous exergy destruction differs significantly from component to component. The inefficiencies of compressors are mainly due to the internal operating conditions, while the exergy destruction within the coolers could particularly be reduced by improving the remaining system components. Valves are either exclusively endogenous or exogenous, depending on their locations in the system. The results also suggest that in order to improve the overall performance of the system, it is more meaningful and effective to improve compressors than other components.

Keywords:

Advanced exergy analysis, irreversibility, exergy destruction, offshore oil and gas processing

1. Introduction

Although combustion of fossil fuel for electricity, transportation and energy are the largest sources of greenhouse gas (GHG) emissions, emissions associated to the extraction of fossil fuels also matters, especially for some of the oil and gas exporting countries. In Norway, the share of GHG emissions originate from petroleum related activities on the continental shelf constituted 27% in

2017 [1]. More than 80% of the CO_2 emissions stem from gas turbines used to generated electricity on the installations. Stricter regulations about emission and a large share of energy in the overall cost of operating the facilities motivate oil and gas industry to improve energy efficiency of their operations. Therefore, it is crucial to understand the sources of inefficiency and estimate the improvement potential in the system.

Exergy analysis has been proven as a useful tool to detect the inefficiency within a system. By incorporating both the First and Second Laws of thermodynamics, exergy analysis is able to identify the location and magnitude of the exergy destructions and losses within a system.

There are a number of studies that analyzing the performance of offshore platforms in terms of exergy. Oliveira and Van Hombeeck [2] initiated the exergy study to offshore installation in 1997. They carried out the exergy analysis of petroleum separation processes on a Brazilian offshore platform. The study pointed out the heating operations that preceded the separation of petroleum is the most exergy consuming processes. Recently, exergy analysis has been the tool in an increasing number of studies concerning the thermodynamic performance of offshore platforms. Several papers were published with focus on the offshore platforms located in the North Sea. Voldsund et al. [3] used a method similar to [2] to analyze a real production day of the oil and gas processing plant on one of the Norwegian offshore platforms. It was concluded that the most exergy destruction took place in processes that increased pressure (compressors and cooling in the compression trains) or decreased pressure (in pressure reduction valves and recycling). Another study performed by Voldsund et al. [4] compared the performance of the oil and gas processing plants on four North Sea oil and gas platforms. This study illustrated that the gas treatment and production manifold systems were responsible for most exergy destruction; although these four oil and gas processing plant differed by their operating conditions and strategies. Similar results were obtained in another study performed by Nguyen et al. [5], where a mature oilfield was assessed by exergy accounting. Nguyen et al. [6] developed a generic model of North Sea oil and gas offshore platforms, which comprised both processing and utility systems. It was found that the shares of exergy destruction between utility systems and the processing plant were about 65% and 35%, respectively, while the variability of the feed composition had little effect on the split of the thermodynamic irreversibility between both plants. Nguyen et al. [7] also investigated the life performance of an offshore platform by comparing three exploitation periods of and oil filed (early-life, plateau and end-life production). They discovered that the exergy destruction changed significantly with time, because of low oil production and increasing water extraction.

Although the benefits of exergy analysis has been highlighted in various applications, the results from an exergy analysis cannot be fully utilized, due to:

i) The interactions between components are not considered.

ii) The real improvement potentials of the components are not considered.

To address these drawbacks and improve the quality of the conclusions from the exergy analysis, the concept of advanced exergy analysis was proposed by Tsatsaronis and co-workers [8-14]. In this paper, we would like to extend previous research work [3] by exploring the applicability of advanced exergy analysis to offshore processing plants. This enable a better understanding of irreversibility of components in the offshore process plant, which allows efforts to be focused on the component/systems that have greatest potential for improvement.

2. System description

The same system as studied in [3] was employed in this study in order to investigate potential benefits of advanced exergy analysis. Readers are referred to [3] for a detailed description of the boundary conditions, process characteristics, simulation of the process flowsheet and calibration of process variables.

A simplified flowsheet of the oil and gas processing at the studied platform is given in Fig. 1. The studied platform is simple but represents the typical configuration of offshore platforms in the North

Sea. In the production manifold, reservoir fluids are received and transferred to separators for the separation into oil, gas and water. The separation train consists of two three-phase high-pressure separators in series with a two-phase low-pressure separator and coalescer. Most of the gas is flashed off in the separators. Flashed gas is then routed to gas recompression and reinjection system before injected into reservoir for pressure maintenance. The stabilized oil from the coalescer is pumped via export system for export. Produced water is treated and thereafter released to sea.

