Tikrit University

The College of Petroleum Processes Engineering

Petroleum Systems Control Engineering Department

Petroleum Refining Processes

Fourth Class

Lecture 11

By

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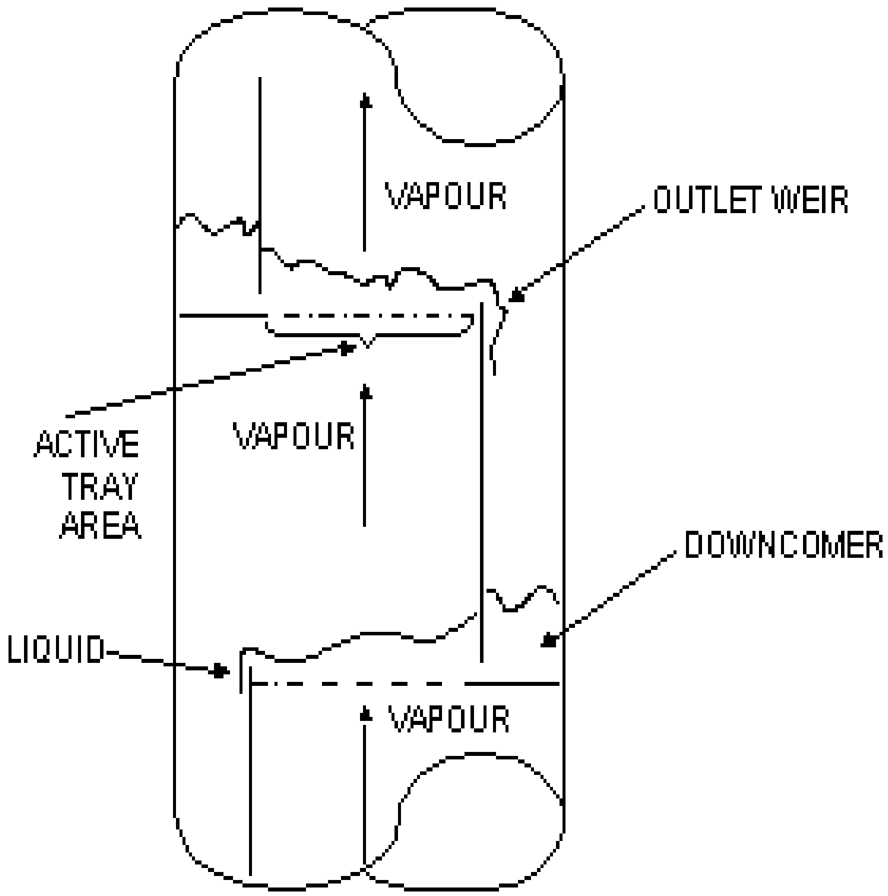
Liquid vapour flow in a tray column



- Each tray has 2 conduits, one on each side, called ‘downcomers’.
- Liquid falls through the downcomers by gravity from one tray to the one below it.
- A weir on the tray ensures that there is always some liquid (holdup) on the tray at a suitable height, e.g. such that the bubble caps are covered by liquid.
- Vapour flows up the column and is forced to pass through the liquid, via the openings on each tray.
- The area allowed for the passage of vapour on each tray is called the active tray area.

Reflux (heat removal) is provided throughout the tower by;

- Condensing the tower overhead vapors and returning a portion of the liquid to the top of the tower as a reflux (external reflux).
- Withdrawing a liquid stream from some intermediate location in the enriching section of the tower, cooling it, then returning it back to the tower a couple of trays above (this is called pumparound) this provides an internal reflux within the tower.
- Part of the condensate (the naphtha and the water) collected in the O/H accumulator is returned to the top of the tower as external reflux, and the remainder is sent to the stabilizer section of the crude unit (or the refinery gas plant).
- The reflux (being at a lower temperature) controls the temperature of the top of the tower thus the quality (end point) of the O/H product.

O/H Condensing System

- The fractionators O/H vapors (usually consisting of gas, un-stabilized naphtha and the stripping steam).
- The pentane and heavier fraction (C5+) is condensed in the overhead cooling system.
- The butane and lighter (C4-) remain in the gas phase.
- Ammonia solution is injected to crude column vapor line and on top tray to control acids formed by hydrolysis of the salt present (e.g. $Na^+Cl^- + H_2O \rightarrow HCl + NaOH$).
- Corrosion inhibitor is also added to prevent corrosion due to HCl and H_2S present.

