New Technologies to Enhance Yield of Crude Fractionation

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Abstract

The objective of crude fractionation is to separate the incoming oil to a refinery into valuable products, namely, gas oils, diesel, kerosene, jet fuel, naphtha, gasoline and LPG. In this article, we review a recent patent where five technologies are presented to increase the ability of separating the aforementioned valuable products using the same energy expenditure, if not less than the current conventional distillation processes. The results of computer simulation of the five designs are used to evaluate each design's performance.

Introduction

In the past couple of decades, increased efficiency and productivity in the process industry have been given increasing attention. With rising energy costs and environmental concerns, novel methods for crude distillation have been sought by petroleum refiners to extract as much profitable products from a barrel of crude as possible without increasing the amount of energy needed. For the purposes of this paper, energy cost will be reported as the minimum heating and cooling utility needed to achieve the desired fractionation of crude oil into its products. Yield will be defined as the actual flow rates of the products produced from crude fractionation. This paper presents the results of five patent technologies running three different grades of crude oil; namely light, intermediate and heavy crudes.

Conventional Crude Fractionation

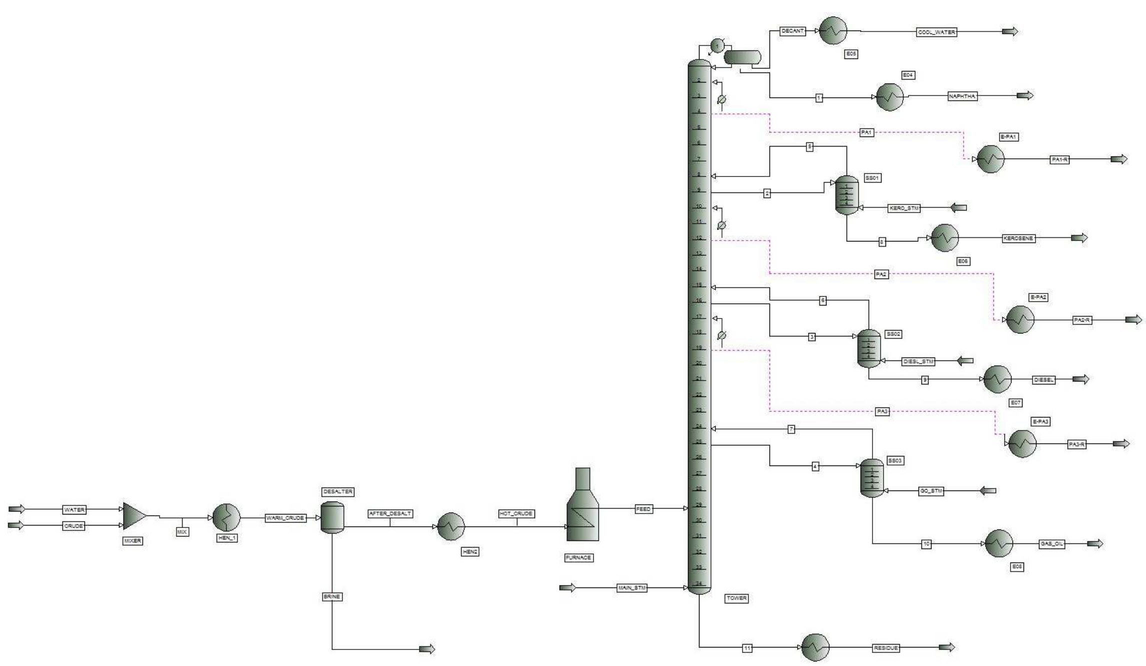

Figure 1 – Conventional crude fractionation

In conventional crude fractionation, the crude oil is mixed with water and warmed through a series of heat exchangers called the HEN (Heat Exchanger Network). The crude/water mixture is then fed to a desalter, where the mixture is electrolyzed to remove the salt in crude that is harmful to downstream equipment. In this process, most of the water is removed as saltwater brine and some water remains dispersed within the crude oil. The crude oil is then sent to a second HEN, and then fed to a furnace that heats the crude to no higher than 360 °C. The crude enters the column, then the vapors and liquid separate upon entering the column, and the vapor rises and cools and the liquid falls and is reheated by steam that is injected at the bottom tray. This is called steam stripping. The different products, or cuts, are drawn off the tower at differing heights and fed to the side strippers. The side strippers are injected with steam to remove lighter components from the product cut. The hot cuts are cooled by using their energy to warm up the crude via the HEN, and sent downstream. Pumparounds are used on the column to reduce the condenser duty and also warm the feed in the HEN. The following patented technologies aim to increase yield and maintain, if not reduce, the minimum steam utility. The column operating procedures are tabulated below on the next page.

	Crude density	Throughput
Light	(36.0 API)	120,000 bbl/day
Intermediate	(27.7 API)	120,000 bbl/day
Heavy	(20.0 API)	120,000 bbl/day

		NBP °C	
vol % distilled	Light	Intermediate	Heavy
5	45	94	133
10	82	131	237
30	186	265	344
50	281	380	482
70	382	506	640
90	552	670	N/A

		Lightend Composition vol %	
ethane	0.13	0.1	0
propane	0.78	0.3	0.04
isobutane	0.49	0.2	0.04
n-butane	1.36	0.7	0.11
isopentane	1.05	0	0.14
n-pentane	1.3	0	0.16
total	5.11	1.3	0.48

	D86 (95% point)
naphtha	182 °C
kerosene	271 °C
diesel	327 °C
gas oil	377 °C

	gap specifications
kerosene-naphtha	16.7 °C
diesel-kerosene	0 °C
gas oil-diesel	-5.7 °C

Table 1 – Column operating parameters

Carrier Effect

The next technology takes advantage of the carrier effect of lighter hydrocarbons. In the below picture, you can see that some of the gas oil and diesel product components are trapped in the residue product stream.

