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Energy and Exergy Analyses of a Refinery Plant (Butadiene Unit)

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ABSTRACT

In this paper the energy and exergy analyses of a butadiene unit is studied. The energy analyses show that the highest energy losses occur in cooling system. The exergy analyses show that the most exergy losses yields in the compressor. It has been found that Less exergy losses in butadiene units show a low potential for process improvement. It was entirely predictable, because Butadiene separation units are low temperature and pressure sources of energy and the works ability of that energy are low.

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INTRODUCTION

Exergy analysis enables one to evaluate quantitatively the causes resulting in increases of exergy due to thermodynamic imperfections of thermal and chemical processes. Exergy express the quality of energy and can be defined as the minimal work necessary to produce a material in its specified state from materials common in the environment in a reversible way, heat being exchanged only with the environment. On the other hand, achieving sustainable solutions to today's energy and environmental problems needs long-term planning and actions. Energy issues are particularly prevalent at present and renewable appear to provide one component of an effective sustainable solution. The world energy needs rely heavily on fossil fuels for electricity generation. The majority of the world's power generation is met by fossil fuels, particularly coal and natural gas. Despite the growth of renewable energy installations like wind and solar power, the heavy dependence on fossil fuels is expected to continue for decades. Despite the depletion of fossil fuel reserves and environmental concerns such as climate change, the growth in oil demand is expected to be 47.5% between 2003 and 2030, 91.6% for natural gas and 94.7% for coal. Crude oil has low value in its original state and has no practical value. Even after separation of gas, water, H₂S and other components, crude oil are still a mixture of thousands of hydrocarbons ranging from very light to very heavy components. Therefore, refinery plants are used to produce the desired final useful products, e.g., liquefied petroleum gas (LPG), kerosene, diesel, gasoline, jet fuels, asphalt, etc. from the crude oil which goes through successive chemical and physical processes. The crude oil distillation is the first step which is purely physical to separate the crude oil into different fractions depending on the difference of boiling temperatures. In most distillation plants, the crude oil is processed into two towers. The first is the atmospheric tower where light hydrocarbons are separated, and the seconds the vacuum tower where heavier hydrocarbons are separated (Dincer, I., M. Rosen, 2007). The crude oil distillation plant has many components of interest to be analyzed thermodynamically from both energy and exergy point of views. Such components are the crude oil heat furnace, the distillation towers and the heat exchangers network. The main aim of such an analysis is to make the system more efficient in a way to maximize the yield of the desired products. In this regard, exergy analysis appears to be (i) an effective method using the conservation of mass and conservation of energy principles together with the second law of thermodynamics for the design and analysis of energy systems, (ii) a suitable technique for furthering the goal of more efficient energy-resource use and for determining the locations, types, and true magnitudes of wastes and losses, and (iii) an efficient technique revealing whether or not and by how much it is possible to design more efficient energy systems by reducing the inefficiencies in the systems. Due to such advantages exergy analysis has received great attention by many researchers for various applications (Hepbasli, A., 2008). As summarized in Al-Muslim *et al.* (2003), limited studies have been undertaken by various researchers, e.g., (Vosough, A., M. Bakhshesh, 2012; Rivero, R., 2004; Ghorbani, B., 2012; Silvio De Oliveira Júnior, 1997; Vosough, A., 2012; Hajidavalloo, E., A. Vosough, 2012; Tarighaleslami, A.H., 2012) to conduct energy and exergy analyses of single- and multistage oil distillation

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plants and their components. In a more recent study. In this present study, the energy and exergy analyses of a butadiene unit are studied and the energy and exergy losses and their paces are indicated and the results of both analyze compare to each other.

1. Methodology:

The following thermodynamic analysis of the plant will consider the balances of mass, energy, entropy and exergy. Unless otherwise specified, the changes in kinetic and potential energies will be neglected and steady state flow will be assumed. For a steady state process, the mass balance for a control volume system in Figure 1 can be written as

$$\sum_i \dot{m}_i = \sum_{out} \dot{m}_e \quad (1)$$

The energy balance for a control volume system is written as

$$\sum_i \dot{E}_i + \dot{Q} = \sum_{out} \dot{E}_{out} + \dot{W} \quad (2)$$

The entropy balance for a control volume system is

$$\sum_i \dot{S} + \sum_i \frac{\dot{Q}}{T} + \dot{s}_{gen} = \sum_{out} \dot{S} + \sum_{out} \frac{\dot{Q}}{T} \quad (3)$$

