

## ENERGY RETROFIT WITH SIMULTANEOUS OPTIMIZATION FOR A CRUDE FRACTIONATION UNIT

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### Abstract

This paper presents the results obtained in the energy retrofit of a Crude Topping Unit. An optimization procedure to explore energy retrofit alternatives that combines changes in operating conditions and pinch analysis is used. Five savings horizons are obtained for the different types of crude studied. In the first stage of the method, a potential savings horizon (maximum possible savings) of approximately \$1.5 million dollars per year is identified. A subsequent economic analysis identifies a retrofit opportunity with a payout of 1.2 years. The savings are around \$0.7 million dollars (47% of its savings horizon) for this case. Finally, additional savings are identified when the reallocation of the returns of the pump-around circuits is considered. These savings bring down the payout period to 1.1 years. Over a five years horizon, the net revenue (total savings over 5 years - capital expenditure) is in the order of \$3.2 millions of dollars

### 1. Introduction

Crude distillation is energy intensive. It consumes approximately an equivalent of 2% of the crude processed. The conventional design used these days, consisting of a column with side strippers and pump-around circuits, was first suggest by Miller (1938) and still dominates throughout the refining industry. A few alternative designs can nonetheless be found in the literature. For example, the use of pre-fractionation columns has been proposed by Brugma (1941) and has nowadays some use. Another old design, the carrier design, had been proposed in the 1920s. This design proposes the use of light components in the stripping section of the column to enhance the separation. Nelson (1958) mentioned other alternative designs. All these designs have been abandoned for reasons that are not entirely known. However, this happened before 1973, the year when energy consumption started to play an important role in process economics. In the past decades, the trade-off between energy efficiency and capital investment has been greatly changed. As soon as energy efficiency became a concern, these designs merit reevaluations.

In practice, one can observe several unconventional and unpublished alternatives of pre-fractionation columns and pre-flashing vessels (Hess, 1998; Edwards, 1998). The current conventional design with pump-around circuits and side-strippers was formalized by Watkins (1979), who also discussed a few variants such as pump-back reflux and stripping by reboilers. The design is summarized in Fig. 1. Crude is mixed with water and preheated in the lower part of the heat exchanger network before entering the desalter, where most of the water containing the salt is removed. Desalted crude enters the upper part of the heat exchanger network to continue the preheating process. The heat exchanger network makes use of the

vapors of the main column condenser, the pump-around circuit streams, and the products that need to be cooled down. Then, the preheated crude enters the furnace, where it is heated up to about 650-700 °F. The partially vaporized crude is fed into the flash zone of the atmospheric column, where the vapor and the liquid separate. The vapor includes all components comprising products, while the liquid is the residue with a small amount of components in the range of gas oil. These components are removed from the residue by steam stripping at the bottom of the column. In addition to the overhead condenser, there are several pump-around circuits along the column, where a liquid stream is taken out, cooled down and sent back to an upper tray. Products are withdrawn as liquid from different trays, and then they are stripped by steam in side strippers to increase their flash points, that is, to remove light components. Bagajewicz (1998) offers a detailed discussion of the effect of the different variables on the energy efficiency of this conventional design.

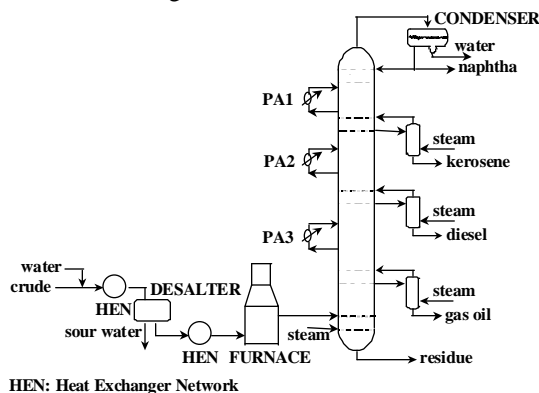


Figure 1. Conventional crude distillation

Crude oil is a complex mixture. There exist about one thousand distinguishable components. Their boiling temperatures vary from around room temperature to over 1000 °F. In addition, a few vapor components called light-ends are present. Crude distillation yields different mixtures that are called naphtha, kerosene, diesel, and gas oil. These products are specified by ASTM D86 distillation temperatures.

In many cases, crude fractionation units are retrofitted with the purpose of increasing throughput. Since the crude fractionation process is energy intensive, other goal consists of retrofitting the pre-heating train so that maximum energy efficiency is achieved. When the former is performed, the latter can be included in a synergistic manner. In addition, it is standard practice to process different types of crude at different times of the year. This adds another dimension to the retrofit problem, in which a unique preheating train, and eventually column modifications, are introduced for the purpose of satisfying different mixtures of crudes being processed at the maximum energy efficiency possible in each case.