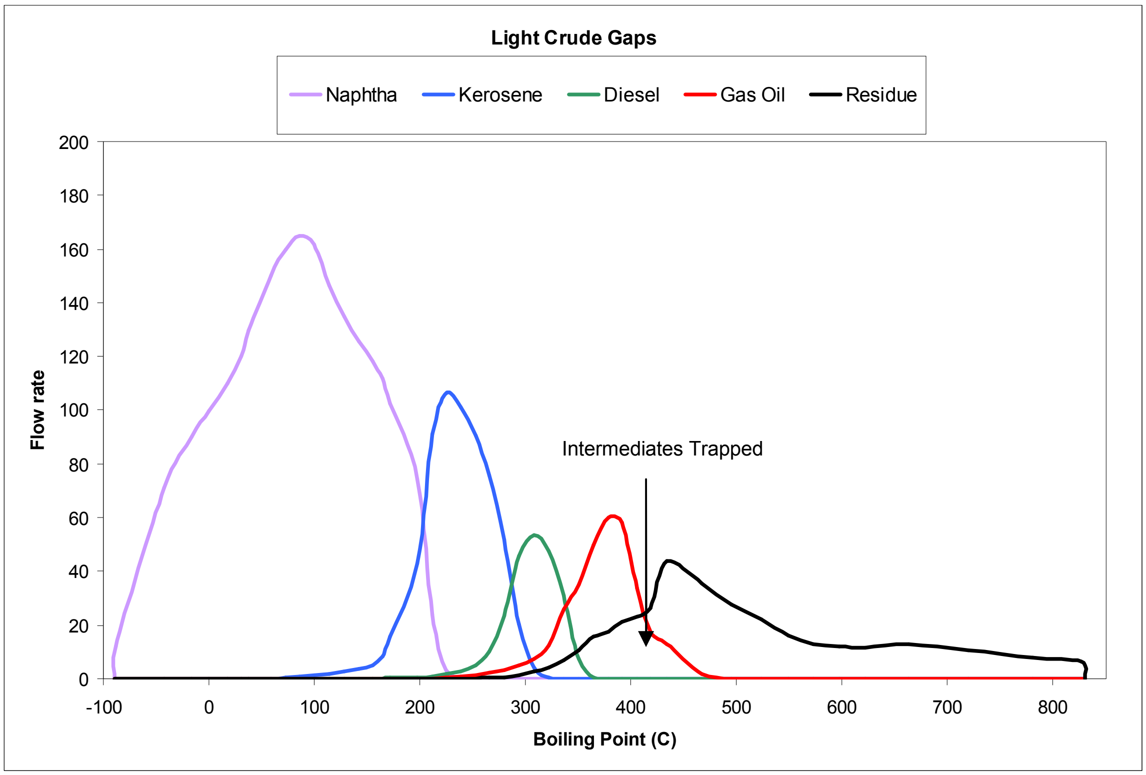

Figure 2 - Column product streams

These components are much more valuable if they are not produced as a part of the residue stream. In order to remove these trapped intermediates, they need to be able to evaporate more readily. These technologies aim to increase the carrier effect to remove the intermediates that are dissolved in the residue stream. The carrier effect is normally present in the distillation column. When the hot crude oil enters the column, the vapor and liquid separate. The light component vapors rise the fastest, followed by the slower intermediate components. The lighter vapors rise fast enough to exert a "pull" on the intermediate components, causing them to travel upwards as well. If the intermediate components are removed first *before* the hot crude enters the column, then the light components will exert the carrier effect on the heavy components, and allow any trapped intermediates to vaporize more easily.

