# 에너지 절약형 원유 상압정제 공정

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# Energy saving in a new crude distillation unit

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## 1. Introduction

Crude oil is the base material of petroleum and petrochemical processes containing hundreds of hydrocarbons used as feedstock in the chemical processes. The crude distillation unit (CDU) is the first step in a refinery processing the crude oil, in which very large amount of energy is consumed due to its large processed amount and high processing temperature. Refinery engineers handling the crude oil have long experience in the CDU, and therefore the distillation columns currently operated are considered to be optimized consuming minimum energy. When a typical crude distillation unit [1] is compared with a common distillation column processing multiple products, its operation is quite different from others, e.g., the separation process of benzene, toluene and xylene mixture [2]. The common arrangement of distillation columns is in a direct or indirect sequence, in which the products are produced by one at a column until the final two products in the sequence of component volatilities. Contrarily, the CDU processes all the products in a single column, which lowers its thermodynamic efficiency due to the mixing between the feed and products.

Many studies of the CDU have been published recently. The thermodynamic efficiency of the CDU was examined by analyzing its exergy loss. The study indicates that more than 86% of exergy loss in the whole unit comes from the furnace of raw crude. A rigorous model of the CDU was developed for the dynamics study of the CDU and heat integration. For the optimization of the sulfur removal process of crude, the detailed model of the sweetening column was developed, and its performance was demonstrated. The optimized heat exchanger network of the CDU was developed to save 32% of energy. Various heat integration techniques were applied to the CDU through heat exchanger network design and vapor recompression. The conventional CDU was modified by a sequence of distillation columns and two- column process, but no significant reduction of energy demand was found the proposals. Other improvements of the CDU include the feed blending and environmental impact analysis.

In this study, a new CDU was proposed using two-column process for the reduction of energy demand. The performance of the proposed CDU was examined by comparing the energy consumption, investment and utility costs, and thermodynamic efficiency with those of the conventional CDU. A HYSYS simulation was conducted for the comparison.

## 2. Process Design

The conventional CDU [1] has a main column of 29 trays with three strippers for middle products. Placing the feed and middle products in the same column restricts the products purity, and therefore the strippers are utilized to elevate the purity. The structure of the proposed CDU is similar to the conventional column except two columns are used as described in Fig. 1. Because the feed condition is the same as in the conventional column, a flash tank, a furnace and a mixer of the conventional CDU are utilized in the same manner. The two columns are a 14 tray column and a 16 tray column with a condenser. The total tray number of the columns is similarly matched to the conventional CDU without the strippers. The general structure of the two columns is similar to a side-stripper divided wall column (DWC) [2], but this structure cannot be built as a DWC due to the unbalanced interlinking streams between two columns. The column operating pressure was set to 0.13 MPa lower than the conventional column for the increased efficiency. The first column works similarly to a prefractionator in the Petlyuk column, and the second does to the main column. In the computation of vapor-liquid equilibrium for the distillation column design, the Peng-Robinson EOS was used.

No reboiler was installed to both columns as in the conventional CDU. The bottom temperature was too high to boil the bottom liquid in a reboiler. The vapor supply at the bottom of the first column was steam as in the stripper of the conventional CDU, and the vapor at the second column was supplied from the first column. The liquid flow in the first column was from the second, and the liquid flow in the second column was the reflux flow from its condenser. Because the naphtha product is about 44% of the crude feed, two vapor flows supply naphtha to the second column, that produces the naphtha product. The location of interlinking streams between the first and second columns was found from the iterative simulation to result in the minimum reflux flow. The specification of products was not given as a certain purity of a single component like in a common distillation column. Instead the specification was a distribution of many components, and therefore the products of the proposed system were adjusted to meet the distribution of components as the conventional CDU products. As listed in Table 1, the feed composition is widely and nearly evenly distributed for all the components. Note that five products were yielded from the 36 components, which is not common in the separation of usual distillation.

## 3. Results and Discussion

The design results of the proposed CDU are presented and compared with those of the conventional CDU. The heat duty, investment and operating costs are compared in both systems to prove the performance improvement of the proposed system.

### 3.1 Design results

Table summarizes the structural and operational information of the conventional CDU and proposed CDU. Because no product stripper was used in the proposed system, its total number of trays was less than the conventional system. The lower column operating pressure in the proposed system led to the lower column operating temperature. The flow rates of five products were adjusted similar to the conventional system. Due to the increased thermodynamic efficiency a large difference was found in the heat duty of the proposed system. The heating duty was 35% less than the conventional system, and the cooling duty was 23% less.

The feed contains 36 components: 5 of real components and 31 of hypothetical components. The composition of a single component does not specify the quality of a product. The product contains many components having compositions in a distribution with a peak. Five components of the peaks were listed in the table for the composition comparison between the conventional and proposed systems. For the better comparison of the product composition the distribution of components in the products is demonstrated. The distributions of five products in the proposed system were comparable to those of the conventional system except AGO. Because the production rate of the AGO was 3% of the feed, slight difference of composition in other products of large production significantly affected the composition.

### 3.2 Economic evaluation

The economics between the conventional and proposed systems is compared in terms of investment and utility costs. The results of economic evaluation are summarized. The investment cost includes the costs of column, trays, and heat exchangers computed from the cost equations given in Appendix. Because the feed heating consumed most of heating energy, the cost of furnace installation was separately listed. The total investment cost of the proposed system was 22% less than that of the conventional system. The cost reduction is due to the utilization of separate columns in the proposed system. By separating the processing columns of feed and middle products, the feed mixing was significantly minimized in the proposed system. The effect of feed mixing has a key role in the thermodynamic efficiency of the Petlyuk column. The comparison of utility cost gave better result with the proposed system. The cost reduction was 51% over the conventional system. The utility cost in furnace used the fuel price of $4 per million Btu.

