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CONDENSATE FRACTIONATION COLUMN: DESIGN VARIATION STUDY BY SIMULATION

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Abstract

This work aims to study the quality of three products of a fractionation column considering different design conditions of the column using natural gas condensate as column feed. The first design was on a single traditional distillation column whereas the consecutive studies were done by modifying the distillation column to yield the same quality of products. This study includes the details quality variation along with the variation of design. The whole simulation study and analysis was done on ASPEN^{TM} HYSYS 7.1.

Keywords

simulation; fractionation; distillation; ASPEN; design.

Introduction

The total production of gas condensate in different gas fields is up to 6725.5 BBLD in Bangladesh [1]. This condensate can be used to produce varieties of useful products by refining. That is why the demand of condensate refining is increasing day by day. New refining plants are being established now a day. With the given specification of raw material a proper process is required to get the desired products. But in many cases the required information for designing a process is not readily available. To obtain prior data before implantation of the plant, simulation is a standard and reliable tool. Distillation column is used for the separation of different fraction of condensate. Heavy part of the condensate is used as diesel whereas the lighter parts are divided into different fractions for different uses. One distillation column is sufficient for producing three products – two solvents and diesel. Several soft-wares have been developed for the petroleum industries. ASPEN^{TM} HYSYS is one such software which is widely accepted and used for refinery simulation. ASPEN^{TM} HYSYS performs the oil distillation calculation through detail plate by plate calculation. This calculation includes generating pseudo-components from the ASTM D86 data and generating properties from them. ASPEN HYSYS contains an oil manager which organizes the data for the pseudo-components separately.

From the very beginning of simulation, refinery was of great interest. The vast simulation scopes for refineries were studied by Koenig [2]. In Koenig [2], long-term planning and day-to-day planning of crude oil refinery was analyzed by linear programming technique and modern operations research was used to discuss the optimization methods. Simulation on petroleum refinery waste treatment process was studied in Hoffman [3]. The corrosive environment of oil refinery was simulated and several problems disturbing safety operations in the units were studied by Hitoshi [4] et al. For optimizing the crude oil operations, different solution approach was discussed in Reddy [5]. Simulation is a useful tool to study the output by a major change in the traditional design of a fractionation column. This type of study has not been done before in Bangladesh according to the author's knowledge. This study highlights on different scopes of designing a fractioning column cost effectively. Considering the trade-off between the product quality and column cost, one can accept what kind of product is required and which design is to be adopted. This paper is outlined as follows: the basis of the study and different design procedures are depicted in the following section. The consecutive sections are on different results obtained from the simulations and some suggestions about it.

Design Basis and Variation

A fractionation column was used to produce two solvents as top and side product and diesel as the bottom product. Design basis was taken for the simulation from the data available from an industry in operation. The industrial data was regenerated in the simulation environment. Then different design modifications were proposed and checked for accordance with the actual product. Maintaining the same product quality (with a slight variation), different modifications was studied. The modifications are unique and exclusive. Three different designs were simulated and compared for the analysis. The actual industrial column is denoted as Column-1. Then this column is modified by eliminating the reboiler. This is denoted as Column-2. Then this study extends by injecting steam at the bottom. But when this was done, extra cost is included for the separation of water whereas the cost of reboiler is excluded. This is denoted by Column-3. Separation was obtained mainly by varying the reflux ratio. Design basis of the study is stated in the Table 1 below –

Table 1: Design basis for simulation

Fluid Package	Peng-Robinson
Method of Simulation	Pseudo-component generation and plate by plate calculation
Solver	HYSIM Inside-Out
Properties generation	HYSYS properties

Fluid package was selected to be Peng-Robinson. The main reason behind this, it is widely used for refinery simulation as it can handle hypothetical pseudo-components. The

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method of simulation for HYSYS is pseudo-component generation and plate by plate calculation from the 'True Boiling Point' or 'ASTM D86' input data. For this simulation, ASTM D86 input data were available from the refinery laboratory. The HYSYS solver uses different numerical methods for simulation and the selected method for the simulation was HYSIM Inside-Out which is suitable for most cases. From properties generation, two databases can be used for ASPEN HYSYS 7.1 – HYSYS properties and ASPEN properties. But as they are exclusive, HYSYS properties were used for property generation of the streams.