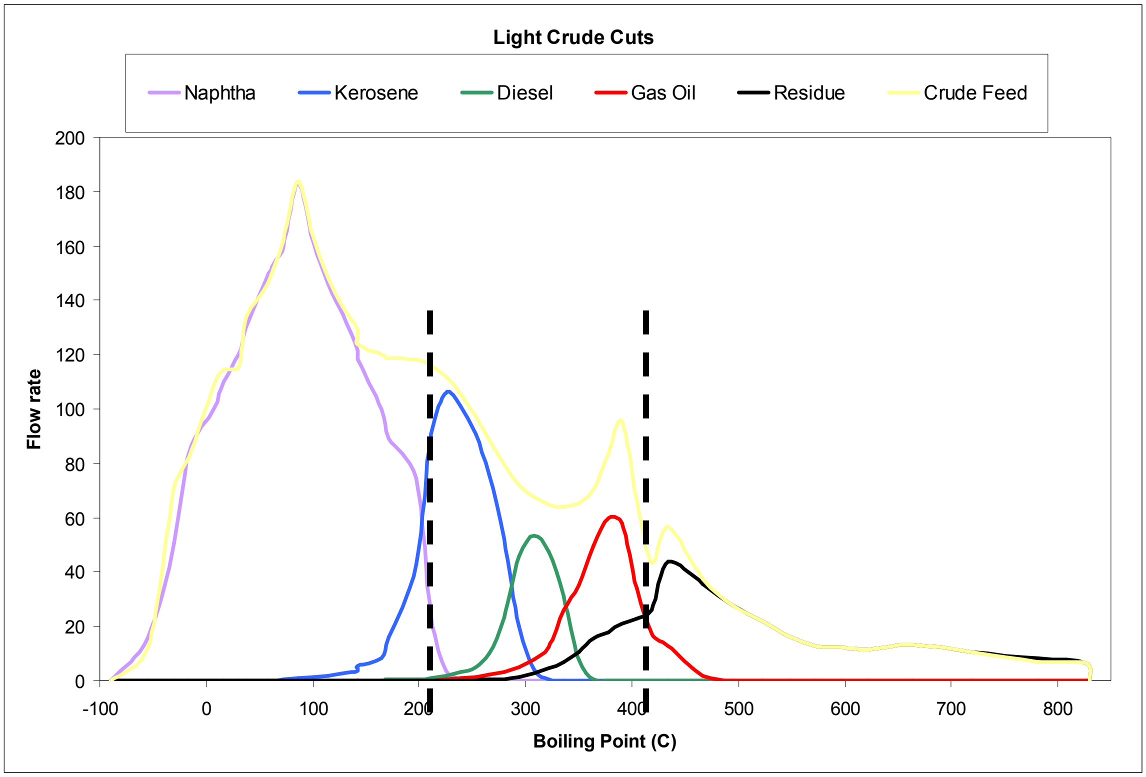

Figure 3 - Graphical representation of components involved in the carrier effect.

The above graph shows the boiling point range of components that are removed to enhance the carrier effect.

Technology I – Vapor and liquid recycle

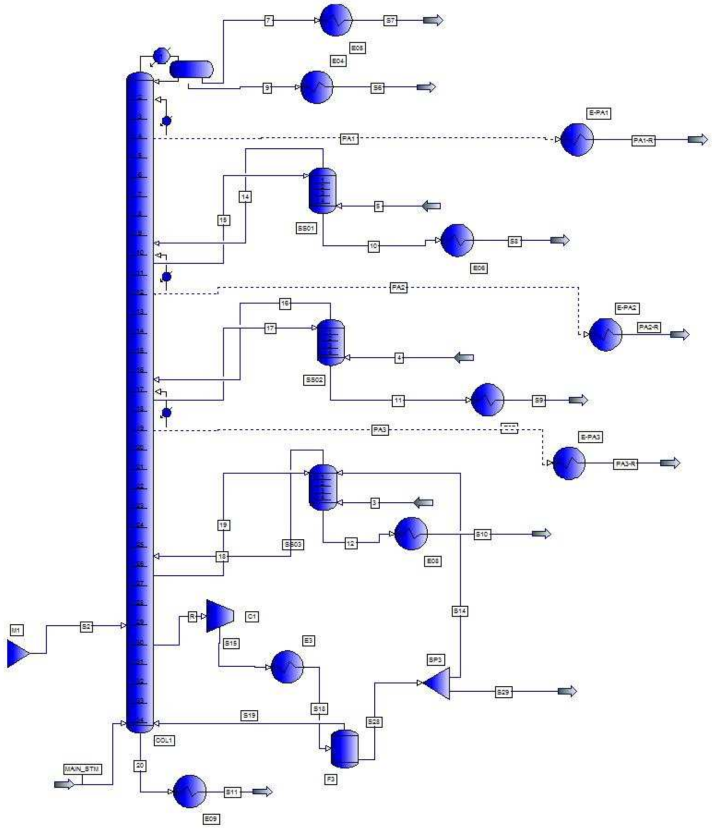

Figure 4 – Vapor and liquid recycle simulation

In vapor and liquid recycling, the feed side of the column is not changed from the conventional configuration. This design draws off a portion of the liquid downcomer on tray 30 and compresses it by 30 psig. The compressed hydrocarbon mixture is then heated to 232°C and fed into a flash drum. The vapor portion is then returned to the column at tray 34 (bottom tray). The purpose of this is to use the carrier properties of the vapor to release any remaining lighter components that remain in the heavier residue. The liquid stream from the flash drum is sent to a stream splitter, where the products, which are assumed to be heavy gas oil, can either be sent downstream for more processing (i.e. vacuum column) or can be sent back to tray 1 of the gas oil side stripper for steam stripping.

