Atmospheric topping unit

After desalting, the crude oil is pumped through a series of heat exchanger and its temperature raised to about 550° F (288° C) by heat exchange with product and reflux streams.

It is then further heated to about 750° F (399° C) in a furnace (i.e. direct fired heater or "pipe still") and charged to flash zone of atmospheric fractionators.

The furnace discharge temperature is sufficiently high to cause vaporization of all products with drawn above the flash zone + about 20% of the bottom product.

The 20% "over flash" allows some fractionation to occur on the trays just above the flashing zone by providing internal reflux in excess of side stream withdrawals.

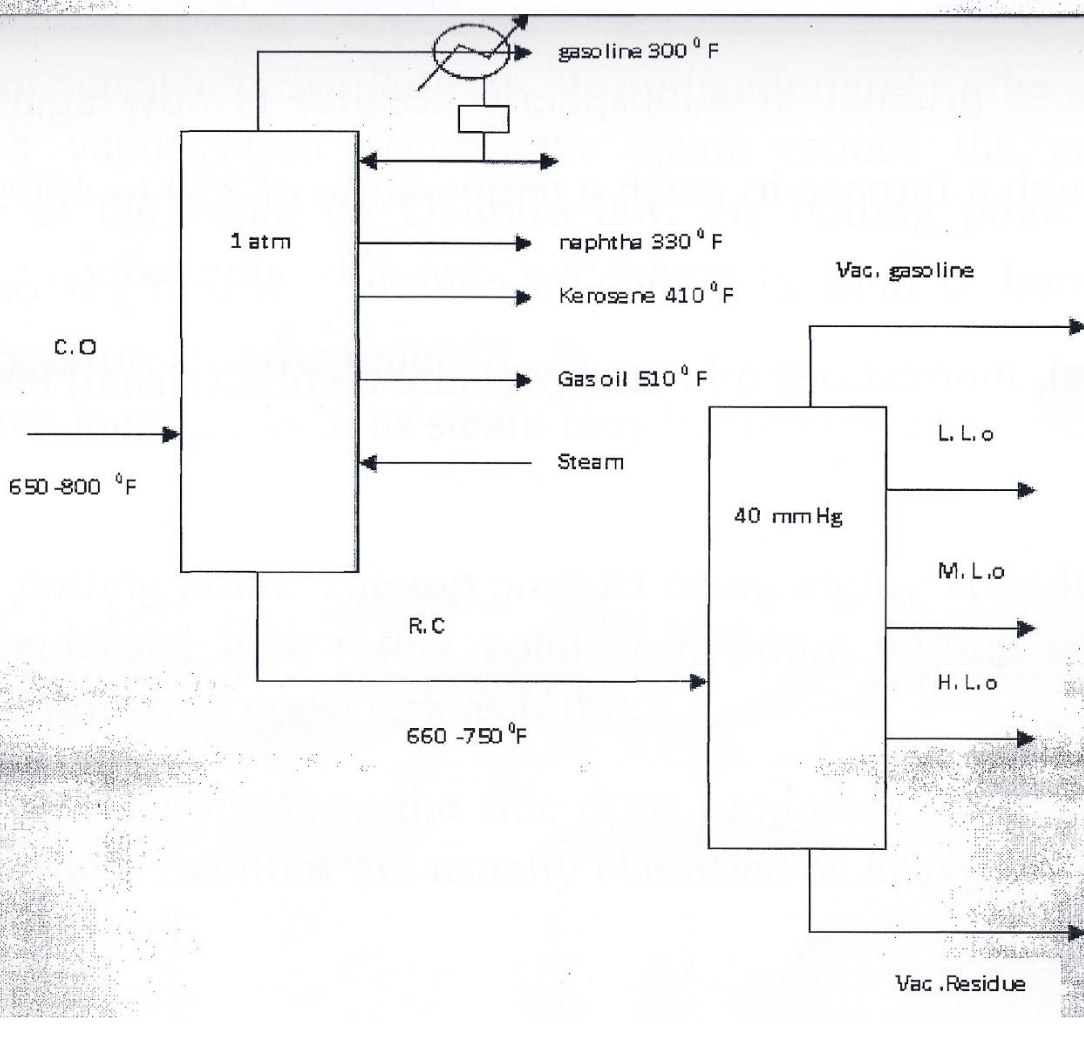
In many petroleum distillations, steam is admitted to the space in which vaporization occurs, the steam reduce the partial pressure in the vapor by Dalton's law, the boiling point of a material may be reduced in only two ways:

1) the pressure may be reduced.
2) or some inert gas such as steam may be introduced.

The distillation causes the fractions to separate in increasing order of boiling point. The top product being highly volatile has to be condensed in a reflux condenser. Some portion of the condensed fraction goes back as reflux.

All other fractions form the side draw products of distillation column. There fractions are usually classified as heavy naphtha, kerosene, gas oil.

Bottom product of atmospheric column is now again routed through a furnace to reach a temperature of 350 to 400°C and is allowed to flash in a vacuum column, vacuum gas oil, heavy diesel, lubrications oil cuts / pressure distillates shall be the side cuts.



Heat and Material Balances

1) The vapor liquid feed enters the tower at a high temperature, and the product are withdrawn at lower temperature , hence heat must be removed, and it is referred as
" reflux heat ".

2) The most satisfactory temperature datum is the **vaporizer temperature** because this temperature can be accurately estimated and is the temperature about which the entire design of tower, and pipe still hinges.

3) By using this datum plane , the heat balance consists simply of the **sensible heat** required to:

a) Cool each product from vaporizer temperature to its withdrawal temperature.

b) Condense the products that are withdrawal as liquid.

Example (1) :

Heat Balance of a Fractionating Tower

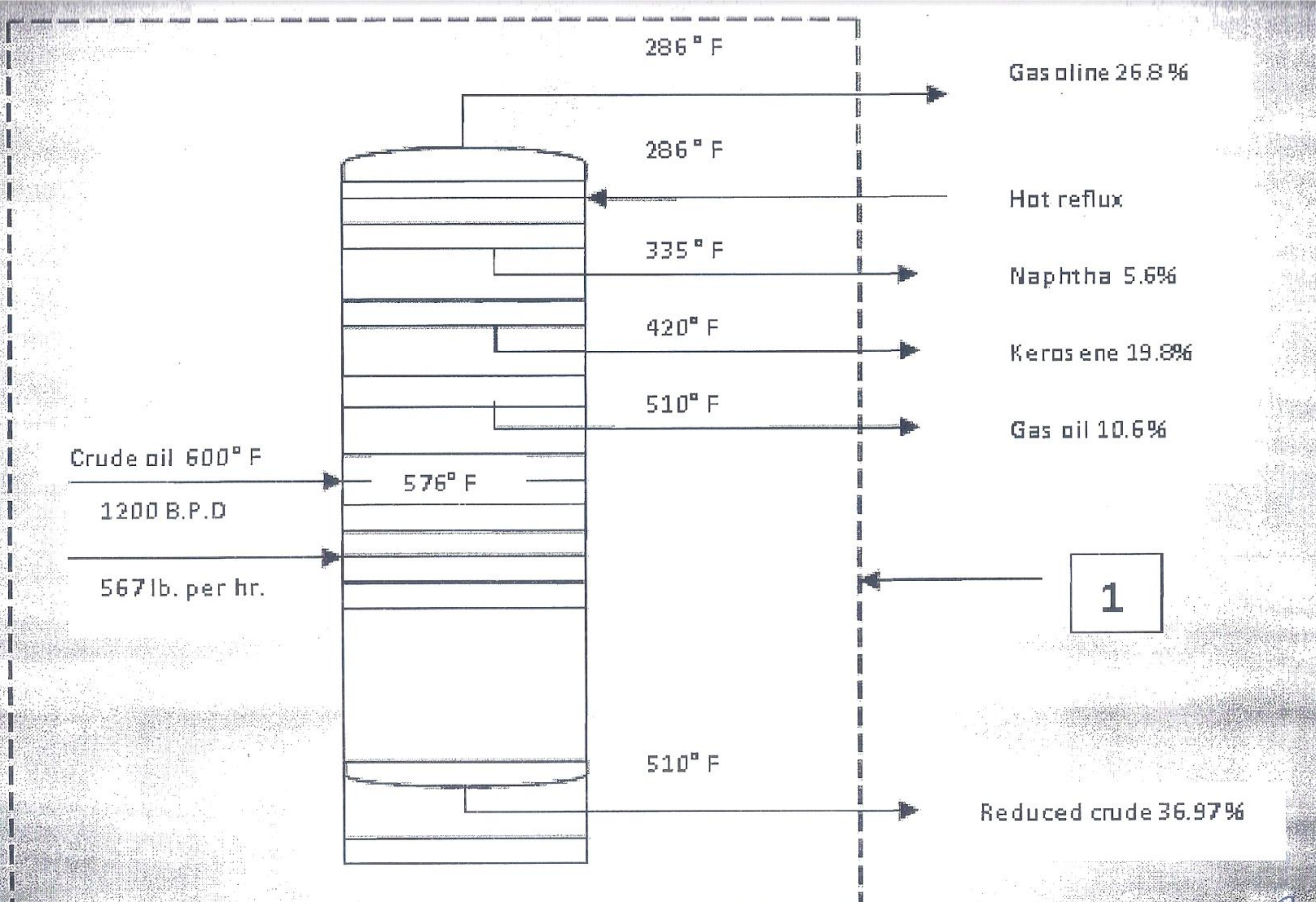
A heat balance of the simple tower system shown in Fig. below will be computed to determine the amount of heat that must be removed to keep the tower in thermal balance.

