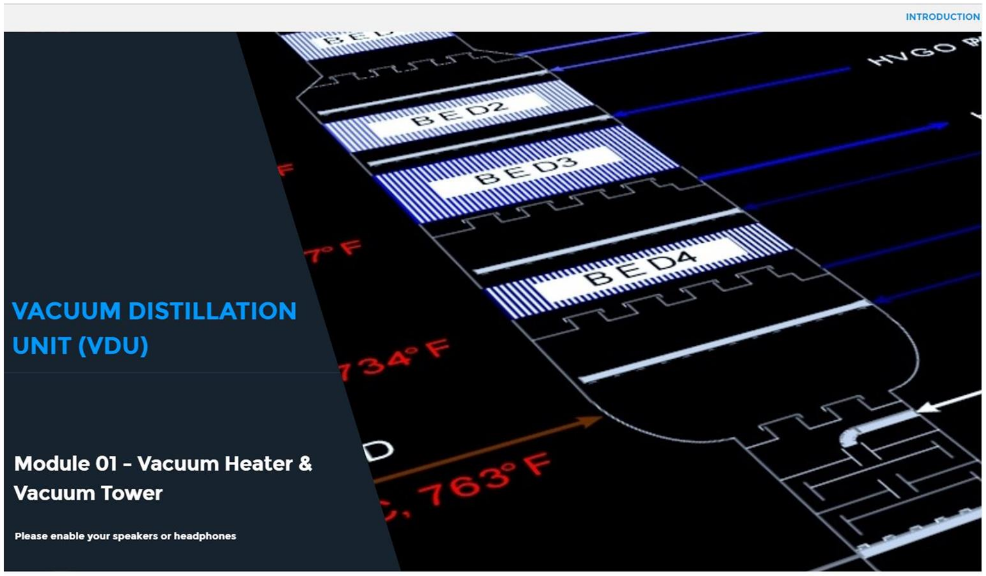
BU MEASUREMENT & ANALYTICS

Refinery Process Units

Vacuum Distillation Unit (VDU) – Module 1: Vacuum Heater & Vacuum Tower



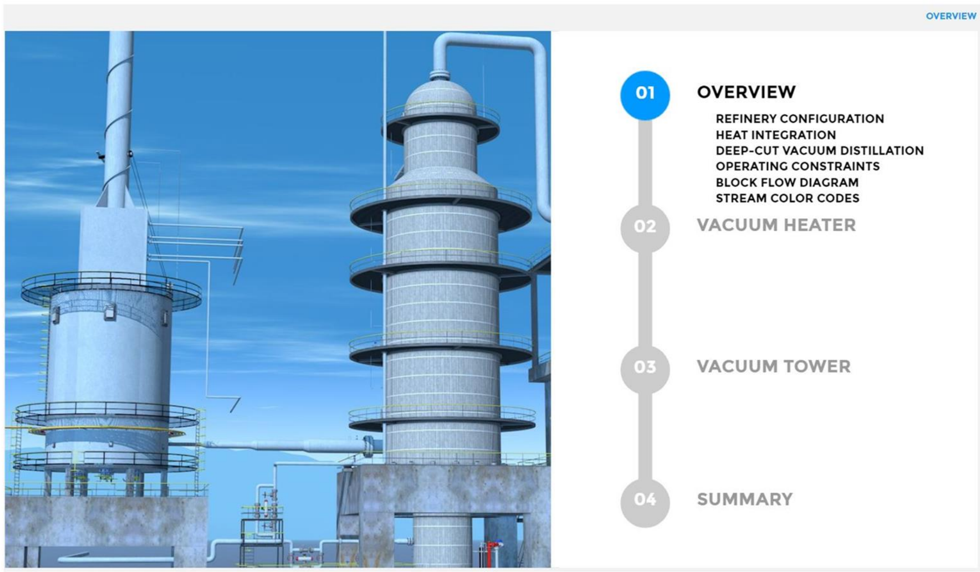
Welcome to Vacuum Distillation Unit Module 01 – Vacuum Heater & Vacuum Tower.

For the Vacuum Heater and Vacuum Tower unit operations, upon completion of this module, you should be able to:

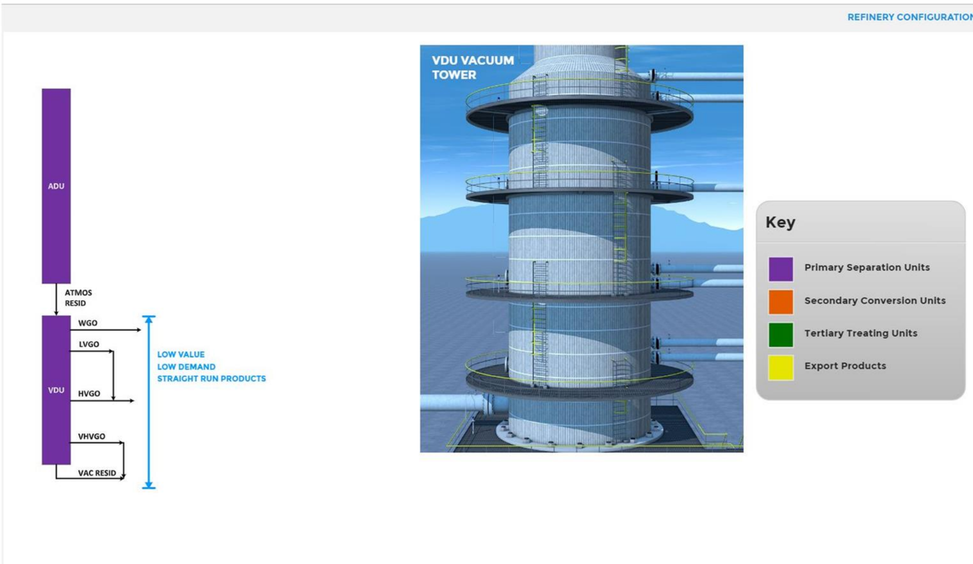
- Describe the process flow
- Name the principal items of equipment
- Describe their function
- Understand the principles of operation
- Recognize their internal components

Additionally, you should be able to demonstrate an awareness of:

- Important process variables and how they're controlled
- Major operating constraints
- Typical operating problems



These are our topics. We'll start with a brief overview.



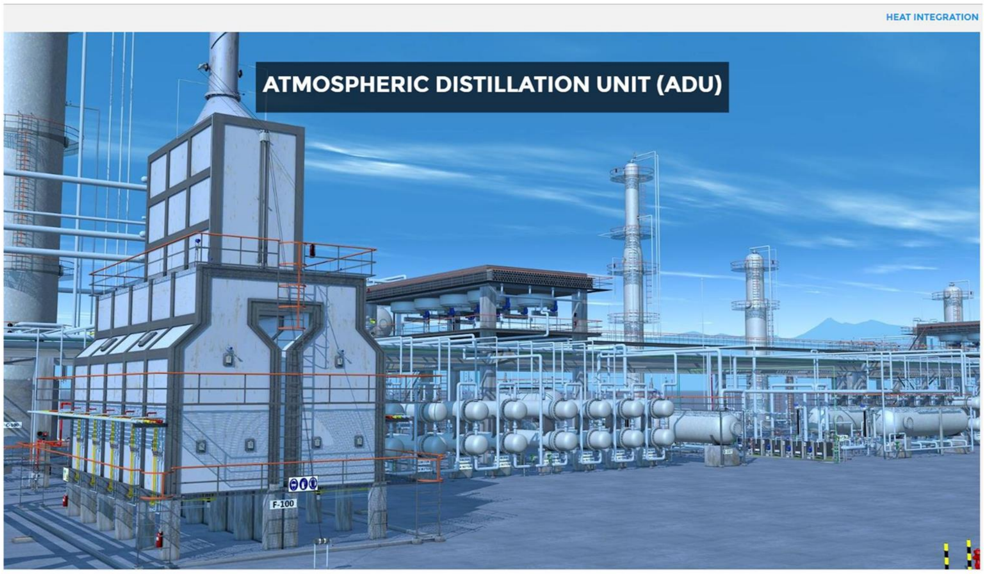
Here's our now-familiar Refinery Configuration Diagram that shows the Primary Separation Units in purple, Secondary Conversion Units in orange, Tertiary Treating Units in green and Export Products in yellow.

The Vacuum Distillation Unit (or VDU) is a primary separation unit.

