**What is a distillation column?**

A distillation column, or tower, is used to separate liquid mixtures into individual constituents based on their boiling points. The liquid is heated to produce vapours which are then condensed, by cooling, back into liquid form. The liquids are then collected in trays or plates positioned at different heights inside the column, their position based on the boiling point of each separate component.

Distillation columns are used in petrochemical, chemical and pharmaceutical industries to purify and separate various chemicals, distillation columns are also used in the production of alcoholic beverages.

The design and specific operation of a distillation column can vary greatly depending on the type of liquid mixture being distilled and the desired product specifications.

**Key Purposes of a Distillation Column**

A distillation column is essential for various industrial processes where the separation and purification of liquids is required.

✓ Purification: It is used to purify liquids by separating impurities and desired products based on their boiling points.

✓ Fractional Distillation Column: In industries like petroleum refining, it separates crude oil into fractions like gasoline, kerosene, and diesel.

✓ Concentration: It concentrates substances by removing less volatile components, commonly used in the production of spirits and essential oils.

✓ Recovery: The column can recover specific components from waste streams, playing a role in recycling and environmental management.

**What is the purpose of a distillation column?**

A distillation column is a critical piece of equipment used primarily in the chemical processing industry to separate mixtures into their parts or fractions. This separation process is fundamental in the production of pure components from various mixtures.

How does a separation column work?

The column works on the principle of differential distillation, where a mixture is heated to create vapours. These vapours then ascend the column, which is cooler at the top than at the bottom. As the vapours rise, they cool and condense at different levels according to their boiling points. Components with lower boiling points condense higher in the column, while those with higher boiling points condense lower down.

**What are the two types of distillation columns?**

Both tray and packed columns are integral to the distillation process, with their selection depending on factors such as the nature of the mixture being separated, desired purity levels and process efficiency requirements.

Tray Column

Structure: This type features a series of trays or plates stacked within the column.

Operation: As the vapour rises through the column, it interacts with the liquid on these trays, facilitating the exchange of heat and mass.

Types of Trays: They can have various tray designs like sieve trays, bubble cap trays, or valve trays, each with unique efficiency and flow characteristics.

Applications: Tray columns are widely used in industries where precise control over the separation process is required, such as in petrochemical refining or the manufacture of fine chemicals.

Packed Column

Structure: Instead of trays, these columns contain a packing material, which can be either random (like rings or saddles) or structured (layered mesh or corrugated sheets).

Operation: The packing increases the surface area for contact between the vapour and liquid phases, enhancing the separation process.

Efficiency: Packed columns are generally more efficient for lower-pressure drops and are better suited for heat-sensitive materials.

Applications: They are commonly used for distillation processes that require a large number of theoretical stages, such as in air separation or the production of fine fragrances.

Each type offers unique advantages, making them suitable for various industrial applications.

**What does a distillation column consist of?**

A distillation column is a sophisticated piece of equipment essential in the separation of liquid mixtures into their components. It consists of several key components, each playing a vital role in the distillation process:

Vertical Shell: The main body of the column, typically tall and cylindrical, where the separation of liquids occurs.

Reboiler: Situated at the base of the column, the reboiler heats the liquid mixture, causing it to vaporize and ascend the column.

Condenser: Located at the top, the condenser cools the vapour, causing it to condense into a liquid. This liquid can be collected or returned to the column as reflux.

Trays or Packing Material: Inside the column, there are either trays (also known as plates) or packing materials. Trays allow for the interaction between vapour and liquid, facilitating the separation process, while packing materials increase the surface area for vapour-liquid contact.

Feed and Withdrawal Points: The feed point is where the mixture to be separated is introduced. Withdrawal points are located at various heights for removing the separated components, known as fractions.

Reflux Drum: This component collects the condensed vapour from the top of the column. Part of this liquid (reflux) is returned to the column to achieve better separation.

Control Systems: These include temperature and pressure monitors and controllers that manage the conditions within the column to optimise the distillation process.

Supports and Insulation: Structural supports ensure the stability of the column, and insulation helps maintain the necessary temperature gradients.