The capacity is 1200bbl per day (2100 gal per hour of a 12.1 to 12.2 Characterization Factor crude oil.

At 576 ^{o}F the gasoline, naphtha, kerosene, and gas oil are vapor and the reduced crude oil is a liquid.

A sufficient quantity of heat must removed from the vapors to cool them as vapors to the temperature at which they are withdrawn from the tower and to condense the naphtha, kerosene, and gas oil at their withdrawal temperature.

	Volume %	API	Lb/gal	Gal/hr	Lb/hr	50 % bp	Mol. wt	Latent heat
Gasoline	26.8	62.8	6.06	563	3415	260	110	**120**
Naphtha	5.63	52.8	6.39	118	754	370	155	**113**
Kerosene	19.8	45.6	6.65	416	2765	460	185	**100**
Gas oil	10.6	39.4	6.89	222	1530	585	240	**90**
Reduced crude	36.97	31.2	7.24	776	5610			
Loss	0.2				96			
Crude	**100.00**	**43.0**	**6.75**	**2100**	**14170**			



Solution : Energy Balance Basis =1hr

Sensible heat **Btu**

Gasoline (vapor) 3415 * (576 - 286) * 0.56 =	589000
Naphtha (vapor) 754 * (576 - 335) * 0.55 =	106000
Kerosene(vapor) 2765 * (576 - 420) * 0.57 =	261000
Gas oil (vapor) 1530 * (576 - 510) * 0.59 =	63000
Reduced crude (liquid) 5610 * (576 - 510) * 0.72 =	276000