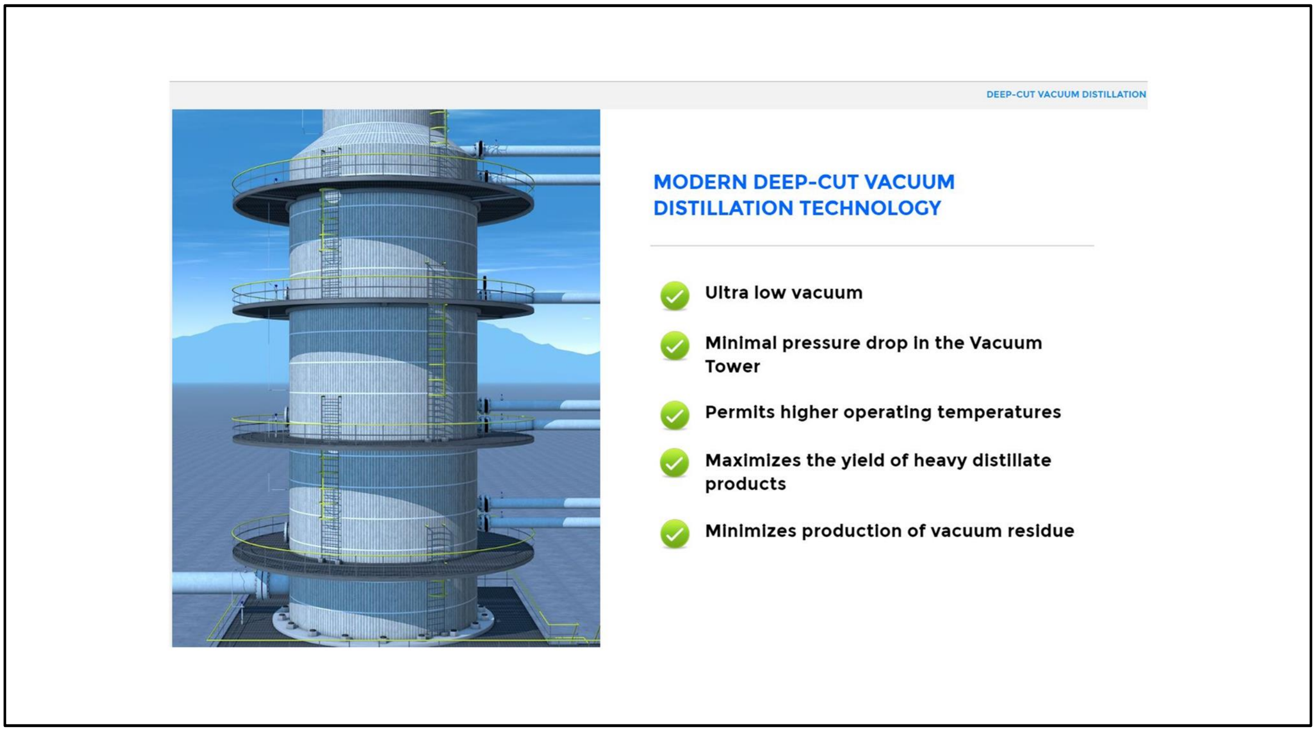
Atmos Resid from the ADU passes to the VDU, where it is fractionated into:

> Wet Gas Oil (WGO), a minor middle distillate byproduct that's passed as feed to the FCCU
>
> Light Vacuum Gas Oil (LVGO) & Heavy Vacuum Gas Oil (HVGO), heavy distillate fractions that are fed to the Gas Oil Hydrotreating Unit to produce a sweet FCCU feed
>
> Very Heavy Vacuum Gas Oil (VHVGO), a heavy distillate fraction that passes to the VBU or DCU for conversion into middle distillates
>
> Vacuum Residue (or Vac Resid for short) that passes either to the VBU for conversion into distillates and a residue of fuel oil, or to the DCU for conversion into distillates, fuel oil and coke

These heavy VDU products have low value and are in low demand, so they are cracked in downstream process units to form smaller, lighter products that can be blended with the high-value, high-demand products from the ADU.



You should recall that the ADU and VDU are heat integrated, with HVGO, VHVGO and Vac Resid being used to preheat ADU Crude Feed and Stabilizer Feed streams.



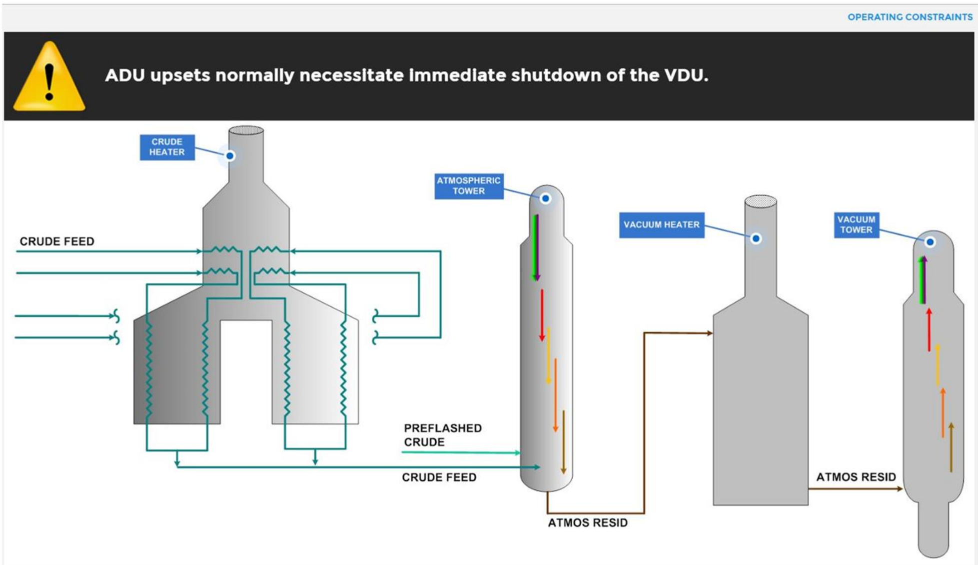
This program is based on modern deep-cut vacuum distillation technology which uses a combination of ultra low vacuum and minimal pressure drop in the Vacuum Tower to permit higher operating temperatures, which in turn maximizes the yield of heavy distillate products and minimizes production of vacuum residue (which has low demand and low value).

That's the upside.

There's a downside to this as well. Deep cut is the most severe form of VDU operation.

The combination of lower operating pressures and higher operating temperatures exposes the VDU internals to the risk of coke formation and pluggage if heavy process streams fall below a minimum velocity or become stagnated in hold-up zones.

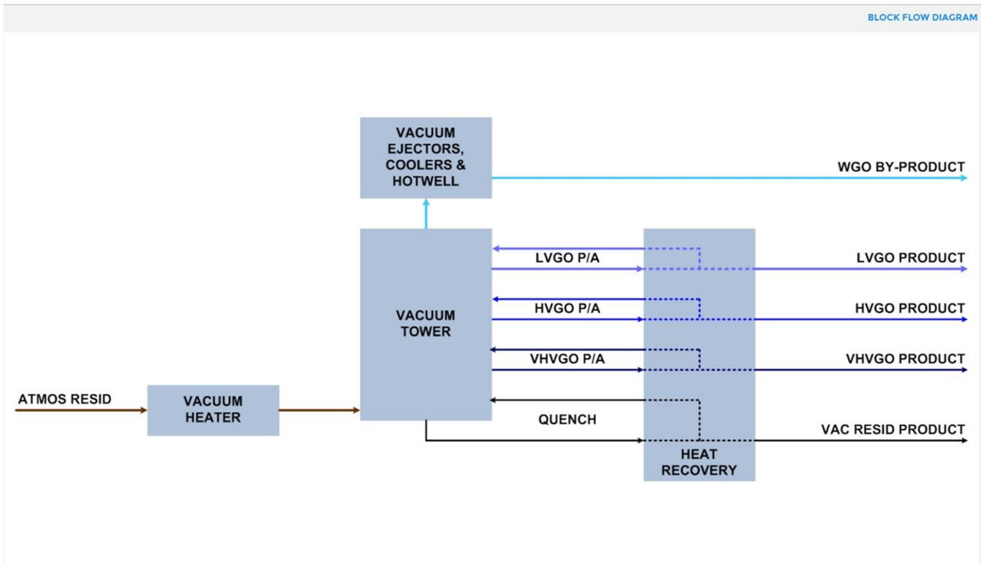
The bottom line is heavy process streams at high temperatures must be kept moving if coke formation is to be avoided. Coke formation usually requires a shutdown of the plant to remove the coke mechanically.



A further operating constraint is the atmospheric residue feed, which is supplied direct from the ADU.

If a process upset on the ADU causes the ADU Crude Heater to trip, light material will dump down the Atmospheric Tower and make its way into the atmospheric residue.

