**Distillation Tower Temperature**

1- Top Temp.
The temperature at the top should be high up to the temperature where all the top product are vaporized without any condensation for any part of it, and avoid vaporization process for the compounds having temperature higher than the temperature of the top product.

If the pressure inside the column equals to atmospheric pressure and there is no vapor is fed to the column, the temperature will be

\[
\text{Top temp.} = 100\% \text{ EVF}
\]

If the pressure is not equal to the atmospheric pressure and there is vapor inside the column, the temperature should be corrected according to the following steps:

**Steps of Calculations**

1. Estimate the amount of heat that should be removed from the column to make it in thermal equilibrium (in Btu/hr)
2. Divide the heat in part 1 on the heat that can remove 1 lb of reflux to calculate the amount of reflux (i.e. Btu/hr / Btu/lb = lb/hr)
3. Estimate the no. of moles of hydrocarbons at the top of column (i.e. Reflux + Product) by weight / M.wt.
4. Estimate the no. of moles of vapor by the same way.
5. Estimate the total no. of moles (3+4).
6. Estimate the partial pressure of hydrocarbons by
   \[
   P_{hy} = P_t \times \frac{n_{hy}}{n_t}
   \]
7. Correct the temperature (100%) of product by using Fig. 17.

2- Side- temperature

Estimation of temperature at side points is the same of that at top temp., except the following differences: a) correct EVF (0%) for the product, b) the no. of moles of hydrocarbons is estimated for the hydrocarbons that pass to the higher tray in addition to this tray.

**Ex:** The amount of heat that should be removed from the distillation column is 100000 Btu/hr in order to make the column in thermal equilibrium. The top product (gasoline) has a yield of 2000 lb/hr (M.wt = 110 lb/lb mol) and Evf 100%=230 F and the pressure is 272.5 psia. The quantity of steam that should be fed inside the column is 500 lb/hr, hot L.H = 100 Btu/lb.

**Sol:**
The amount of reflux = 100000/100 = 1000 lb/hr
The no. of moles of hydrocarbons at the top of column = (1000 + 2000) / 110 = 27.273 lb mol/hr
The no. of moles of vapor 500 / 18 = 27.778 lb mol/hr
The total no. of moles = 27.273 + 27.778 = 55.051 lb mol/hr
The partial pressure of hydrocarbons = 272.5 * (27.273/55.051) = 135 psia
From Fig. 17 the correct temp = 400 F.

Note: if the reflux is cold reflux, the amount of heat = L.H + Cp.ΔT
**Light End Fractionation**

Within refineries there are numerous other, smaller distillation towers called columns, designed to separate specific and unique products. Columns all work on the same principles as the towers described above. For example, a depropanizer is a small column designed to separate propane and lighter gases from butane and heavier components in the light end unit.

- The light end gases are the top cut of crude distillation. Iso and normal butanes ($C_4H_{10}$) and lighter gases such as methane ($CH_4$), ethane ($C_2H_6$), propane ($C_3H_8$) and hydrogen ($H_2$) are then recovered and separated in the refinery gas plant. Typically: Hydrogen, methane and sometimes ethane are diverted to the refinery fuel gas header for use in site heaters and furnaces
- Ethane is used as the chemical feedstock for ethylene upon transfer to a petrochemical complex
- Propane is used for liquefied petroleum gas (LPG) sales or as the chemical feedstock for propylene
- N-butane is used for motor gasoline blending. Iso-butane is used as feedstock to the alkylation

![Fig. 24: Light End Fractionation](image-url)
**Thermal Cracking and Coking**

Thermal cracking is the cracking of heavy residues under severe thermal conditions. The liquid products of this process are highly olefinic, aromatic and have high sulfur content. They require hydrogen treatment to improve their properties.

Coking is the process of carbon rejection from the heavy residues producing lighter components lower in sulfur, since most of the sulfur is retained in the coke.

There are three classes of industrial thermal cracking processes. The first is mild cracking (as in visbreaking) in which mild heating is applied to crack the residue just enough to lower its viscosity and also to produce some light products. The second process is delayed coking in which moderate thermal cracking converts the residue into lighter products, leaving coke behind. The third process involves severe thermal cracking: part of the coke is burned and used to heat the feed in the cracking reactor, as in fluid coking.

<table>
<thead>
<tr>
<th>Table</th>
<th>Thermal cracking process</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visbreaking</strong></td>
<td>Mild heating 471–493 °C (880–920 °F) at 50–200 psig</td>
</tr>
<tr>
<td></td>
<td>Reduce viscosity of fuel oil</td>
</tr>
<tr>
<td></td>
<td>Low conversion (10%) at 221 °C (430 °F)</td>
</tr>
<tr>
<td></td>
<td>Heated coil or soaking drum</td>
</tr>
<tr>
<td><strong>Delayed coking</strong></td>
<td>Moderate heating 482–516 °C (900–960 °F) at 90 psig</td>
</tr>
<tr>
<td></td>
<td>Soak drums 452–482 °C (845–900 °F)</td>
</tr>
<tr>
<td></td>
<td>Residence time: until they are full of coke</td>
</tr>
<tr>
<td></td>
<td>Coke is removed hydraulically</td>
</tr>
<tr>
<td></td>
<td>Coke yield ~ 30 wt%</td>
</tr>
<tr>
<td><strong>Fluid coking and flexicoking</strong></td>
<td>Severe heating 482–566 °C (900–1050 °F) at 10 psig</td>
</tr>
<tr>
<td></td>
<td>Fluidized bed with steam</td>
</tr>
<tr>
<td></td>
<td>Higher yields of light ends</td>
</tr>
<tr>
<td></td>
<td>Less coke yield (20% for fluid coking and 2% for flexicoking)</td>
</tr>
</tbody>
</table>