The ASTM D86 data obtained from the refinery for condensate of 'Sylhet Gas Field' that were used as input for the oil manager in HYSYS are tabulated below:

Table 2: Input data for oil manager

Liquid Volume Evaporated %	Temperature, ^{0}C
5.00e-003	52.00
10.00	90.00
20.00	101.00
30.00	109.00
40.00	118.00
50.00	128.00
60.00	141.00
70.00	159.00
80.00	184.00
90.00	235.00
95.00	266.00

Lagrange method was selected for intrapolation to generate pseudo-components from the curve. 24 components were generated from intrapolation and water was added to the component list as steam. The flow rate, temperature and pressure data for the condensate which was used as the feed to the distillation column are same as those of actual plant data. Three products were produced in the distillation column: Solvent – A, Solvent – B and Diesel. The available plant data that were used for the actual column are tabulated in Table 3. These data were used as input for the simulation to regenerate and check the actual plant data.

Table 3: Available column data from the plant

Item	Value
Number of Plates	24
Feed Plate Position	18
Solvent-B Draw Position	16
Reflux Ratio	2.7
Feed Flow Rate	1045 lb/hr
Solvent-A Flow Rate	600 lb/hr
Solvent-B Flow Rate	280 lb/hr
Diesel Rate	165 lb/hr

Simulation Results

The first of the three simulations regenerated the actual data which was obtained from the plant. The idea is to verify if any major design change is made, would it be able to produce the products of same quality? The schematic diagram of a condensate fractionation plant is shown in Figure 1. The actual distillation column was a traditional distillation column which has a reboiler at the bottom and a condenser at the top. The flow sheet of the original column can be seen in Figure 2(a). Among the three products, the top product was named as Solvent-A and it was the lightest of all. It would be used as thinner for paints. Solvent-B was the side draw from the column. It was composed of mostly kerosinic components. Diesel was the bottom product of the column and heaviest of all.

For a design change, the reboiler was eliminated from the column. Then extensive simulation was done to maintain the product quality to the actual. For this, the feed stage was changed to 24 and the side draw plate was changed to 10. So the column worked as a rectifying column. The schematic of the column is shown in Figure 2(b).

The feed position, side draw and steam injection for the three columns are shown in the table below-

Table-4: Column data for the simulations

	Column - 1	Column-2	Column-3
Total no. of stage	24	24	24
Feed Stage	18	24	18
Side Draw Stage	16	10	17
Steam Injection Stage	----	----	24

The convenience of the design was the reduction of cost due to the removal of reboiler from the column. But with the reduction of the cost, the product quality was changed. This is the trade-off between reduction of cost and quality.

The next simulation study was done on a distillation column which has no reboiler but steam was injected at the bottom. This can be seen in Figure 2(c). This design requires a separator for the separation of water from the oil. Solvent-A carried most of water and Solvent-B contained small amount of water whereas diesel did not contain any water. With steam stripping, the product quality was changed also.

The comparative results are shown in Figure 3. Here, the ASTM D86 curves were shown for different products – Solvent-A, Solvent-B and Diesel. In Figure 3(a), the quality comparison for Solvent-A is shown. From the figure, it can be easily understood that three columns have almost the same product quality except a slight variation for Column-1. That is because, Column-1 had more degree of freedom than the other two and it contains the lighter components than the other two. Column-2 and 3 has almost the same quality product and contains a little amount of heavier components excess to Column-1.

