

An Exergy Analysis on a Crude Oil Atmospheric Distillation Column

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Distillation units is the first plant in a refinery, in which several intermediate products are obtained through atmospheric and vacuum distillation of the crude oil mixture. Such unit essentially consists of the crude oil heating furnace, the distillation columns and heat exchangers network. It is important to determine the critical points in the unit from the exergy view point in order to decrease exergy losses and energy consumption. In this paper, the atmospheric distillation column of Tabriz refinery is studied as a case study using exergy analysis. Tabriz refinery uses two different types of crude as feedstock, Ahwaz-Bangestan and imported crude oil named NEW-CROS. In exergy analysis, the principal methods of reducing exergy loss are: changing feed location, reflux ratio adjustment, feed conditioning, side reboiling and side condensing. This study showed that changing stream split on one of the pump-arounds causes a reduction of 12.8 % in exergy losses. A new configuration of the distillation column feed stream, reduced the exergy loss by 18 % comparing to the base case. In this new configuration, the pre-flash vapor stream instead of being mixed with the flash liquid stream after passing the main furnace was directly introduced into the column at a tray with compatible temperature and composition. This not only reduced the exergy loss, but also offered a reduction of 4 % in fuel consumption.

1. Introduction

The basis of thermodynamics is stated in the first and second law. The first law describes the conservation of energy, while the second law is used to describe the quality of energy and material. The term exergy was introduced by Rant in 1953. The basis of the second law analysis was made by Gouy in 1889 and Stodola in 1898 by the law, which has been named after them by Szargut, 1980. In 1932 Keenan defined the concept of physical exergy, at that time called availability, and used it for the analysis of a steam turbine. The concept of chemical exergy and its associated reference states has been introduced by Szargut 1986. The regular use of exergy analysis starts in the second half of this century (Cornelisone, 1997). On the other hand, distillation is the largest single energy consumer in the chemical process industries. However, distillation does

not consume energy but degrades the heat input to the re-boiler that is subsequently rejected in the condenser. The most effective way to reduce the energy consumption of distillation is by effective heat integration and exergy analysis (Smith, 2010).

2. Exergy

2.1 Exergy Concept

Exergy is defined as the Maximum amount of work which can be obtained as a process is changed reversibly from the given state to a state of equilibrium with the environment, or the maximum work that can be obtained from any quantity of energy (Kotas, 1995). However, in reality there are only irreversible processes. For practical reasons a reference environment has been defined for the environment. In this paper, the reference system is defined with a reference temperature of 298.15 K and a reference pressure of 1 atm, unless otherwise stated.

Generally, energy includes two parts: The part of energy which is able to be transferred to work in a reversible process which called Exergy and Anergy, the part of energy which is not able to be transferred to work in a reversible process.

$$Energy = Exergy + Anergy \quad (1)$$

Exergy calculation is based on the determination of two thermodynamic state functions, enthalpy and entropy (Rivero, 1997). In this way, if a system is considered defined by its independent variables, pressure, temperature, composition, etc. and placed in a given environment “0”, the exergy of the system is defined by the general expression:

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

The first term on the right hand side of equation 2 represents the total enthalpy of the system, the second term on the right hand side represents the total entropy of the system and the term T_0 is the environment temperature.

2.2 Exergy Losses

The exergy losses of a system can be split in two (Rivero, 1997). On one side are those resulting from the irreversibility of the processes taking place in the system (internal losses), and on the other side, those resulting from an exergy discharge to the environment (external losses). The irreversible exergy losses are the difference between the total input exergy (Ex_{i_i}) and the total output exergy (Ex_{i_o}). These losses can also be calculated using the Gouy–Stodola theorem (Rivero et al., 2004):

$$Irr = \sum Ex_{input} - \sum Ex_{output} = T_0 \Delta S \quad (3)$$

$$Irr = Ex_{i_i} - Ex_{i_o} \quad (4)$$

The irreversible exergy losses can also be expressed considering the system as a couple (source–sink, donor–acceptor, fuel–product), obtained from the difference between the net supplied exergy Ex_{ns} (by the source(s), donor(s) or fuel(s)) and the net produced exergy Ex_{np} (to the sink(s), acceptor(s) or product(s)) (Rivero et al., 2004):

$$Irr = \sum \Delta Ex_{sources} - \sum \Delta Ex_{sinks} = T_0 \Delta S \quad (5)$$

$$Irr = Ex_{ns} - Ex_{np} \quad (6)$$

3. Distillation Column Targeting Thermal Analysis

Crude oil distillation processes consume energy intensively, and rank second for energy consumption in the refining industry, after the catalytic reforming processes. A relatively small energy saving opportunity in the distillation process will have an impressive economic impact (Smith, 2010). The thermal analysis capability is useful in identifying design targets for improvements in energy consumption and efficiency. This capability is based on the concept of minimum thermodynamic condition for a distillation column. The minimum thermodynamic condition pertains to thermodynamically reversible column operation. In this condition, a distillation column would operate at minimum reflux, with an infinite number of stages, and with heaters and coolers placed at each stage with appropriate heat loads for the operating and equilibrium lines to coincide. In other words, the reboiling and condensing loads are distributed over the temperature range of operation of the column (Zemp et al., 1997).

