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Multiple Pre-Flash Design of Crude Fractionation Units

Technical Report Submitted to:

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Executive Summary

Since there is a rising demand of energy, and a depleting supply of energy, energy conservation is becoming extremely important. Analyzing processes or methods that can be improved in energy efficiency is becoming extremely important. One process that consumes much of the energy in this world is crude processing. The current method for conventional crude fractionation requires 2% of the oil that it processes. The increased cost of energy has made it attractive to look at alternative methods to save energy in the distillation of crude even if it requires more capital investment, especially when an entire new plant need not be built to implement the alternative method. It is proposed that a conventional column with multiple pre-flashes could save a notable amount of energy over conventional crude distillation. Simulations of a multiple pre-flash method were created to determine if this method would be an energy saving addition to the conventional model.

Heat integration of conventional crude fractionation by use of a single pre-flash unit has shown to be less energy efficient than conventional units alone when maintaining the same product yield. However, there is a reduction in the heat requirement when the flow rate of gas oil is reduced. Marginal improvements have been shown for heavy crude fractionation while maintaining high gas oil yield. This work shows the results of use of multiple pre-flash units in several configurations. The heat integration of conventional units with multiple pre-flash units is analyzed using both light and heavy crude fractionation and compared to purely conventional units.

Multiple pre-flashing increases the minimum heat utility, residue yield, and reduces gas oil yield. There is no profit increase with multiple pre-flash. A new design however, developed alongside this study, showed an improvement on energy savings from the conventional case. The details of this new design cannot be released at this time due to protection of possible intellectual property. However, this paper will report the results of this new design in terms of its product yield and economical impact. The new design shows noticeable energy improvement and gas oil recovery from conventional distillation (heavy crude only, further studies are warranted). The new design yields a profit increase of $7 million per year from the conventional case for heavy crude and negative values for light crude.

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1. Introduction

1.1 Background

The main purpose of this research paper is to develop a more energy efficient pre-flash design than the current single pre-flash design from Bagajewicz[Error! Bookmark not defined.]. The simulations for the developing process were created through SIMSCI's ProII. This paper details the methods used to develop the simulation, the previous methods used, and the results.

1.2 Conventional Crude Distillation

To fully understand the pre-flash method, first, the conventional method should be understood. This section reviews the conventional method as described by Bagajewicz[1]. The conventional method used can be seen in Figure 1. This figure shows the steps involved in crude processing. First the crude is mixed with water, where it then enters a heat exchanger network to be heated before it enters the desalter. In the desalter, most of the water containing the salt from the crude is separated out. After the desalter the crude enters a heat exchanger network, where the heat is supplied from pumparounds on the column. After the heat exchanger network, the crude then enters a furnace where it is heated to a range of 340-370°C. The rest of the crude then enters the flash zone of the distillation column at tray 29.