Technology II – Feed Preflash and splitting

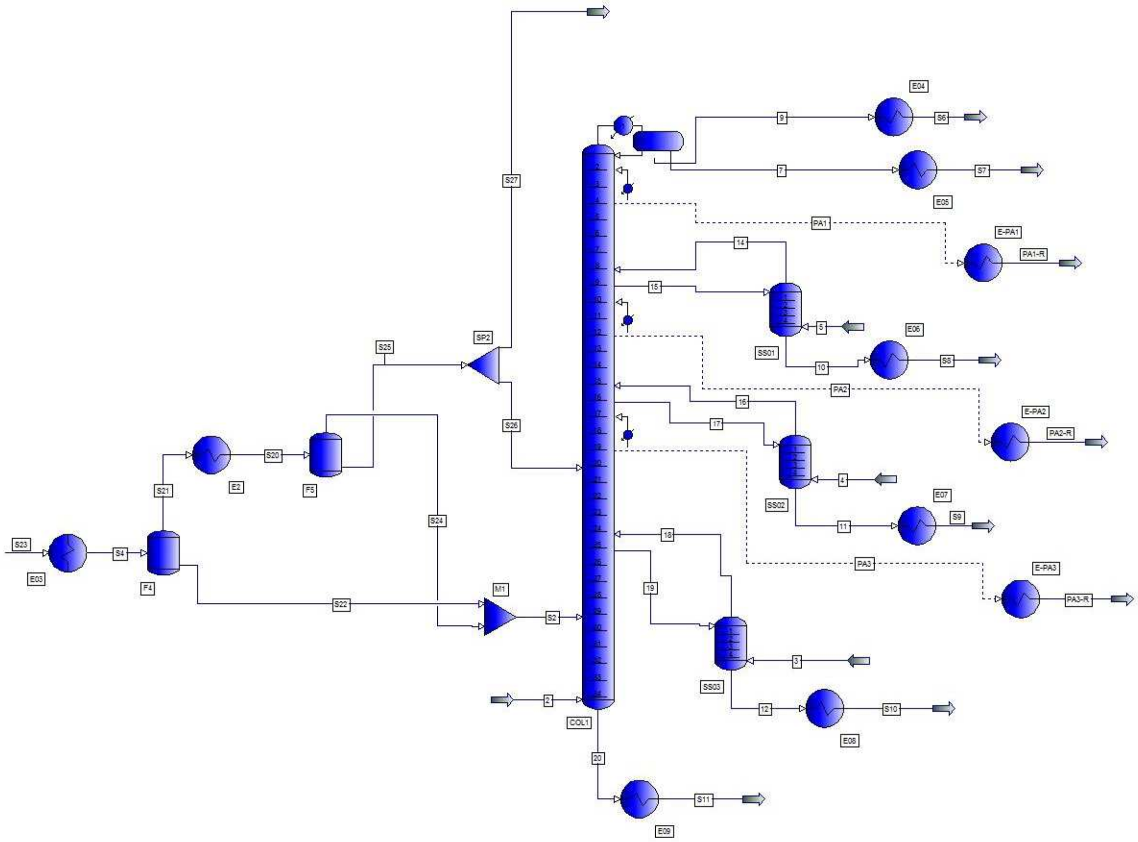

Figure 5 – Feed preflash and splitting simulation.

This design contains the normal desalter (not pictured) and preheating. In this particular case, the first heat exchanger heats the crude to 360°C and flashes it. The liquids are fed to the column. The vapor stream is then cooled to approx. 277°C and flashed again. The vapors are mixed with the heavy liquids from the first flash and fed to the column. The liquids from the second flash are sent to a stream splitter where the user can adjust how much of the intermediate liquids are fed to the column at tray 20. The remaining intermediates can be sent further downstream for processing. The side stripping sections have not been altered.