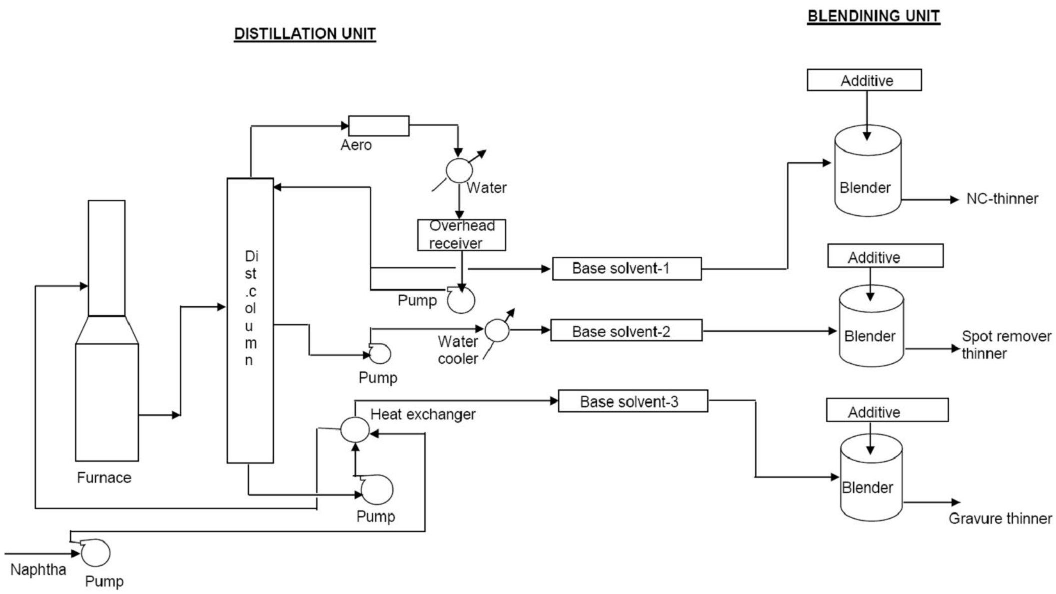

Fig 1. Schematic diagram of a condensate fractionation plant

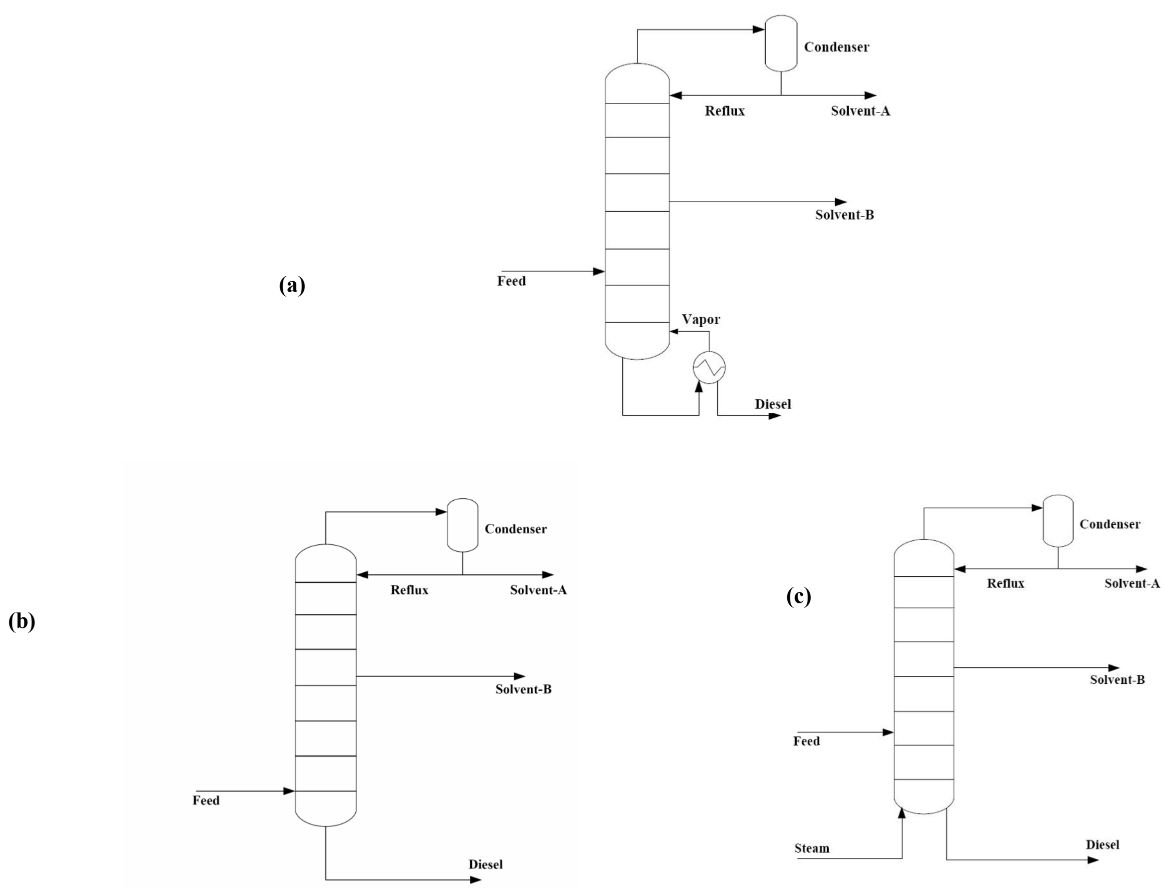

Fig 2. Design variations of the fractionation column – (a) Column-1, (b) Column-2, (c) Column-3

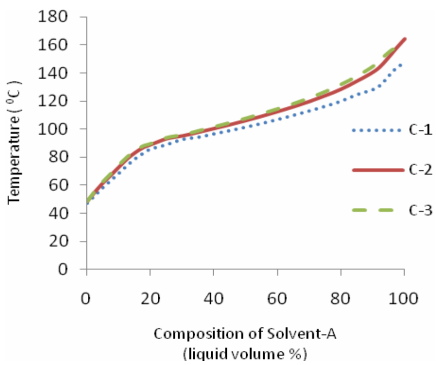

Fig 3(a). ASTM D86 data for Solvent-A obtained from the three different design consideration

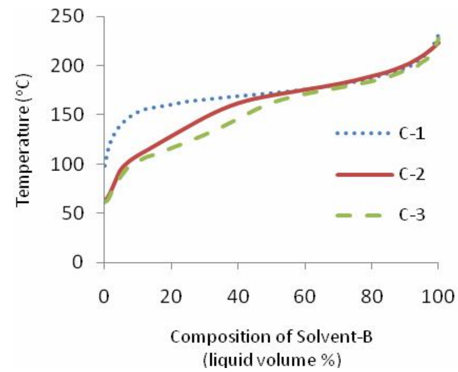

Fig 3(b). ASTM D86 data for Solvent-B obtained from the three different design consideration

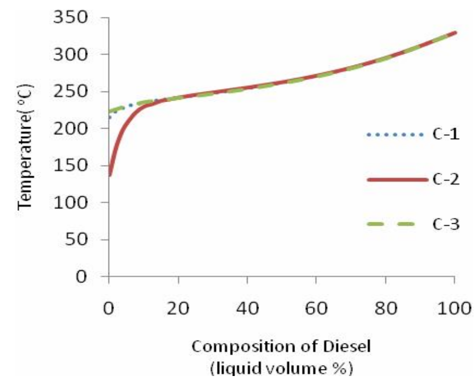

Fig 3(c). ASTM D86 data for Diesel obtained from the three different design consideration

In Figure 2(b), the ASTM D86 data for the comparison of the Solvent-B is shown. Column-1 has a lead over the other columns. It contains almost 30% of some components which gives the boiling point around 160^{o} C whereas the other two columns have a lack of those components. At the deviation region, they have some components of an average boiling point of 120. Then at 50% of composition, the boiling point data from ASTM D86 collide and they remain the same till the final boiling point. So here remains the trade-off between quality and cost minimization. Column-1 definitely suffices the need for the consumers but Column-2 and 3 have some deviations from the original. This deviation clearly indicates that Column-2 and 3 contains some extra lighter components whereas Column-1 does not. Those lighter components will make the Solvent-B to evaporate easily. If this is a product which is to be used as solvent for paint, then obviously this will not be a problem. But for other purposes, this fast evaporating tendency of the product must have to be taken under consideration. For this particular simulation, as material balance was kept constant, product quality cannot be upgraded from this. Figure 3(c) shows the bottom product quality from the columns. This is interesting to note that Column-1 and Column-3 both have the same quality of diesel whereas Column-2 contains some extra lighter parts. These lighter parts change the quality of diesel as this diesel would boil or evaporate faster. The explanation of this difference is pretty simple; Column-2 has no heating system at the bottom like reboiler or steam injecting point. So it lacks behind the other columns to strip the lighter parts of the condensate to the top section of the column. But it is noteworthy that after 10%, it coincides with the other two columns till the final boiling point.