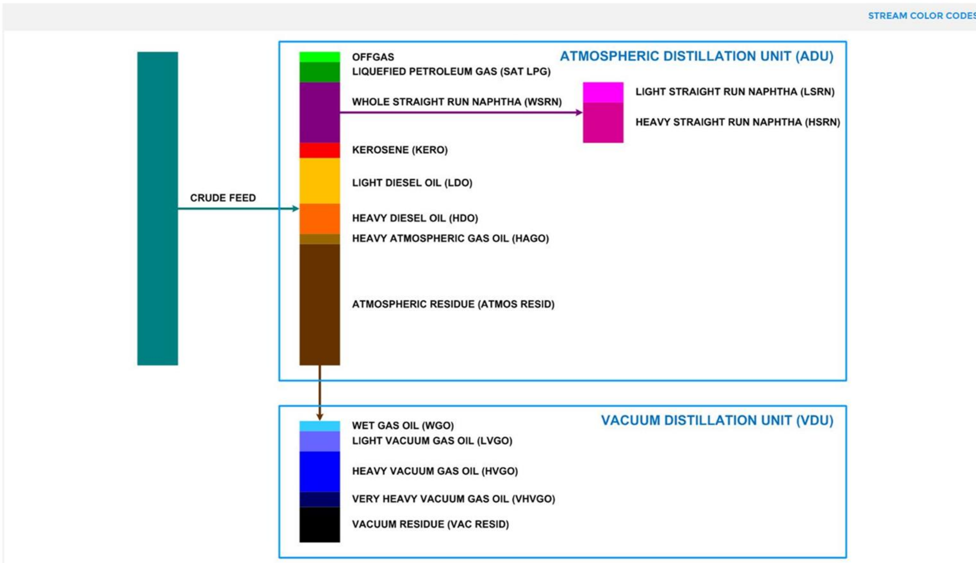
When this hits the VDU, it causes major disruption of operating pressures, so ADU upsets normally necessitate immediate shutdown of the VDU.



This Block Flow Diagram shows the four VDU unit operations.

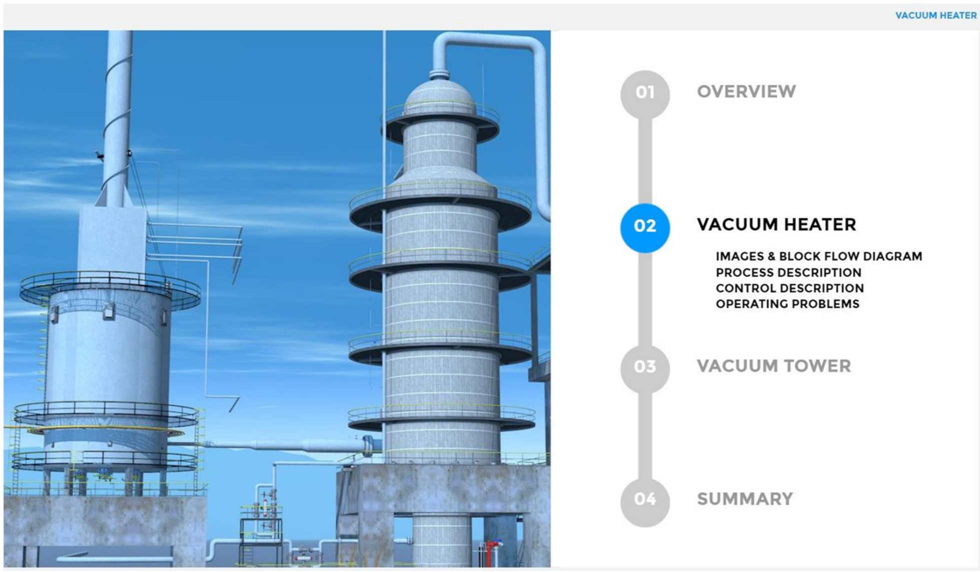
In Module 01, we will cover the first two unit operations, Vacuum Heater and Vacuum Tower.

Then, in Module 02 we'll cover the remaining two unit operations, Vacuum Ejectors, Coolers & Hotwell and Heat Recovery.

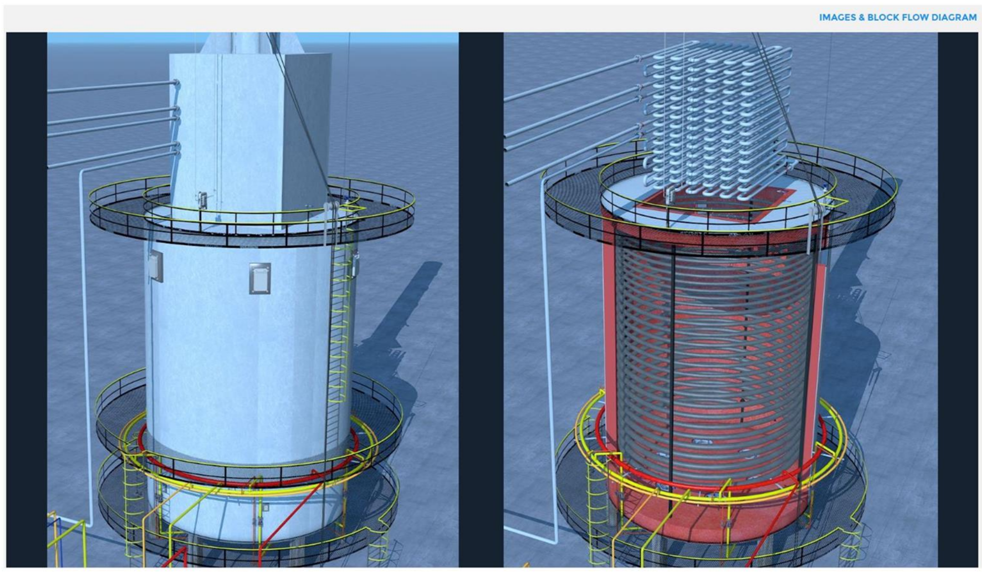


Here is a reminder of the stream color-codes that we used in the ADU Programs, as we'll be using these again in this program.

Please take a moment to familiarize yourself with the color-codes and then click next when you are ready to move on.

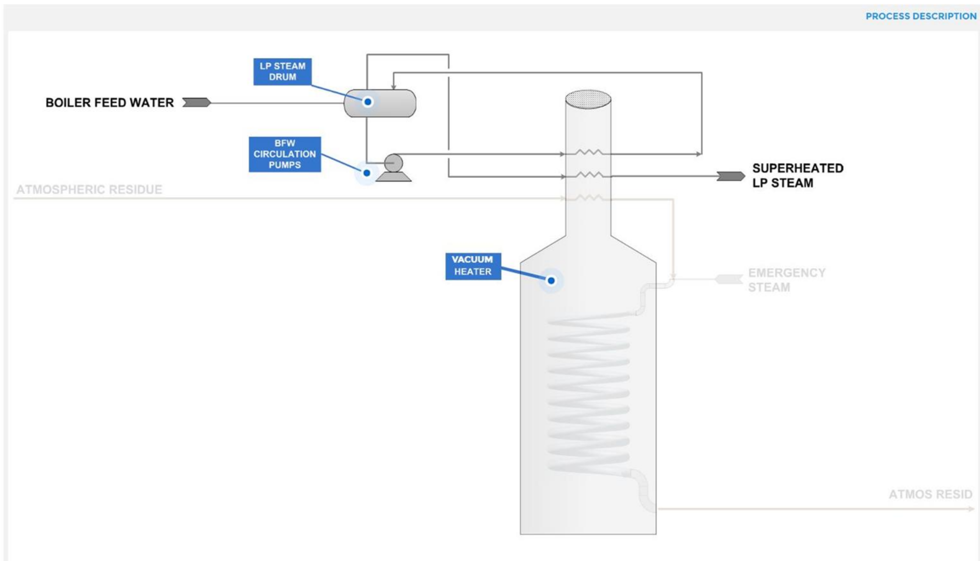


We'll continue with the vacuum heater.



These images show external and internal views of the vacuum heater with its horizontal feed preheat and steam production convection section tubes and helical radiant coil.

The vacuum heater raises the temperature of the atmospheric residue to ensure optimal operation of the downstream vacuum tower.