**How can you troubleshoot distillation columns?**

1. Identify the symptoms

Troubleshooting distillation columns begins with identifying the symptoms that indicate a problem. These can be determined from the column's operating conditions, such as pressure, temperature, flow rates, and compositions, or from the physical appearance of the column, like vapor plumes, noise, or vibration. Common symptoms include a high or low pressure drop across the column or a section of the column, an unstable or oscillating operation, excessive heat or cooling duty, and abnormal tray or packing behavior like flooding, foaming, weeping, or dry spots. Additionally, you may observe a high or low reflux ratio or boil-up ratio and high or low product purity or recovery. Off-specification products or intermediate streams are also indicators of a problem.

2. Collect and analyze data

The next step in troubleshooting distillation columns is to collect and analyze data that can help you diagnose the problem. You need to gather historical and current data from the column's instruments, such as pressure gauges, temperature sensors, flow meters, and analyzers, as well as from the column's design and simulation models, if available. Additionally, you should inspect the column's internals for any signs of damage, corrosion, fouling, or misalignment. To analyze the data, you can use various tools and techniques such as plotting operating curves like McCabe-Thiele diagrams or HETP charts, performing mass and energy balances around the column and its sections, calculating the column's efficiency, capacity, and loading factors, comparing actual and expected performance of the column and its components, and identifying any deviations or trends from normal or design conditions.

3. Find the root causes

The third step in troubleshooting distillation columns is to find the root causes of the problem. To do this, you need to use logic and evidence to narrow down the possible causes and eliminate the unlikely ones. To help you find the root cause, you can use the 5 Whys technique, which involves asking why a problem occurred and then asking why again until you reach the root cause. Additionally, you can use a fishbone diagram, which helps you organize potential causes into categories. Alternatively, you can apply a fault tree analysis, which traces the problem back to its origins by using a tree-like structure of events and conditions.

4. Implement corrective actions

The final step in troubleshooting distillation columns is to implement corrective actions that can solve the problem and prevent it from recurring. You need to evaluate the feasibility, effectiveness, and cost of the possible solutions before deciding on the best one. Additionally, you must test and monitor the results of the solution and document the lessons learned. Common corrective actions include adjusting the operating parameters, such as pressure, temperature, flow rates, and compositions; replacing or repairing damaged or faulty equipment; cleaning or removing fouling or plugging materials; and modifying or upgrading the column's design or configuration. For example, you could add or remove trays, change the packing type or size, or install internals.

**What are the Common Column Issues?**

Distillation columns are known for their propensity to consume large amounts of energy, among other challenges.

The main bottlenecks that hinder the separation process are:

1. Fouling: Multiple factors, either independently or together can cause fouling tendencies in columns. Vaporization of volatile chemicals, droplet formation from condensation, and corrosion-inducing chemical reactions are just some of the phenomena that occur inside a column, making the packing and other internal components susceptible to fouling.

2. Mechanical Issues: Equipment vibrations can cause column components to shift over time or even cause mechanisms within the columns to come apart, resulting in damage to the internal structures.

3. Internal Pressure Reduction: Reduced separation efficiency can result from low vapor flow which leads to a drop in pressure inside the column. If the pressure exerted by the vapor is insufficient, it won’t hold up the liquid on the tray, resulting in the leakage of liquid through the column internal’s perforations. This is known as “weeping” and can be detrimental to the purity of your distillation, sometimes requiring the batch to be reprocessed.

4. Foaming: Foaming can occur in situations when the liquid expands and changes into vapor or gas at too high of a velocity and evaporation rate. Design, condition and placement of the trays in the column can also attribute to the foaming problem. In fact, if trays are too close together, entrainment can occur (i.e. foaming fluid in a lower tray mixes with the liquid on the above tray).

All of the above issues can have a direct effect on the handling capacity of your distillation column.

Start-up/Commissioning

Some of the biggest hazards in the life of a distillation column present themselves during the initial commissioning phases, or recommissioning after a turnaround.

Improper purging of air from the tower

During installation, or after a turnaround, a distillation tower will initially be full of air. The air needs to be removed before introducing hydrocarbons or other flammables. A common way of doing this with readily available utilities is to: (a) push out the air by opening steam to the tower base and venting from the top, then (b) replace the steam with fuel gas or similar. Step (a) is usually considered to be complete when steam can be seen venting from the top of the tower (this takes some hours, since much of the steam initially condenses as a result of heating the tower wall and internals). The primary concern during air-freeing is to make sure that the tower is not isolated with steam inside because of the potential for the steam to condense and create a vacuum in the tower, which it may not be designed to handle.