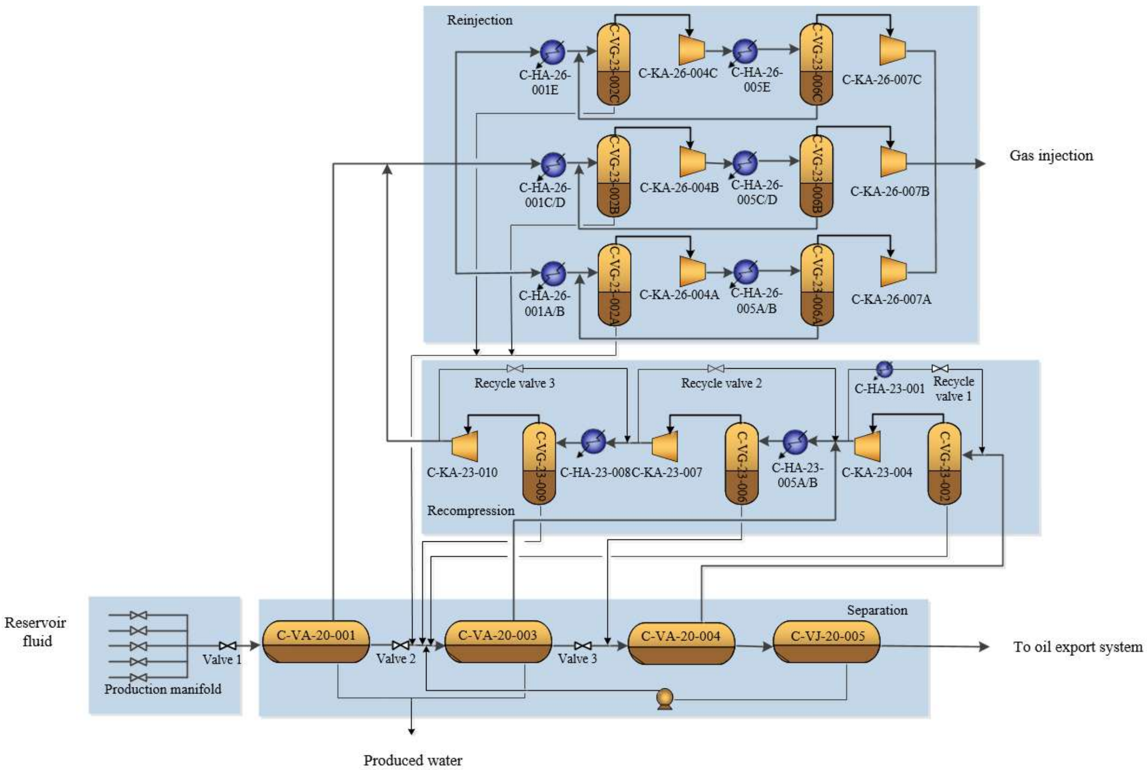

Figure 1. Simplified process flowsheet of studied platform

3. Methodology

3.1. Conventional exergy analysis

Exergy is the maximum theoretical work obtainable from an overall system consisting of a system and the environment as the system comes into equilibrium with the environment or, alternatively, the minimum theoretical work that is required to bring a system from environmental state to a specified state [15].

By assuming that the exergy loss occurs only at system level [16], the exergy balance of the k-th component in a system at steady state can be formulated [17] as

$$E_{D,k} = E_{F,k} - E_{P,k} \tag{1}$$

Fuel exergy ($E_{F,k}$) is the exergy input required to generate desired product exergy ($E_{P,k}$). The sum of the exergy destruction ($E_{D,k}$) of the components is the total exergy destruction of the considered system.

The exergy destruction ratio provides information about the performance of each component and enables the comparison of dissimilar components. It is defined [17] as

$$y^{*}_{D,k} = \frac{E_{D,k}}{\sum E_{D,k}} \tag{2}$$

3.2. Advanced exergy analysis

In an advanced exergy analysis, the total exergy destruction is split into endogenous/exogenous and avoidable/unavoidable parts, which provide better understanding of irreversibility in an energy conversion system.

3.2.1. Endogenous and exogenous exergy destruction

Splitting the total exergy destruction into endogenous and exogenous parts reveals the origin of the irreversibility. The endogenous exergy destruction in a component is caused by the irreversibility taking place in the component itself while the exogenous exergy destruction is due to the irreversibility inside the remaining components [9].