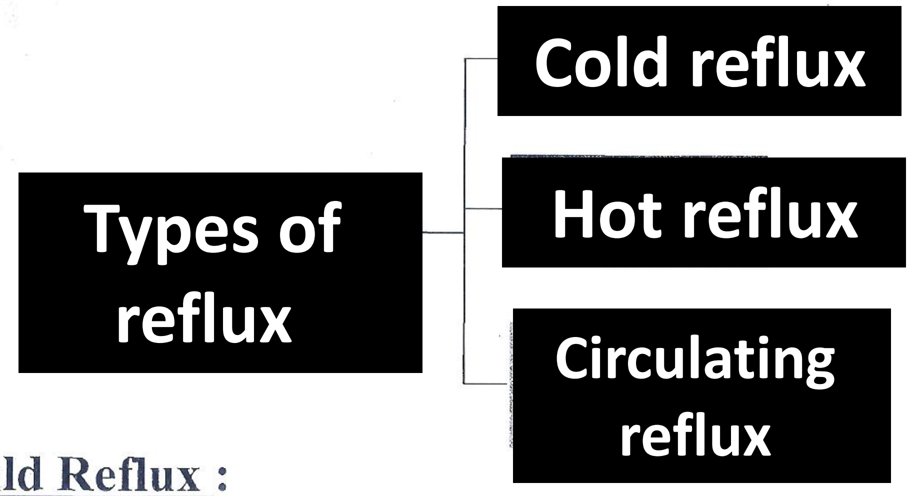
	1295000
Steam (vapor) 567 * (535 - 286) * 0.5 =	70600

	1365600

Latent heat **Btu**

Gasoline	(withdraw as vapor)	
Naphtha	754x113 =	85100
Kerosene	2765x100=	276500
Gas oil	1530x90=	138000

Total heat to be removed		1865200



1) Cold Reflux :

Is defined as reflux that is supplied at some temperature below the temperature at the top of the tower. Each pound of this reflux removes a quantity of heat equal to the its latent heat and the sensible heat required to raise it temperature from the storage tank temperature to the temperature at the top of the tower