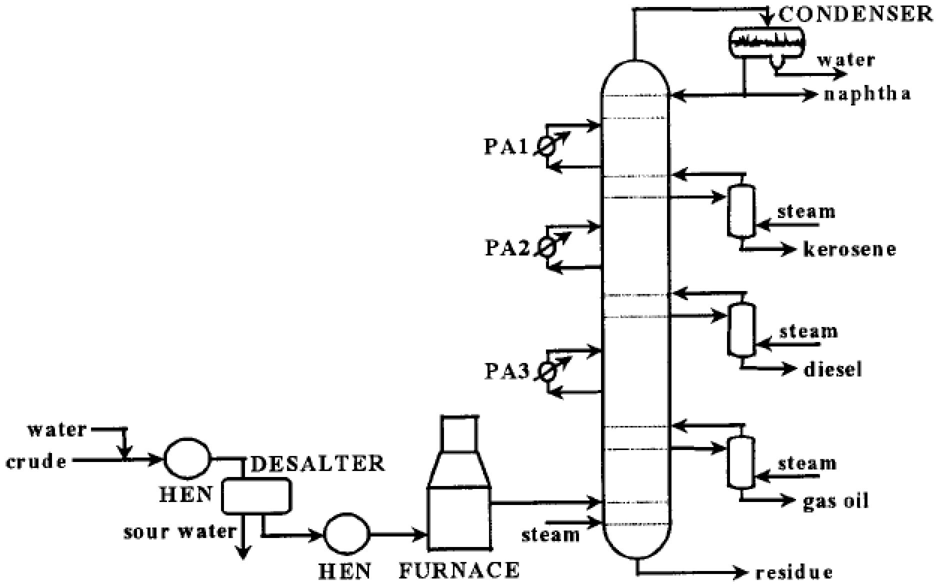

Figure 1. The conventional method for crude fractionation

This crude contains vapor and liquid, where the liquid is mostly residue, and some gas oil. As can be seen in the picture, the column does not have a reboiler. However, steam is fed in the bottom of the column five trays below the feed tray. The steam injection assists in stripping the liquid fed to the column, and this is necessary because there is gas oil in the residue that needs to be separated.

The column separates out five products: naphtha, kerosene, diesel, gas oil, and residue. The naphtha and the residue are obtained as if this was a regular distillation column, and the kerosene, diesel and gas oil are pulled from the column and sent to a side stripper. Kerosene is taken from tray 9, diesel is taken from tray 16, and gas oil is taken from tray 25. The side strippers are essentially miniature distillation columns. Steam is fed to the side stripper to strip the lighter components which are then sent back to the column, and the liquid is taken as the product. Side strippers normally consist of 4 trays.

The last major aspect of the conventional method is the pumparound units. These are used to reduce the minimum heat utility. Liquid is taken from a tray, sent into the heat exchanger networks, shown in Figure 1, to heat the crude oil before it enters the column. This reduces the heat utility in the furnace, and cold utility in the condenser. The first pumparound should be placed immediately below the condenser, having no trays between the pump around return and the condenser. The second pump around is positioned just below the kerosene withdrawal tray, between trays 10 and 12, and the last pumparound is positioned between trays 17 and 19. While pumparounds help to recover wasted heat from the condenser, heat utility is still required to heat the crude feed to the flash zone temperature.

1.3 Pre-Flash Method

Pre-flashing is similar to the conventional method, with all specifications in the column held constant. This method however flashes the crude before it enters the column, in an attempt to save energy. This method was attempted before by Bagajewicz[Error! Bookmark not defined.], but not as in great of detail and with only one flash. For this paper, many simulations were conducted with a various number of pre-flashes to determine optimal energy conservation.

This method is more energy efficient than the conventional method because by flashing the feed beforehand this allows the light components in the feed to bypass the flash zone which saves energy as they don’t need to be heated to 360°C. However, since the light components of the feed are not present in the flash zone, there is worse separation. The gas oil D86 point and flow rate is particularly affected as it requires much stripping to separate the gas oil from the residue. This requires more steam in the column and also reduces the amount of gas oil obtained. This tradeoff between energy savings and gas oil recovery may be favorable when gas oil is in low demand.

With multiple flashes, more light ends are allowed to be removed without having to heat the crude to as high of a temperature. This saves energy that is required to put into the furnace for all of the light components that were removed by the pre-flashes. For example, without any of the flashes, every component will be heated to 360^{o}C, thus demanding more energy. With 1 pre-flash, some of the components, such as naphtha, will be sent into the column below 360^{o}C. With multiple flashes this same concept can be used, only now more components are flashed and do not require to be heated to 360°C. In all of this heat transfer, since almost no process is 100% efficient, energy is lost. If less heat transfer is required, then there will be less of an energy loss. Pre-flashing allows for less energy to be transferred and results in more energy conservation.

Heat available at low temperatures is in excess for the column while heat at high temperatures is not. Less duty being required in the high temperature region of the heat supply diagram greatly reduces the total hot utility required. Since flashing the feed bypasses this high temperature region, it significantly reduces the amount of hot utility required.