**Visbreaking Process**

Visbreaking is a mild thermal cracking of vacuum or atmospheric residues to produce light products and 75–85% cracked material of lower viscosity that can be used as fuel oil.

**Feed Sources**

The feed to visbreaker can be either
- Atmospheric residue (AR)
- Vacuum residue (VR)

Vacuum residue is the heaviest distillation product and it contains two fractions: heavy hydrocarbons and very heavy molecular weight molecules, such as asphaltene and resins.

**Visbreaking Reactions**

The possible reactions in visbreaking are:
- Paraffinic side chain breaking which will also lower the pour point;
- Cracking of naphthens rings at temperature above 482 °C (900 °F);
- Coke formation by polymerization, condensation, dehydrogenation and dealkylation; and
Further cracking will be the result of asphaltene and coke leaving the liquid phase (delayed coking).

**Product Yield and Properties**

Four products are produced in the visbreaking process: gases ($C_4$), Naphtha ($C_5 - 166^\circ C$ ($C_5 - 330^\circ F$)), gas oil $166-350^\circ C$ ($330-660^\circ F$) and residue or tar $350+^\circ C$ ($660+^\circ F$). Typical yields are given in Table below.

<table>
<thead>
<tr>
<th>Product</th>
<th>wt% of charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gases ($C_4$)</td>
<td>2–4</td>
</tr>
<tr>
<td>Naphtha ($C_5 - 330^\circ F$)</td>
<td>5–7</td>
</tr>
<tr>
<td>Gas oil ($330-660^\circ F$)</td>
<td>10–15</td>
</tr>
<tr>
<td>Tar ($660+^\circ F$)</td>
<td>75–85</td>
</tr>
</tbody>
</table>

**Prediction of Visbreaking Yields**

Products yields:

\[
\text{Conversion} = \%\text{Conv} = \left( \frac{\text{Gas wt}\% + \text{Naphtha wt}\%}{\text{Feed( VR) wt}\%} \right) \times 100
\]

\[
\text{Gas wt}\% = 0.189825 \times \%\text{Conv} + 0.677163
\]

\[
\text{Gasoline wt}\% = 0.738321 \times \%\text{Conv} + 0.260174
\]

\[
\text{Residue wt}\% = -0.146668 \times (\%\text{Conv})^2 - 2.203644 \times \%\text{Conv} + 98.677947
\]

\[
\text{H}_2\text{S in Gas wt}\% = 0.02023 \times \%\text{Conv} + 0.06043 \times \text{wt}\%S_f - 0.156
\]

where $S_f$ refers to sulphur in feed

\[
\text{Gas oil wt}\% = 100 - \text{Gas wt}\% - \text{Gasoline wt}\% - \text{Residue wt}\% - \text{H}_2\text{S wt}\%
\]

**Sulphur(S) in visbreaker products:**

\[
\text{S in H}_2\text{S in Gas} = (\text{H}_2\text{S} \times 32/34)
\]

\[
\text{wt}\% \text{ S in Gasoline} = 0.260112 \times \text{wt}\%S_f
\]

\[
\text{wt}\% \text{ S in Gas oil} = 0.539924 \times \text{wt}\%S_f
\]

$S$ in Residue = $S$ in Feed – $S$ in gasoline – $S$ in GO – $S$ in H$_2$S

**Gravity of visbreaking products:**

\[
\text{Gasoline API} = -0.26215 \times \%\text{Conv} + 0.315121 \times \text{API}_f + 56.83723
\]

\[
\text{Gas oil API} = -0.052919 \times \%\text{Conv} + 0.52228042 \times \text{API}_f + 12.9318914
\]

\[
\text{Residue API} = -0.7462183 \times \%\text{Conv} + 1.29131825 \times \text{API}_f - 2.6831388
\]
where API\(_f\) is feed API gravity and \(S_f\) is the sulphur content in feed.

**Example:** A vacuum residue is fed into a coil visbreaker at a rate of 200,000 lb/h. It has an API = 8.5 and sulphur content of 3%. Assume 6 wt% conversion. Make a material balance for the visbreaker.