So if this quality difference can be tolerated, then this design is also acceptable. Otherwise, the third design would be the better choice except the original. But these plots are not enough to understand the product quality. The oil distributions of the products were studied. These studies are presented in the form of bar plots which would provide the necessary insight about the products in the next section

Product Quality Comparison

In distillation column for partial fractionation of petroleum, the feed stream is separated into different fractions according to the boiling points. But for commercial purpose, the different product streams may be considered as mixtures of different amount of light gasoline, heavy gasoline/naphtha, kerosene, light diesel, heavy diesel etc. In this study, column upper products (light fractions) are rich in naphtha whereas the bottom products are rich in light and heavy diesel. The ASTM D86 ranges for these cuts are as follows –

Table 5: Table for product cuts

Name	Ranges (^{0}C)
Naphtha	70 – 180
Kerosene	180 – 240
Light Diesel	240 – 290
Heavy Diesel	290 – 340

The simulation was done with the objective to modify a physically existing column. The column fractionates gas condensate to produce marketable product. The top product is named as Solvent-A, side product is named as Solvent-B and bottom product is named as Diesel. According to the simulations made in this work, the following qualities of the products are found in the three columns.

Quality of Solvent – A

Solvent-A is a lighter product found from the top of a distillation column by partial fractionation of natural gas condensate. Since, the lighter products mainly contains naphtha in higher amount so the quality of Solvent-A is verified by analyzing the percentage of naphtha present in the top product.

The Figure-4(a) illustrate that after partial fractionation of natural gas condensate in a typical distillation column having a condenser at top and a reboiler in bottom will produce a product named Solvent–A with a quality of 80.3 % naphtha.

In the second case, when the column contains only the condenser and no reboiler is used for heating the bottom liquids, the top product contains 82% naphtha.

For third case when the column structure is same as the second one but steam is used at the bottom stage for stripping of the bottom liquids, then Solvent-A contains 82.4% naphtha.

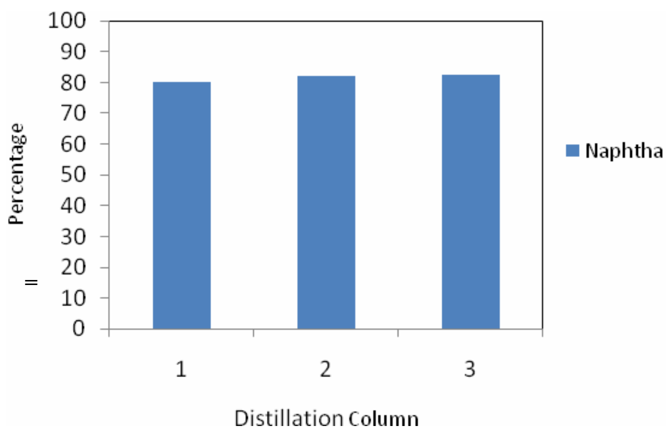

Fig 4(a). The percentage of Naphtha in Solvent–A for three distillation columns.

From Figure-4(a) it is clear that for Column-2 when there is no reboiler, the quality of Solvent-A does not differ much from the product found in a typical distillation column. Also Column-3 when steam is added in the bottom stage the quality does not differ from the original case. So, in these cases omission of a reboiler from the column will decrease the investment as well as operating cost of the plant keeping the product quality very nearly the same.

Quality of Solvent-B

Solvent-B is a side stream of the distillation columns collected from stage-16 for Column-1, stage-10 for Column-2 and stage-17 for Column-3. It contains mainly mixture of naphtha and kerosene. The following figure shows the quality of Solvent-B found from three separate distillation columns.