In addition to requiring less heat duty, pre-flashing the feed also reduces the traffic in the column. This allows for smaller columns since the vapor traffic in the flashing zone (the region of greatest vapor traffic) will be significantly reduced. Thus, the cost of the flashes may be offset by a smaller required column in the case of a grassroots plant. This is because if the vapor is allowed to bypass the flashing zone, it can be fed closer to where it will be drawn in the column. However, this hinders separation as the components will pass through a fewer number of trays.

2. Column Controllability

2.1 Parameters

In evaluating the column, the gaps between the 95% and 5% D86 points will be monitored. The 95% D86 points are specified, and the 5% D86 points vary. If the gaps between the 95% and 5% points are sufficient then there is good separation between the products. The 95% and 5% D86 temperatures are determined by the temperature which either 95% or 5% of the volume of a sample is vaporized. Gaps are defined as the temperature at which 5% of a heavier product vaporizes minus the temperature at which 95% of a lighter product vaporizes.

Figure 2 illustrates gap values.

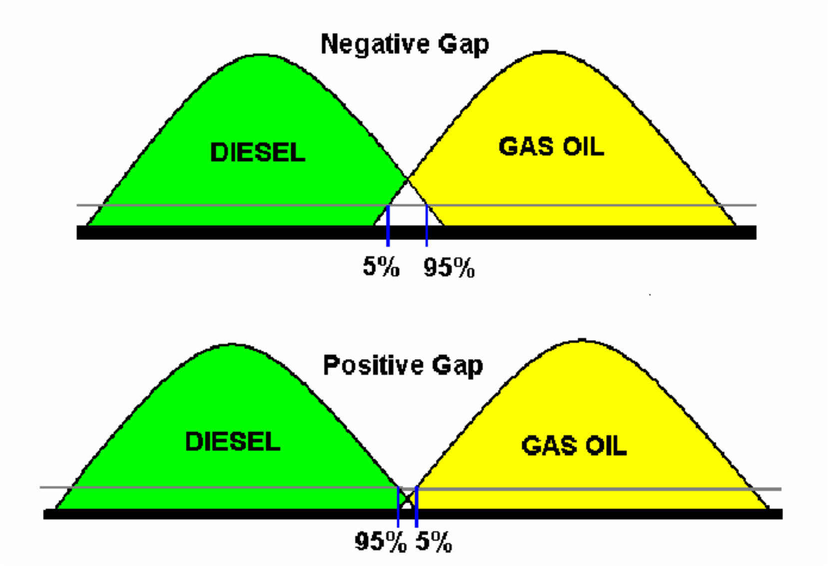

Figure 2. Visual representation of gaps

D86 points are the temperatures at which a certain specified percentage of the volume of a mixture will vaporize. They are determined by the American Standardized Test Method (ASTM) D86. This method is referred to as the D86 method. For our evaluation of the products in the distillation column we used 95% D86 and 5% D86 points which respectively refer to the temperature at which 95% of the volume of a mixture will vaporize and the temperature at which 5% of a mixture will vaporize respectively. Table 1 and Table 2 report the D86 points for light and heavy crude used for each simulation. The accepted gas oil gap is actually 377 – 410^{o}C for flexibility of a crude distillation column, but 410^{o}C worked the best for light crude simulations, and 390^{o}C worked the best for heavy crude simulations.

Light Crude 95% D-86 Points (^{o}C)	
Naphtha	182
Kerosene	271
Diesel	327
Gas Oil	410
Residue	820

Table 1. Light Crude D86 Points

Heavy Crude 95% D-86 Points (^{o}C)	
Naphtha	182
Kerosene	271
Diesel	327
Gas Oil	390
Residue	1220

Table 2. Heavy Crude D86 Points

Table 3 and Table 4 report the light and heavy crude gaps for each simulation. The gaps for light crude are matched from conventional distillation. The heavy crude gaps for Naphtha-Kerosene and Kerosene-Diesel are considerably higher than what was found in Bagajewicz[1].

Light Crude Gaps (^{o}C)	
Naphtha-Kerosene	16.7
Kerosene-Diesel	0
Diesel-Gas oil	-2.9

Table 3. Light Crude Gaps

Heavy Crude Gaps (^{o}C)	
Naphtha-Kerosene	30.8
Kerosene-Diesel	4.4
Diesel-Gas oil	-6.6

Table 4. Heavy Crude Gaps

Figure 3 is a graph of light crude gaps from conventional distillation.