Atmospheric Residue Section (bottom section)

Several trays are generally incorporated below the flash zone section and steam is introduced below the bottom tray to:

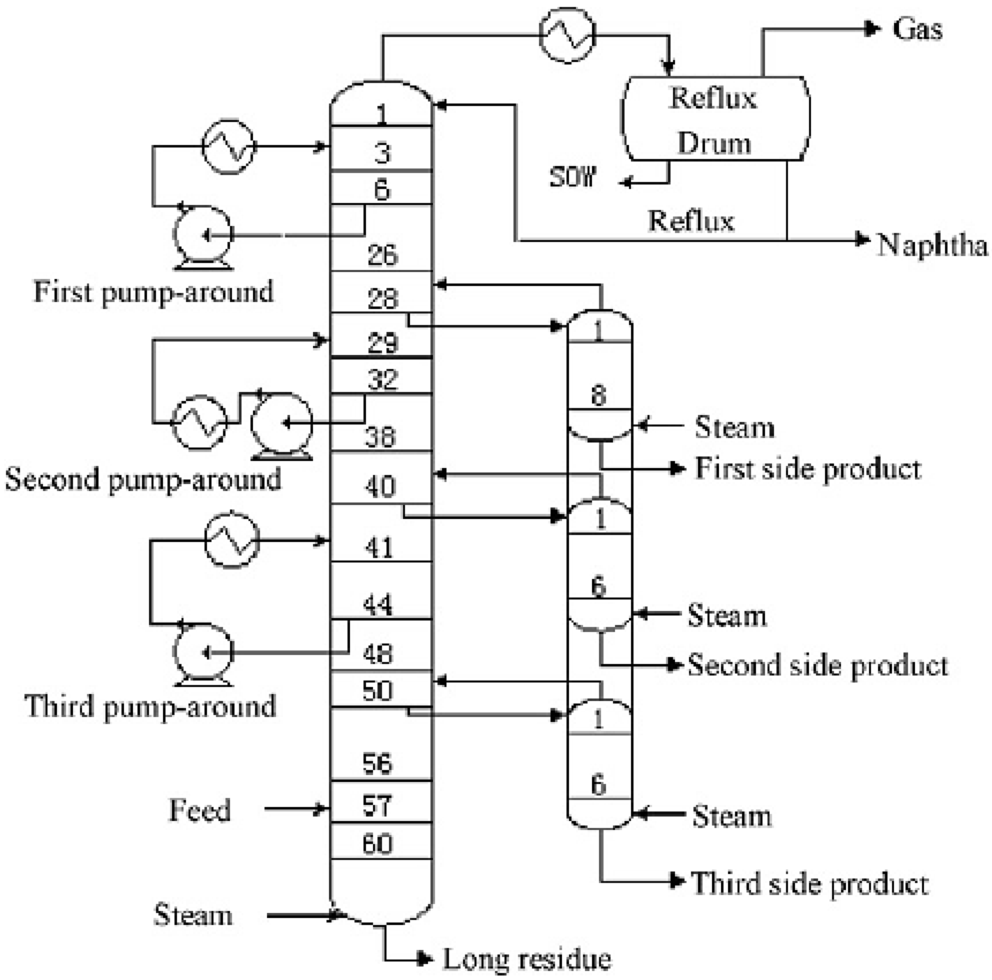
- Lower the partial pressure and, thus, the boiling point of the residue to avoid thermal cracking and degradation of the bottom product (Thermal cracking produces coke, which tends to block heat exchangers and other equipment resulting in poor heat transfer and lower efficiencies).
- Strip any remaining gas oil (more valuable) from the liquid in the flash zone (residue).
- Produce high-flash-point bottoms (by stripping the low boiling point material).

Stripping Stream

- Crude towers do not normally use reboilers because of the tendency of the residue to crack at high temperatures clogging the heat exchanger.
- Superheated steam is used instead to reduce the partial pressure of the hydrocarbon and thus lower the required vaporization temperature.