In this paper, the results of the application of a retrofit procedure especially developed for crude units are presented. The basic steps of the procedure are presented first, and they are followed by results of their direct application.

## 2. Retrofit Procedure

The retrofit procedure is carried out in the following sequential steps.

1. *Simulation of the existing unit.* The quality and quantity of products and several other parameters are determined (temperatures, heat exchangers duties, etc).
2. *Flowsheet simplification.* The current heat exchanger network (HEN) is replaced by one-side heaters and coolers. The new units have the purpose of accounting for the required duties to meet final stream temperatures, only.
3. *Determination of the basic savings horizons.* A pinch analysis of the aforementioned simplified network is performed. The analysis is followed by an optimization. The optimization targets maximum-energy recovery by varying operating conditions (temperatures, pump-around circuit rates, steam injection rates, etc). The analysis is done for each of the crudes to be fed to the unit. This will lead to different horizons for each case. In all cases, the optimization is carried out under the constraints of constant product quality.
4. *Synthesis of the horizon networks.* Using pinch design methodology, a realizing network for each crude horizon is constructed. These horizon networks constitute grass-root designs, and they could greatly differ from the existing HEN.
5. *Proposition of a retrofit network.* A comparison of the existing network with the basic horizon

networks is conducted. Common patterns are established to propose a retrofit network. The diagram in Fig. 2 summarizes the nature of the retrofit. Horizon networks are too expensive and their payout period is too long. Therefore, less expensive networks are sought, so that the capital expenditure is limited and the payout period is reasonable.

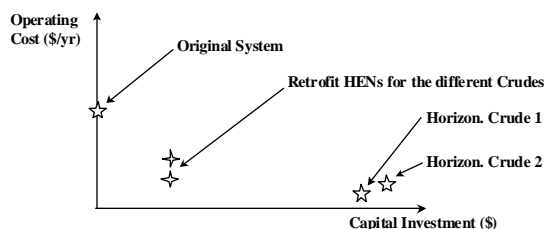


Figure 2. Nature of the retrofit.

6. *Test of feasibility the new retrofit network.* The proposed changes are implemented in the existing network. Simulations with different crude mixtures are conducted to evaluate the flexibility of the network. Feasibility of in situ implementation is also tested.
7. *Cost analysis.* An estimation of operating and capital cost to determine the payout of the project is conducted.

## 3. Results and Discussion

The case study consists of an atmospheric unit processing mixtures of different types of crude. The crude blend selection is made based on financial and seasonal reasons. Three basic crudes, named CR1, CR2, and CR3, are used for blending.

### 3.1 Simulation of the Existing Plant

The simplified flowsheet of the unit is simulated using each of the crudes. This simplified flowsheet is used to mimic current conditions. Then, the optimization procedure is run for the three types of crude. While doing this optimization, the products quality is maintained constant. The variables varied are the pump-around circuit duty, the main fractionator inlet temperature, and the steam flowrates.

### 3.2 Savings Horizons

Five horizons, obtained using CR1, CR2, and CR3 crudes, are simulated. The use of two sets of specifications for CR1 (original and modified) renders two horizons. Similarly, CR2 was run using two sets of specs.

The utility consumption of the present HEN is compared with its horizon, and the horizon that is obtained after optimization is accomplished (Table 1). Roughly, the savings are in the order of 65 MMBtu/hr. This is equivalent to approximately \$1.5 million/year (\$2.15 /MMBTU, 80% furnace efficiency and 8700 hrs/yr were used). This value is only based on the

simulation of CR1, for which the current energy consumption is known. This optimum horizon is obtained exploring variables such that the target products would not differ in quality and/or quantity.

Table 1. Energy consumption ( $10^6$  Btu/hr)

Type of crude	Base case		Optimized
	Current HEN	Horizon HEN	Horizon HEN
CR1 (Original specs)	135.9	75.73	70.25
CR1 (New specs)	N/A	N/A	67.75
CR2 (Original specs)	N/A	72.34	63.79
CR2 (New specs)	N/A	N/A	75.05
CR3 (Original specs)	N/A	74.82	47.73

Using these data, five heat exchanger networks representing the horizon savings are designed. As these networks establish a *horizon* for the retrofit, but not a *goal*, they are only used as starting point to perform the retrofit studies.