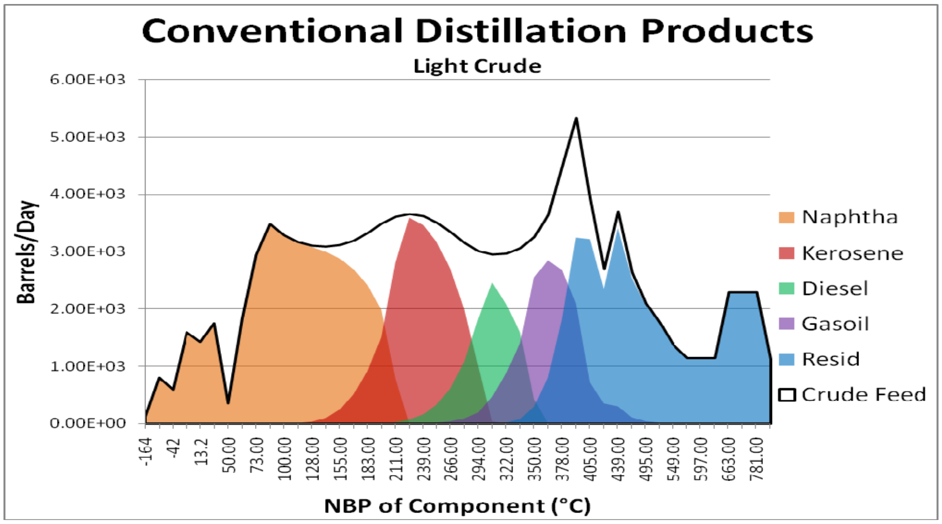

Figure 3. Light Crude Gaps from Conventional Distillation

2.2 Variables

There were certain variables that were held constant as specifications throughout this simulation The D86 95% points of each product was held constant at values specified by Bagajewicz[1] and were used as a specifiation in the column. The draw rates were listed as variables in the column and were varied in order to match the D86 95% points as higher draw rates result in lower D86 95% points. However the flow rates of the products was also a specification and a controller was used to specify them. The gaps were controlled by adjusting the amount of stripping steam in the side strippers. As discussed before, steam helps separation because it strips the light components by providing partial pressure without diluting the liquid phase. Controllers were used to adjust the steam and held the gaps at their specified values. The steam in the bottom of the column was generally not a variable since the gap and D86 point for gas oil was allowed to float since it is specified in a range rather than a single point. The duty of the furnace was also varied and was varied by a controller such that the temperature of the flash zone would remain at 360^oC. An additional variable in the column was the duty of the condensor which the simulator varied to obtain the required specifications.

3. Method

3.1 Previous Work

As stated above, most things were held constant as if it was a conventional column. The crude leaves the furnace at 360°C to enter the column. The column is a 34 tray column, with kerosene leaving from tray 9, diesel leaving from tray 16, and gas oil leaving from tray 25. The condenser temperature is set at 32°C. Flow rates of stripping streams are also not adjusted. The minimum approach temperature is taken as 40°F. The pre-flash drum is operated at 163°C and the vapors enter the column at tray 15. The 95% distillation temperatures taken from Bagajewicz[1], for conventional distillation, are also held constant. The D86 point gaps and the gas oil flow rate were the two major factors affected. D86 point gaps, which are described in detail later on in the report, were smaller, and gas oil flow rate decreased from the regular conventional method.

3.2 Multiple Pre-Flash Method

Several simulations using multiple flashes were developed in this study. To determine the energy efficiency of the multiple pre-flash methods, it was compared to the conventional case. The results of seven simulations are reported in this paper and compared to the conventional case. The first four cases are single pre-flash where the vapor is fed to tray 10, 15, 20, and 25. The fifth and sixth cases are 2 and 4 pre-flash cases where the vapor is fed to trays 10 and 15 for the 2 pre-flash case and 10, 15, 20, and 25 for the 4 pre-flash case. The seventh case is the new design of which the details cannot be revealed as discussed before.