Side Draw Stripper (stripping the light ends)

- The liquid side stream withdrawn from the tower will contain low-boiling components, which lower the flash point of the product. (Because the lighter products in the vapor phase pass through the heavy products in the liquid phase and the two are in equilibrium on every tray).
- These 'light ends' are stripped from each side stream in a separate side-strippers.
- Side strippers is used to remove light ends from the product stream thus improving (increasing) their flash points & initial boiling point IBP.
  - Side strippers could be either **separated nor mounted side strippers.**



Three side strippers mounted on each other

- The strip-out /light ends (along with the stripping steam) leave the stripper at the top and enters the fractionator in the vapor zone directly above the tray of the side draw.
- The stripped products withdraw from the bottom of each stripper. Products Draw (side streams)
- Kerosene product is drawn from kerosene tray and is introduced to the top tray of Kerosene stripper.
- Diesel (light gasoil) product is drawn from light gasoil tray and is introduced to the top tray of diesel stripper.

- Each of the side stream products removed from the tower decrease the amount of liquid traffic below the point of draw-off.
- Increasing the amount of kerosene withdrawal, will result in a decrease in the amount of liquid going down through the tower.

This will lead to less condensation of vapors going up and more of the diesel cut will rise up and go into kerosene (↑FBP).

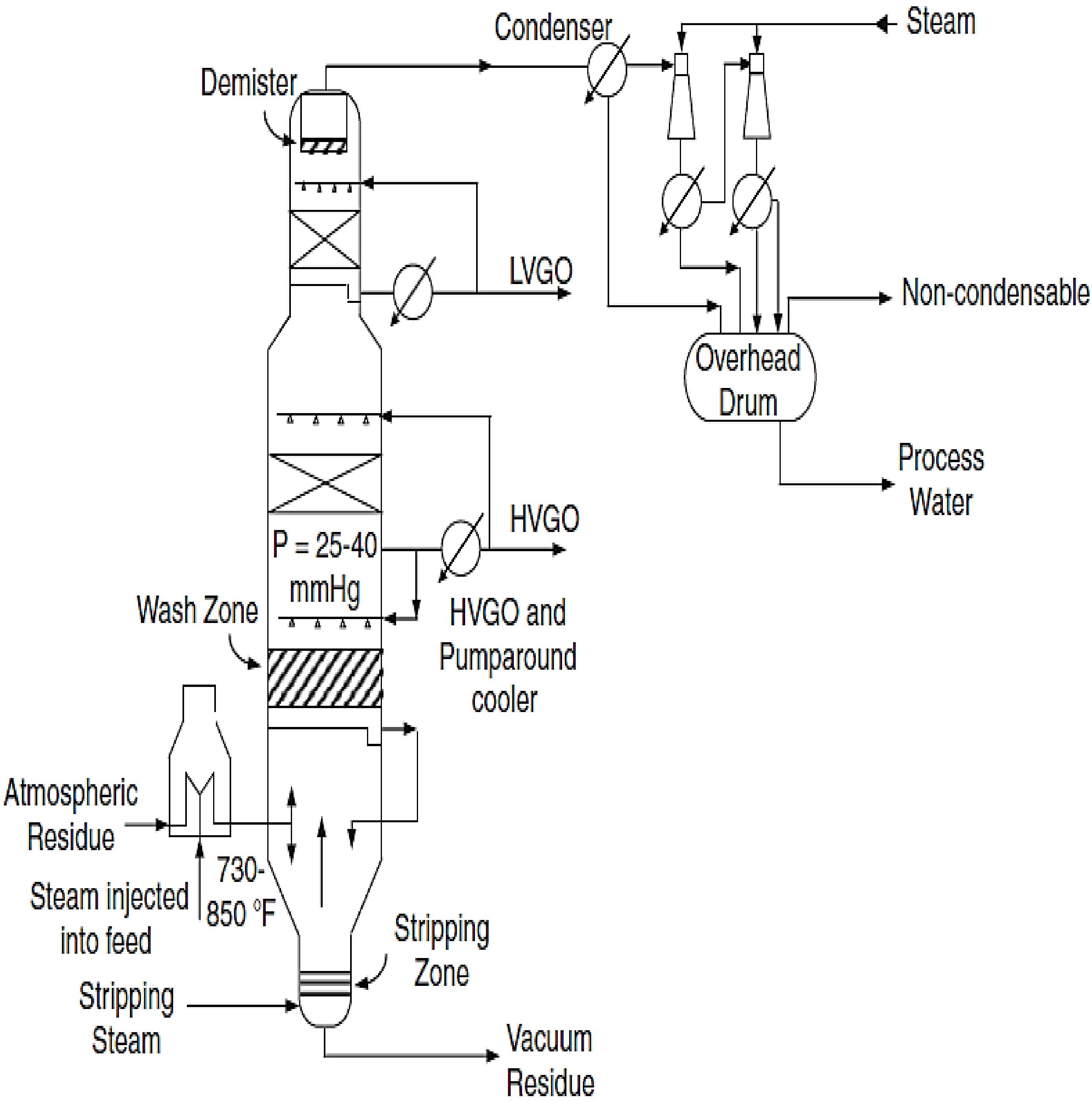
- The opposite is also true.
- The over flash is a liquid drawn from tray (above the flash zone) and returned to tray (below the flash zone).
- The over flash (which is 5 vol. % of the crude) helps to remove the heavy material from the diesel product and improves the fractionation (separation) between the diesel and the atmospheric residue cuts.