The exergy balance for a control volume system is written as

$$\sum_i \dot{E}_x + \sum_i \left(1 - \frac{T}{T_k}\right) \dot{Q}_k = \sum_{out} \dot{E}_{x,out} + \dot{W} e_x^{tm} + \dot{E}_{x,d} \quad (4)$$

Where the exergy rate of a stream is

$$\dot{E}_x = \dot{m} e_x \quad (5)$$

$$\dot{m} e_x = \dot{m} (e_x^{tm} + e_x^{ch}) \quad (6)$$

The above exergy balance is written in a general form. For the combustion process, the heat input will be included when calculating the chemical exergy of gas. The heat exergy term in Equation (4) will be used to calculate the exergy loss associated with heat loss to the surroundings. The specific exergy is given by

$$e_x^{tm} = (h - h_0) - T_0(s - s_0) \quad (7)$$

3. Results:

Energy carriers of utility to butadiene separation unit are used to transfer to energy conversion unit after converted into useful forms of energy. Extractive distillation is the main processes that take place in this part of the unit. During this operation, because no chemical reaction is done, that energy losses of thermodynamic process assume zero. Energy input to this section include: Inlet feed Energy (E_S), Outlet effectiveness energy of conversation energy unit (E_U), ER: The energy recovered by heat exchangers in energy recovery unit (E_R), output energy associated with the production and flow of this section (E_o), Thermodynamic Energy losses (E_T).

$$E_U = E_P - E_W - E_B \quad (8)$$

$$E_R = E_o - E_J - E_E \quad (9)$$

Output energy of this sector includes:

Thermodynamic Energy losses (E_T), Energy input with the inlet feed and steam used as heat source. The energy balance of the BD process unit is given in table 1.

The processes performed in BD units are physical processes. Energy losses due to that is equal to zero (E_T = 0). The result is:

$$E_N = E_U + E_R + E_S = 1371 + 16296 + 14944 = 32611 \text{ KW}$$

The calculated results in Table(2) shows that about 4.2% of the energy needed to perform various operations on BD unit are provided by utility and 50% by energy recovery unit, using heat exchangers and recycling energy output from the towers.

Table 1: The energy balance of the BD process unit.

Energy type	Input energy (Kw)	%	Output energy (Kw)	%
E_U	1371	4.2	-	-
E_S	14944	45.8	-	-
E_R	16296	50	-	-
E_T	0	-	-	-
E_o	-	-	32611	100
Total	32611	100	32611	100

The energy recovery Butadiene unit:

Recovery unit in the BD unit heat exchanger includes of 7 heat exchanger and, 13 cooling systems. Input energy to this sector is:

Output energy of process unit to recovery unit is E_O .

Output energies of this sector include:

E_R : The energy recovered by heat exchangers

E_E : The energy recovered by this section

E_{JC} : energy loss through cooling system

E_{JM} : energy loss through the output currents of the unit and sent to the repository

Heat energy recovered by $E_R = 16296$

Energy recovered by cooling $E_{JC} = 7022$

Energy recovered by the unit of product output $E_{JM} = 6568$

The energy input associated with products (E_O) to the energy recovery unit to a separate type of BD and sent to other units of recycled energy (E_E) is:

$$E_J = E_{JM} + E_{JC}$$

$$E_O = E_R + E_J + E_E \Rightarrow E_E = E_O - (E_R + E_{JM} + E_{JC}) \Rightarrow E_E = 2725 \text{ KW}$$

The final balance of energy recovery units shows in table 2.

Table 2: Energy balance of recovery units.

Energy type	Input energy (Kw)	%	Output energy (Kw)	%
E_O	32611	100	-	-
E_R	-	-	16296	-
E_E	-	-	2725	-
E_{JC}	-	-	7022	-
E_{JM}	-	-	6568	100
Total	32611	100	32611	100

According to the results obtained in the above table the efficiency of BD energy recovery unit is equal to:

$$\eta_{recovery} = \frac{E_R + E_E}{E_O} = \frac{E_R}{E_E} + \frac{E_E}{E_O} = \eta_{Recycling} + \eta_{REXPOR T}$$

$$\eta_{RC} = \frac{E_R}{E_O} = \frac{16296}{32611} = 50\%$$

$$\Rightarrow \eta_R = \eta_{RC} + \eta_{RE} = 58.3\%$$

$$\eta_{RE} = \frac{E_E}{E_O} = \frac{2725}{32611} = 8.3\%$$

4. Discussion:

According to the results of energy balance of BD units, (energy conservation unit, recovery and process unit), the total energy balance and the percentage of energy loss for the system(BD) is given in table 3.