Technology III – Compressed Vapor Recycle

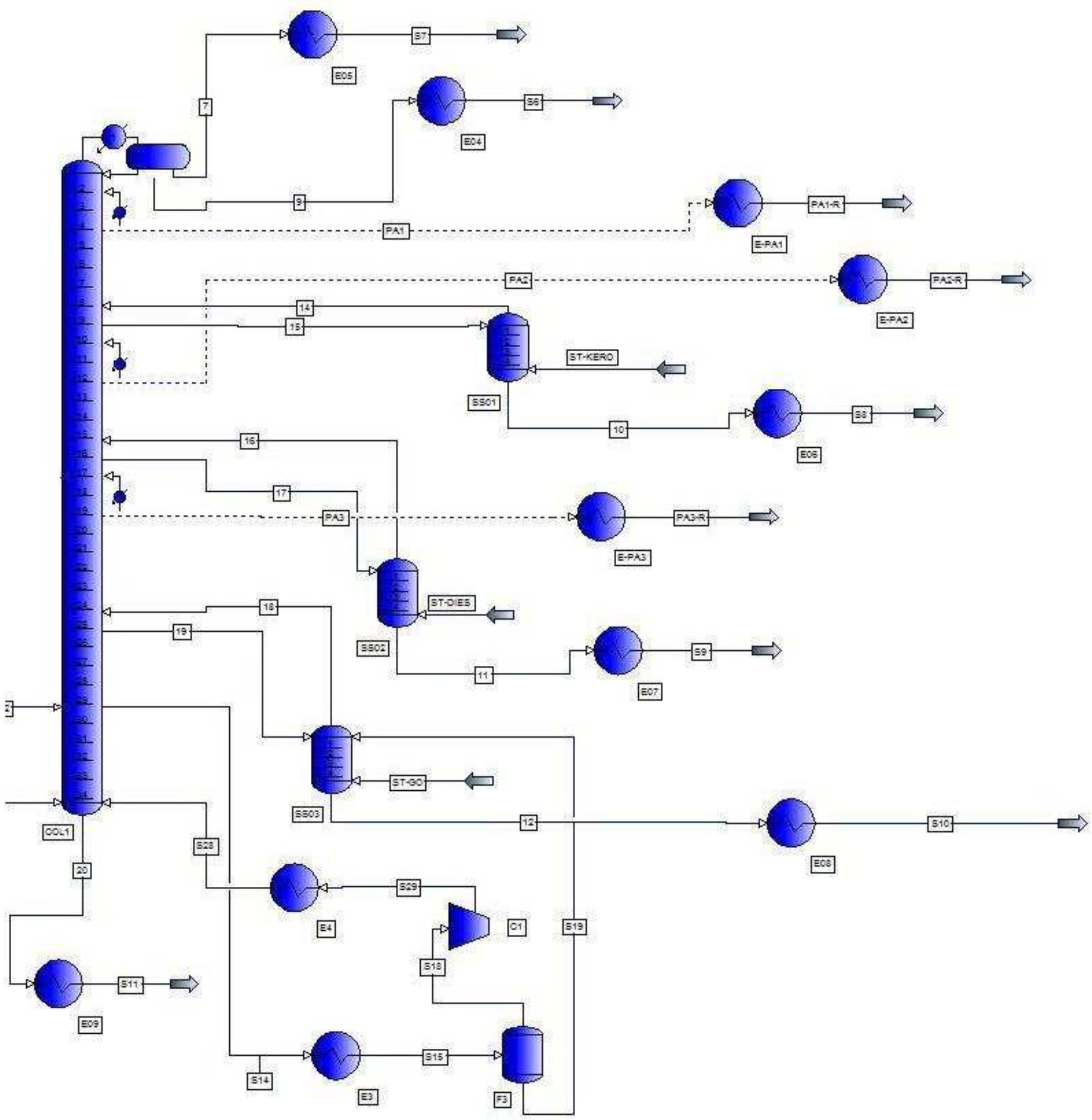

Figure 6 – Compressed vapor recycle simulation

In this arraignment, it should be noted that it is similar to technology 1, the vapor returning to tray 34 is compressed by 30 psi before being re-injected into the column. The vapors entering at greater pressure will increase the separation of the lighter components before the residue is drawn out.

Technology IV – Combined 2&3

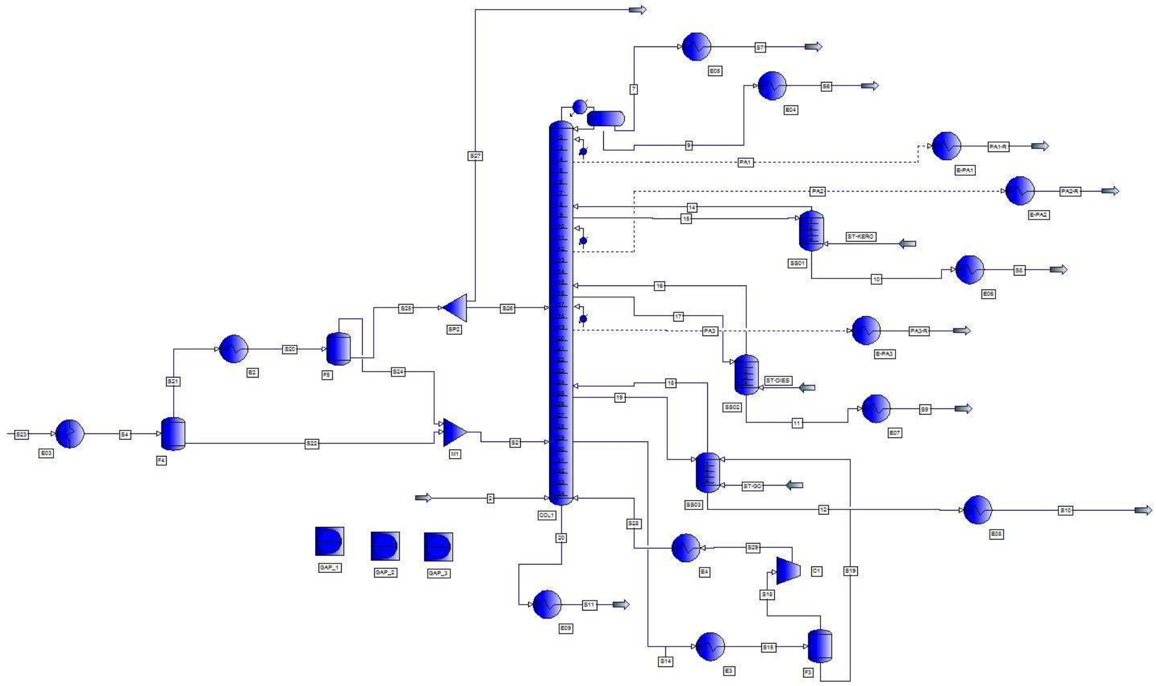

Figure 7 – Combined patent technologies

This patented design takes the two aforementioned technologies to decrease residue yield and decrease the minimum utility.