Vacuum Distillation of Atmospheric Residue

- To extract more distillates from the atmospheric residue, the bottom from the atmospheric CDU is sent to the vacuum distillation unit.
- The vacuum distillates are classified as light vacuum gas oil (LVGO), medium vacuum gas oil (MVGO), and heavy vacuum gas oil (HVGO).
- The distillation must be performed at absolute pressures as low as 10 to 40 mmHg to limit the operating temperature to less than 370°C.

Major equipment

- Vacuum furnace and vacuum distillation column.
- Product stripper and products coolers.
- Overhead ejector system.



Process flow diagram of the vacuum distillation unit

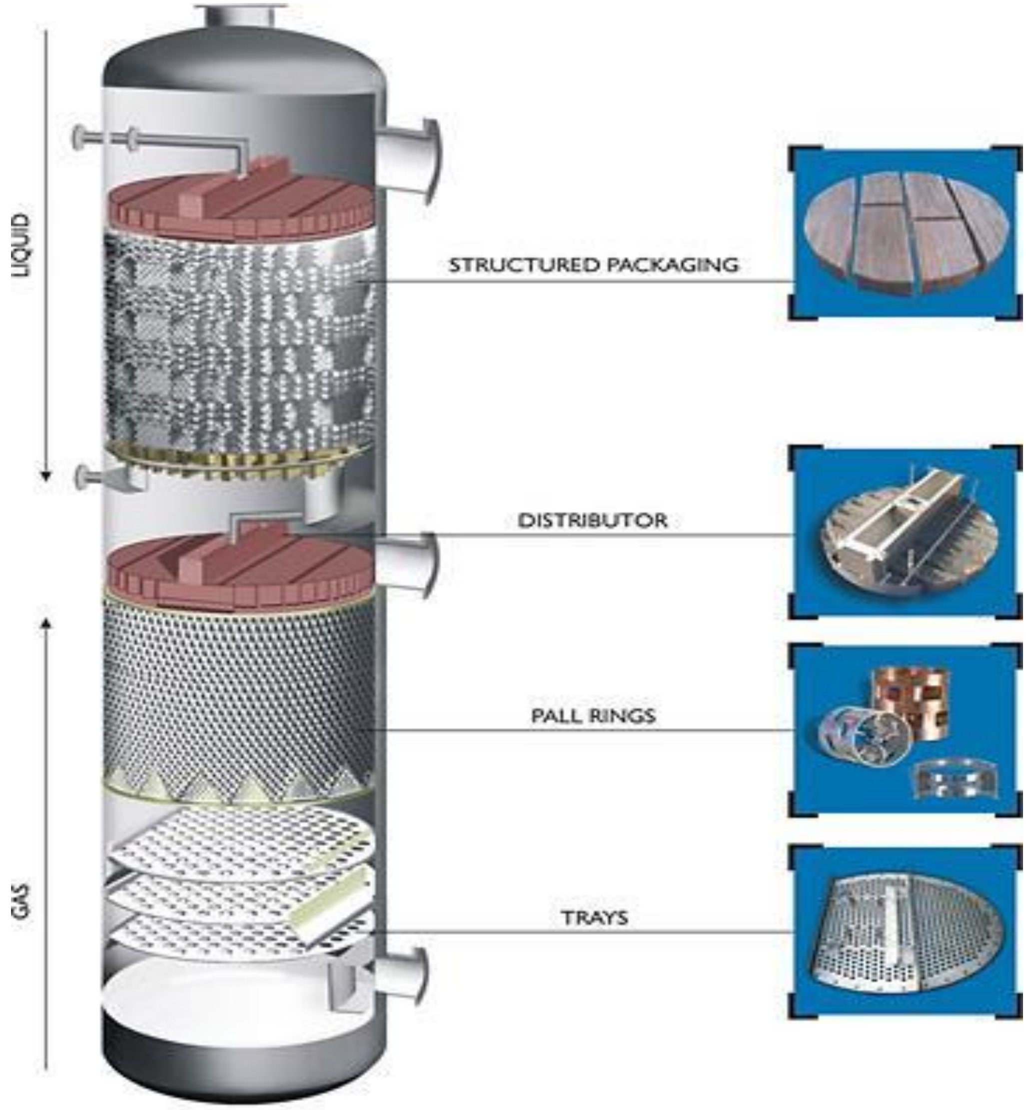
Vacuum Fractionator

- The vacuum tower has 4 stripping trays (below the feed) and 6 wash trays (above the feed).
- The tower has a packed bed (**2” metal ball rings**) to enhance fractionation and condense the (HVGO) and the wash oil.
- Three chimney trays for collecting liquid product for withdrawal of LVGO, HVGO, and heater recycle.
- A demister eliminator to prevent liquid entrainment with the vapor due to excessive vaporization generated by the vacuum.
- Steam injection to the heater tube passes and the fractionator bottom which further improves vaporization, minimize thermal cracking and coking.