Process Description:

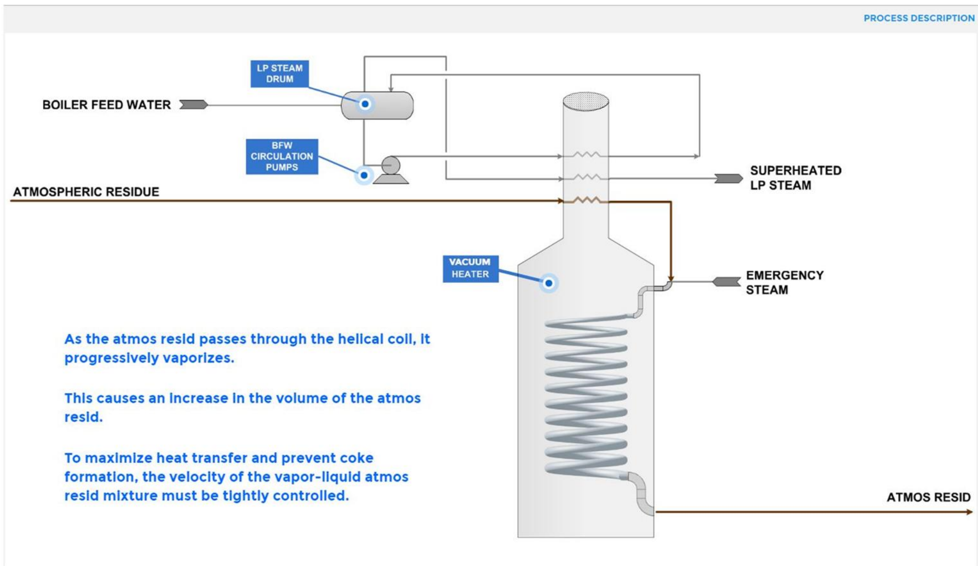
Liquid atmospheric residue feed from the ADU enters the Vacuum Heater, where it is preheated in horizontal tubes in the convection section and then vaporized in helical coils in the radiant section before exiting and passing to the downstream Vacuum Tower.

To recover heat from the radiant firebox hot flue gases, boiler feed water is circulated through a steam generation coil in the upper convection section of the heater and returned to a Low Pressure Steam Drum.

Boiler feed water and saturated low pressure steam disengage in the LP Steam Drum.

The steam makes another pass through the upper convection section where it is superheated before being used as stripping steam in the downstream Vacuum Tower.

The LP Steam Drum has a make-up of boiler feed water from the ADU Deaerator.



As the atmos resid passes through the helical coil, it progressively vaporizes.

This causes an increase in the volume of the atmos resid.

To maximize heat transfer and at the same time prevent coke formation, the velocity of the vapor-liquid atmos resid mixture must be tightly controlled.

This is achieved by progressively increasing the helical coil diameter from inlet to outlet.

The atmos resid exits the radiant helical coil mostly as a vapor, passing through a diffuser and entering an even larger diameter section of a transfer line that connects the heater with the downstream Vacuum Tower.

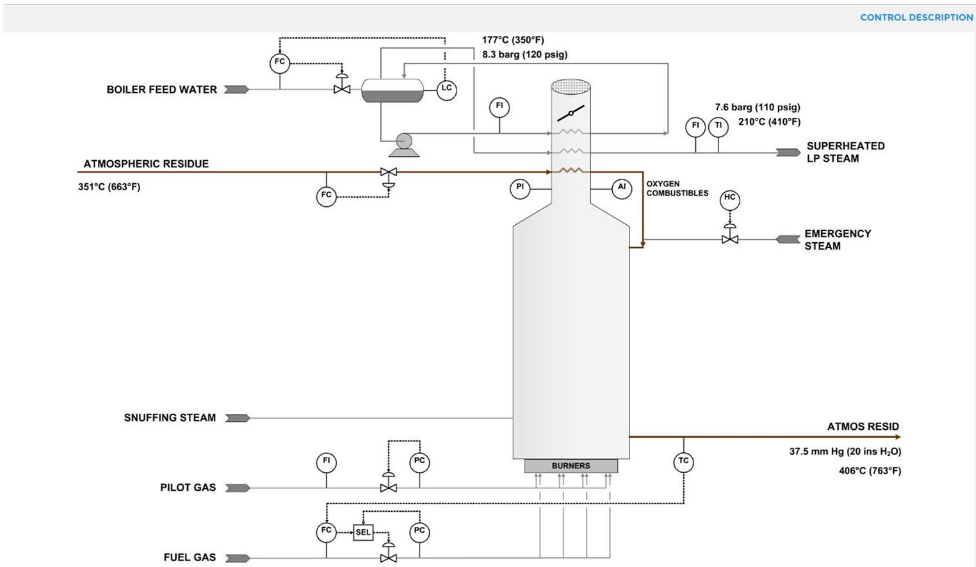
The transfer line continues to expand in diameter as it approaches the Vacuum Tower.

The continually enlarging radiant helical coil and transfer line diameters also serve to minimize heater pressure drop and thereby minimize the pressure in the downstream Vacuum Tower flash zone.

To minimize the length of the transfer line and hence minimize pressure drop, the Vacuum Heater and Vacuum Tower are located side-by-side.

The diagram we've shown you here is a simplified one and we've only shown a limited number of size transitions.

In practice, you can expect to see even larger helical coil and transfer line diameters and more than one set of coils and diffusers.



Control Description:

The atmos resid feed to the Vacuum Heater is flow controlled. If emergency steam is required, it's adjusted by the operator, using a hand controller.

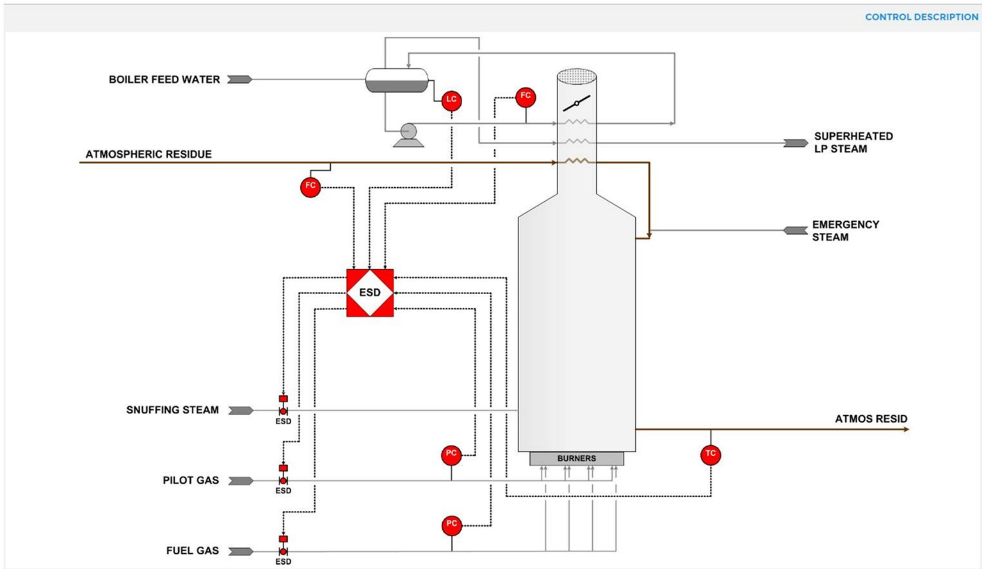
A temperature controller, located in the transfer line, raises the temperature of the atmos resid from 351ºC (663ºF) to 406ºC (763ºF) by resetting a flow controller in the burner fuel gas supply.

A constraint controller ensures the fuel gas pressure at the burners remains within safe firing limits.

The pilot gas supply to the burners is pressure controlled.

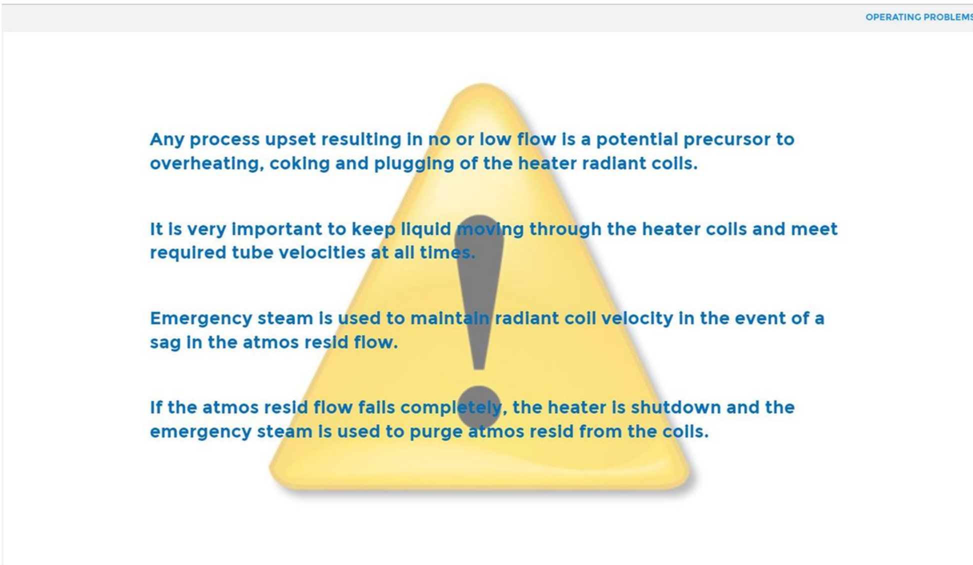
The LP Steam Drum level is controlled by resetting a make up boiler feed water flow controller in a cascade control arrangement.