## 4. Conclusions

A new crude distillation system was proposed for the reduced energy use. The problem associated with the single column operation of the conventional crude distillation unit was solved with two-column operation. The single column operation significantly reduces the thermodynamic efficiency of the system due to the feed tray mixing requiring more energy. The computed results of performance in the proposed system indicate that the proposed system saves 35% of heating duty over the conventional system, and the reduction of cooling duty is 23%. The economic analysis shows that a 22% decrease of investment cost and a 51% reduction of utility cost are found from the proposed system compared with the conventional system. The comparison of thermodynamic efficiency demonstrates a 0.7% point elevation over the conventional system.

## References

1. Wang, Z, Xu, Q, Ho, T. Optimal Retrofit Design of Crude Distillation Units for Processing Shale Gas/Natural Gas Condensate Oil. Chem.Eng.Technol., **39**, 1099 (2016).
2. Kim, YH. Energy saving of benzene separation process for environmentally friendly gasoline using an extended DWC (divided wall column). Energy **58**, 100 (2016).

Table 1. Economic evaluation of the conventional and proposed systems. Units are in million U.S. dollars, and the utility cost is annual.

| Variable | Conventional CDU | | | | Proposed CDU | |
|---|---|---|---|---|---|---|
| | Main | Side 1 | Side 2 | Side 3 | Col 1 | Col 2 |
| Investment | | | | | | |
| Column | 1.232 | 0.038 | 0.025 | 0.022 | 0.401 | 0.771 |
| Tray | 0.167 | 0.002 | 0.001 | 0.001 | 0.037 | 0.093 |
| Heat Exch. | 1.934 | 0.179 | | | | 2.700 |
| Furnace | 5.545 | | | | 5.277 | |
| Pump Around | 1.240/0.927/0.927 | | | | | 0.298 |
| Total | | | | 12.24 | | 9.577 |
| Utility | | | | | | |
| Furnace | 5.544 | | | | 5.230 | |
| Steam | 3.836/1.100 | 0.300 | 0.348 | 0.289 | 0.327 | |
| Total | | | | 11.417 | | 5.557 |

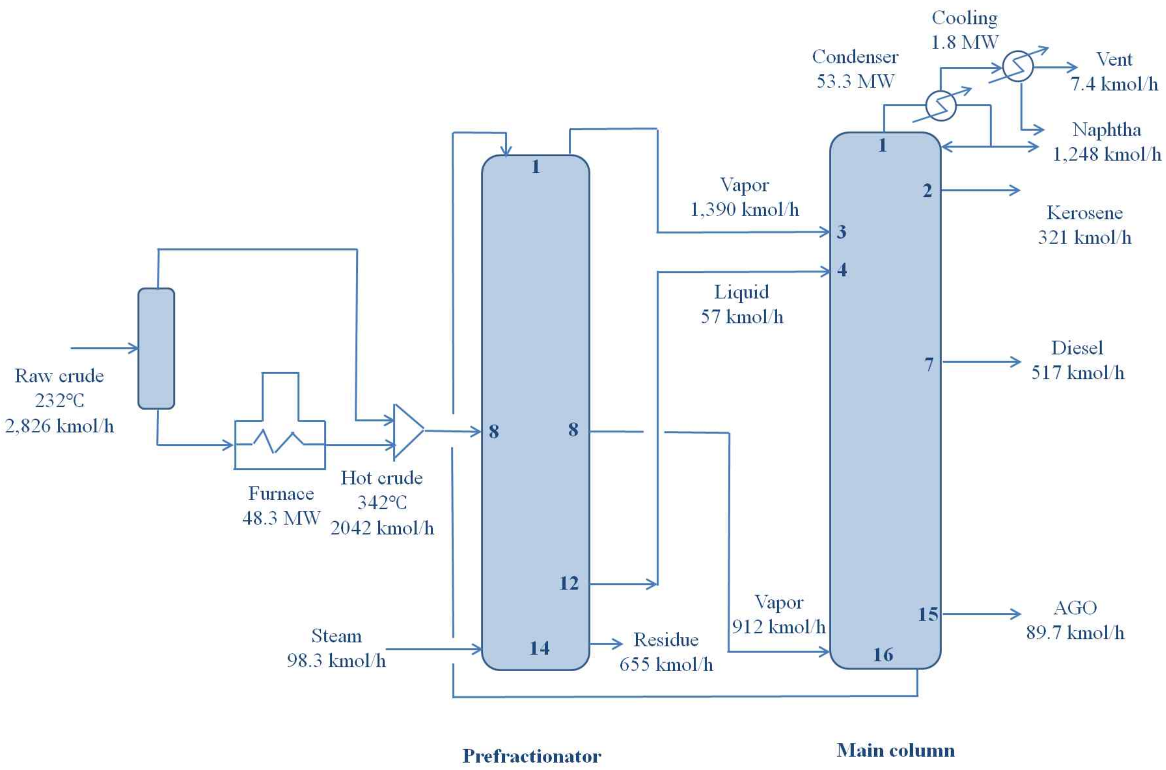


Fig. 1. Schematic diagram of the proposed crude distillation unit (CDU).