On a start-up project observed by one of the authors, steam was venting from the tower top for a few hours. It was then observed during a walkthrough that the steam venting had stopped. The initial reaction was “great, we’re making progress. Let’s just make sure that gas is flowing into the tower by confirming there is no vacuum in the column”. One of the team opened a drain valve, put their hand by it, and almost had their hand sucked into the tower. At this point we were on our own in the middle of a large unit owned by a client company (we were licensor of the process technology, not the operating company), and were the nearest responders to a situation in which the tower could imminently collapse, resulting in millions of dollars damage and several months of delayed operation. The two options that we considered were: (a) run to the control room, and maybe five to ten minutes later get an operator to come out and fix things, during which time the tower might collapse, or (b) leave the drain valve open, introducing air into a system that might also contain fuel gas, potentially resulting in a fire or explosion. We opted for (b) followed by (a), and things worked out all right.

Safety issues identified

Air-freeing might take longer with a divided wall if there is reason for flows of the purge steam to preferentially move up one side of the wall versus the other (or conversely, it may be possible to think that purging is complete by viewing steam at the tower vent, when in fact there is still some air on the side of the divided wall where the steam flow is restricted)

A conventional steam-out procedure should consider the location(s) of the purge steam feed to the tower and the tower layout, to be confident that the purge is reaching both sides of a divided wall

Inadequate cleaning of debris from the tower

Incidents have occurred as a result of heavy scale or loose bolts, gloves, weld slag etc from initial installation activities that are inadvertently left behind when the tower is closed.

In the same distillation column mentioned in the previous story (which was used to separate a range of hydrocarbons from liquefied petroleum gas (LPG) to heavy gas oil), the tower was eventually air-freed, the unit was started up, and the feed mixture sent to the tower for separation. The tower and trays were constructed of carbon steel and there was some scale present in the system.

Once bulk hot liquid started flowing through the tower, all the debris, (including scale and “leftover components” such as nuts, bolts etc) was washed to the bottom of the tower and the bottoms pumps. The pumps were protected with suction strainers, but because of the huge amount of debris, the strainers then became plugged only seconds into operation. In order to clean the strainers, the pumps had to be shut down, the strainer isolated, the line opened, the strainer removed and cleaned with a steam hose, then reinstalled, line reopened, and pump restarted. This process was difficult enough for the operators to keep up with given the rapidity of strainer pluggage. But in addition, the process fluid at the bottom of the tower was above its autoignition temperature, and there was not enough interval between the strainers plugging on adjacent pumps to allow the system to cool down before removing the strainer for cleaning. Therefore, the operators were forced to open up the strainer pipe segment and deal with a fire that started when the strainer contents contacted the air. They managed this perilous activity by having people present with a steam lance to snuff the flames and cool the equipment, while someone else cleared the debris from the strainer. This activity took hours, but was completed without anyone being hurt. It would have been preferable to avoid the problem in the first place by having someone simply hose down the debris from the tower before the tower was closed.

Safety issues identified

With dividing wall towers, there may be more opportunities for loose debris to accumulate in undetected locations

Special packing shapes or high-efficiency valve trays may be more sensitive to residual debris accumulation from fabrication, although those applications are also presumed to be more likely to use stainless steel or other materials of construction that would reduce scale formation

Materials of construction

New equipment is typically designed to withstand the combination of thermal and chemical pressure, and other stresses that are anticipated for its operation. It is not uncommon for materials to be provided that do not meet the specification. There are simple field tests that can validate the materials of construction including portable X-ray diffraction devices for positive material identification.

Generally, incorrect materials that sneak through any screening/testing manifest themselves as problems during the normal operation. This may result in corrosion/disappearance of the component, and the ineffective separation that results. Usually there are no direct safety issues unless the outer wall of the tower, or connections to the tower, are made of incorrect materials.

We do know of a case where this issue arose because of the use of a dividing wall. The system was processing a mixed naphtha stream that contained residual fluorides from an upstream reaction. Unexpectedly, condensation occurred on a dividing wall. This does not normally occur in a traditional distillation where there is no wall since the tower shell is continually swept with liquid. The result was that the dividing wall corroded faster than the shell. The dividing wall was not the pressure boundary, so there was no safety implication from the corrosion itself. However, the design team should consider the potential consequences of such a breakdown of a dividing wall.