To do this division, theoretical operating conditions need to be established for each component. Assumptions for establishing the theoretical operating conditions will be further discussed in Section 4.1.

The endogenous exergy destruction is calculated by a hybrid process [9]. There, only the component being considered runs at the real condition, while all other components operate in an ideal way. The exergy destruction within the component obtained in a hybrid process represents the endogenous exergy destruction of this component. By introduction of the irreversibility step by step, the endogenous exergy destruction for each component can be obtained.

The exogenous exergy destruction rate, associated to the irreversibility of the remaining components, is acquired from

$$E_{D,k}^{EX} = E_{D,k} - E_{D,k}^{EN} \quad (3)$$

3.2.2. Avoidable and unavoidable exergy destruction

The unavoidable exergy destruction is part of the exergy destruction that cannot be further reduced due to technological constraints and limitation of materials and manufacturing methods. It is evaluated by the methodology described in [8] and is calculated by

$$E_{D,k}^{UN} = E_{P,k}^{real} \times (\frac{E_{D,k}}{E_{P,k}})^{UN} \quad (4)$$

Here, $(E_{D,k}/E_{P,k})^{UN}$ is the ratio between the exergy destruction and the product exergy for the component simulated at unavoidable conditions. The simulation is performed by isolating the component from the overall system and assuming that the flows entering the component have the same thermodynamic parameters as in the real case.

The difference between the exergy destruction and the unavoidable exergy destruction gives the avoidable exergy destruction, which can be expresses as following

$$E_{D,k}^{AV} = E_{D,k} - E_{D,k}^{UN} \quad (5)$$

The avoidable exergy destruction represents the part of the exergy destruction that can be eliminated by process optimization or technological improvement and highlights the room for improvement.

In addition, the avoidable exergy destruction on system level is obtained by establishing a system where all the components in the system operate under the avoidable operating condition simultaneously.

3.2.3. Combination of split exergy destruction

Four useful terms can be derived by combining the foregoing splitting concepts. They are calculated as

$$E_{D,k}^{UN,EN} = E_{P,k}^{EN} \times (\frac{E_{D,k}}{E_{P,k}})^{UN} \quad (6)$$

$$E_{D,k}^{UN,EX} = E_{D,k}^{UN} - E_{D,k}^{UN,EX} \quad (7)$$

$$E_{D,k}^{AV,EX} = E_{D,k}^{EN} - E_{D,k}^{UN,EN} \quad (8)$$

$$E_{D,k}^{AV,EX} = E_{D,k}^{EX} - E_{D,k}^{UN,EX} \quad (9)$$

Avoidable endogenous exergy destruction ($E_{D,k}^{AV,EN}$) can be reduced by improving the efficiency of the considered component, while avoidable exogenous exergy destruction ($E_{D,k}^{AV,EX}$) can be reduced by improving the efficiency in the remaining components. Unavoidable endogenous exergy destruction ($E_{D,k}^{UN,EN}$) cannot be further eliminated due to the technical limitations in the components themselves, while the technical limitations in the remaining components determine the unavoidable exogenous exergy destruction ($E_{D,k}^{UN,EX}$).

When optimizing the overall system, attention should be centered on endogenous avoidable and exogenous avoidable exergy destruction.

4. Assumptions for advanced exergy analysis

In this section, considerations for defining the theoretical and unavoidable conditions for each component are discussed. Table 1 presents the main assumptions made for theoretical and unavoidable operating conditions.

4.1. Theoretical conditions

Several approaches for calculation of endogenous exergy destruction have been developed during the last decade. In this study, the most convenient and robust method, known as thermodynamic-cycle-based method [9] was applied. For defining the theoretical conditions of each component, $E_D=0$ is assumed. When this is not possible, the conditions with a minimum value of E_D should be satisfied [13].

For compressors, it is straightforward to define the theoretical condition. We have $E_D=0$ when the isentropic efficiency is equal to unity. In addition, for those compressors that are protected by anti-surge recycle, no anti-surge recycle is assumed under the theoretical conditions.

For coolers, minimum exergy destruction is attainable at $\Delta T_{pinch}=0$ and zero pressure drop.

