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Original Research Article

Exergy Analysis for Evaluation of Energy Consumptions in Hydrocarbon Plants

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ABSTRACT

In order to clarify the situation in energy consuming devices in hydrocarbon plants (Olefin, butadiene and butene1), by using thermodynamic laws (1st and 2nd) and apply energy and exergy balances to all equipment's, loss rate and the amount of renewable energy for each group of equipment such as pumps, towers, heat exchangers and … were calculated and with the process changes, it was tried to utilize current energy as much as possible. Since the irreversibility's cannot be omitted completely in processes, the rate of energy loss was reduced as much as possible by change in operation condition. Finally, the factors that influence the creation of irreversible processes have been discussed.

Keywords: Three exergy, energy, renewable, irreversibility's

Introduction

To express the actual developments in various processes of thermodynamic concepts used are different. In such cases terms like energy waste, increase the amount of entropy and irreversible with similar meanings are used and all their different views of a general rule, the second law of

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thermodynamic offer. Perhaps the concept of energy loss and irreversible process, even dating back more than the law of energy conservation and the phrase is the first law of thermodynamic.

The phrase "consumption of exergy" or "wasting energy" as such terms to describe the above order and first used by the Globe in 1889 AD was expressed. His new thermodynamic function, which only reflects the amount of thermal energy to mechanical energy convertible, was introduced. In this sense, then by Kynan U.S. as "available energy" was named the German rent in 1956 called "exergy" [1-6].

2. Exergy Concept

According to the definition Zargvt, Exergy is maximum work available in a reversible thermodynamic process. If a material change in the initial state to a secondary state that is in balance with the environment to reach [7]. Rykrt knows in reverse, the exergy mechanical or electrical energy needed to deliver material that is in equilibrium with the environment to the new secondary state in a reversible thermodynamic process. The definitions described above can be considered energy includes two parts: part of the energy can be converted to a reversible process is called exergy and another part that is converted to anergy is called.

$$E = An + Ex \quad (1)$$

The conversion of exergy to anergy is done in every actual thermodynamic process (irreversible) and this is the expression of second law of thermodynamic. Obviously, for a reversible process (ideal), the value exergy and anergy during the process will remain unchanged [8, 9].

3. Exergy as a thermodynamic function

Exergy certain mass of matter in accordance with the following formula is provided [8, 10-12].

$$\Delta Ex = (H - H_0) - T_0(S - S_0) = \Delta H - T_0 \Delta S \quad (2)$$

In which the ambient temperature T_0 and H_0, S0 are enthalpy and entropy values in terms of reference respectively. The reference conditions chosen so that $S_0 = H_0 = 0$, thus:

$$\Delta Ex = H - T_0 S \tag{3}$$

For solids and incompressible fluids:

$$\Delta H = H_0 + \int_{T_0}^{T} C_P dT \quad \& \quad \Delta S = S_0 + \int_{T_0}^{T} \frac{C_P}{T} dT \tag{4}$$

When H_0=S_0=0

$$\Delta Ex = \int_{T_0}^{T} \left(1 - \frac{T_0}{T}\right) C_P dT \tag{5}$$

For compressible fluids, the effects of pressure changes should be also considered. For ideal gases we have:

$$\Delta S = S_0 + \int_{T_0}^{T} (\frac{C_P}{T}) dT - R\ln(\frac{P}{P_0}) \tag{6}$$

When H_0=S_0=0

$$\Delta Ex = \int_{T_0}^{T} \left(1 - \frac{T_0}{T}\right) C_P dT + RT_0 \ln(\frac{P}{P_0}) \tag{7}$$

For the cases such as that the process combined with phase change, must also be considered in the calculations, for example if the solid temperature T_0 liquid temperature T will reach, we have [13].

$$\Delta Ex = \int_{T_0}^{T} \left(1 - \frac{T_0}{T}\right) C_{P_{solid}} dT + L_f \left(1 - \frac{T_0}{T}\right) + \int_{T_f}^{T} \left(1 - \frac{T_0}{T}\right) C_{P_{liquid}} dT \tag{8}$$

Where

L_f: heat of fusion

T_f: fusion temperature

Obviously exergy function is obtained from total state functions (entropy and enthalpy) that are also a state function.

