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EXERGY ANALYZING METHOD IN PROCESS INTEGRATION OF THE NITRIC ACID PRODUCTION PLANT

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Abstract. *In the first paper, the basic principles of a simple and efficient method of 2nd Law analysis for the improvement of chemical processes are given. In this paper, the practical application of the presented theoretical suppositions is described on a reference object. As a referent object the dual pressure nitric acid plant is chosen. The physical model of this plant is described. The existing plant design is analyzed using the exergy analyzing method. Considering 13 common-sense guidelines, new possible designs are obtained. Also, a comparative analysis of the given designs, considering energy savings and capital costs, is given. The results are given in the form of tables and diagrams.*

Key Words: *Exergy Consumption, Nitric Acid, Process Efficiency*

1. INTRODUCTION

Most chemical plants are designed with little or no considerations given to the 2nd Law of thermodynamics. As a result there is an often ample opportunity to use a 2nd Law analysis to increase plant efficiency. As an example, the proposed design for a dual pressure nitric acid plant will be discussed.

EXERGY ANALYSIS OF THE PROPOSED DESIGN

This plant produces 51.3-weight % nitric acid and has a capacity of 37,865 metric tons per hour of HNO_3 (100% basis). The process flow sheet of this plant is given in Figure 1. In this process, ammonia vapor is mixed with excess air and oxidized to nitrogen dioxide in the converter (C). Nitrogen dioxide is formed as the converter gas is cooled to 50°C in the heat exchanger system (E_2 to E_6), and nitric acid is formed in the absorber. The gas (10) leaving exchanger E_6 is compressed from 3 to 10.25 bars in compressor C_2, and, after the oxidation vessel, it goes to the absorber for nitric acid production. The energy of the converter gas and

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tail gas from the absorber is used for steam generation and to power turbines T_1 and T_2. The net power exported is about 105 kWh per ton of the produced nitric acid.

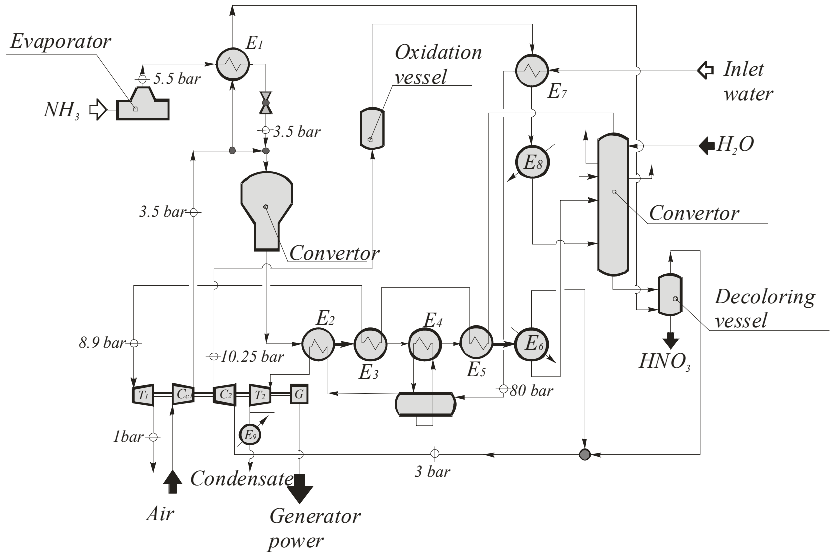

Fig. 1. Dual-pressure Nitric Acid Process Flow Sheet

The scope of this study is limited to the recovery of exergy from the converter gas as it is cooled from 840°C (stream 5) to 50°C (streams 10 and 26), the gas leaving the oxidation vessel (stream 19) as it is being cooled to 43°C (stream 21), and the tail gas from the absorber (stream 22) till it is exhausted to the stack.

The process can be easily improved by an appropriate 2nd Law analysis of the energy recovery section. Basically, we apply simple 13 common-sense 2nd Law guidelines, which are given in the first paper.