The firebox draft is maintained by adjustment of the stack damper and the flue gas oxygen and combustibles targets are maintained by adjustment of the burner air registers.



The Vacuum Heater is protected against unstable burner firing pressures and low or no flows in the convection and radiant section tubes by a high integrity emergency shutdown (ESD) system that isolates pilot gas and fuel gas to the burners and admits snuffing steam to the firebox.

The ESD system is initiated automatically by any of the trip initiators shown here and can also be activated manually by the operator.



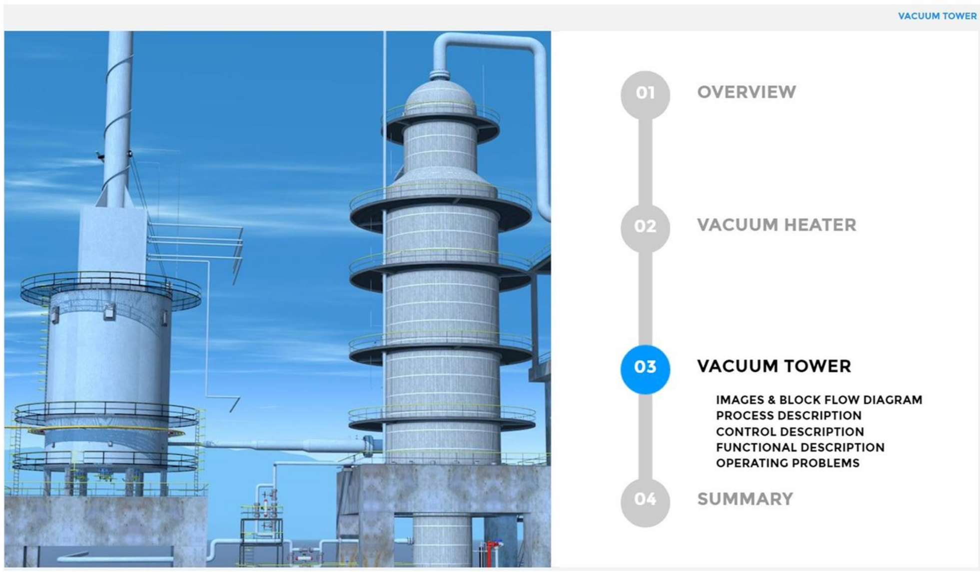
Operating Problems:

The combination of heavy atmos resid feed and high operating temperatures mean that any process upset resulting in no or low flow is a potential precursor to overheating, coking and plugging of the heater radiant coils.

It's very important to keep liquid moving through the heater coils and meet required tube velocities at all times.

Emergency steam is used to maintain radiant coil velocity in the event of a sag in the atmos resid flow.

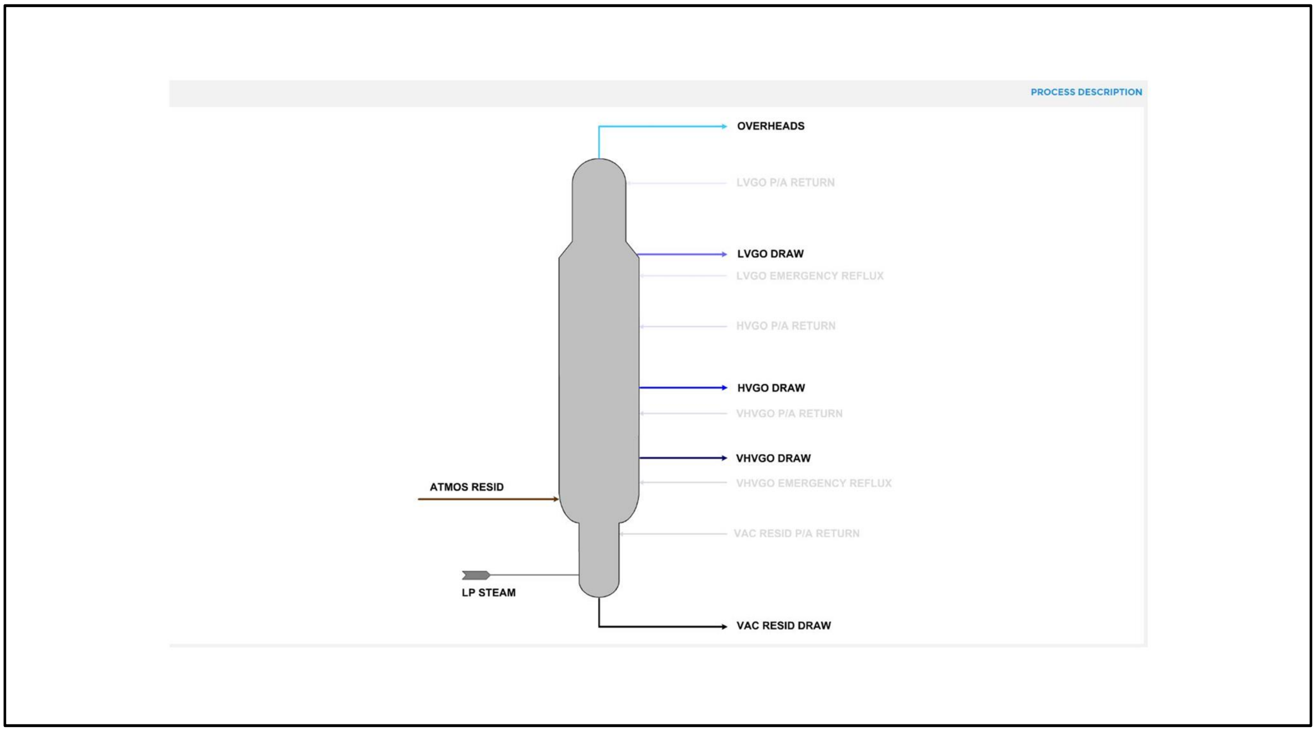
If the atmos resid flow fails completely, the heater is shutdown and the emergency steam is used to purge atmos resid from the coils.



Moving on, we'll take a look at the vacuum tower.

Once again, the associated equipment is pictured here.

The Vacuum Tower is the heart of the VDU, and is where the atmos resid is fractionated into distillate products and a residue.



Process Description:

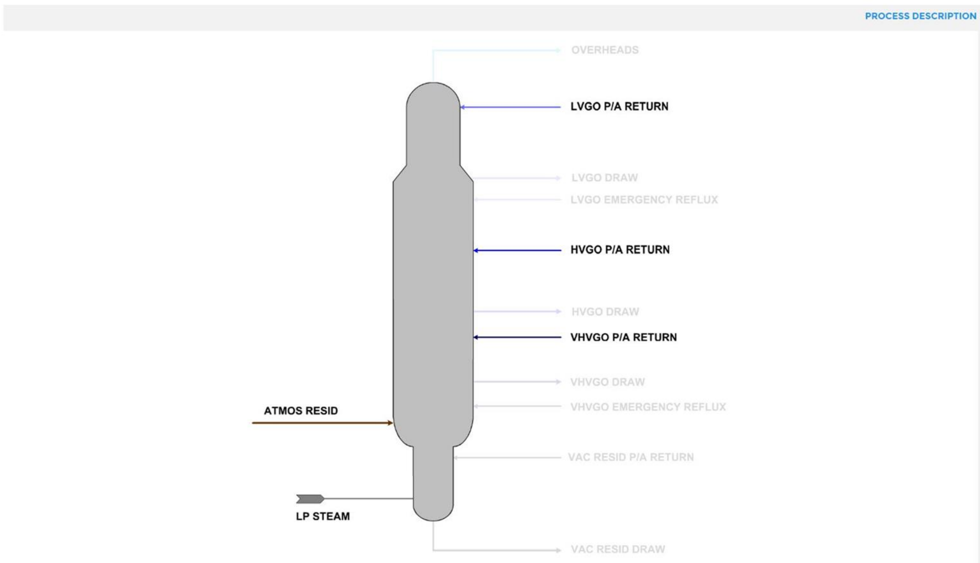
Assisted by superheated stripping steam, the Vacuum Tower distills atmos resid into the following products:

A middle distillate overheads stream

Light vacuum gas oil (LVGO), heavy vacuum gas oil (HVGO) and very heavy vacuum gas oil (VHVGO) streams

Vacuum residue stream

On some VDUs, you may also hear VHVGO referred to as ‘slop wax’.