Valves are evaluated alternatively depending on their locations in the system. The throttling valves at the manifold should be replaced with expanders with isentropic efficiency equal to unity [13]. The exergy destruction of anti-surge valve is caused by off-design operating conditions of the associated compressors. Therefore it can be concluded that the exergy destruction of anti-surge valves is exclusively exogenous.

4.2. Unavoidable conditions

Unavoidable conditions are constrained by technological limitations and determined somewhat arbitrarily based on the authors' knowledge and experience [10].

In the analysis, the compressors were assumed operated at isentropic efficiency η_{is}=80%. Exergy destruction caused by anti-surge recycle is regarded avoidable if the compressors are replaced with some that fit the flowrate. Consequently, exergy destruction taking place in the anti-surge valves can all be avoided.

The avoidable exergy destruction of a cooler depends on the outlet temperature of the cooler, which is limited by the hydrate formation temperature of the stream flowing out of it. To determine the outlet temperature under unavoidable conditions, we first have to calculate the hydrate formation temperature of the stream. The cooler outlet temperature was then set 5 ^{o}C higher than the hydrate formation temperature.

Table 1. Assumptions for calculation of exergy destruction rate under real, unavoidable and theoretical conditions

System	Component	Real	Unavoidable	Theoretical
Production manifold	Choke valves	Isenthalpic	Replaced by expander with η_{is}=40 %	Isentropic
Recompression train	C-KA-23-004 C-KA-23-007 C-KA-23-010	η_{is}=46.52 % η_{is}=68.99 % η_{is}=56.38 %	η_{is}=80 %, no anti surge recycle	η_{is}=100 %, no anti surge recycle
	Recycle valve 1,2,3	Isenthalpic	Mass flow = 0	Mass flow = 0
	C-HA-23-001	T_{out}=39.9 °C, Δp/p=0.25 bar	Mas flow = 0	Mas flow = 0
	C-HA-23-005A/B	T_{out}=21 °C, Δp/p=0.52 bar	T_{out} =17 °C, Δp/p=1 %	T_{out}=17 °C, Δp/p=0 bar
	C-HA-23-008	T_{out}=24 °C, Δp/p=0.46 bar	T_{out} =17 °C, Δp/p=1 %	T_{out}=17 °C, Δp/p=0 bar
Reinjection A	C-HA-26-001A/B	T_{out}=28 °C, Δp/p=1.2 bar	T_{out} =23 °C, Δp/p=1 %	T_{out}=17 °C, Δp/p=0 bar
	C-KA-26-004A	η_{is}=63.85 %	η_{is}=80 %	η_{is}=100 %
	C-HA-26-005A/B	T_{out}=28 °C, Δp/p=0 bar	T_{out}=26.7°C, Δp/p=0 bar	T_{out}=17 °C, Δp/p=0 bar
	C-KA-26-007A	η_{is}=54.40 %	η_{is} =80 %	η_{is}=100 %
Reinjection B	C-HA-26-001C/D	T_{out}=28 °C, Δp/p=1.1 bar	T_{out} =23 °C, Δp/p=1 %	T_{out}=17 °C, Δp/p=0 bar
	C-KA-26-004B	η_{is}=63.77 %	η_{is} =80 %	η_{is}=100 %
	C-HA-26-005C/D	T_{out}=28 °C, Δp/p=0.7 bar	T_{out}=26.7 °C, Δp/p=0.7bar	T_{out}=17 °C, Δp/p=0 bar
	C-KA-26-007B	η_{is}=56.89 %	η_{is}=80 %	η_{is}=100 %
Reinjection C	C-HA-26-001E	T_{out}=30 °C, Δp/p=3.9 bar	T_{out}=23 °C, Δp/p=1 %	T_{out}=17 °C, Δp/p=0 bar
	C-KA-26-004C	η_{is}=68.75%	η_{is}=80 %	η_{is}=100 %
	C-HA-26-005E	T_{out}=30 °C, Δp/p=2.7 bar	T_{out}=26.4 °C, Δp/p=1 %	T_{out}=17 °C, Δp/p=0 bar
	C-KA-26-007C	η_{is}=64.34 %	η_{is}=80 %	η_{is}=100 %

It is known, however, that a valve is a dissipative component. As long as valves are used at the production manifold, the exergy destruction caused by the irreversibility of the valve cannot be eliminated unless manifold valves are to be replaced by other devices. In this regard, multi-phase expanders may be an option. A multiphase expander can recover some energy from high pressure feed streams and produce power. Since there is no practical application of such a device, it is hard to estimate the efficiency of the expanders. In this study, the isentropic efficiency was assumed conservatively to η_{is}=40%.