Safety issues identified

More complex systems have a greater opportunity for incorrect materials to be used

Unexpected material compatibility issues, such as the condensation concern described above

Liquid filling the tower

During a start-up operation in particular, it is possible to literally “flood” (liquid fill) a tower, as opposed to the more textbook version of flooding (having too much liquid/vapour traffic), which we discuss later. Perhaps the most well-known example of this occurred in 2005 at BP’s Texas City Refinery which resulted in 15 fatalities. During the start-up of the tower, an initial inventory of hydrocarbons was intentionally created in the tower bottom to allow for liquid/liquid traffic to be established when warming the tower later. However, the board operator failed to open the column bottoms line to tankage and was misguided by a level reading. The level instrument was a displacer-type device and was designed, in association with its transmitter, to measure the liquid level in a 1.5 m span such that 100% of its calibration corresponded to some 3.1 m in a tower that was 50 m tall. The apparent reduction in level was a result of the fluid at the base of the tower being at a higher temperature and therefore lower density within the displacer level device, which did not have temperature compensation. As the bottoms temperature in the column increased, the density fell, which was reflected by the apparent reduction in indicated level from 100% to 80%. The displacer level device no longer measured the level in the column but was responding instead to changes in the density of the fluid. Having a reading of less than 100% on the bottoms instrument suggested that more liquid could be added safely to the point where eventually the tower was completely liquid full. Once more heat was put into the tower, this liquid expanded and built pressure which was relieved through relief valves and sent to an atmospheric blowdown stack. There were problems with other, independent high-level alarms: one was not working and the other was ignored, as it was normal practice for this to be in alarm during start-up. The blowdown stack was designed to handle relief valve discharges of vapour. In this case, the bulk hot liquid discharge was vented from the top of the stack, fell to the ground, and found an ignition source.

In addition to the Texas City accident, several other incidents have been caused where level instruments confuse operators as they are responding to fluids with a density outside design parameters, either due to temperature or composition variations.

Safety issues identified

More level gauges could become faulty or be misinterpreted – particularly with dividing wall columns

More complex systems have greater potential for operators to misdiagnose what is going on in the column

Operators may have less practice in bringing upset systems back to stability – particularly where they have a higher level of automation, such as with multivariable predictive control systems

Normal operation

Fouling

Distillation columns perform best when the feedstock is clean and free from particulates. However, this is not always the case and sometimes there is a scale buildup in the column. There have been cases where limited scale buildup has not been a problem with conventional tower internals (eg standard saddle packing). However, when this has been replaced with a higher efficiency packing, the scale buildup over time does become an issue and can affect distillation performance.

Safety issues identified

While reduced efficiency in isolation would not be an issue, a continued buildup could lead to higher pressure drop and potentially unstable column operation. Column pressure relief systems are typically located at the top, so increased bottoms pressure may bring conditions closer to design limits than for conventional packing. Good operating practices should prevent issues with overpressurisation

There are increased risks associated with isolating, decontamination, and opening-up process equipment for maintenance, so if the column requires more regular shutdown and decontamination for cleaning of packing, this may increase the overall operational risk

Flooding

Flooding occurs when the upward flow of vapours and/or downward flow of liquid increases to a point at which liquid can no longer flow down the column. Such an event occurred at a plant not long after initial commissioning. In any start-up on new plants, it takes time for the board operators to get a “feel” for how equipment operates and responds to changes in setpoints. This can be more prevalent at facilities with less experienced operators.

Even so, experienced operators can create a flooded tower. A distillation arrangement including overhead condenser, receiver, reflux, and bottoms reboiler loop is shown in the figure opposite.

The typical sequence of events that leads to flooding of a distillation column is as follows:

1. Overhead and/or bottoms product compositions are off-spec for whatever reason.

2. Initial operator instinct is “Hmm; it looks like we may need more reflux to generate more liquid traffic”. So, the operator adds more reflux.

3. This quenches the tower, and doesn’t help the bottoms product quality, so the next instinct is to add more heat to the reboiler.

4. This doesn’t help either, so Steps 2 and 3 are repeated until the tower confronts other issues such as high pressure and unstable operation.

In one particular commissioning case, no progress was being made to resolve issues, so it was decided to give up trying to fix the situation and instead opt to just crash the column (stop heat) and rebuild from scratch. Fortunately, that was a workable option without causing operational issues because commissioning was underway and the tower was not yet fully integrated with the rest of the plant.