3.3 Process Used in Obtaining Optimized Results

To simulate the pre-flashing, the crude was sent through a heat exchanger, then once it was heated up, was sent to a flash tank. This process can be seen in Figure 4. This design was used for the entire flow sheet, with each stream entering from trays 10 to 29. This picture gives the impression that all 20 pre-flashes in this simulation are used, however manipulating the duties on each heat exchanger allowes for any flash to be turned off. Flashes not used have the duties of the heat exchangers before them set to zero. Through this process we were able to test this simulation with varying flashes.

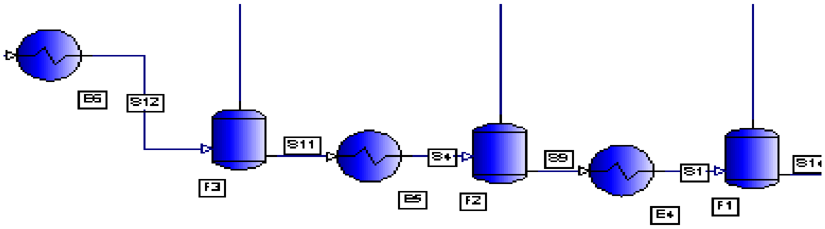

Figure 4. ProII simulation of flash tanks

Figure 5 shows a picture of the flowsheet developed. It closely resembles the conventional column, aside from the pre flashes. In the Figure 5, 20 lines can be seen entering the left side of the column, these are coming from the pre-flashes.