- Heat is removed from the tower by three circulating pumparound systems.
- **Top pumparound** for (LVGO) to improve fractionation and remove heat from the tower.
- **Middle pumparound** for (HVGO) to improve fractionation, remove heat from the tower, and heat recovery.
- In the vacuum tower boot, the residue product is **partially recycled to quench (cool)** the residue and reduce the residence time at high temperature to avoid cracking. No improvement of fractionation here since the **bottom pumparound** is at the bottom below the feed, the steam, and the last tray.
- Portion of the HVGO is refluxed back to the tower to provide better fractionation between the HVGO and vacuum residue in the trays 5-10 and improve HVGO end point.
- **Larger diameters** are used in the vacuum distillation columns than the atmospheric columns to **control the space velocity of the vapor**.

- A wash section immediately above the flash-zone ensures that the metal content in the lowest side draw is minimized.
- Heavy distillate from the wash trays is recycled to the heater inlet or withdrawn as metal cut.

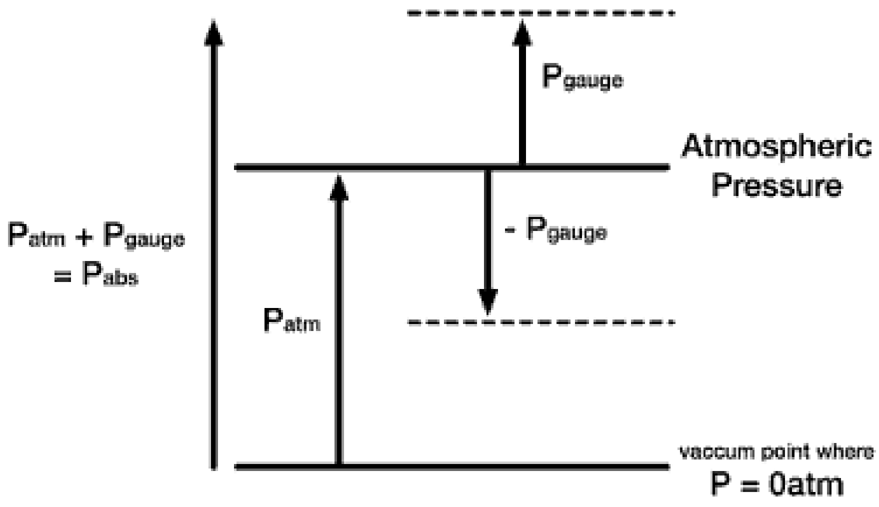
The vacuum distillation column internals