The CGCCs are helpful in identifying the targets for potential column modifications. These modifications include (Dhole and Linnhoff, 1993): Feed location (appropriate placement), Reflux ratio modification (reflux ratio vs. number of stages), Feed conditioning (heating or cooling) and Side condensing or reboiling. Spreading out the heating duties of the reboiler and the cooling duties of the condenser implies potential savings because the reboiler is adding heat at a higher temperature than needed and the condenser is removing heat at a lower temperature (Hirata, 2009).

An additional capability is provided through exergy analysis. The exergy profiles are plotted by calculating the exergy loss at each stage of the column, and then taking into account all entering and leaving material and heat streams. In general, the exergy loss profiles can be used as a tool to examine the degradation of potential work availability (irreversibility) in a distillation column due to: Momentum loss (pressure driving force) Thermal loss (temperature driving force) and Chemical potential loss (mass transfer driving force)

4. Case Study

In this paper, the atmospheric column of Tabriz refinery is used as case study. For this purpose data has collected from atmospheric distillation unit of the refinery. Tabriz refinery uses two different types of crudes as feedstock, Ahwaz-Bangestan and imported crude oil named NEW-CROS (Caspian Sea Republics Oil Swap).

This study indicates the best way to reduce the energy consumption of crude oil atmospheric column due to decreasing exergy losses by using exergy analysis is investigated. Thermodynamic properties are evaluated using the Braun K-10 (BK10). By using the following data atmospheric column of Tabriz refinery has been studied: Height: 61.42 m, ID: 5.33 m, Tray Section: No. of Trays: 51, Packed Section: Packed bed height: 3.05 m, Feed inlet at stage 47, No. of pump-around: 3, No. of strippers: 3

The physical and chemical properties of feeds are reported by RIPI, NIOC (Research Institute of Petroleum Industries, National Iranian Oil Company).

4.1 Crude Oil Replacement and Blending

Crude oil is a mixture of hydrocarbons and small amounts of sulfur compounds, oxygen, nitrogen and metals which are not possible to distinguish them from each other, only compounds such as light methane, ethane, propane, and benzene, so they are identifiable. Therefore, to identify and define a group of crude oil, standards such as specific gravity, percentage of intermediate gravity ($^{\circ}$ API Gravity), and sulfur content can be used. Table 1 shows that both feed stocks of Tabriz refinery can be used or blend together regarding to their same property.

Table 1: Comparison table of Ahwaz- Bangestan and NEW- CROS crude oils

Crude Oil Type	API Gravity 60°F	Specific Gravity @ 15 °C kg/l	Sulfur Content Wt.%
Ahwaz- Bangestan	33.60	0.857	1.40
NEW- CROS	32.42	0.863	1.42

Exergy analysis on atmospheric distillation column carried out by using Ahwaz-Bangestan and NEW- CROS feedstock separately and in third case a blending mixture of 50 %-50 % vol. has been studied. By comparing the results of Stage vs. Exergy Loss, it shows exergy loss of -29.58506 Mkal/h in main column and 47.0788 Mkal/h of furnace heat load for all three cases. Therefore, the type of crude oil has not any effect on exergy losses and thermal analysis of the distillation column.

4.2 Changing Stream Split on the Pump-arounds

As Smith mentioned (Smith, 2010), if the flow rate or temperature drop of one of the pump-arounds is increased, there will be more heat to recover in the preheat train, which in turn may decrease the furnace duty for preheating the crude oil.

