“DESIGN GUIDELINES FOR PROPYLENE SPLITTERS”

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Introduction:

The Chemical Processing Industry has been continually pushing the capacity envelope of new and existing distillation columns. While increasing the capacity of existing columns is not unusual, great care needs to be taken when a revamp is being considered. There is a fine line between success and failure when a column is designed at or near the upper end of the capacity envelope.

The authors will detail the methodology used when designing a new or considering a capacity increase for an existing propylene splitter. This paper will discuss design aspects that need to be considered when designing a propylene splitter. The authors will also present a generic case study of a propylene splitter revamp.

Some of the topics that will be covered by the authors are:

1. Process simulation of a propylene splitter – proper simulation techniques
2. From the simulation to the field – tray efficiencies
3. Utilizing a process simulation to develop column hydraulics
4. The types of internals that have been used in propylene splitter columns
5. Design considerations that need to be addressed when considering a revamp.

General Design of a Distillation Column:

Separations are a major part of the chemical processing industry. It has been estimated that the capital investment in separation equipment is 40-50% of the total for a conventional fluid processing unit. In a plant one of the main unit operations is material separation. This includes distillation, storage tanks, flash drums and other equipment of this nature. Of the total energy consumption of an average plant, the separation process accounts for about 50% to 70% of the energy consumption of the plant. Within that area of the material separation, the distillation unit operation method accounts for normally greater than 80% of the energy consumed for this process.

In general, initial design of a distillation tower involves specifying the separation of a feed of known composition and temperature. Constraints require a minimum acceptable purity of the overhead and the bottoms products. The desired separation can be achieved with relatively low energy requirements by using a large number of trays, thus incurring larger capital costs with the reflux ratio at its minimum value. On the other hand, by increasing the reflux ratio, the overhead composition specification can be met by a fewer number of trays but with higher energy costs.

Design of a Propylene Splitter:

Determining the design of a Propylene Splitter requires an understanding of the simulation model used to generate the internal loads and physical properties, vapor and liquid equilibrium data utilized, tray hydraulics, and how the selection of the internals will affect the actual efficiency of the installed equipment in the field.

The typical design of a propylene splitter is not complex and there are two general variations in design. The first is a called high-pressure system, and the second is called a heat pumped system. A high-pressure system is designed to utilize cooling water as the source to cool the overhead vapor, and a high pressure is needed to condense the propylene vapor at ambient temperatures of about 40 degrees C.

A heat pump system utilizes a compressor to reduce the tower pressure to allow the distillation column to be smaller. In most distillation application, relative volatilities can be improved by lowering the pressure. This results in lower number of stages required and reflux ratios, but at the cost of higher energy requirements of the compressor.

A good rule of thumb is that if the propylene system is associated with an ethylene plant, in which there is typicality an abundance of quench water that can be used to heat the C3 Splitter reboiler a non heat pump system may be the best choice. If no source of sufficient low-grade heat is available for example in a refinery FCC unit or propane dehydrogenation unit, then the use of a Heat Pump is typically the economical choice.