In the transition states with particle transport and changing concentrations or in other words mixing (with separation) at constant temperature and pressure is combined exergy from the chemical transformation and called chemical exergy (Ex_C). This amount of exergy for an ideal solution (mixed) with two components is as follows [14-16].

$$\Delta Ex_C = RT_0\left[x\ln x + (1-x)\ln(1-x)\right] \quad (9)$$

Where

x: mole or weight fraction of each component

R: universal gas constant

Exergy change of a chemical reaction equals the Gibbs energy change in reaction at environmental temperature.

$$\Delta Ex_{OR} = \Delta G(T_0) \quad (10)$$

Exergy change caused by mixing several pure substances is as follows:

$$\Delta Ex_{OC} = \Delta H - RT_0 \sum n_i Ln \frac{1}{f_i} \quad (11)$$

Assuming that the ideal practice of mixing, the above relationship can be simplified as follows:

$$\Delta Ex_{OC} = -RT_0 \sum n_i Ln \frac{1}{y_i} \quad (12)$$

Exergy value for a two-component non-ideal solution, the mixing transformation and also associated with energy changes is:

$$\Delta Ex_C = \Delta H_C - T_0\left(\frac{\Delta H_C}{T} - R\left[x\ln\gamma_1 x + (1-x)\ln\gamma_2(1-x)\right]\right) \quad (13)$$

Where

ΔH_C: Separation or mixing energy

γ_1, $\gamma 2$: activity coefficients for each component

Exergy from heat flow Q, obtained from a source with temperature T, is the following:

$$Ex_{(Q)} = Q(1-\frac{T_0}{T}) \quad (14)$$

The relationship needed enthalpy and entropy quantities for each flow in real terms (P,T) and environmental conditions (P_0,T_0).To calculate these parameters, the program needs to be simulated. In industrial processes according to kind of process for exergy calculation, the special relationship with good approximation is used [8].

$$\Delta Ex = \Delta H(1-\frac{T_0}{T}) \qquad @\, T\ \&\ P = Const. \quad (15)$$

$$\Delta Ex = \Delta H(1-\frac{T_0}{T_{LM}}) \quad T_{LM} = (T_2 - T_1)/\ln(T_2/T_1) \quad @P = Const. \quad (16)$$

$$\Delta Ex = nRT_0 \ln(\frac{P_2}{P_1}) \quad @h = Const. \quad (17)$$

4. Calculation Method

In order to achieve accurate data for analysis and existing computing exergy loss of industrial equipment's, using engineering software HYSYS, the total industrial unit was simulated at steady state conditions. Under these conditions, the simulation which has been done operates as a internal processor software. So by changing operating conditions for each stream, simulated section can able to calculate thermodynamic properties according to type of fluid flow regime and the results was sent to original software which has been prepared for exergy calculation. In this stage, Equipped with the desired selection, and data entry on operation mode, thermodynamic properties would be obtained. After that the software can compute exergy losses and then final results will be led to external devices for printing. Figure (1) shows schematic communication HYSYS software engineering and software [17-19].