Table 3: Energy balance of three different parts of BD units.

Energy type	Input energy (Kw)	%	Output energy (Kw)	%
E_{PS}	117	0.7	-	-
E_{PE}	2390	13.7	-	-
E_S	14944	58.6	-	-
E_E	-	-	2725	15.6
E_{JC}	-	-	7022	40
E_{JM}	-	-	6568	37.7
E_{WP}	-	-	1135	6.7
Total	17451	100	17451	100

The overall efficiency of energy BD is:

$$\eta_o = \frac{E_B + E_E}{E_S + E_P - E_T} = \frac{E_N(1 - \eta_T)\eta_R + E_P\eta_C + E_S - E_N}{E_S + E_P - E_T}$$

$$E_T = 0 \Rightarrow \eta_T = 0$$

$$E_P = 2507 \text{ KW}$$

$$E_N = E_O = 32611 \text{ KW}$$

$$E_S = 14944 \text{ KW}$$

$$\eta_C = \left[\frac{E_U + E_B}{E_P} \right] = 54.7\%$$

$$\eta_R = 58.3\%$$

According to the above equations, the overall BD efficiency unit is:

$$\eta_o = 15.6\%$$

Figure 1 represents the amount of energy losses which is calculated based on the first law of the thermodynamics.

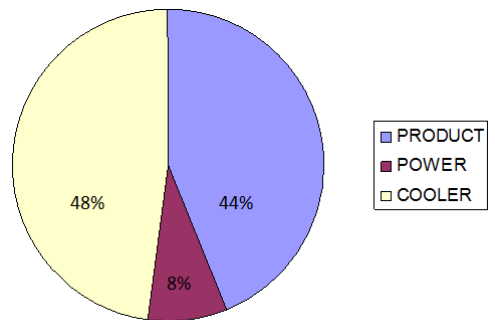


Fig. 1: The present of energy losses based on the first law of thermodynamics in different part of BD plant.

The energy losses that calculated by first law thermodynamic is not accurate because some of this energy is not able to do work. The actual amount of energy loss for a system based on the second law of the thermodynamics concept can be calculated. Exergy is the maximum amount of work that can obtain from energy when it reaches equilibrium with the environment. Table 4 depicted the exergy balance of BD units.

Table 4: The exergy balance of BD units.

Exergy losses resource	Energy losses (Kw)	Energy losses %	Sources temperature (C°)	η_{II}	Exergy losses (Kw)	Exergy losses %
Cooling systems	7022	47.7	37	0.039	274	22.7
Products	6568	44.6	40	0.048	315	26
Compressor	657	4.5	-	-	613.6	50.7
Ejector	106.3	0.7	45	0.063	6.7	0.6
Pumps	372	2.5	-	-	-	-
Total	14725	100	-	-	1209.3	100

The total amount of waste exergy is (1209 kW). Figure 2 shows the the percentage of waste exergy in various places in BD.

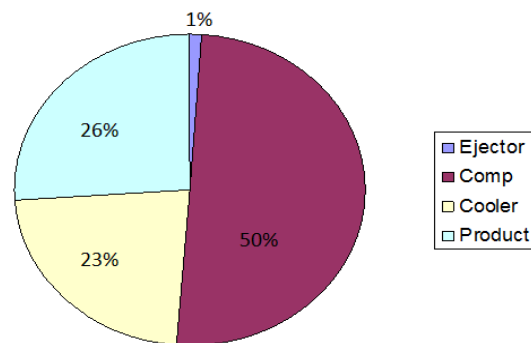


Fig. 2: The present of exergy losses based on the second law of thermodynamic.

5. Conclusion:

In this paper the energy and exergy losses and their place are indicated. Less exergy losses in BD units show a low potential for process improvement. However, it should be remembered that exergy analysis alone is not sufficient to select and judge about a process, but this analysis is a diagnostic tool along with other types of process analysis. The tables (1-4) show the first law analyses of BD units. According to the table(5), the largest exergy losses of BD yields in the compressor C-441, following by the repository products (Products). The total energy losses in BD units is 14725 kW that only 1209 kW of it can be recycled based second law analyses. It was entirely predictable, because Butadiene separation units are allow temperature and pressure sources of energy and the works ability of that energy are low.

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