**Sol.:**
The solution of this example is summarized in Table below.

<table>
<thead>
<tr>
<th>Feed rate = 200,000 lb/h</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(S_f) = 3 wt%</td>
<td></td>
</tr>
<tr>
<td>Conversion = 6 wt%</td>
<td></td>
</tr>
</tbody>
</table>

**Visbreaking**

<table>
<thead>
<tr>
<th>Products yield</th>
<th>wt%</th>
<th>lb/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas (= 0.189825 \times %\text{Conv} + 0.677163)</td>
<td>1.82</td>
<td>3632</td>
</tr>
<tr>
<td>Gasoline (= 0.738321 \times %\text{Conv} + 0.260174)</td>
<td>4.69</td>
<td>9380</td>
</tr>
<tr>
<td>Residue (= -0.146668 \times %\text{Conv}^2 - 2.203444 \times %\text{Conv} + 98.677947)</td>
<td>79.58</td>
<td>159,152</td>
</tr>
<tr>
<td>(H_2S = 0.02023 \times %\text{Conv} + 0.06043 \times \text{wt}% S - 0.156)</td>
<td>0.15</td>
<td>300</td>
</tr>
<tr>
<td>Gas oil (= 100 - \text{Gas} - \text{Gasoline} - \text{Residue} - H_2S)</td>
<td>13.76</td>
<td>27,536</td>
</tr>
<tr>
<td>100.00</td>
<td>200,000</td>
<td></td>
</tr>
</tbody>
</table>

**Sulphur in visbreaker products**

| S in \(H_2S = H_2S\) in gas \((32/33)\) | 94.12 | 282 |
| S in Gasoline = 0.260112 \(S_f\) | 0.78 | 73 |
| S in GO = 0.539924 \(S_f\) | 1.62 | 444 |
| S in Residue = S in Feed – S in gasoline – S in GO – S in \(H_2S\) | 3.48 | 5200 |

**Gravity of visbreaking products**

<table>
<thead>
<tr>
<th>API</th>
<th>SG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline (= -0.26215 \times %\text{Conv} + 0.315121 \times \text{API}_f + 56.83723)</td>
<td>57.9</td>
</tr>
<tr>
<td>Gas oil (= -0.052919 \times %\text{Conv} + 0.52228042 \times \text{API}_f + 12.9318914)</td>
<td>17.1</td>
</tr>
<tr>
<td>Resid (= -0.7462183 \times %\text{Conv} + 1.29131825 \times \text{API}_f - 2.6831388)</td>
<td>3.8</td>
</tr>
</tbody>
</table>

**Process Description**

There are two types of visbreakers: coil visbreaking, in which thermal cracking occurs in the coil of the furnace, and the soak visbreaker, in which cracking occurs in a soak drum.

**Coil Visbreaker**

Vacuum or atmospheric residue feedstock is heated and then mildly cracked in the visbreaker furnace. Reaction temperatures range from 850 to 900 F (450 to 480 °C), and operating pressures vary from as low as 3 bar to as high as 10 bar. As shown in Figure A, coil furnace visbreaking is used and the visbroken products are immediately quenched to stop the cracking reaction. The quenching step is essential to prevent coking in the fractionation tower. The gas oil and the visbreaker residue are most commonly used as quenching streams.
After quenching, the effluent is directed to the lower section of the fractionator where it is flashed. The fractionator separates the products into gas, gasoline, gas oil and visbreaker tar (residue).

**Soaker Visbreaker**

The process scheme described above is usually referred to as furnace or coil cracking. Some visbreakers employ a soaker between the visbreaker furnace and the quenching step, similar to the conventional thermal cracking processes. This type of operation is termed soaker cracking as shown in Figure B.

![Fractionation Process Diagram](image)

Both process configurations have their advantages and applications. Coil cracking yields a slightly more stable visbreaker product, which are important for some feedstocks and applications. It is generally more flexible and allows the production of heavy cuts, boiling in the vacuum gas oil range. Soaker cracking usually requires less capital investment, consumes less fuel and has longer on-stream times.

**Ex.** It is required to decoke a visbreaker coil with an inside diameter = 9 cm and 700 m long with a coke layer of 0.35 cm thickness. This is done in two steps:

a) Air is introduced to combust the coke layer whose density is 1202 Kg/m$^3$

b) Steam at 450 °C and flow rate of 1000 Kg/hr is introduced to the coil to remove debris and cleaning-up. The exit temperature is 700 °C. Coke contains 92 wt% carbon and 8 wt% sulphur.

For how long should steam be switched on, in hours?
Data: specific heat of steam = 2.13 kJ/(Kg °C) heat of carbon combustion = 32,770 kJ/Kg, heat of sulphur combustion $= 9,300$ kJ/Kg.

**Solution:**

Volume of coke layer = $3.14(0.09)(700)(0.0035) = 0.6924$ m$^3$

Weight of coke = $0.6924(1202) = 832.3$ Kg

Heat of carbon combustion in coke = $832.2(0.92)(32,770) = 25 \times 10^6$ kJ

Heat of sulphur combustion in coke = $832.2(0.08)(9300) = 0.69 \times 10^6$ kJ

Total heat = $25.69 \times 10^6$ kJ

Rate of heat gained by steam = $m \times C_{p}(T_{out} - T_{in})$

$1000(2.13)(700 - 450) = 5.53 \times 10^6$ kJ/h

Time for switching steam = $25.69 \times 10^6 / 5.53 \times 10^6 = 48.5$ h