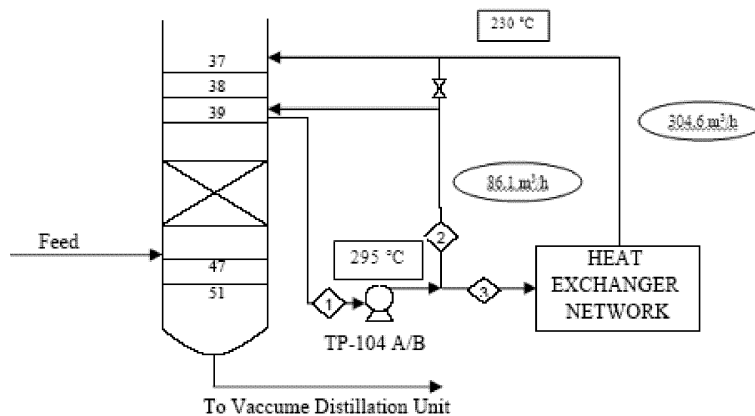


Figure 1: Changing stream split on the Pump-around TP-104 A/B of column

By changing Stream Split on one of the Pump-arounds TP-104 A/B (as shown in figure1) the Stage vs. Exergy Loss of the column is modified. By reducing the flow of stream 2 and increase to stream 3 there will be an increase in temperature of stream 3 up to 273.5 °C. By comparing the results of Stage vs. Exergy Loss, exergy loss decreases to -25.79995 Mkal/h which means 12.8 % of energy reduction. Indeed, increasing of about 0.002% of furnace heat loads to 47.0795 Mkal/h.

4.3 Changing in Configuration of Feed Stream

Change in feed conditioning is the third suggestion to improve exergy losses in the column. Indeed, the furnace is one of the most energy consumable equipments in oil refineries (Tarighaleslami et al., 2009). In new configuration the pre-flash vapor stream was not mixed with the flash liquid stream after passing the furnace, the overhead of flash drum enters in stage 22 which has the same temperature (Figure 2).

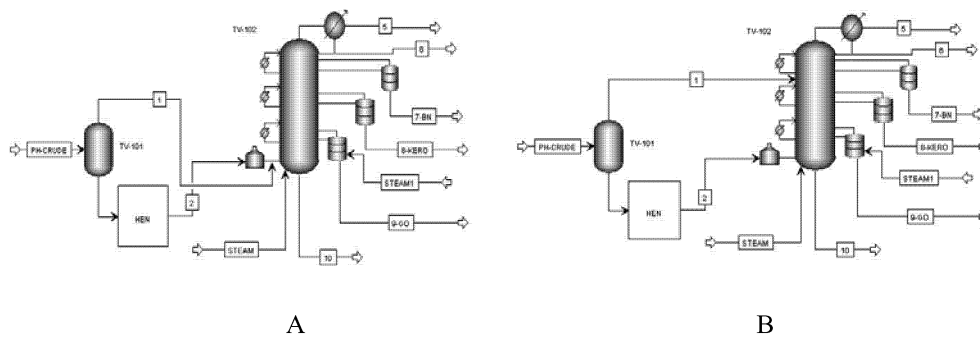


Figure 1: Changing in configuration of feed stream, before split, A and after split, B

Therefore, the exergy analysis results show -24.26377 Mkal/h of exergy loss and 18 % of reduction in comparison to the original case. In case of introducing the overhead of flash drum into the column at a tray with compatible temperature and composition, it not only reduced the exergy loss but also has a reduction of 4 % in fuel consumption of the furnace regarding to decreasing the heat duty of furnace from 47.0788 to 45.3944 Mkal/h.

5. Conclusion

In this study, an exergy analysis on a crude oil atmospheric distillation column in oil refinery has been investigated. The investigation carried out on atmospheric distillation column of Tabriz refinery as case study in several situations. Therefore, the results are comparing by using Stage vs. Exergy Loss analysis as followings:

1- Exergy analysis on atmospheric distillation column carried out by using Ahwaz-Bangestan and NEW- CROS feedstock separately and in third case a blending mixture of 50 %-50 % vol. has been studied. By comparing the results, it shows there is no significant change occurred in order to change of feedstock. Hence, any blending mixture of different feedstock in same level can be used.

2- By using side boiling of pump-around exergy loss will decrease instead of a small penalty on furnace heat load.

3- The final suggestion and best condition is when the pre-flash vapor stream was not mixed with the flash liquid stream after passing the furnace, the overhead of flash drum enters in the stage which has the same temperature. Hence, the maximum exergy loss reduction occurred in comparison to the original case. In addition, it has a significant reduction in fuel consumption of the furnace.

The summary of results by using different methods is shown in Table 2.

Table 2: Comparison table for different methods

Distillation Column Condition	Exergy Loss Mkcal/h	Energy Consumption Reduction (%)	Furnace Heat Load Mkcal/h	Furnace Heat Load Reduction (%)
Ahz-Bng Crude Oil	-29.58506	-	47.0788	-
NEW-CROS Crude Oil	-29.58506	-	47.0788	-
50 %-50 % vol. Blend	-29.58506	-	47.0788	-
Pump-around Change	-25.79995	12.8	47.0797	-0.0015
Split Feed (Suggestion)	-24.26377	18	45.3944	4

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