- Internals must provide good vapor-liquid contacting while, at the same time, maintaining a very low pressure-increase from the top of the column to the bottom.
- Therefore, the vacuum distillation column **are equipped with packing** for fractionation and heat exchanging zones.
- Packings reduce the pressure drop in the column which is necessary for creating a low vacuum in the lower section of the column.
- **Vacuum columns uses distillation trays only where withdrawing products from the side of the column (referred to as side draws).**
- **This packing material can be either structured sheet metal or randomly dumped packing such as ball rings.**

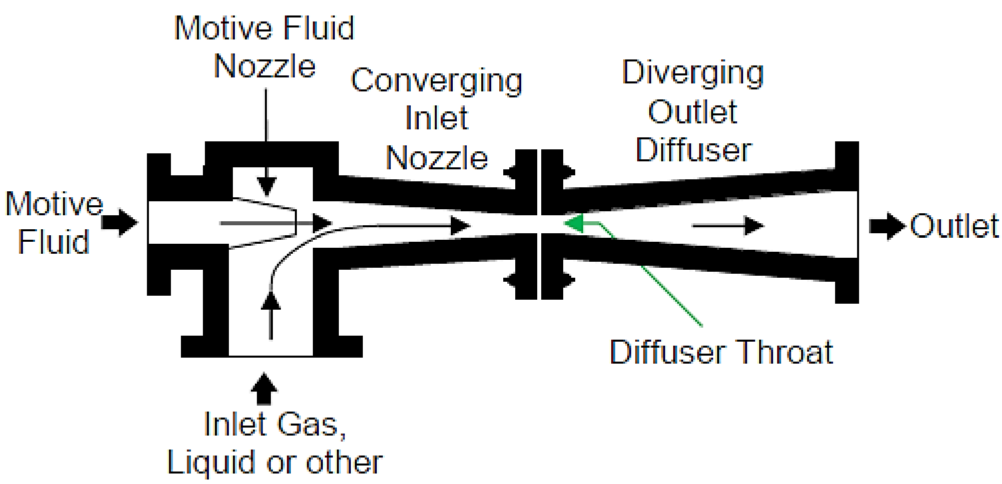


Vacuum generating system

- The type of vacuum pump needed will depend on the degree of vacuum required, the capacity of the system, and the rate of air in-leakage.
- **Steam-jet ejectors** are versatile and economic vacuum pumps and are frequently used, particularly in vacuum distillation. They can handle high vapor flow rates and, when several ejectors are used in series, can produce low pressures, down to about 0.1mmHg (0.13 mbar).