High Pressure Systems

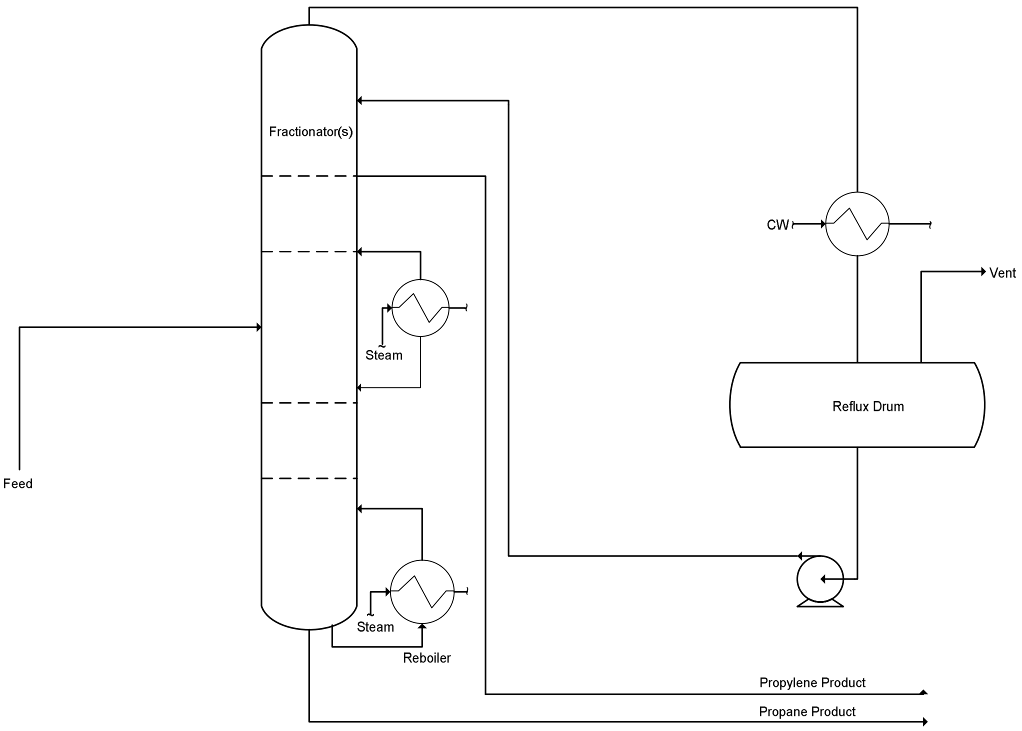

Figure 1

The first is a called a high-pressure system, and the second is called a heat pumped system. A high-pressure system is designed to utilize cooling water as the source to cool the overhead vapor, and a high-pressure system is needed to condense the propylene vapor at ambient temperatures of about 40 degrees C.

Heat Pumped Systems

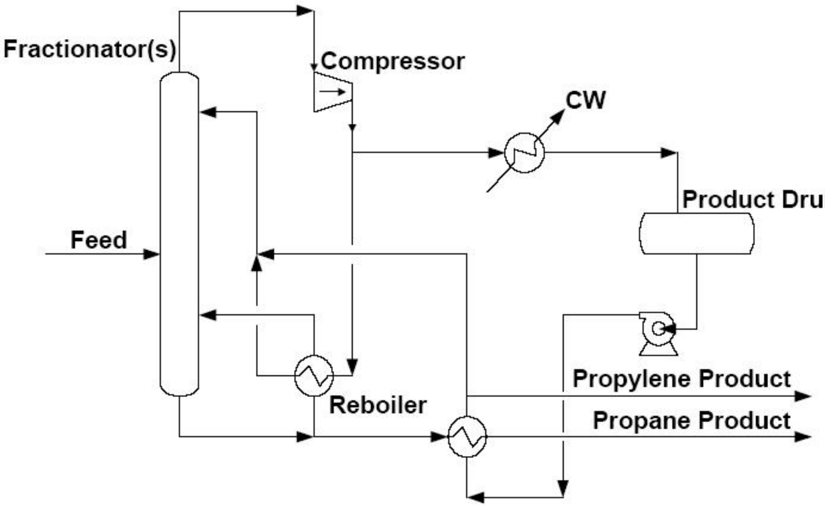

Figure 2

A heat pump system utilizes a compressor to reduce the tower pressure to allow the distillation column to be smaller. In most distillation applications relative volatilities can be improved by lowering the column pressure. This results in lower number of required theoretical stages and reflux flow. These savings are offset by the required energy cost of the compressor.

Process Simulation of a Propylene Splitter – Proper Simulation Techniques

Simulation of a propylene splitter seems very simple and can be done quickly by 3rd year engineering students. There are a small number of components and the equipment layout is not complex. The challenge of a propylene splitter is that, unless you use the correct vapor and liquid equilibrium data, the simulation can have greater than 15% inaccuracies as compared to actual field data.