A flooding situation generally is not a safety concern, except if it progresses to the point of overpressurising the system, at which point the tower should be protected by pressure relief valves.

Safety issues identified

Divided wall column:

There may be more of a tendency to inadvertently create a flooded condition on one side of the wall in order to optimise performance on the other side of the wall

The added complexity may require a greater degree of knowledge and understanding by the operators on how to bring the column(s) back to more stable operation

Concentration buildup

Some distillation operations, particularly in which non-ideal solutions are involved that lead to low or high-boiling azeotropic mixtures, can result in concentration of a particular component on a certain tray or level within the column. This could lead to problems with materials of construction or, in the case of certain compounds, chemical stability issues.

Safety issues identified

Hybrid distillation schemes, for example extractive distillation, may lead to a buildup of concentration of certain components in a particular area

Dividing wall columns may have similar issues with unexpected buildup in certain locations

Poor/erroneous controls

Controls for distillation systems can be relatively simple, but despite that there have been several incidents associated with overfilling columns due to faulty controls and/or maloperation (eg BP Texas City, 2005, and Milford Haven Refinery, 19941). Faults with level instruments are sometimes difficult to diagnose and increasingly complex systems can make it even harder.

Safety issues identified

Hybrid and dividing wall columns add to the complexity and may make it more difficult for operators to understand what is going on inside the column(s)

The more advanced control systems are intended to aid the operator in areas such as safety, efficiency, and control of upset conditions. However, when experiencing abnormal operations, there are potential issues that the control system has not been designed to manage. In addition, operators may lose some of their troubleshooting skills as these are not practiced as often due to the control system doing such a great job most of the time

Feedstock change/contamination

There are cases where a chemical that is completely foreign to the main process flow enters the tower. One potential scenario is a leak or failure of a tube in a shell-and-tube heat exchanger in the feed preheating or tower reboiling system, leading to a heat medium such as steam entering the system. This is commonly disruptive to the normal operation of the tower; in some cases, the contaminant flashes upon entering the tower, resulting in trays or other internals being displaced and causing an extended shutdown.

Safety issues identified

Where the technology involves a higher pressure drop, or perhaps even with a similar pressure drop, the consequences could be more severe than in a standard sieve-tray or packing-type tower. The process hazards review should recognise the potential for obvious contamination events and ensure that the equipment can sustain such events without catastrophic failure

Breaking of sight glass/other loss of containment

Loss of containment is a hazard present on all processes. In distillation columns, this might involve breakage of a sight glass (eg being accidentally hit with a wrench) or other equipment located near the bottom of the tower. For example, a field operator could inadvertently cause damage by using the equipment as a convenient platform for climbing to reach an instrument, valve, or other poorly placed device.

Many instruments will be connected by small-bore piping (although these should be avoided), potential weak points susceptible to damage by abuse or other failure modes. There are many other possible loss-of-containment scenarios, including improper closure/gasketing of flanges, long-term corrosion etc.

Safety issues identified

A greater number of measurement devices connected to the column(s) provides an increased potential for failure

Failure of column intervals

Several industry accidents have occurred in which packing support grids have failed or trays have become detached from their supports. One situation occurred where a packed column was not operating efficiently and various investigations were undertaken. The column was then opened up for inspection during a turnaround. Once the column was completely empty, the cause was obvious: all of the packing was sitting in the sump following a failure of the support grid.

In some cases, failure can also be caused by one or multiple severe flooding incidents, where the packing (and support grid) has been lifted. Other failure cases have occurred due to corrosion of the support grids or associated attachments.

Safety issues identified

For dividing wall columns, it may be more difficult to control temperature/pressure surges between column sections

Advanced internals may be susceptible to unexpected corrosion phenomenon or more susceptible to flooding (being bounced)

Pressure relief systems are typically located on top of the column, or the reflux drum. If the column internals fail and block the column, this may compromise the relief capacity, leading to overpressure and potential rupture of the column. Note: hazard studies at the design stage should ensure the relief system is always available and cannot be isolated, especially with the more complex distillation designs

A distillation column's basic temperature distribution is warmer at the bottom and colder at the top. For a simple two-component distillation the temperature at the bottom is just lower than the boiling point of the heavier component. The temperature at the top of the column is just above the boiling point of the lighter component.

At the bottom of the column, we would like the heavy component to remain as a liquid and the lighter component to stay as a gas. So, we set the temperature at the bottom to match this requirement. This temperature is set by adding heat via a reboiler. Typically, the heat added to the bottom of the column is easy to control, via steam or hot oil flow rates.