Technology V – Combined 2&1

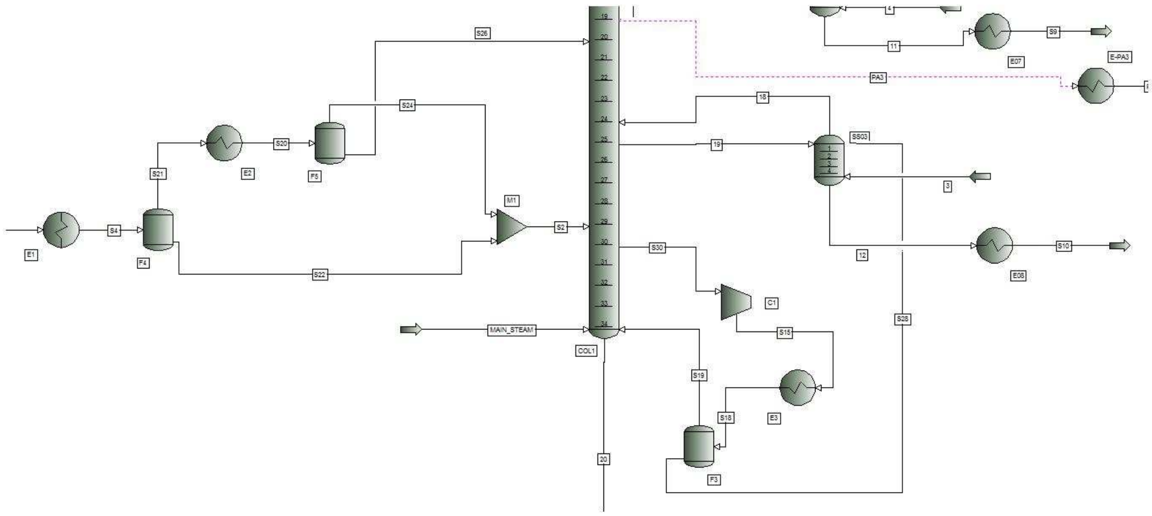

Figure 8 - Technology 5 – Combined patent technologies

This technology takes advantage of the preflash and the vapor stripping technologies.

Results

Each technology will be presented with its results. The product flow rates are in barrels per hour and the utilities are in MMBTU per hour. The results are balanced by adding in economics. The economics make it easier to see how the increases in product rates and reduction in energy usage relate to the profitability of the technology. The following numbers for poduct prices and crude oil were used for economic evaluation of the technologies. The prices were found on the Energy Information Administration website.

	Product cost ($/bbl)
Crude Oil	37.89
Naptha	110.00
Kerosene	95.00
Diesel	109.90
Gas Oil	75.90
Residue	67.90

Figure 9 - Prices from the EIA.

The heating utility was assumed to be natural gas fired heat. Its cost was estimated to be $8.00 per MMBTU.

The minimum utility was calculated by the straight pinch analysis. Specifications for the pumparounds, crude assay, and product specifications were given by Bagajewicz and Ji.

Technology I – Vapor and liquid recycle

				Light Crude		
	Conventional			Invention 1		
		$/year			% change	$/year
Hot Utility (MMBtu/hr)	286	$ 20,014,848		284	-1%	$ 19,902,720
Cold Utility (MMBtu/hr)	308	$ 54,446,273		318	3%	$ 56,071,008
Naphtha (bbl/hr)	1630	$ 1,570,637,834		1630	0%	$ 1,570,828,071
Kerosene (bbl/hr)	892	$ 741,972,375		890	0%	$ 741,070,562
Diesel (bbl/hr)	421	$ 405,081,861		425	1%	$ 408,867,261
Gas Oil (bbl/hr)	765	$ 508,699,868		836	9%	$ 555,593,350
Residue (bbl/hr)	1295	$ 770,264,402		1222	-6%	$ 726,559,740
	Total	**$ 2,262,613,000**		Profit Opportunity		**$ 4,750,000**
				Intermediate Crude		
		$/day			% change	$/year
Hot Utility (MMBtu/hr)	239	$ 16,714,080		237	-1%	$ 16,615,968
Cold Utility (MMBtu/hr)	158	$ 27,850,072		170	8%	$ 30,057,592
Naphtha (bbl/hr)	1024	$ 986,816,158		1023	0%	$ 985,954,217
Kerosene (bbl/hr)	589	$ 490,280,335		591	0%	$ 491,489,377
Diesel (bbl/hr)	411	$ 395,336,618		431	5%	$ 414,565,663
Gas Oil (bbl/hr)	279	$ 185,656,297		317	13%	$ 210,571,839
Residue (bbl/hr)	2699	$ 1,605,533,760		2641	-2%	$ 1,571,090,040
	Total	**$ 1,959,477,000**		Profit Opportunity		**$ 7,939,000**
				Heavy Crude		
		$/day			% change	$/year
Hot Utility (MMBtu/hr)	198	$ 13,840,800		197	0%	$ 13,826,784
Cold Utility (MMBtu/hr)	53	$ 9,377,545		83	56%	$ 14,587,292
Naphtha (bbl/hr)	349	$ 336,417,631		349	0%	$ 336,532,037
Kerosene (bbl/hr)	347	$ 288,477,089		344	-1%	$ 286,466,258
Diesel (bbl/hr)	514	$ 495,015,956		527	3%	$ 507,590,108
Gas Oil (bbl/hr)	194	$ 128,795,964		221	14%	$ 147,162,336
Residue (bbl/hr)	3598	$ 2,140,253,991		3560	-1%	$ 2,117,515,078
	Total	**$ 1,706,160,000**		Profit Opportunity		**$ 1,110,000**