Physical properties are critical to the success of a simulation model and are also very important to the accuracy of the model. Poor physical property data may prevent your simulation model from converging. The most typical problem is missing parameters in the thermodynamic package utilized. This is not unusual in most commercial simulation packages.

Physical property parameters for most compounds are not known for every thermodynamic model at every pressure and temperature range. Many times this fact is overlooked when a design model is constructed. Simulation models are constructed and executed with thermodynamic parameters missing. Although the model may appear to be correct but may be incorrect because of the missing thermodynamic data. Then there is the problem that all of the thermodynamic data are present but the data are not accurate. This problem is even worse than the problem of missing data since the results from the simulation model will appear to be correct, but are totally wrong. Most simulation packages won't alert the users that there is a problem. It is the job of the user to determine if the results from a simulation model are accurate (1).

The best way to confirm if your thermodynamic data are correct is to see if you can find any laboratory data or data from literature on your system. This may not always be practical because good thermodynamic test data are hard to find. Sometimes that data may have to be generated in a pilot plant before any design work begins.

Research the system being modeled. Published thermodynamic data on the system being modeled may exist. If data is obtained, the data must cover the same temperature and pressure range that you are designing. Next, run a simulation with the same system and see if you can match the data. Most data on propylene splitters has been compiled from years of operating experience. Many companies that license technology have done extensive testing and have developed propylene splitter data for design purposes.

The most accurate Vapor Liquid Equilibrium (VLE) data for Propylene Splitters might be Ping Robinson, but there is a huge data base of distillation columns designed and built utilizing Soave Redlich Kwong (SRK), and many designers utilize SRK to be able to utilize the existing database for actual tray efficiency in the field. The standard SRK equation of state model handles the propane / propylene binary K values adequately over the typical operating pressure range of these towers, which is 5 bar (100 psia) to 20 bar (320 psia). The other miscellaneous lights, heavies and intermediate boilers, such as Propadiene (PD), methyl-acetylene (MA or propylene), ethane and iso-butane, are also adequately modeled using the SRK equation of state. (3)

Methyl-acetylene (MA) is an intermediate boiler that is lighter than propane and heavier than propylene. Even at small ppm concentrations in the feed will, over time, result in a build up of MA in the tower. Concentrations inside C3 Splitter towers 10 to 20 trays from the bottom can be as high as 15% to 20% depending on the severity of propylene recovery required. Many propylene splitter systems have a sample point in this 10 to 20 tray range from the bottom to be able to sample the MA concentration in the column. MA, being a triple bonded hydrocarbon at elevated concentrations, above 40%, can auto decompose with potential adverse consequences. Propadiene (PD) is heaver than both propane and propylene and will never have a significant concentration in the overhead product.

Many choices are available for enthalpy models in simulation packages. SRK will do an adequate job but there may be better choices. This is important because there are always light components (i.e. methane, ethylene) that will be present in the feed and they will be close to their critical temperature. The choice of enthalpy model will help in the tower consistently achieving convergence. (3)

One other area of concern is the specific heat of liquid propylene. Some Propylene Splitters will have sub-cooled reflux return or a sub-cooled feed. The performance of a C3 Splitter tower is heavily dependent on a proper heat balance on the tower. Sub-cooled streams have to be accounted for properly. Propylene pure component liquid specific heat data is quite varied. The variation in reputable data has an error band of over 15%.

There are many choices in the vapor density, enthalpy, specific heat, viscosity, and surface tension model correlations. It is important to be able to tune your model to actual field data so that your model will reflect the real world.

High Pressure:

High-pressure distillation in a column can have challenges. There are many factors to be considered when designing at high operating pressures. (1).