5. Results and discussion

5.1. Result of conventional exergy analysis

The advanced exergy analysis was performed based on the results from conventional exergy analysis. In order to investigate potential advantages of the advanced exergy analysis, it was necessary first to have a look at the results obtained from a conventional exergy analysis.

As mentioned above, this study was an extension of previous research [3]. The results from [3] were therefore taken as input to this study. It is worth to mention that minor changes were made for the calculation of exergy destruction rates for all coolers in the system. Here, we distinguished between exergy destruction within the coolers and exergy loss due to irreversible mix of the discharged cooling medium into seawater.

The exergy destruction of the main components are summarized in Table 2. In this paper, exergy destruction is presented on component level, while in [3] the exergy destruction was lumped by type of components and systems. Viewing the exergy destruction on component level enables the comparison between components, and makes it possible to conclude the priority of main components for improvement.

Table 2. Results for conventional exergy analysis of oil and gas processing plant

System	Components	$E_{D,k}$ (kW)	$y^*_{D,k}$,%
Production manifold	Valve @ Manifold C-07	853	4.6
	Valve @ Manifold C-16	934	5.0
	Valve @ Manifold C-23	1634	8.8
	Valve @ Manifold C-24	383	2.1
	Valve @ Manifold C-26	364	2.0
	Mixer 1	71	0.4
	Valve 1	253	1.4
	Heat loss	125	0.7
	Total	4617	24.9
Separation train	Valve 2	414	2.2
	Valve 3	39	0.2
	Mixer 2	229	1.2
	Other components	141	0.8
	Total	823	4.4
Recompression train	C-KA-23-004	380	2.1
	C-KA-23-007	398	2.1
	C-KA-23-010	638	3.4
	Recycle valve 1	300	1.6
	Recycle valve 2	655	3.5
	Recycle valve 3	738	4.0
	C-HA-23-001	141	0.8
	C-HA-23-005A/B	199	1.1
	C-HA-23-008	276	1.5
	Other components	125	0.7
	Total	3851	20.8
Reinjection train A	C-KA-26-004A	736	4.0
	C-KA-26-007A	815	4.4
	C-HA-26-001A/B	265	1.4
	C-HA-26-005A/B	396	2.1
	Other components	0.11	0.001
	Total	2211	11.9
Reinjection train B	C-KA-26-004B	803	4.3
	C-KA-26-007B	769	4.2
	C-HA-26-001C/D	279	1.5
	C-HA-26-005C/D	451	2.4
	Other components	0.12	0.001
	Total	2302	12.4
Reinjection train C	C-KA-26-004C	1160	6.3
	C-KA-26-007C	1178	6.4
	C-HA-26-001E	671	3.6
	C-HA-26-005E	821	4.4
	Other components	0.17	0.001
	Total	3830	20.7
Reinjection train	Other components	134	0.7
	Total	8477	45.8
Fuel gas system	Heater	139	0.7
	Valve 4	140	0.8
	Valve 5	182	1.0
	Other components	48	0.3
	Total	508	2.7
Export pumping	Booster pump	38	0.002
	Export pump	77	0.004
	Heat exchanger	81	0.004
	Other components	47	0.003
	Total	244	0.013
	Total Exergy Destructed	18520	

It is clear, as indicated by the exergy destruction ratios in Table 2, the highest exergy destruction ratio was found for throttling valve at manifold of well C23. 1634 kW exergy was destroyed in the valve due to the pressure drop from 165.1 bar to 73.1 bar. Compressor C-KA-26-007C had the second highest exergy destruction, followed by compressor C-KA-26-004C. Totally, 2338 kW exergy was destroyed in these two compressors due to high flow rate in reinjection train C and low isentropic efficiency of the compressors. Apart from above mentioned components, most of the exergy destruction in the system was distributed among valves, compressors and coolers, ranging from 300 kW to 935 kW.

Pumps, however, had relatively low exergy destruction. Low exergy destruction was also reported for separator, mixer and splitter, where the exergy destruction of these components were lumped together and shown as "other components" in the table. Low exergy destruction implied that these components did not have a significant effect over the overall system efficiency.

System-wise, the gas treatment train gave the biggest proportion of the total exergy destruction, and accounting for 45 % of total exergy destruction. The production manifold and recompression train followed with relatively large exergy destruction values, while the values of exergy destruction for the separation and export train were low.