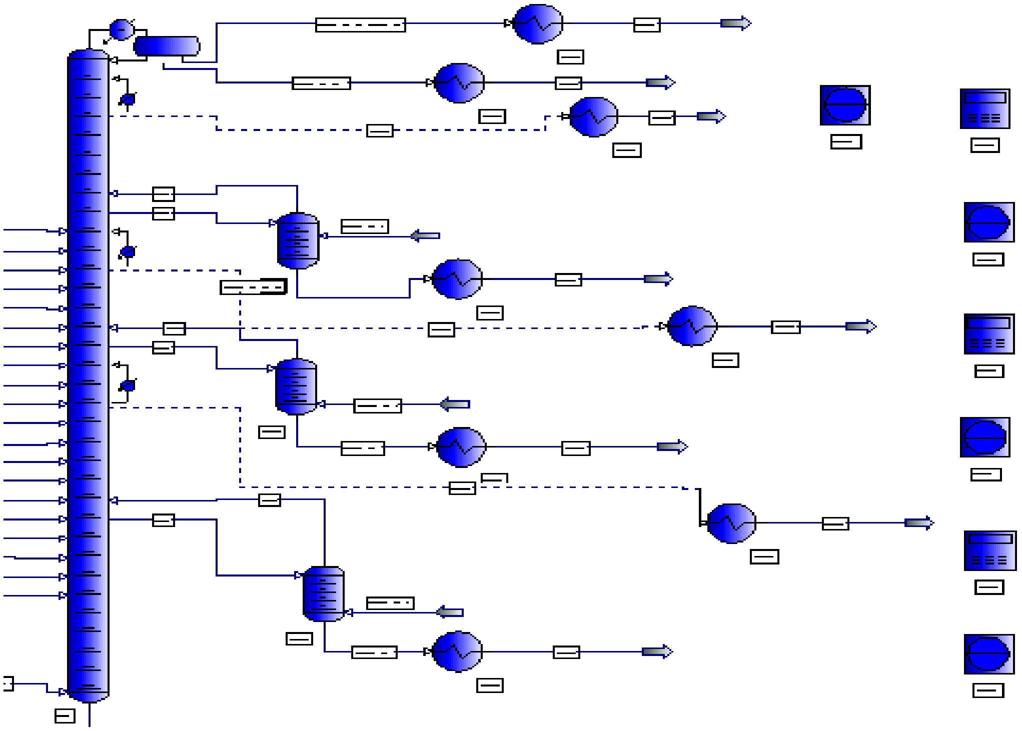

Figure 5. Pre-flash column

For each simulation, a systematic approach was used to determine the optimum temperature for each flash tank used, and the optimum duty taken from each pumparound. First, the column is simulated with all flash tanks turned off as to run it like a conventional case. Then, the duty of all pumparound units are set to zero. Next, the flash tank where the vapors enter the lowest location on the column is turned on first. This is done by increasing the inlet temperature to that flash by using the preceding heat exchanger in the process. The temperature is slowly increased until the heat utility reaches a minimum. The next flash tank is turn on in the process, and the same procedure is followed until all flashes to be used in that simulation are at the optimum temperature. Then the pumparounds are systematically added to the column using the procedure outlined by Bagajewicz[1]. Finally, the flash tank inlet temperatures are revisited to see if the heat utility can be reduced further after adding the pumparounds.

4. Results

Light and heavy crude was used for these simulations. The crude was taken from Bagajewicz[1] for use of all simulations. The crude assay is based off of percent volume vaporized at different temperatures using true boiling points.

4.1 Light Crude

The flow rates remained the same for each product with the exception of gas oil and residue. As the number of flashes increases, it can be seen from Figure 6 that the gas oil yield decreases. This is due to the loss of carrier effect of the lights due to pre-flashing. However, the new design recovers more gas oil than any pre-flash method shown here, but not as much as the conventional case with light crude.

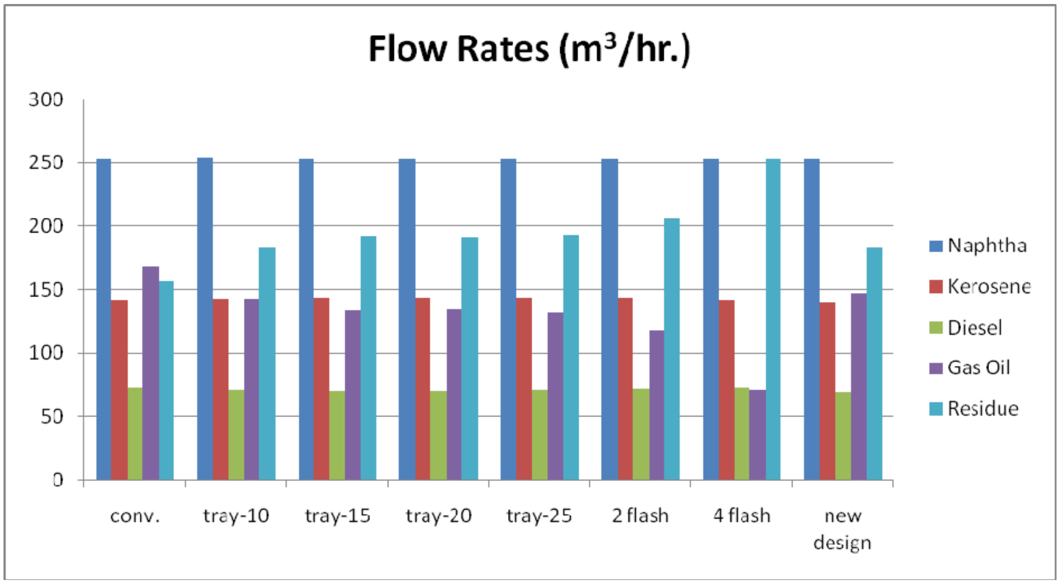

Figure 6. Light Crude Product Flow Rates

From Figure 7, the minimum heat utility increases with the number of pre-flashes used. The new design shows and improvement on minimum heat utility from the conventional case.