The exergy consumptions fall into 3 sets: recovery set (E_2, E_3, E_4, E_5, E_7 and the steam drum), discard set (E_6, E_8, E_9, and the loss in the stack gas), and transform set (compressors and turbines).

Equations to estimate the exergy consumptions in the absence of entropy data are derived. They are used as guides leading to process design changes.

In the energy recovery section, an exergy change depends only on the changes in temperature and pressure of streams. For a stream with negligible pressure drop undergoing heat exchange, and a stream of a constant heat capacity, the expression for exergy consumed at a heat exchanger is:

$$Ex_{isk} = ToQ\left(\frac{1}{T_{lm,Hs}} - \frac{1}{T_{lm,Ts}}\right), \quad (1)$$

where T_{lm},C_s (T_{lm},H_s) is the log mean absolute temperature of the cold (hot) stream. This equation is an excellent approximation in most cases.

For an adiabatic compressors and turbines, the exergy consumption may be estimated by assuming that the ideal gas law holds:

$$Ex_{cons} = T_0[\frac{\Delta H}{T_{lm}} - GR\ln\frac{p_2}{p_1}] \quad (2)$$

This equation is not appropriate for steam turbine T_2, since the ideal gas assumption is not valid. Entropy data, available from the steam tables, can be used to calculate the exergy consumed at turbine T_2.

Likewise, the tail gas may be taken as an ideal gas. The exergy consumption for the tail gas being discharged to the ambient is:

$$Ex_{cons} = T_0 Gc_p \ln\frac{T_0}{T_1} - Gc_p(T_0 - T_1) \quad (3)$$

The technological scheme of the referent object with the following T-H and T-s diagrams is given in Figure 2. Using 2nd Law 13 common-sense guidelines, the modeling of previously defined sets of this system is done. The inefficiencies in the energy recovery section are:

1. Stream 19 is to be cooled from 236°C to 43°C, and dumping heat at 156°C to cooling water is an unnecessary waste and violates guideline 3.

2. Considering the heat capacities and mass flows of the streams, it is obvious that exchanging heat between streams 19 and 30 violates guideline 6, since the heat capacity of the boiler feedwater is furthest from that of the NO_2. It would be an improvement to exchange the heat between the stream 19 and the tail gas 22.

3. The tail gas goes to the stack at too high temperature to be dumping to the ambient (guideline 3). Instead, more heat from the converter gas should have been used to generate steam.

The above-described changes in the energy recovery section will be quite beneficial since these are streams with big mass flows (guideline 11).

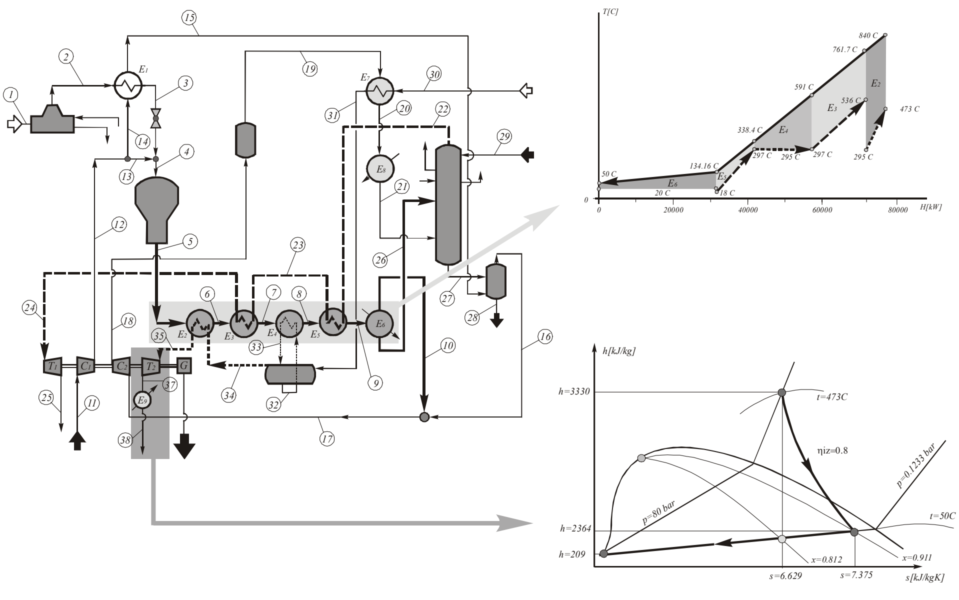

Fig. 2. The Technological Scheme of the Referent Object with Following T-H and T-s Diagrams