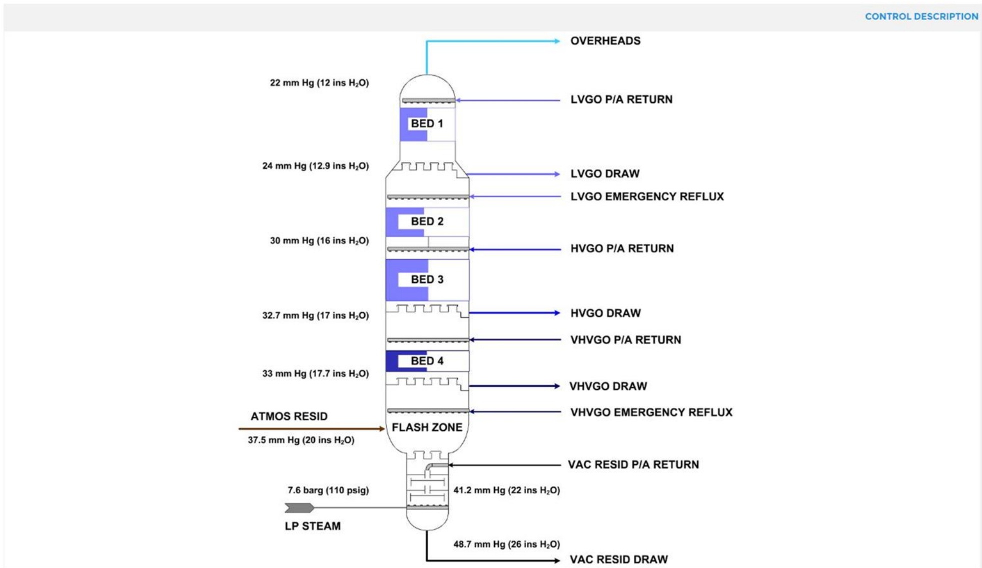


With the exception of the overheads, a portion of each product is recycled back to the Vacuum Tower:

The LVGO, HVGO and VHVGO pumparounds provide a continuous supply of reflux

The LVGO and VHVGO emergency reflux streams prevent internal components drying out and coking up during a process upset

The vac resid acts as a quench for the bottom of the tower, which operates at very high temperature



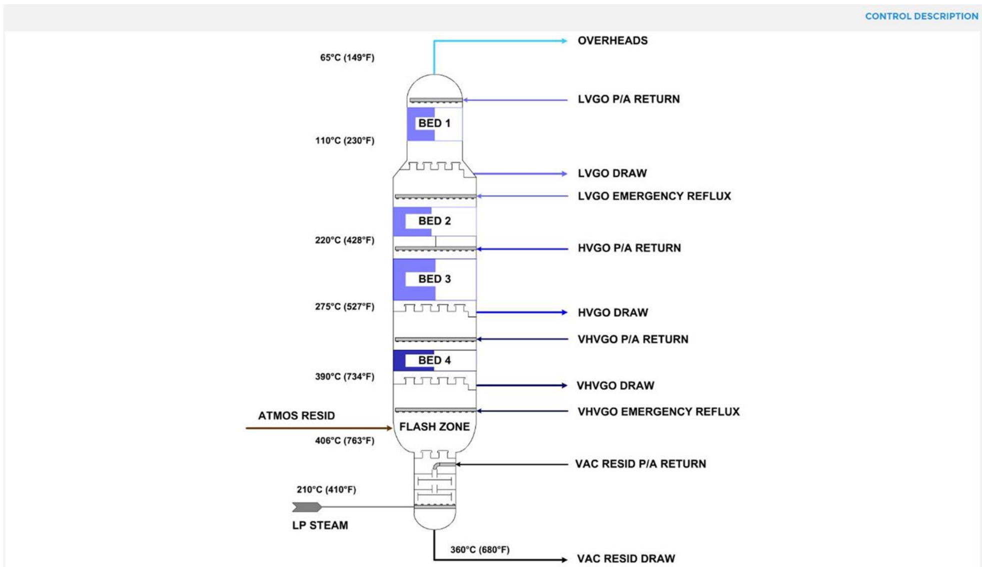
Control Description:

The pressures shown here are expressed as vacuums. The source of the vacuum is the downstream Ejector Package which we'll be looking at in the following module.

The vacuum is controlled by adjustment of the Ejector steam and cooling water flow rates.

The pressure control objective is to maintain the vacuum at the flash zone as close as possible to 37.5 mm Hg (20 ins H_2O), which is determined by the vacuum at the top of the tower and the pressure drop over the tower internals.

The flash zone is the hottest region of the tower and any deterioration in vacuum pushes operation in the direction of higher temperatures and greater risk of coke formation.



The flash zone temperature is controlled at or below 406ºC (763ºF) by regulating the heater firing rate - this sets the vapor upflow in the tower.

The VHVGO, HVGO and LVGO pumparounds remove heat - this sets the liquid downflow in the tower.

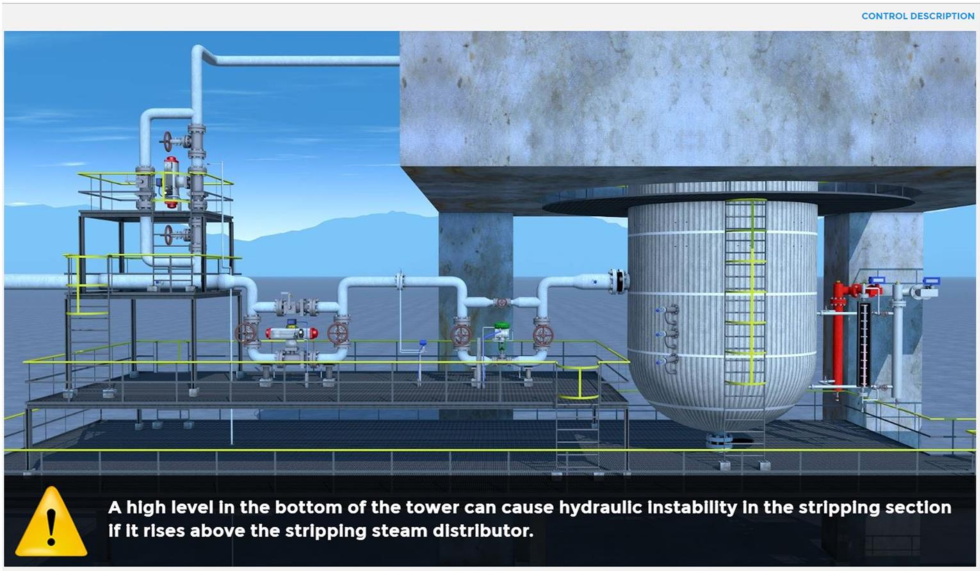
The stripping steam is superheated to 210ºC (410ºF) so that it doesn't have a quenching effect on the flash zone temperature.

The tower top temperature is maintained at 65ºC (149ºF) to keep it above the dew point temperature of the overheads stream, avoiding corrosion.

The tower intermediate temperatures are controlled by adjustment of pumparound flow rates and return temperatures.

The tower bottom temperature is controlled at 360ºC (680ºF) by adjusting the flow rate and return temperature of the vac resid quench stream.

We'll be looking at pumparound and quench control systems in the last section of the following module.



A high level in the bottom of the tower can cause hydraulic instability in the stripping section if it rises above the stripping steam distributor.

The consequences are severe damage to the sieve trays, resulting in an inability to perform their stripping function and meet the bottoms specification.

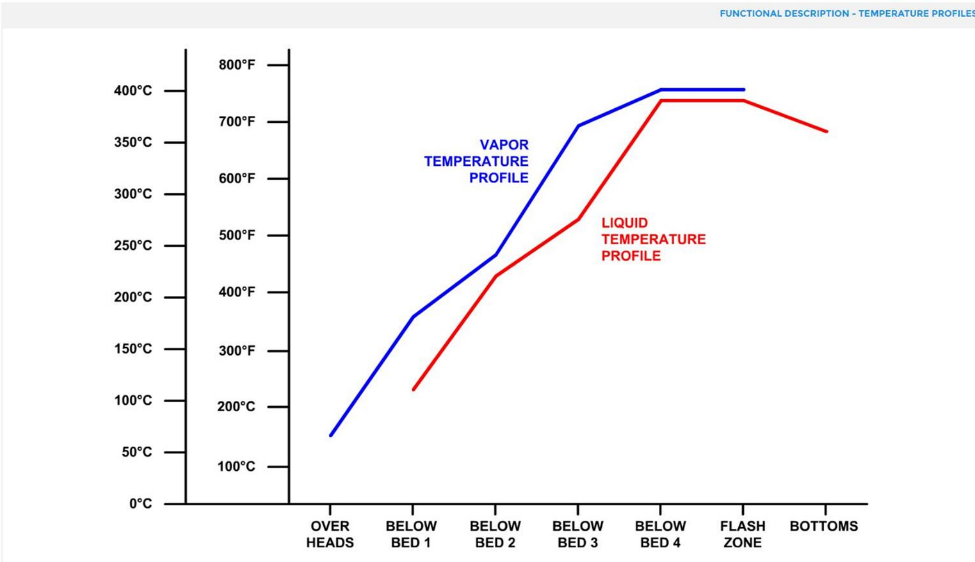
A shutdown would be required to repair or replace the damaged trays.