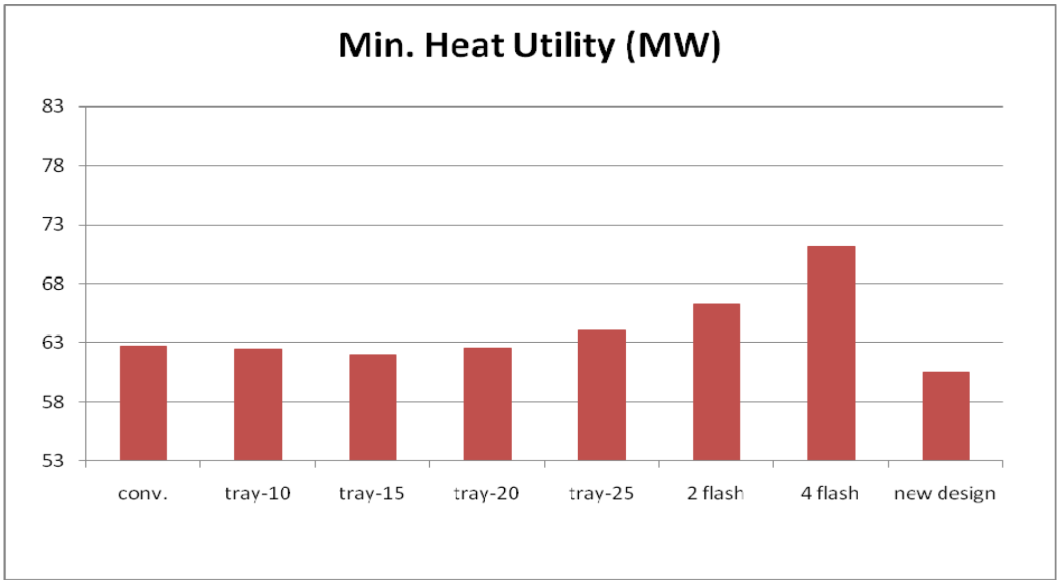

Figure 7. Min. Heat Utility for Light Crude

4.2 Heavy Crude

The flow rates remained the same for each product with the exception of gas oil and residue. Residue is not shown in Figure 8 to emphasize the other products. As the number of flashes increases, it can be seen from Figure 8 that the gas oil yield decreases. This is due to the loss of carrier effect of the lights due to pre-flashing. However, the new design recovers more gas oil than any pre-flash method shown here and from the conventional case with heavy crude.

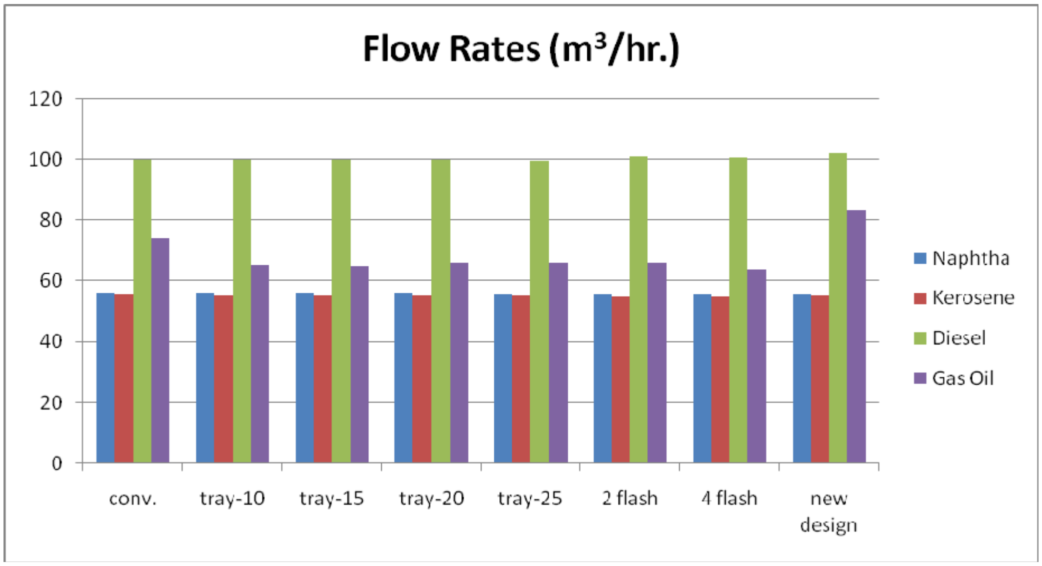

Figure 8. Heavy Crude Product Flow Rates

From Figure 9, the minimum heat utility varies with the number of pre-flashes used and where the vapor is sent. The new design shows and improvement on minimum heat utility from the conventional case.