It should be noted that as a dissipative component, valves should not be taken into consideration when prioritizing the components for improvement. Therefore, from the viewpoint of conventional exergy analysis, we could conclude that the overall system can be thermodynamically improved using the following priorities for the components: the compressors in reinjection train C (C-KA-26-007C and C-KA-26-004C) should be improved first, the second priority is the cooler C-HA-26-005E, and the third priority is simultaneously the improvement of compressor C-KA-26-007A and C-KA-26-004B. Pumps and separators were less important with respect to the improvement of overall system.

5.2. Result of advanced exergy analysis

As suggested by conventional exergy analysis, it is more meaningful and advisable to focus on the components and the sub-systems with large exergy destruction. Thus, advanced exergy analysis was performed to systems as production manifold, recompression train and reinjection train, which provide the greatest opportunities for improvement. The results of detailed advanced exergy analysis for the main components are presented in Table 3.

5.2.1. Endogenous and exogenous exergy destruction

As can been seen in Table 3, the proportion of endogenous exergy destruction differed significantly from component to component.

For all the compressors, $E_{D,k}^{EN} >> E_{D,k}^{EX}$, which meant that the interactions among the compressors and other components of the process were very weak, and that the exergy destruction was mainly caused by the irreversibility within the compressors themselves. In other words, attention should be paid on the internal irreversibility of the compressors in order to improve the performance of the system. The negative value of exogenous exergy destruction of compressor C-KA-23-010 was the result of an increased flowrate in the recompression train under theoretical operating conditions.

The results showed variations in endogenous and exogenous exergy destruction for the coolers. In the recompression train, the exogenous exergy destruction dominated. This result was obtained with the assumption of no anti-surge recycle around compressor. The percentage of exogenous exergy destruction may change substantially with the change of anti-surge recycle rate over the field lifetime. In the reinjection train, the value of the endogenous exergy destruction was higher than the value of exogenous exergy destruction for the first stage coolers, while the results were opposite for the second coolers. A higher value of exogenous exergy destruction indicated that in order to reduce the exergy destruction, it is more effective to improve the performance of remaining components.

Considering the valves installed on anti-surge recycle line, the exergy destruction was exclusively exogenous as explained in Section 4.1. Zero exergy destruction for anti-surge valve was attainable by improving the associated compressors. Conversely, valves at the production manifold were exclusively endogenous. This meant that the exergy destruction within the valves was independent of the irreversibility within the remaining components of the process, and the exergy destruction could be decreased only through improvement of the component itself. It was known, however, that the exergy destruction due to the irreversibility in the valve could not be further reduced, unless manifold valves were replaced by other devices. Nevertheless, the implementation of such devices is challenging due to instable flowrate of reservoir fluid. The presence of significant amounts of impurities and sand also hinders the practical application of such devices.