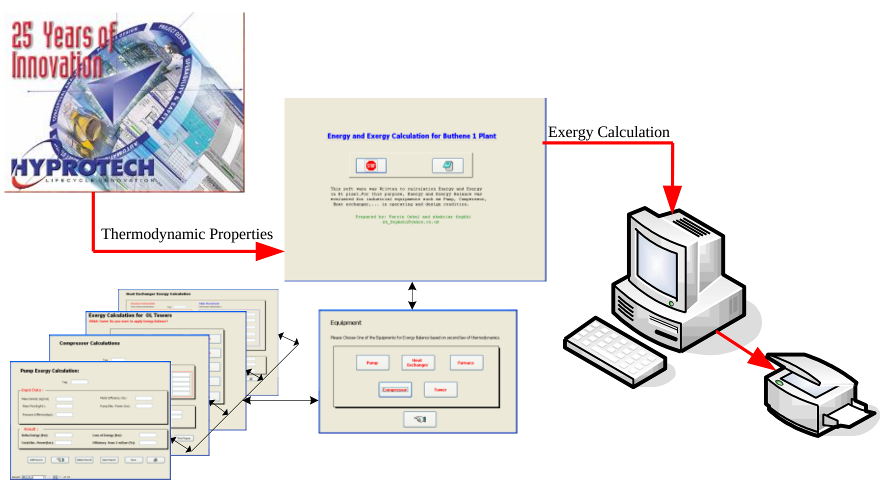

Figure 1. Schematic communication between software and hardware to achieve the final results.

5. Results

For equipments such as pumps, heat exchangers, compressors, furnaces and towers, the communications between software and hardware according to the method above that mention, were established under operational conditions, then exergy and energy losses were calculated. Tables (1) to (3) shows final results from the applied exergy and energy balances for each equipment in three plants [20-25].

Table 1. Energy and exergy results for each group of active devices in Butene 1 plant

Equipment Name	Number of Active Equipments	Loss (MW)	
		Energy (Operation)	Exergy (Operation)
Pump	13	0.1367	0.0027
Heat Exchanger	9	0.0904	0.032
Compressor	1	0.0535	0.009
Tower	2	0.6137	0.0195
Reactor	1	1.5832	0.1160

Table 2. Energy and exergy results for each group of active devices in Butadiene plant

Equipment Name	Number of Active Equipments	Loss (MW)	
		Energy (Operation)	Exergy (Operation)
Pump	14	0.4170	0. 1030
Heat Exchanger	16	2.3950	0.8970
Compressor	1	0.2120	0.0071
Tower	7	14.290	2.3640

Table 3. Energy and exergy results for each group of active devices in Olefin plant

Equipment Name	Number of Active Equipments	Loss (MW)	
		Energy (Operation)	Exergy (Operation)
Pump	38	2.75	0.0962
Heat Exchanger	39	65.36	4.9
Compressor	6	621.8	73.74
Tower	14	536.12	157.72
Furnace	7	431.57	164.24

Table 4. Maximum percentage of energy which can be recovered in each plant

Plant	Loss (MW)		Maximum Recoverable Energy%
	Energy (Operation)	Exergy (Operation)	
Butene 1	2.4775	0.1792	7.23
Butadiene	17.314	3.3711	19.47
Olefin	1657.6	400.6	24.16

In order to determine the numerical magnitude in terms of recoverable energy, making it equivalent barrels of crude oil with API = 32.6 was performed. Accordingly:

$$\text{for Butene1 plant :}$$
$$2447.5\frac{kj}{s}\times 0.0723\times\frac{86400s}{1day}\times\frac{1Btu}{1.055056kj}\times\frac{1kg}{40308Btu}\times\frac{1m^3}{862.3kg}\times\frac{1000lit}{1m^3}\times\frac{1bbl}{159lit}=2.622\frac{bbl}{day}$$

This amount for Butadiene and Olefin plants will be estimated 50.64 and 5936.11 barrel per day respectively. Hence, for hydrocarbon section of Amir Kabir petrochemical complex, total wasted crude oil is about 5989.3 bbl/day can be estimated [26-28].

This value of energy was wasted daily in one part of operating unit of petrochemical complex. If the field study companies' operating in the higher production tonnage is defined according to the useful life of equipment, certainly very large numbers on the loss amount will be included. Improvement of this situation with a very slight spending will be accessible by controlling of operating conditions in terms of energy consumption [29-31]. In most cases, these costs could be as provided in the form of technical recommendations to improve operating conditions can manifestation. Thus the end of this study provides sufficient recommendations have been set [32-35].

6. Conclusion

Six main groups of devices were reviewed in this study. According to the results (table 5), pumps, heat exchangers and reactor had a good performance [36-38].