At the top of the column, the situation is reversed. We would like the light component to remain a gas while the heavier component is condensed to a liquid and falls back down the column. The top temperature is set just above the boiling point of the lighter component. The temperature control situation is different here from the bottom of the column because we usually want the top product to be a liquid when we send it for storage. So, we condense all of the gas coming out of the top of the column to liquid. This liquid stream is split with some returning to the column and some going to storage. The top temperature is often controlled by changing the reflux rate, i.e., the flow rate of liquid sent back to the top of the column. A higher reflux rate means cooler liquid falls down the column against the rising warmer gas, and the top temperature is lower.

Overall heat is added at the bottom of the column and heat is extracted at the top of the column. Inside the column, the temperature balance is created between the hot gas rising up the column and the cooler liquid falling down the column.

Pressure Profile

There is typically a pressure gradient across the column with the pressure being higher at the bottom of the column than at the top. This pressure gradient occurs as the liquid coming down the column impedes the flow of vapor up the column and imposes a pressure loss on the flow. In steady-state distillations, the pressure in the column is held constant, and the temperature is varied to control the composition of the product streams.

Detail

Pressure

Under normal, usual conditions it is the vapor pressure of the liquid on the top tray that fixes the pressure at that location before the generated vapors exit to enter the overhead condenser. This is the basic parameter that fixes the column pressure. The pressure at other sites within the column depends on the ability of the vapors and liquids to distribute themselves up and down the column with minimum pressure drops.

Therefore, the composition – or purity – of the liquid on the top tray rather defines what pressure the column is expected – or designed – to operate at. The external reflux ratio (L/D) has a bearing on fixing that composition – as the various L/V’s (internal reflux ratios) that are generated down the column have on the various trays’ compositions.

What is L/D?

It is the external reflux ratio. It is defined as the ratio of the liquid returned to the column divided by the liquid removed as product, i.e., R = L/D.

External reflux vas internal reflux

As the external reflux cools the top of the tower, vapors made of heavier fractions condense and liquid made of heavier faction flows down the tower it's referred to as internal reflux

What is L/V internal reflux ratio?

It is the liquid/vapor flow ratio inside the upper section of the column.

After the top pressure is specified, the bottom pressure will be dictated by pressure drop along the column which depends on the relevant selected technology and the load of vapor and liquid inside the column. The corresponding bubble point of bottom pressure will specify the bottom temperature.

The purpose of reflux is to provide down-flowing liquid throughout the rectification section to contact with the up-flowing vapor in order to achieve stage-by-stage equilibrium heat and mass transfer and, hence, purification of the top product. When sub-cooled reflux is introduced to the top tray, it must be heated up to its bubble point before the lighter components will vaporize.

Where does the heat come from?

The only place it can come from is from condensing vapor that is approaching the top tray from below. When this vapor condenses, it adds to the total liquid flowing from tray 1 down the column. In other words, sub-cooled reflux introduces a greater volume (or mass or molar) flow of reflux than is delivered to the column by the external reflux flow controller.

If the degree of sub-cooling was constant, then this wouldn’t be such a big source of disturbance; however, this is usually not the case. The amount of sub-cooling will vary with the temperature of the cooling medium (ambient air, cooling water, another process stream, etc.).

Temperature: The column gets cooler as you go up

There are two control points while fixing top and bottom boundary temperatures in a distillation column. At the bottom it is reboiler and at the top it is reflux. Within the column, the temperature gets set by relative volatility or more precisely by the partial pressure of HC [feed] according to Rault’s law. The volatility of components in the column is different. If P is the total pressure in the column, this is equal to the sum of P1 + P2 + P3 + ---- partial pressures at a different height. While total pressure is constant in the column, the partial pressures of HC components are different along with the height. Partial pressure = Mole fraction x Vapor pressure of pure component at a height [Rault’s law. Since the volatility of hydrocarbon becomes more as you go up, the vapor pressure becomes more, and consequently, saturation temperature gets lower. Therefore, the column gets cooler as we go up. In a steady state, the partial pressures do not change much.

Sub-cooled reflux will eventually trigger internal reflux and can substantially improve the quality of the top cut. The downside is it may destabilize the column in exceptional cases if it adds resistance to rising vapor in a given column diameter.