REVISED DESIGNS TO ELIMINATE UNNECESSARY 2ND LAW INEFFICIENCIES

Revision 1 shown in Figure 3 is reconfigured to accomplish the matching of stream 22 with stream 19 in E7, and to eliminate any heating of the tail gas by the converter gas in E_3. The stack gas temperature has been reduced to 45.5°C and much less exergy is dumped to the ambiance. The converter gas heat is used to generate more steam. The net power output has increased and the efficiency of the energy recovery section also increases.

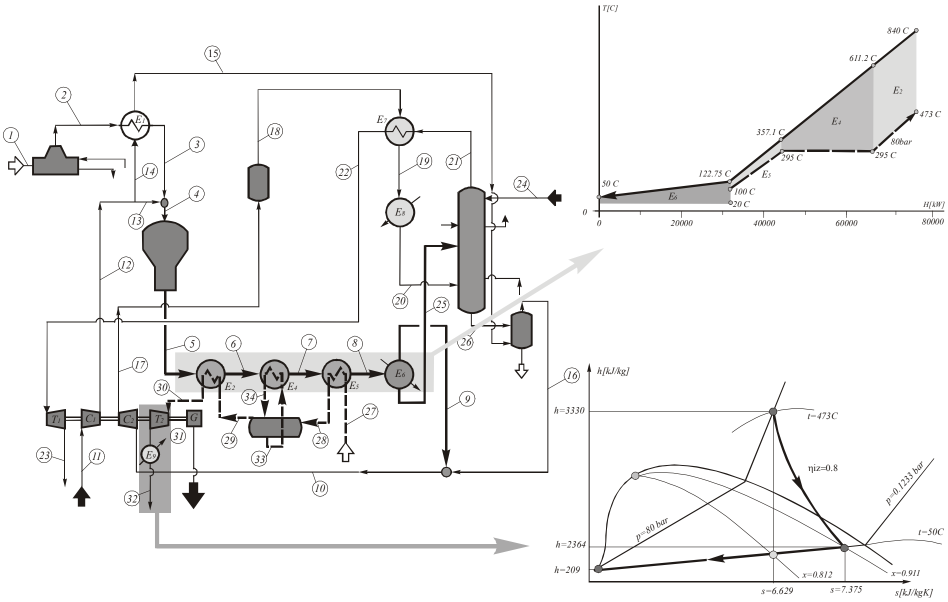

Fig. 3. The Technological Scheme of the Referent Object with Following T-H and T-s Diagrams – Revised Design 1

These process changes are technically feasible. They do not require any significant increase in the capital costs. The scheme and the following diagrams of the revised design are given in Figure 4. The results are given in Table 1.

The thermodynamic driving force between the converter gas cooling curve and the steam generation system decreases as the pressure increases. The reconfigured design can be made more efficient by generating steam at higher pressure. In **Revision 2**, steam is generated at 124 bars and 650°C. This is shown in Figure 4. The consumption in the recovery set decreases as is shown in Table 1 while the net power increases. Capital costs also increase due to a new high pressure system and larger heat exchangers required by the reduction in the temperature driving force.