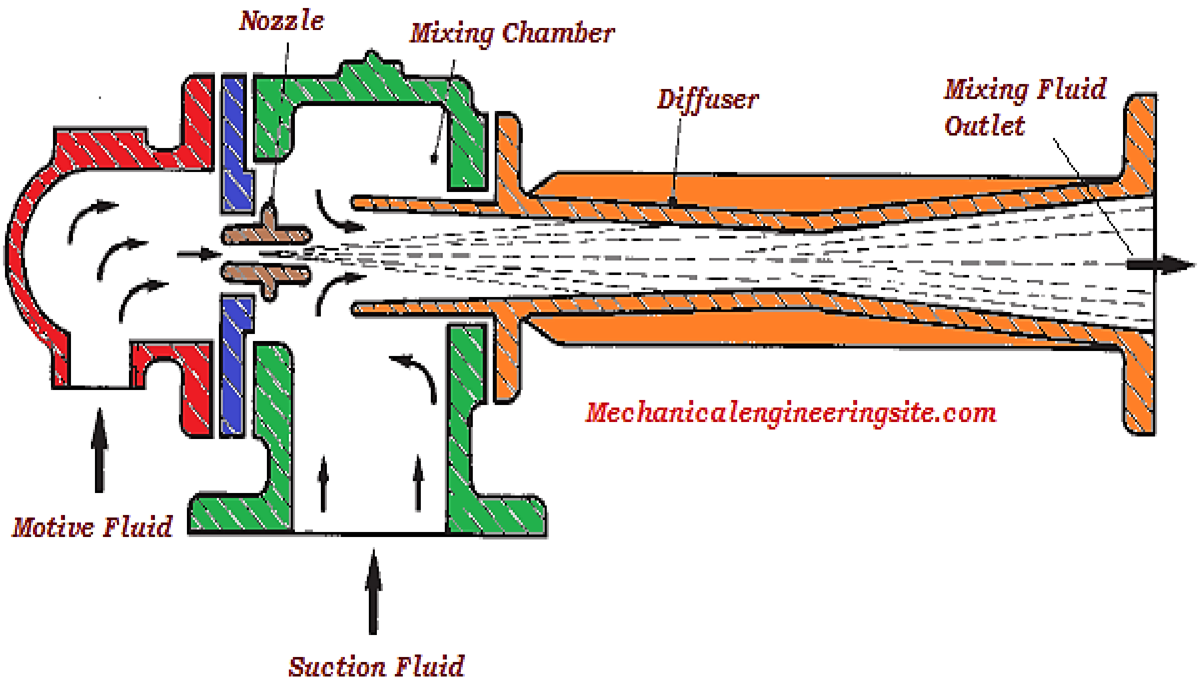

Pgauge
Atmospheric Pressure
Patm + Pgauge = Pabs
- Pgauge
Patm
vaccum point where
P = 0atm


30
20
40
10
50
60
bar


Motive Fluid Nozzle
Converging Inlet Nozzle
Diverging Outlet Diffuser
Motive Fluid
Outlet
Diffuser Throat
Inlet Gas, Liquid or other

The advantages of ejector:

- Simple, reliable means of producing vacuum
- low installed cost as well
- They are commonly found in process plants having available steam
- They provide many years of trouble-free operation



Flow pattern in steam ejector

The most important components are the jet nozzle **(venturi nozzle). There are different design**
principles: single-stage and multistage ejectors.

Atmospheric Tower Operating Conditions

OPERATING PARAMETER	UNITS	
TEMPERATURES	°F	
TRANSFER LINE		660
FLASH ZONE		657
TOWER TOP		359
KEROSENE DRAW-OFF		469
PUMPAROUND DRAW OFF		548
PUMPAROUND RETURN		345
LIGHT DIESEL DRAW OFF		603
TOWER BOTTOM		648
PRESSURE	psig	
REFLUX DRUM		2.0
TOWER TOP		10.3
FLASH ZONE		14.7
REFLUX RATIO, REFLUX/LIQUID DIST.		0.6
STRIPPING STEAM		
TO ATMOSPHERIC TOWER	lbs/bbl RESID	5.5
TO KEROSENE STRIPPER	lbs/bbl RESID	5.9
TO DIESEL STRIPPER	lbs/bbl RESID	2.1
ATMOSPHERIC HEATER		
PROCESS FLUID CONDITIONS		
TEMPERATURE IN	°F	453
TEMPERATURE OUT	°F	660
PRESSURE DROP	psi	138
TUBE SKIN TEMPERATURE (AVG)	°F	735
STACK GAS TEMPERATURE	°F	725
FRACTIONATION EFFICIENCY		
95%–5% ASTM DISTRIBUTION GAP		
ATMOSPHERIC NAPHTHA-KEROSENE		GAP + 10
KEROSENE-LIGHT DIESEL		GAP – 36

Vacuum Tower Operating Conditions

OPERATING PARAMETER	UNITS	
TEMPERATURES	°F	
TRANSFER LINE		740
FLASH ZONE		711
TOWER TOP		307
HEAVY DIESEL DRAW-OFF		447
TOP REFLUX TEMPERATURE		121
HVGO DRAW-OFF		613
TOWER BOTTOM		670
PRESSURE	mmHg	
TOWER TOP		64
FLASH ZONE		125
TOP REFLUX RATIO; REFLUX/FEED		0.15
HOT REFLUX RATIO; REFLUX/FEED		0.97
WASH OIL RATIO; WASH OIL/FEED		0.14
BOTTOM QUENCH OIL RATIO; QUENCH/FEED		0.24
STRIPPING STEAM		
TO VACUUM TOWER	lbs/bbl RESID	8.0
TO HVGO STRIPPER	lbs/bbl RESID	4.6
VACUUM HEATER		
PROCESS FLUID CONDITIONS		
TEMPERATURE IN	°F	645
TEMPERATURE OUT	°F	736
PRESSURE DROP	psi	73
TUBE SKIN TEMPERATURE (AVG)	°F	850
STACK GAS TEMPERATURE	°F	845
FRACTIONATION EFFICIENCY		
95%–5% ASTM DISTRIBUTION GAP		
LIGHT DIESEL–HEAVY DIESEL		GAP – 145
HEAVY DIESEL-HVGO		GAP + 25