Table 3. Results for advanced exergy analysis of oil and gas processing plant

System/Comonent	$E_{D,k}^{EN}$ (kW)	$E_{D,k}^{EX}$ (kW)	$\frac{E_{D,k}^{EN}}{E_{D,k}}$	$E_{D,k}^{AV}$ (kW)	$E_{D,k}^{UN}$ (kW)	$\frac{E_{D,k}^{AV}}{E_{D,k}}$	$E_{D,k}^{AV,EN}$ (kW)	$E_{D,k}^{UN,EN}$ (kW)	$E_{D,k}^{AV,EX}$ (kW)	$E_{D,k}^{UN,EX}$ (kW)
Production manifold										
Manifold C-07 Valve	853	0	1	338	515	0.40	0	853	0	0
Manifold C-16 Valve	934	0	1	369	565	0.40	0	934	0	0
Manifold C-23 Valve	1634	0	1	643	991	0.39	0	1634	0	0
Manifold C-24 Valve	383	0	1	152	230	0.40	0	383	0	0
Manifold C-26 Valve	364	0	1	145	219	0.40	0	364	0	0
Recompression train										
C-KA-23-004	378	2	0.99	372	8	0.98	371	7	1	1
C-KA-23-007	394	4	0.99	324	74	0.81	314	81	11	-7
C-KA-23-010	663	-25	1.04	569	69	0.89	583	81	-14	-11
Recycle valve 1	0	300	0	300	0	1	0	0	300	0
Recycle valve 2	0	655	0	655	0	1	0	0	655	0
Recycle valve 3	0	738	0	738	0	1	0	0	738	0
C-HA-23-001	0	141	0	141	0	1	0	0	141	0
C-HA-23-005A/B	32	168	0.16	87	112	0.44	-2	34	89	78
C-HA-23-008	41	235	0.15	49	227	0.18	-24	65	73	162
Reinjection A										
C-KA-26-004A	694	42	0.94	385	351	0.52	380	313	4	38
C-KA-26-007A	784	31	0.96	542	272	0.67	538	246	4	27
C-HA-26-001A/B	157	108	0.59	42	223	0.16	2	156	40	68
C-HA-26-005A/B	144	252	0.36	9	387	0.02	-81	224	89	163
Reinjection B										
C-KA-26-004B	759	44	0.95	421	382	0.52	417	342	4	40
C-KA-26-007B	732	36	0.95	489	279	0.64	483	250	6	30
C-HA-26-001C/D	165	115	0.59	59	220	0.21	-1	166	43	72
C-HA-26-005C/D	173	278	0.38	9	441	0.02	-85	258	94	184
Reinjection C										
C-KA-26-004C	1020	140	0.88	489	671	0.42	471	549	17	123
C-KA-26-007C	1086	92	0.92	611	567	0.52	600	486	11	81
C-HA-26-001E	461	210	0.69	268	403	0.40	189	272	79	131
C-HA-26-005E	308	513	0.37	88	733	0.11	-71	378	158	355

5.2.2. Avoidable and unavoidable exergy destruction

The avoidable exergy destruction revealed the real potential for improving a component. It is apparent from Table 3 that the compressors had relatively large fuel-saving potential; more than 42% of the exergy destruction could be avoided by increasing the efficiency of the compressors. This also implied that the compressors operated far from their optimal point at current operating conditions.

Coolers, on the other hands, had relative low avoidable exergy destruction. The saving potentials for the coolers were limited by the pinch temperature. The cooler outlet temperature could not be further reduced due to constraints posed on the pipe material and hydrate problems.

The destructed exergy within the anti-surge valve depended on the performance of the associated compressors. Theoretically, this part of exergy destruction could all be avoided. Furthermore, it can be seen that the saving potentials of the valves at the production manifold were proportional to the assumed isentropic efficiency of the introduced expanders. However, we should be aware of the availability and reliability of the expander replacing the valves.

Figure 2 gives the avoidable exergy destruction on system level. The recompression train had largest energy saving potential, and the saving potential for reinjection train was also high.

Moreover, the overall system had a 4% improvement potential in terms of exergy efficiency when main components were operated under unavoidable conditions.

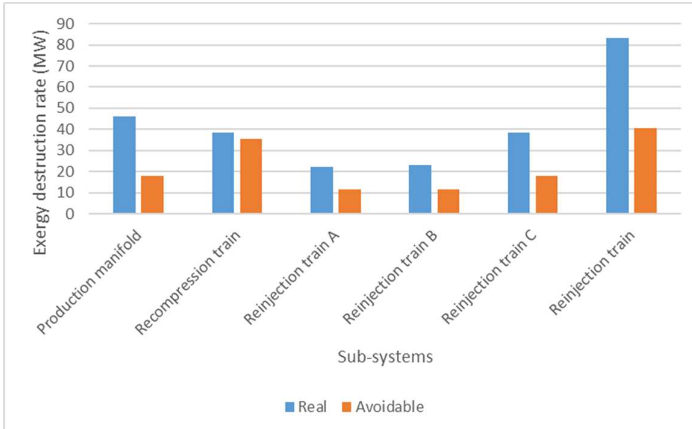

Figure 2. Exergy destruction for the main sub-systems under real and unavoidable operating conditions.

5.2.3. Combined splitting

Figure 3 outlines the percentages for combined exergy destruction. Avoidable endogenous and avoidable exogenous indicate the influence of irreversibility of the component itself and the remaining components on improving potential for the investigated components. As shown in Table 3, the values of avoidable endogenous of compressors were much higher than the values of avoidable exogenous of the compressor, as well as the avoidable endogenous and avoidable exogenous exergy destruction of the coolers. This meant that the main attention should be paid on the improvement of compressors. Negative values were observed for the avoidable endogenous exergy destruction within some coolers. This resulted from stronger effect on reduction exergy destruction from the remaining components than within the coolers themselves. So far, we could conclude that compressors were the most important components with respect to system performance enhancement.