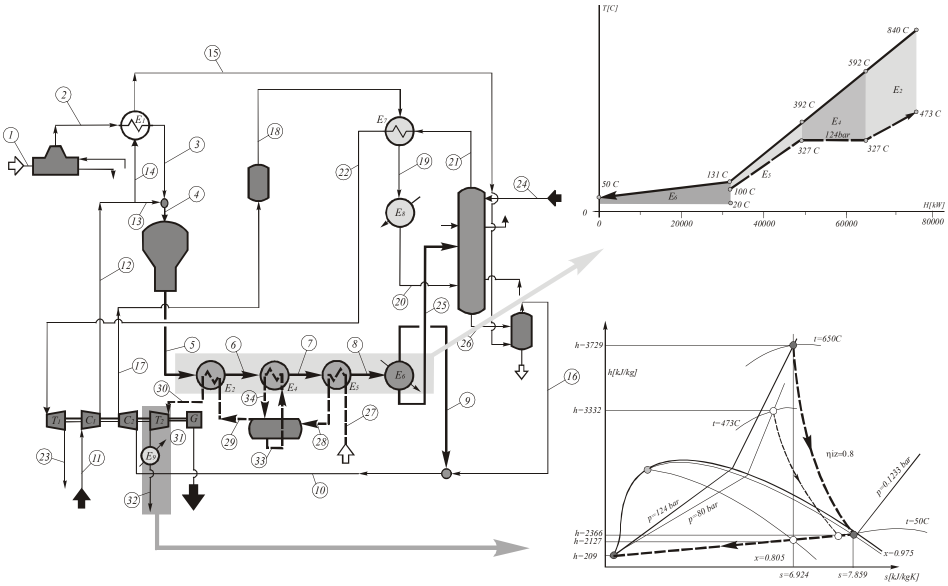

Fig. 4. The Technological Scheme of the Referent object with Following T-H and T-s diagrams - Revised Design 2

Revision 3 is shown in Fig. 5. The amount of 124 bars, at 650°C, is expanded in a new back pressure turbine to 40 bars, and then, reheated by the converter gas, it goes back to 650°C. Then it is sent to turbine T_2. The power output for this revision is an improvement over original design but the new high pressure turbine is required in addition to a more expensive high-pressure steam system.

It is possible to decrease the cost of the previous revision by heating the tail gas (instead of reheating the steam) while still maintaining the 124 bar steam system. This change is shown in Fig. 6. The exergy consumptions for **Revision 4** are also shown in Table 1. The result of this design change is net power output lower than in Revision 3, but it is still greater than the original proposal.

CONCLUSIONS

A simple and efficient method of 2nd Law analysis for the improvement of chemical processes has been proposed and demonstrated. As a referent object the dual pressure nitric acid plant is chosen. It starts with application of 13 common-sense 2nd Law guidelines to detect any unnecessary inefficiency in the process. An improved design is achieved by making process changes that eliminate these inefficiencies. Equations were derived to calculate exergy consumptions. Further on, the technically feasible process changes are made to reduce the thermodynamics driving forces. These changes reduce the exergy consumption, and increase the process efficiency, but do so at the expense of increased capital costs. The changes of exergy consumption and net power output of revised designs 1 to 4 over the referent design are given in Figure 7.