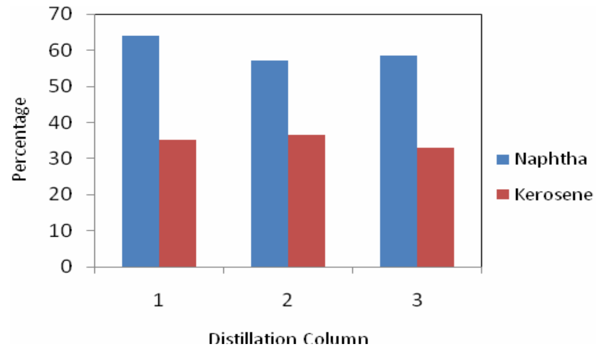

Fig 4(b). The percentage of Naphtha and kerosene in Solvent–B for three distillation columns

For the first case the percentage of naphtha and kerosene in Solvent-B is 64.1% and 35.5% respectively. For the second case these compositions are 57.2% and 36.5% respectively. For third case these values are 58.6% and 33% respectively.

From the figure, it can be said that the quality of Solvent-B has slight degradation for second and third case than the first case. Although second and third cases have degraded quality of Solvent-B, still it is in the acceptable limit.

In all the simulation work it was the primary objective to maintain the amount of product same in all the considered design modifications i.e., the quantity of Solvent-A, Solvent-B and diesel must be same from the three distillation column using 1045 lb/hr of natural gas condensate as feed. In all the three cases the amount of Solvent-B produced is 280 lb/hr. To maintain the amount of product same, a slight degradation in quality of the product has occurred and it is assured by the authors that, the quality can be maintained constant with sacrificing the amount of products.

Quality of Diesel

The column bottom products are usually diesel and it mainly contains mixture of light diesel, heavy diesel and a considerable amount of kerosene. The figure 4(c) describes the quality of diesel found from the three distillation columns.

For a typical distillation column (column-1) the percentage of kerosene, light diesel and heavy diesel in diesel is 28, 40.3 and 27.8% respectively. For second and third column this compositions are 21.6, 40.8 and 27.8% and 28.9, 39.9 and 27.3% respectively.

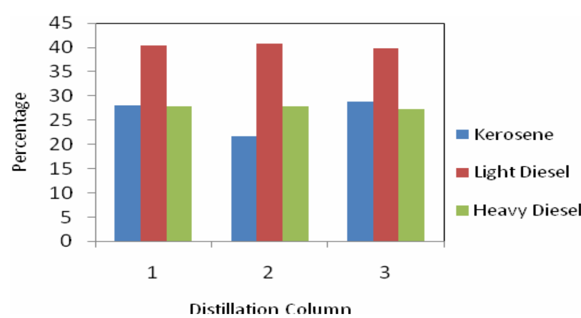

Fig. 4(c). The percentage of Kerosene, Light diesel and Heavy diesel in Diesel for three distillation columns

It has already been mentioned that, there is a tradeoff between material balance and quality of the products. To keep the amount of product same, quality of product must be sacrificed. That's why for the second column the percentage of kerosene is much less than that for first and third column. The qualities of other fractions (light diesel and heavy diesel) are almost same for the entire three columns.

Conclusion

This study presents an interactive study of major design changes from the traditional fractionation column. The remarkable outcomes of the study are: (a) if the cost of reboiler is to be excluded, the quality of Solvent-B and diesel will degrade. The degradation of the products was studied in this paper in details. So if the product quality is acceptable, then this strategy should be adopted (b) the quality of Solvent-B and diesel can be regained by injecting steam at the bottom of the column. This steam strips the lighter fractions to the top. But this will increase the cost of water separation from Solvent-A and Solvent –B. This strategy can also be applied whenever suitable.

In the end, it can be concluded that this work mainly contributes by providing different results from the simulation on various design modification of a gas condensate fractionation column. A more rigorous study can be done by dividing one column into two which can provide a different set of data and some new possibilities.

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