Process upsets have shown that the level can rise quickly, leaving insufficient time for the operator to manually open the atmospheric vent and isolate the stripping steam to the tower.

These risks and their associated consequences can be minimized by the presence of an ESD System that diverts the stripping steam to atmosphere.

A trip is automatically initiated by a high level in the bottom of the Vacuum Tower.

A trip can also be manually initiated by the control operator as a precaution during plant upsets.

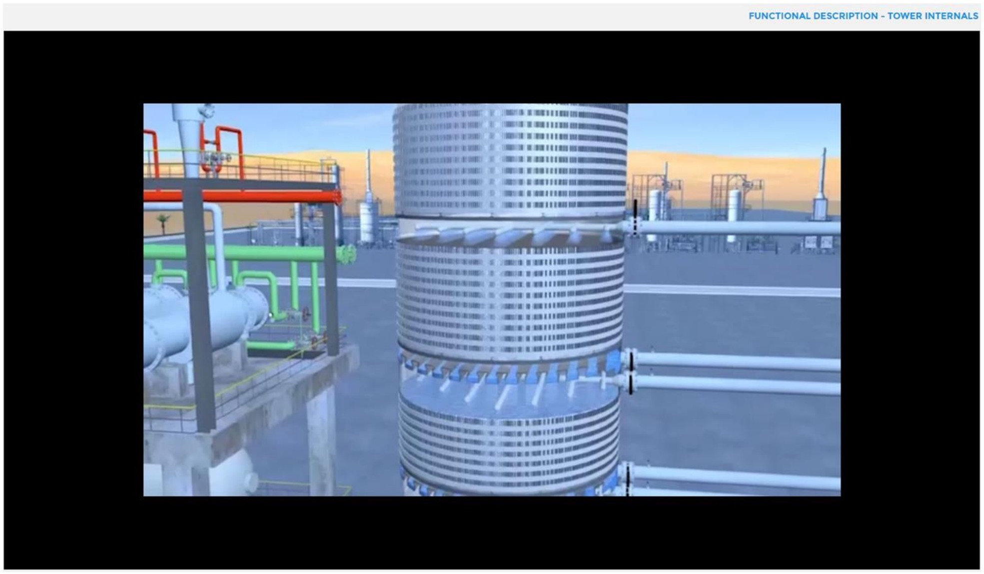


Functional Description:

This diagram shows the temperature profiles for the ascending vapor and descending liquid in the tower.

The closer the two are at any given point in the tower, the more efficient the heat transfer.

From this diagram, you can see that heat transfer efficiency is at its highest below beds 2 and 4 and at its lowest below bed 3.



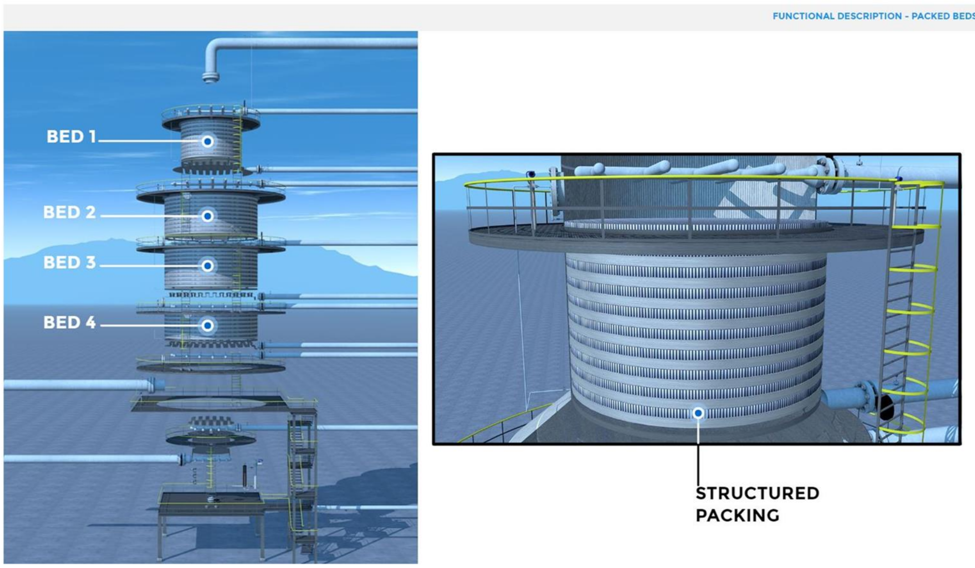
The Vacuum Tower internals are designed to achieve several important operational objectives:

To minimize the pressure drop from bottom to top of the tower - this helps maximize the vacuum that can be achieved - maximizing the vacuum minimizes the operating temperatures required, which lowers the chance of coke formation

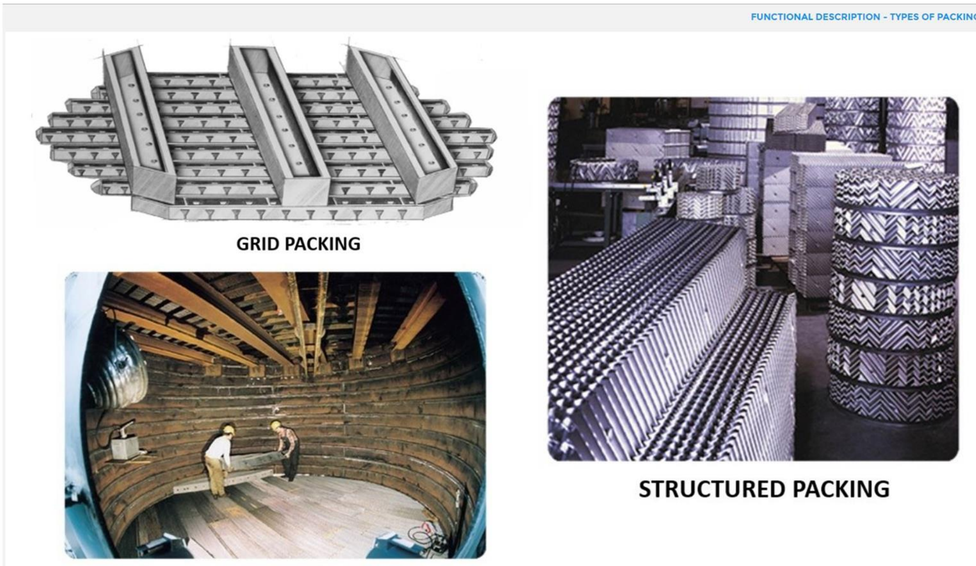
To ensure high efficiency contact between rising vapor and descending liquid

To provide a means of withdrawing products from the side of the tower

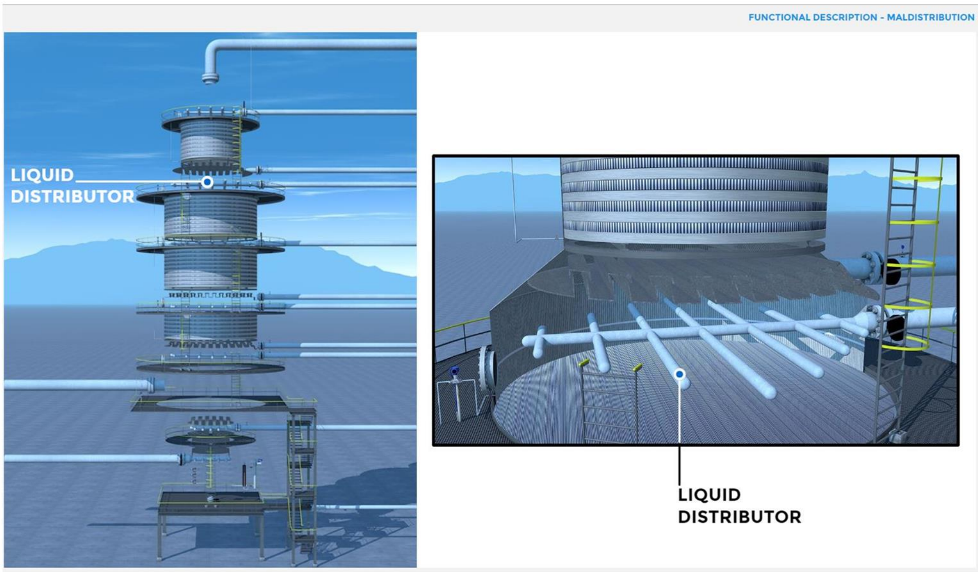
To prevent liquid stagnation, i.e. extended holdup - to prevent coke formation, it’s important to keep the liquid moving



This Vacuum Tower has four packed beds, fabricated from grid or structured packing materials that provide a high surface area for contact between rising vapor and descending liquid.