1. At higher operating pressures the relative volatility of the system is lower which increases the separation difficulty. As a direct result of increased separation difficulty the reflux requirements for the column would increase. The column would also require more stages and increased duties for the reboiler and condenser to perform the separation. Propylene Fractionators are high liquid traffic columns that require internals that can handle high liquid traffic.

2. At higher operating pressures the reboiler temperature rises, thereby requiring a more expensive heating medium. If the same heating medium is used a reboiler with a larger heat transfer area would be required.

3. At high operating pressures the vapor density would increase and therefore lower the required vapor handling capacity. This would lead to a reduction in the diameter of the column, which would reduce the capital equipment costs.

High Pressure Distillation Tray/Column Design:

As the distillation pressure is increased, the vapor density increases. When the critical pressure is approached, the compressibility factor of a saturated vapor usually has a value less than 0.75. Thus the vapor density of the gas phase is quite high at pressures greater than 40% of critical. As the operating pressure is increased for the same C_s (Capacity Factor) value, the vapor mass flow rate will be much greater than at atmospheric operating pressure because of the high vapor density. While at the same time the liquid mass flow rate will be greater at high operating pressure than at atmospheric operating pressure. Therefore, liquid flow rates per unit of column cross-sectional area will be higher as operating pressure increases. The capacity of the fractionating device at high pressure may be dependent on its ability to handle these high liquid flow rates.

In a propylene fractionator column, the tower cross sectional area is the sum of the trays active area plus the total downcomer area. The amount of required active area (Vapor-Liquid Bubbling Area) is determined by vapor flow rate. The downcomers handle a mixture of clear liquid, froth, and aerated liquid. The downcomer area required to handle the high liquid flow not only increases with the liquid flow rate, but also with the difficulty in achieving separation between the liquid and vapor phases. The volume required for the downcomer increases at a lower surface and a smaller density difference between the liquid and vapor. Because of the large downcomer area required to handle the high liquid flow rates the area may be 40% to 80% greater than the calculated tray active area for the vapor flow rates for propylene fractionator distillation. The downcomer area becomes a significant factor in the determination of the tower diameter.

Simulation Accuracy:

In order to determine the accuracy of a simulation it is always desirable to construct a McCable-Thiele diagram from the data generated from the simulation. The data from the simulation can be easily transferred to a software package where the graph can be constructed. This graph is used more as a tool to identify possible problems that won't be discovered until the column fails. The following is a list of the areas where a McCable-Thiele diagram can be used as a powerful analysis tool (1).

1. Pinched regions - Pinching is readily seen on an x-y diagram.
2. Mislocated feed points - The feed point should be where the q-line intersects the equilibrium curve. This is generally the rule in binary

distillation. However, it is not always true in multicomponent distillation. A key ratio plot is often developed in the design phase. This type of plot is far superior to an x-y diagram for identifying mislocated feeds, especially with large multicomponent systems.

3. Determining if the column is being over refluxed or reboiled - This can be recognized by too wide of a gap between the component balance line and the equilibrium curve throughout the column.

4. Identify cases where feed or intermediate heat exchangers are needed.

Most commercial simulation programs will provide the information required to generate these plots.

Column Sizing:

Once the internal liquid and vapor traffic is obtained from the simulation model, the diameter of the column must be obtained. Most simulation packages have tower-sizing routine. These routines are fairly easy to use and yield quick results. However, these results should be verified by calculation.

Column sizing is done on a trial and error basis. The first step is to set the design limits. The design limits are as follows:

1. Maximum Design rates – Vapor/Liquid Traffic is needed at Maximum Operating rates.

2. Design rates - Vapor/Liquid Traffic is needed at Design Operating Conditions.

3. Minimum Design rates - Vapor/Liquid Traffic is needed at Minimum Operating rates.

Sizing calculations need to be performed in areas of the column where the vapor/liquid traffic is expected to be highest and lowest for each section. For example,

1. The top tray and bottom tray in the column.

2. The feed tray.

3. Any product draw-off tray or heat addition/removal tray.