Figure 10 - Technology 1 results

Technology II – Feed Preflash and splitting

		Invention 2		
			% change	$/year
Hot Utility (MMBtu/hr)		215	-25%	$ 15,088,224
Cold Utility (MMBtu/hr)		282	-9%	$ 49,783,991
Naphtha (bbl/hr)		1623	0%	$ 1,563,986,938
Kerosene (bbl/hr)		893	0%	$ 742,995,106
Diesel (bbl/hr)		400	-5%	$ 385,351,156
Gas Oil (bbl/hr)		865	13%	$ 575,208,912
Residue (bbl/hr)		1222	-6%	$ 726,679,701
		Profit Opportunity		**$ 7,155,000**
			% change	$/year
Hot Utility (MMBtu/hr)		206	-14%	$ 14,457,504
Cold Utility (MMBtu/hr)		144	-9%	$ 25,377,650
Naphtha (bbl/hr)		1022	0%	$ 984,451,599
Kerosene (bbl/hr)		586	-1%	$ 487,321,951
Diesel (bbl/hr)		419	2%	$ 403,196,311
Gas Oil (bbl/hr)		354	27%	$ 235,635,730
Residue (bbl/hr)		2622	-3%	$ 1,559,696,287
		Profit Opportunity		**$ 11,408,000**
			% change	$/year
Hot Utility (MMBtu/hr)		180	-9%	$ 12,586,368
Cold Utility (MMBtu/hr)		45	-16%	$ 7,858,771
Naphtha (bbl/hr)		346	-1%	$ 333,166,442
Kerosene (bbl/hr)		341	-2%	$ 283,654,993
Diesel (bbl/hr)		522	2%	$ 502,938,754
Gas Oil (bbl/hr)		255	32%	$ 169,543,335
Residue (bbl/hr)		3538	-2%	$ 2,104,445,641
		Profit Opportunity		**$ 7,562,000**

Figure 11 - Technology 2 results

Technology III – Compressed Vapor Recycle

		Invention 3		
			% change	$/year
Hot Utility (MMBtu/hr)		321	12%	$ 22,488,672
Cold Utility (MMBtu/hr)		302	-2%	$ 53,263,043
Naphtha (bbl/hr)		1629	0%	$ 1,569,457,353
Kerosene (bbl/hr)		902	1%	$ 750,640,521
Diesel (bbl/hr)		396	-6%	$ 381,035,473
Gas Oil (bbl/hr)		1085	42%	$ 721,587,440
Residue (bbl/hr)		991	-23%	$ 589,475,070
		Profit Opportunity		**$ 14,249,000**
			% change	$/year
Hot Utility (MMBtu/hr)		269	13%	$ 18,830,496
Cold Utility (MMBtu/hr)		152	-3%	$ 26,878,764
Naphtha (bbl/hr)		1023	0%	$ 985,414,907
Kerosene (bbl/hr)		588	0%	$ 489,320,176
Diesel (bbl/hr)		431	5%	$ 414,754,152
Gas Oil (bbl/hr)		475	70%	$ 315,767,027
Residue (bbl/hr)		2486	-8%	$ 1,478,780,213
		Profit Opportunity		**$ 19,268,000**
			% change	$/year
Hot Utility (MMBtu/hr)		211	7%	$ 14,793,888
Cold Utility (MMBtu/hr)		52	-2%	$ 9,236,264
Naphtha (bbl/hr)		347	-1%	$ 333,992,449
Kerosene (bbl/hr)		342	-1%	$ 284,260,491
Diesel (bbl/hr)		550	7%	$ 529,424,825
Gas Oil (bbl/hr)		313	62%	$ 208,310,047
Residue (bbl/hr)		3451	-4%	$ 2,052,408,576
		Profit Opportunity		**$ 18,624,000**

Figure 12 - Technology 3 results

Technology IV – Combined 2&3

		Invention 4			
			% change		$/year
Hot Utility (MMBtu/hr)		355	24%	$	24,843,360
Cold Utility (MMBtu/hr)		326	6%	$	57,483,821
Naphtha (bbl/hr)		1629	0%	$	1,569,415,320
Kerosene (bbl/hr)		902	1%	$	750,644,400
Diesel (bbl/hr)		396	-6%	$	381,046,159
Gas Oil (bbl/hr)		1085	42%	$	721,598,605
Residue (bbl/hr)		991	-23%	$	589,450,764
		Profit Opportunity		**$**	**7,633,000**
			% change		$/year
Hot Utility (MMBtu/hr)		221	-8%	$	15,452,640
Cold Utility (MMBtu/hr)		160	2%	$	28,326,897
Naphtha (bbl/hr)		1016	-1%	$	979,471,142
Kerosene (bbl/hr)		596	1%	$	495,665,545
Diesel (bbl/hr)		389	-5%	$	374,475,964
Gas Oil (bbl/hr)		380	36%	$	252,464,546
Residue (bbl/hr)		2622	-3%	$	1,559,476,755
		Profit Opportunity		**$**	**(1,285,000)**
			% change		$/year
Hot Utility (MMBtu/hr)		186	-6%	$	13,034,880
Cold Utility (MMBtu/hr)		56	5%	$	9,854,369
Naphtha (bbl/hr)		347	-1%	$	333,891,678
Kerosene (bbl/hr)		340	-2%	$	283,185,287
Diesel (bbl/hr)		514	0%	$	495,034,553
Gas Oil (bbl/hr)		253	31%	$	168,363,636
Residue (bbl/hr)		3548	-1%	$	2,110,085,031
		Profit Opportunity		**$**	**1,929,000**