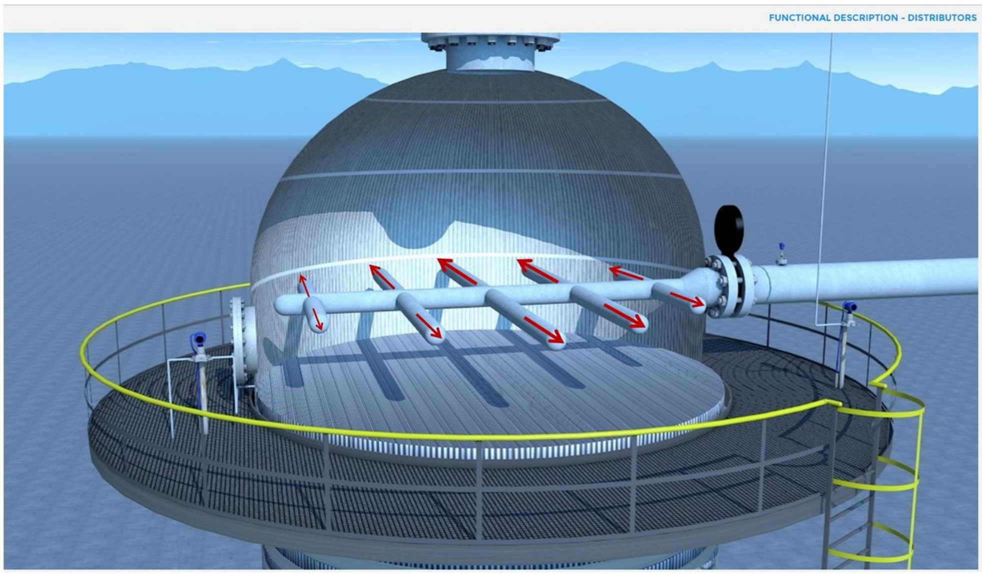
Grid and structured packing arrangements are factory assembled in sections that are passed through shell manways for installation.



Packed towers are much more sensitive to maldistribution than trayed towers.

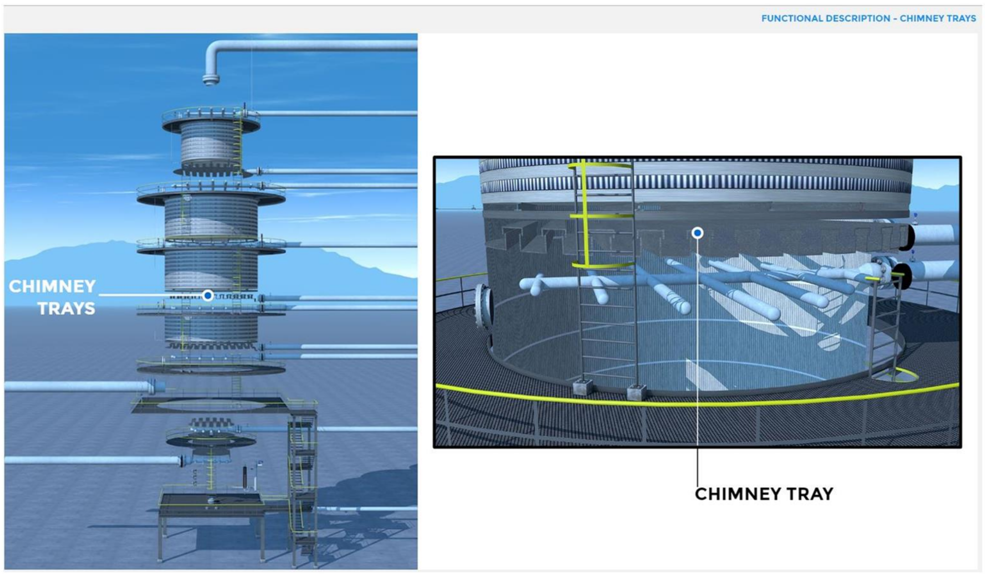
Maldistribution results in poor contact between the rising vapor and descending liquid, which inhibits heat transfer and lowers efficiency.

Liquid distributors provide a uniform flow pattern of liquid over the packed bed and are required at any location where an external liquid stream is introduced to the tower (e.g. pumparound or emergency reflux)



In the device pictured here, liquid enters the distributor under gravity or pressure and exits via the laterals, producing a spray that's directed downwards.

The spray liquid is often filtered prior to entering the tower to prevent blockage of the distributor openings.



Chimney trays collect LVGO, HVGO and VHVGO descending from the packed sections above, enabling these streams to be withdrawn from the side of the tower.

A fourth chimney tray is located above the vac resid pumparound return for the purpose of distributing liquid evenly over the sieve trays below.

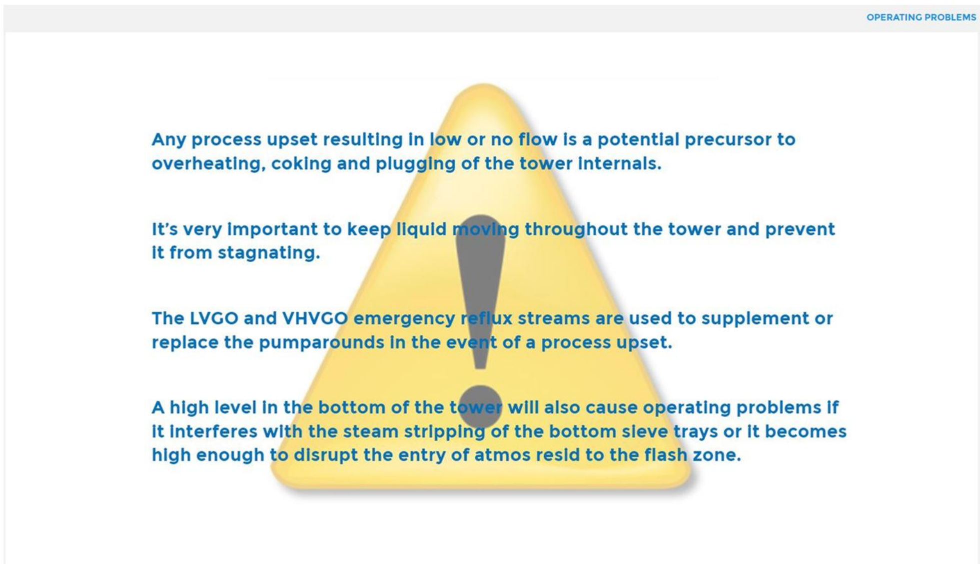
This picture shows a typical chimney tray arrangement.

On the positive side, chimney trays provide liquid hold-up, providing a supply of liquid to prevent dry up of trays or packing below during process upsets.

On the negative side, chimney trays have a high pressure drop, which doesn’t help the pressure in the flash zone.

Sieve trays in the bottom of the tower provide contact between rising stripping steam and descending vac resid.

The steam carries traces of distillate material back up into the flash zone above. A typical sieve tray is pictured here.



Operating Problems:

Any process upset resulting in low or no flow is a potential precursor to overheating, coking and plugging of the tower internals.

It’s very important to keep liquid moving throughout the tower and prevent it from stagnating.

The LVGO and VHVGO emergency reflux streams are used to supplement or replace the pumparounds in the event of a process upset, keeping the tower internals thoroughly wetted.

A high level in the bottom of the tower will also cause operating problems if it interferes with the steam stripping of the bottom sieve trays or it becomes high enough to disrupt the entry of atmos resid to the flash zone.

And this completes Module 01, in which we have covered the Vacuum Heater & Vacuum Tower unit operations.

To summarize:

> The function of the Vacuum Heater unit operation is to raise the temperature of the Atmospheric Residue to ensure optimal operation of the downstream Vacuum Tower
>
> The function of the Vacuum Tower unit operation is to fractionate atmospheric residue from the ADU into distillate products and a residue

For each of these unit operations, you should be familiar with:

> Principal items of equipment and their function
>
> Important process variables and associated controls
>
> Principles of operation and the internal components of key items of equipment
>
> Typical operating problems

Your task now is to take the VDU Module 01 Quiz to ensure you have fully understood the material. If you find the questions challenging, you should consider repeating this module before moving on.

Good luck!

You can now close this window and move on to the next module.