Table 5. Percentage of losses based on thermodynamics' laws and recoverable energy for each group

Equipment Name	Number of Active Equipments	Loss (MW)		Percentage Based on 1^{st} low	Percentage Based on 2^{nd} low	Recoverable Energy (%)
		Energy (Operation)	Exergy (Operation)			
Pump	65	3.303	0.2019	0.2	0.05	6.05
Heat Exchanger	64	67.845	5.829	4.04	1.44	8.59 11.85
Compressor	8	622.06	73.75	37.08	18.24	29.05
Tower	23	551.02	160.10	32.85	39.68	38.05
Furnace	7	431.57	164.24	25.72	40.61	7.32
Reactor	1	1.5832	0.1160	0.09	0.02	

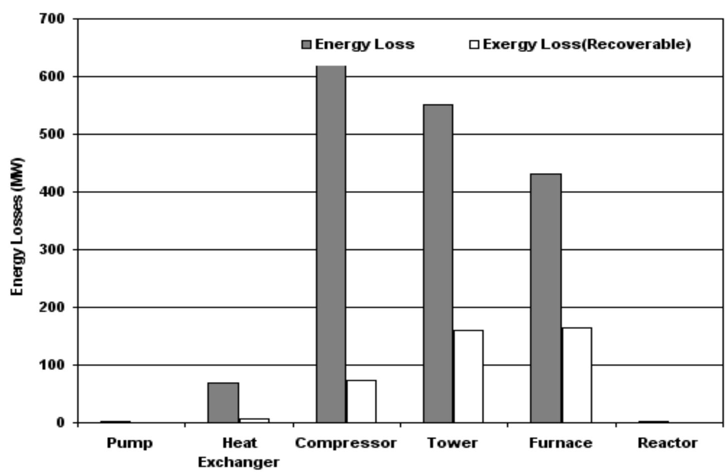

Figure 2. Recoverable Energy for each active group of devices

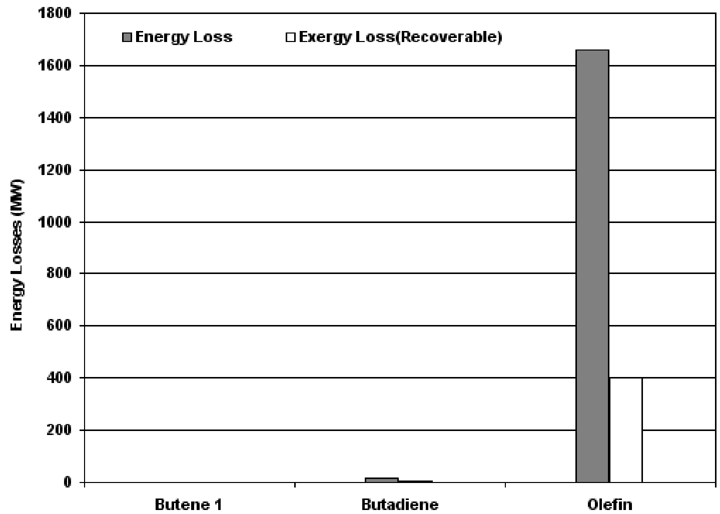

Figure 3. Comparison of recoverable Energy between industrial plants

For another device, the factors that influence the creation of irreversible processes have been discussed in bellow [39-41].

Furnace

Losses problem in the furnace can be examined at three local areas.

1-Input streams temperature to furnace

2-Output streams temperature from furnace

3-Heat losses in the furnace [42-45].

1-Input streams temperature to furnace

Raw materials for reaction in furnaces are including liquid feed (light-heavy end) or gas feed (ethane), water vapor and air [46-48]. Feeds should be preheated in order to react, have initial temperature. In order to reduce feed partial pressure in the process of thermal cracking, Steam was injected to feed [49-51]. Usually in thermal cracking process to complete the process, about 20% excess air is used. If each item listed above is not done as a controlled, the deviation from the design condition is done in this stage. For example, large open air damper causes additional air entering more and thus reduce the operating temperature inside the furnace [52-55].