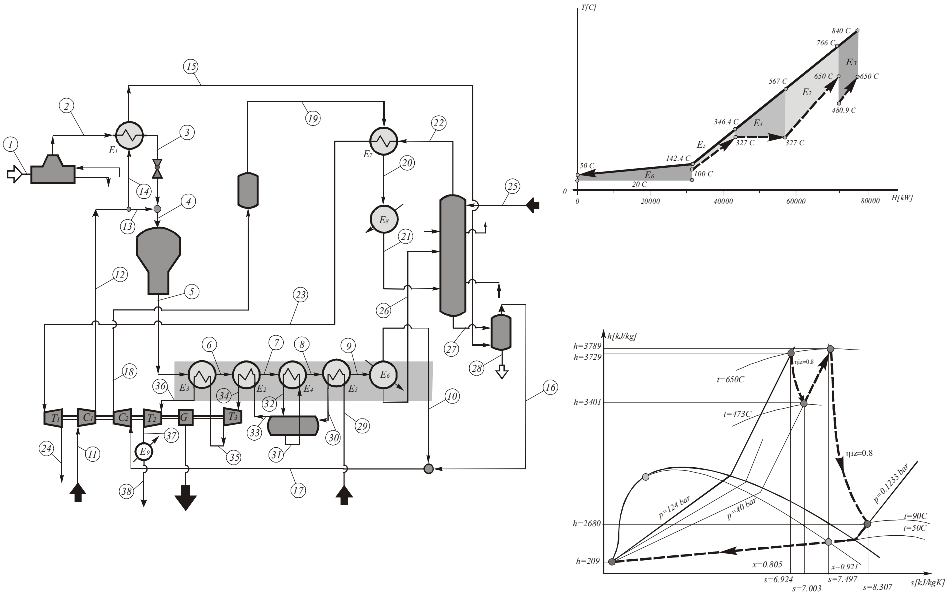

Fig. 5. The Technological Scheme of the Referent Object with Following T-H and T-s Diagrams - Revised Design 3

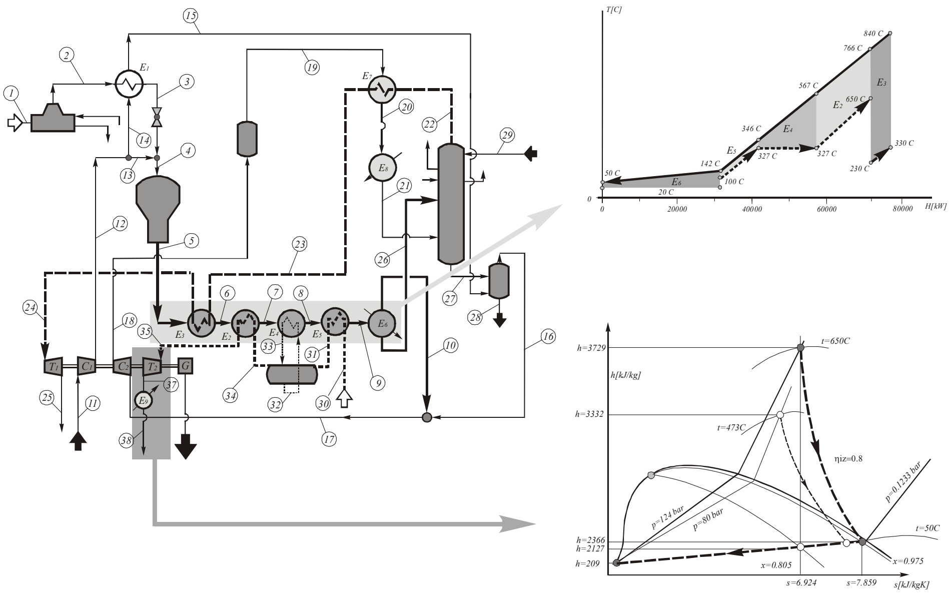

Fig. 6. The Technological Scheme of the Referent Object with Following T-H and T-s Diagrams - Revised Design 4