Figure 13 - Technology 4 results

Technology V – Combined 2&1

		Invention 5		
			% change	$/year
Hot Utility (MMBtu/hr)		215	-25%	$ 15,043,870
Cold Utility (MMBtu/hr)		272	-12%	$ 48,083,035
Naphtha (bbl/hr)		1623	0%	$ 1,564,154,064
Kerosene (bbl/hr)		893	0%	$ 742,968,187
Diesel (bbl/hr)		398	-5%	$ 383,385,579
Gas Oil (bbl/hr)		859	12%	$ 570,842,807
Residue (bbl/hr)		1230	-5%	$ 731,715,985
		Profit Opportunity		**$ 7,745,000**
			% change	$/year
Hot Utility (MMBtu/hr)		205	-14%	$ 14,390,718
Cold Utility (MMBtu/hr)		158	0%	$ 27,868,969
Naphtha (bbl/hr)		1021	0%	$ 983,507,976
Kerosene (bbl/hr)		587	0%	$ 488,235,096
Diesel (bbl/hr)		437	6%	$ 420,373,435
Gas Oil (bbl/hr)		389	39%	$ 258,857,293
Residue (bbl/hr)		2569	-5%	$ 1,528,289,398
		Profit Opportunity		**$ 17,945,000**
			% change	$/year
Hot Utility (MMBtu/hr)		179	-10%	$ 12,509,280
Cold Utility (MMBtu/hr)		75	41%	$ 13,265,376
Naphtha (bbl/hr)		347	-1%	$ 334,272,840
Kerosene (bbl/hr)		343	-1%	$ 285,393,004
Diesel (bbl/hr)		564	10%	$ 542,683,668
Gas Oil (bbl/hr)		294	52%	$ 195,730,547
Residue (bbl/hr)		3454	-4%	$ 2,054,625,509
		Profit Opportunity		**$ 21,189,000**

Figure 14 - Technology 5 results

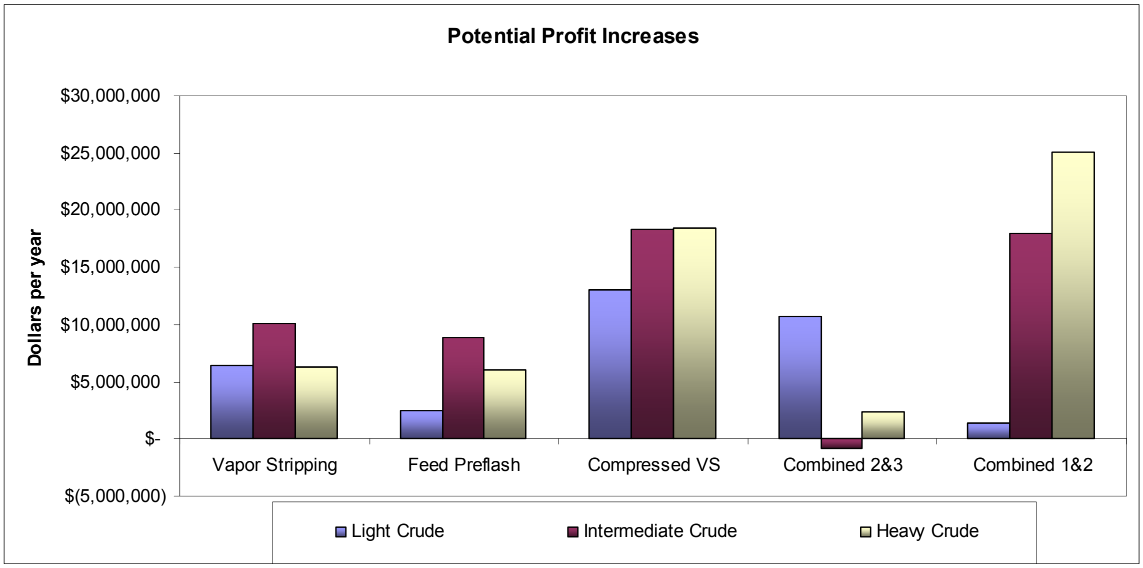

Figure 15 - Graphical representation of potential profit increase.

Conclusions

It is apparent that the patent designs are well suited for increasing the yields of gas oil and decreasing the yield of residue. For all crudes, the new technologies do not increase the yield of naphtha and kerosene, nor do they decrease them by any appreciable amount, with only 1.8% being the largest decline. As for energy usage, the feed preflash had the best performing energy usage reduction across all types of crude, with light crude having the best results. The combined technology 2&3 was the worst performer. This is due to the fact that a majority of the intermediates removed in the preflash remain in a "recycle loop" inside the column.

As the types of crude being found are increasingly comprised of heavier and heavier components, the compressed vapor recycle design would be an advantageous retrofit for refineries. It has the highest gas oil and diesel production increases of the intermediate and heavy crudes, with a very small reduction in naphtha and kerosene production. Technology five would be an excellent retrofit as crude oil increasingly heavier and heavier.

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Energy Information Administration