2-Output streams temperature from furnace

Materials output of the furnace are including combustion products and air form stack. Products must be delivered to secondary exchangers under constant temperature conditions. After cooling in exchangers to raise the pressure in the combustion products were directed to the main compressor unit. Furnace air emissions from stack according to the negative pressure in the furnace are conducted outside the furnace [56-58]. If this air temperature cannot be used, air temperature bigger than the environment has led to the outside environment. For this case by using oxygen analyzer at top of the stack for monitoring oxygen concentration, input air flow rate can be controlled [59-62].

3- Heat losses in the furnace

Heat losses within the furnace are caused by cover loss brick of furnace structure, not the torch set and the lack of de-coke operations on time. Each item listed must periodically be controlled. According to study in the Amir Kabir Petrochemical Company, the main factor in increasing losses in olefin unit, excessive use of excess air bigger than standard amount was diagnosed. Also oxygen analyzers and oxygen-sensitive sensors on top of stacks are out of service. Result of its having such a situation, undesired operating conditions in terms of energy consumption has contributed. Also light fuel (H_2 86%) which is produced in olefin unit instead of natural gas is used and this new fuel is not proper for old torch.

4- Tower

Energy analysis for towers is contain two kinds of physical and chemical exergy. In term of numerical magnitude, chemical exergy always is much less than physical exergy. Therefore, to evaluate energy consumption, according to the feasibility and achievement of physical variables such as temperature and pressure, changes in physical conditions in the tower will be the top priority. According to exergy conception, only part of losses can be recovered. Restrictions imposed by the recovery of energy, temperature conditions for resources are under 100˚C. Under these conditions due to low driving force was not economically recyclable and energy in the stream was delivered to atmosphere.

5- Compressor

- **Repairing gas leaks on compressed gas lines**

Leakages are the greatest single cause of energy loss in manufacturing facilities associated with compressed systems. It takes energy to compress the gas, and thus the loss of compressed gas is a loss of energy for the facility. A compressor must work harder and longer to make up for the lost gas and must use more energy in the process. Several studies at plants have revealed that up to 40 percent of the compressed gas is lost through leaks. Eliminating the gas leaks totally is impractical, and a leakage rate of 10 percent is considered acceptable.

Gas leaks, in general, occur at the joints, flange connections elbows, reducing bushes, sudden expansions, valve systems, filters, hoses, check valves, relief valves, extensions and the equipment connected to the compressed gas lines. Expansion and connection as a result of thermal cycling and vibration are common causes of loosening at the joints, and thus gas leaks. Therefore, it is a good practice to check the joints for tightness and to tighten them periodically.

- **Installing high efficiency motors**

Important considerations in the selection of a motor for a compressor are the operating profile of the compressor and the efficiency of the motor at part load conditions. The part load efficiency of a motor is as important as the full load efficiency if the compressor is expected to operate at part load during a significant portion of the total operating time. A typical motor has a nearly flat efficiency curve between half load and full load and peak efficiency is usually at about 75% load. Efficiency falls off pretty steeply below half load, and thus operation below 50% load should be avoided as much as possible.

- **Reducing the gas pressure setting**

Another source of energy waste in compressed gas systems is compressing the gas to a higher pressure than required by the air- driven equipment since it takes more energy to compress gas to higher pressure. In such cases considerable energy saving can be realized by determining the minimum required pressure and then reducing the gas pressure control setting on the compressor accordingly.

Nomenclatures

Ex	:	Exergy Stream	P	:	Pressure	O	:	Environmental Condition
f	:	fugacity	Q	:	Heat Stream	i	:	Property of component i
H	:	Enthalpy	S	:	Entropy	LM	:	Mean logarithmic
n	:	Number of moles	T	:	Absolute Temperature	OC	:	Related to changes in the composition%
						OR	:	Related to Reactions

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