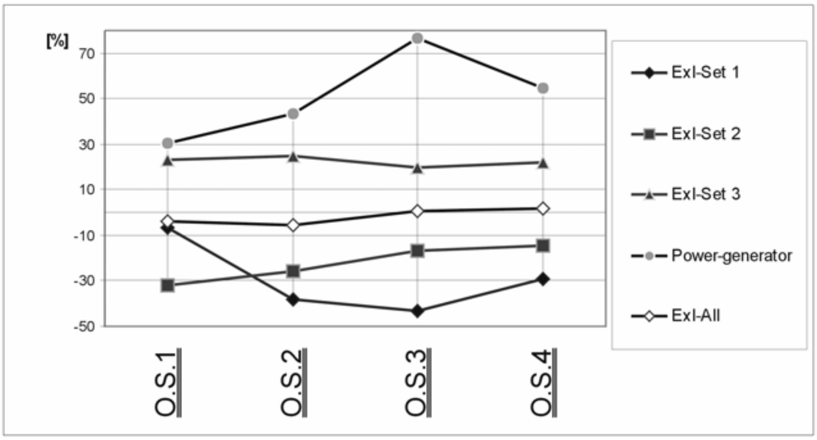

Fig. 7. Exergy Consumption and Net Power of Referent and revised Designs

Table 1. Optimization Results

	Referent design		Revised design 1		Revised design 2		Revised design 3		Revised design 4	
	kW	%	kW	%	kW	kW	%	kW	%	kW
Energy recovery set										
R2	839.1856		1423.812		1383.851		930.1853		931.811	
R3	1240.187		0		0		346.9542		1146.233	
R4	1741.738		2999.136		1322.151		1110.985		1110.985	
R5	1507.861		548.1032		475.2976		486.1654		486.1654	
R7	250.9397		367.1866		367.1866		367.1866		367.1866	
DRUM	145.46		0		0		0		0	
total	5725.368	21.01352	5338.238	20.43515	3548.486	13.82635	3241.476	11.79176	4042.38	14.58729
Energy discard set										
R6	5648.273		4388.39		5385.725		6442.396		6442.396	
R8	1171.28		26.43832		26.14221		26.14221		26.14221	
R9	1670.601		2977.89		2647.558		2609.717		2439.786	
0.gas	2445.953		44.42		44.41885		44.41885		426.8549	
total	10936.11	40.13821	7437.141	28.4699	8103.844	31.57588	9122.673	33.18623	9335.179	33.68682
Energy transform set										
KM1	1332.242		1332.242		1332.242		1332.242		1340.143	
KM2	1204.253		1204.253		1204.253		1204.253		1296.768	
TR1	1928.425		1928.425		1928.425		1928.425		1932.683	
TR2	1812.585		3254.686		3377.581		2697.651		3097.303	
TR3	0		0		0		366.0146		0	
total	6277.506	23.04	7719.607	29.5512	7842.501	30.55758	7528.586	27.3873	7666.897	27.66668
Net power	4307.14	15.80827	5627.83	21.54374	6169.836	24.04019	7596.594	27.6347	6667.209	24.05921
total	27246.12	100	26122.82	100	25664.67	100	27489.33	100	27711.66	100

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Basic symbols		*Subscripts*	
G (kg/s)	– mass flow	*cons*	– consumption
E (kJ)	– energy (kJ)	*lm*	– logarithm mean
Ex (kW)	– exergy (kJ/kg	*Hs*	– hot stream
Q (kJ/kg)	– heat (kJ/kg)	*Cs*	– cold stream
T (K)	– temperature (K)	*0*	– ambient
c	– heat capacity	*p*	– constant pressure
H (kJ/kg)	– enthalpy	*1, 2,…,35*	– index
S	– entropy		

METOD EKSERGIJSKE ANALIZE U INTEGRACIJI PROCESA U POSTROJENJU ZA PROIZVODNJU AZOTNE KISELINE

Mirjana Laković, Predrag Živković, Predrag Rašković

Zahtevi u pogledu ekonomskih i termodinamičkih performansi komponenata, postrojenja i sistema, u smislu konverzije, distribucije i potrošnje različitih vidova energije se neprekidno povećavaju. Osnova za proučavanje energetskih sistema su održanje mase i Prvi princip termodinamike. Velike mogućnosti za povećanje efikasnosti procesa se javljaju kao rezultat razmatranja datih Drugim principom termodinamikae

U ovom radu su date najpre teorijske osnove primene Drugog principa termodinamike na poboljšanje efikasnosti procesa, a zatim je njegova primena prikazana na referentnom objektu. Kao referentni objekat izabrano je dvopritisno postrojenje za proizvodnju azotne kiseline. Najpre je dat opis procesa proizvodnje azotne kiseline i opis i analiza predloženog postrojenja, a zatim su izvedene jednačine za proračun utroška eksergije bez podataka o entropiji i izvršena eksergijska analiza predloženog postrojenja. Na osnovu osnovnih preporuka Drugog principa termodinamike za povećanje efikasnosti energetskih sistema i izvršene eksergijske analize, data su moguća nova, tehnički izvodljiva rešenja kojima bi se povećala energetska efikasnost postrojenja. Rešenja su data u vidu šema toka i tabelarno.

Ključne reči: *utrošak eksergije, azotna kiselina, efikasnost procesa.*