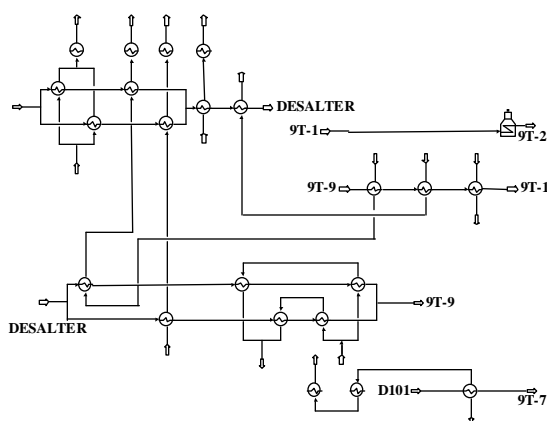


Figure 3. Existing HEN

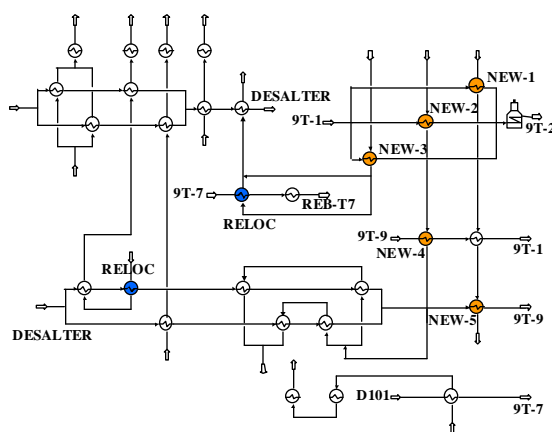


Figure 4. Retrofit HEN

### 3.3 Retrofit Network

The retrofit network is obtained by the addition of five new exchangers and by considering the relocation of two existing exchangers. Original and final networks are shown in Fig. 3 and Fig. 4, respectively.

### 3.4 Simulation of Retrofit Network

To check the flexibility of the new retrofit network, CR2 crude is introduced in the simulations. Starting with pure CR2 crude, cases with increasing amounts of CR1 were simulated. The furnace heat load is considerably lower than in the case of CR1 crude.

Table 2: Energy consumption ( $10^6$  Btu/hr.)

Crude	Base case	Horizon	Retrofit case
100% CR1	132.47	75.73	107.27
80% CR2, 20% CR1	N/A	N/A	101.34
90% CR2, 10% CR1	N/A	N/A	100.22
100% CR2	N/A	72.34	98.12

### 3.5 Column Changes

To explore if extra savings can be expected making changes in the pump around circuit of the main column, a heat supply-demand diagram for the unit was constructed (Fig. 5).

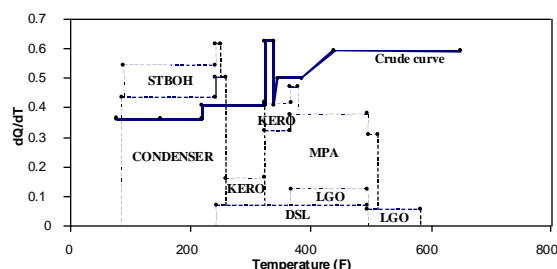


Figure 5. Heat supply-demand diagram

This diagram overlaps the supply and demand of heat. The demand in this case is the crude stream only. Any supply that exceeds the demand at any given temperature can only be used to satisfy demand at lower temperatures (left).

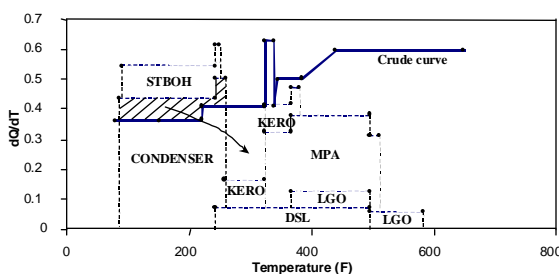


Figure 6. Heat supply-demand diagram

In exploring this diagram, one discovers that there is a large supply surplus in the condenser of the atmospheric main column. This supply can be used, only if it is transferred to the pump around circuit (Fig. 6) across the pinch.

However, the existing equipment may not be able to deliver such variation in duty. Indeed, after

performing the simulation varying the flowrate of the pump around circuit, only a slightly decrease in the heating utility is observed. This is an indication that for the given temperatures the area installed is not enough for the task requested.

Table 3: Economical Comparison

	<b>Retrofit Case</b>	<b>Retrofit case with main column changes</b>
Capital Expenditure	\$ 875,806	\$ 925,806
Furnace load changes	31.5 MMBtu/hr	37.1 MMBtu/hr
Steam savings	3.1 MMBtu/hr	3.2 MMBtu/hr
Total Savings	34.6 MMBtu/hr	40.3 MMBtu/hr
Payout	1.2 years	1.1 years

Relocation of the return pipe is therefore proposed to increase the temperature of the pump around circuit. Important extra savings are obtained changing the return tray.

#### 4. Conclusions

A retrofit procedure is applied to a Crude Topping Unit. This procedure reveals great opportunities for obtaining energy savings. Partial implementation of

these opportunities is proposed and the feasibility of the changes is evaluated. A retrofit design is presented, and the economical evaluation of its implementation is performed.

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