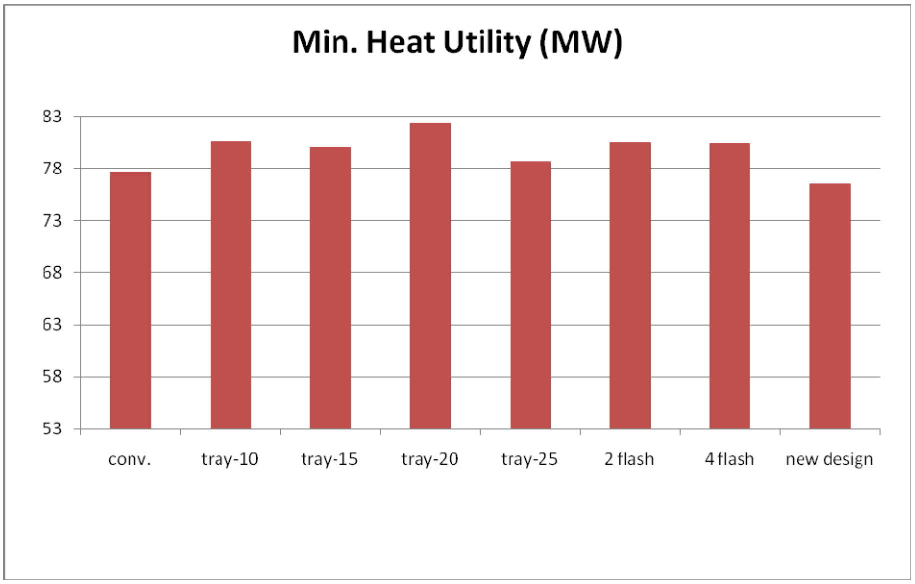

Figure 9. Min Heat Utility for Heavy Crude

4.3 Economics

This analysis is based on annual economics of continuous operation of 120,000 bbl of crude oil per day. This is a differential analysis from the conventional case. Table 5 shows that pre-flash crude fractionation and the new design does not yield a profit increase from the conventional case. This is due to the yield reduction of the product gas oil.

Process	Utility Cost Increase	Profit Increase	Gross Profit Increase
1 flash tray-15	-$690,000	-$17,220,000	-$16,530,000
2 flash	$3,280,000	-$19,520,000	-$22,790,000
4 flash	$7,790,000	-$395,350,000	-$403,150,000
new design	-$1,980,000	-$14,270,000	-$12,290,000

Table 5. Economic Analysis for Light Crude Simulations

Table 6 shows that pre-flash crude fractionation does not yield a profit increase from the conventional case. However, the new design does show a profit increase of $7 million dollars from the conventional case. This is due to a decrease in minimum heat utility and an increase in gas oil yield.

Process	Utility Cost Increase	Profit Increase	Gross Profit Increase
1 flash tray-15	$2,120,000	-$4,310,000	-$6,430,000
2 flash	$2,580,000	-$3,080,000	-$5,660,000
4 flash	$2,490,000	-$4,400,000	-$6,890,000
new design	-$1,110,000	$7,160,000	$8,270,000

Table 6. Economic Analysis for Heavy Crude Simulations

5. Conclusion

Multiple pre-flashing increases the minimum heat utility, residue yield, and reduces gas oil yield. There is no profit increase with multiple pre-flash. The new design shows noticeable energy improvement and gas oil recovery from conventional distillation (heavy crude only). Further studies are warranted. The new design yields a profit increase of $7 million per year for heavy crude and negative values for light crude.

5. Aknowlegdements

Miguel Bagajewicz

Stephanie English

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Dan Dobesh

6. References

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[1] Bagajewicz M. and S. Ji. *Rigorous Procedure for the Design of Conventional Atmospheric Crude Fractionation Units Part I: Targeting*. Industrial and Engineering Chemistry Research. Vol. 40, No 2, pp. 617-626 (2001).