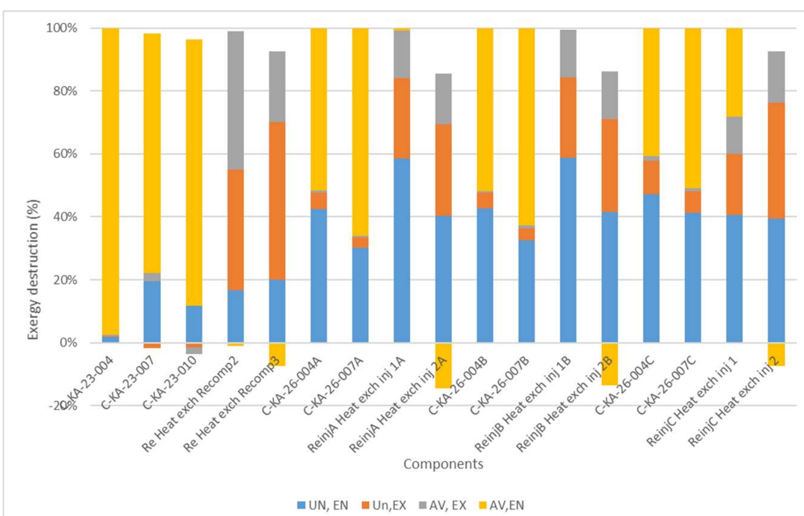

Figure 3. Breakdown of exergy destruction into unavoidable endogenous, unavoidable exogenous, avoidable exogenous and avoidable endogenous parts for main components.

5.3. Improvement strategy

By splitting the exergy destruction into different parts, the advanced exergy analysis provides more insight than the conventional exergy analysis. The improvement priorities suggested from advanced exergy analysis perspective are presented in Table 4, with comparison to the results obtained from a conventional exergy analysis. For the conventional exergy analysis, the improvement priorities were ranked based on the values of exergy destruction without considering the valves. The sequence for optimization in advanced exergy analysis was determined from the avoidable endogenous exergy destruction. The validation of the improvement priorities given by the advanced exergy analysis will be addressed in the future work.

Table 4. Suggested optimization sequence from conventional and advanced exergy analysis

Improvement priority	Conventional exergy analysis	Advanced exergy analysis
1	C-KA-26-007C	C-KA-26-007C
2	C-KA-26-004C	C-KA-23-010
3	C-HA-26-005E	C-KA-26-007A
4	C-KA-26-007A	C-KA-26-007B
5	C-KA-26-004B	C-KA-26-004C
6	C-KA-26-007B	C-KA-26-004B
7	C-KA-26-004A	C-KA-26-004A
8	C-HA-26-001E	C-KA-23-004
9	C-KA-23-010	C-KA-23-007
10	C-HA-26-005C/D	C-HA-26-001E

6. Conclusions

Oil and gas processing has been analyzed by means of an advanced exergy method to reveal the sources of inefficiencies and improvement potentials of components, and of the overall system. The main conclusions from the advanced exergy analysis can be summarized as:

- The advanced exergy analysis not only points out the component that should be improved, but also the sequence for optimization. The advanced exergy analysis indicated that the focus of system improvement should be on compressors with order of second-stage compressor in reinjection train C, third-stage compressor in recompression train, first-stage compressor in reinjection train C and second-stage compressor in reinjection train B, respectively, while conventional exergy analysis pinpointed that improvement priority should be given to second-stage compressor, first-stage compressor and second-stage cooler in reinjection train C.
- The proportion of exogenous exergy destruction differed considerably from component to component. A large amount of exergy destruction taking place in coolers were caused by the irreversibility in other components, while the exergy destruction of the compressors were attributed to their inherent irreversibility.
- Results showed that, in general, the avoidable exergy destruction in the recompression train was considerable when compared to the unavoidable and total exergy destruction. On the contrary, coolers had relatively low energy saving potential. For the overall system, 4% was achievable with respect to exergy efficiency improvement when all main components were operated at unavoidable conditions
- The advanced exergy analysis also suggested that the improvement of the compressors would be more meaningful and effective to improve the overall system efficiency.

It should be emphasized that the results obtained in advanced exergy analysis have a strong dependence on the assumptions for theoretical and unavoidable conditions. Additionally, the results is valid for current operating conditions and may change due to varying operating conditions over field lifetime.

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