$$Q = m\lambda + mC_{pL}\Delta T$$

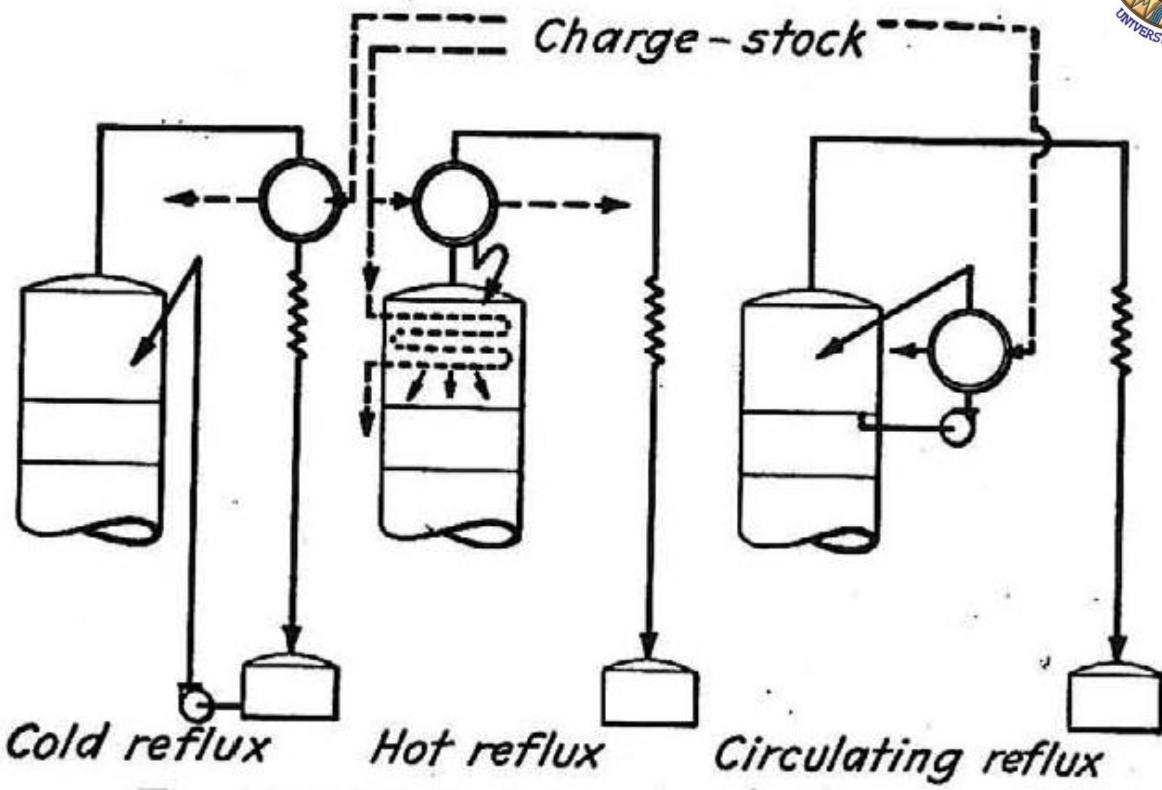
2) Hot Reflux:-

Admitted to the tower at the same temperature . Reflux or over flow from plate to plate in the tower is essentially hot reflux because it is always substantially at its boiling point. Hot reflux capable of removing only the latent heat because no difference in temperature is involved

$$Q = m\lambda$$

3) Circulating Reflux : It is not vaporized. It is only able to remove the sensible heat that is represented by its change in temperature as it circulate. This reflux is withdrawn from the tower as a liquid at a high temperature as a liquid and is returned to the tower after having been cooled.

$$Q = mC_{pL}\Delta T$$



Example (2) : **(Quantity of Reflux)**

A tower fractionating system is such that 1865200 Btu/hr of reflux heat must be removed.

Example (1) illustrates the method of determining the reflux heat.

How many pounds of (1) hot (2) cold, and (3) circulating reflux are required?

Solution

Hot reflux:

λ (Gasoline) =123 Btu/lb

lb of hot reflux = 1865200/120 = 15500 lb/hr

mole hot reflux = 15500/110 = 141

mole gasoline = 3415/110 = 31

moles vapor = 141 + 31 = 172

moles steam = 567/18 = 31.5

total moles at the top of the tower = 172 + 31.5 = 203.5

total pressure at the top of the tower = 780 mm Hg
the partial pressure in the gas phase is (172/203.5) * 780
= 660 mmHg (according to Daltons law $P_i = y_i P_T$)

The dew point of 100% gasoline on EFV curve = 296 °F (at 760 mm Hg)

>> At 660 mm Hg the temperature is calculated according to Claussius – Clapeyron Eq.

$$\ln \frac{p}{p_o} = \frac{\lambda}{R}\left(\frac{1}{T_o} - \frac{1}{T}\right)$$

R= 1.987 Btu/lbmole.°R

$$\ln \frac{660}{760} = \frac{120x110}{1.987}\left(\frac{1}{296+460} - \frac{1}{T}\right)$$

T=284 °F

The actual top temperature when using hot reflux = 286 °F

Cold reflux :

Assume storage tank at 80°F

$$\text{Lb cold reflux} = \frac{1865200}{120+(286-80)*0.58} = 7950$$

Moles cold reflux	= 7950/110 = 72.3
Mole gasoline	31
Moles vapor	103.3
Moles steam	31.5
Total moles	134.8

$$p = \frac{103.3}{134.8} * 780 = 600 \text{ mm Hg}$$

The equilibrium temperature of 296°F corrected to 600 mmHg= 275 °F

Circulating reflux :

When circulating reflux was used the top temperature was 244 °F.
Assuming the reflux is cooled from 264 to 166 °F.

Mole gasoline	31
Mole steam	31.5
Total moles	62.5

$$\text{Partial pressure} = \frac{31}{62.5} * 780 = 387 \ \text{mmHg}$$

Correction 296 to 387 mm pressure gives 253 °F

$$\text{Lb circulating reflux} = \frac{18652000}{120 + (264 - 166) * 0.605} = 10403$$

17 Moles reflux = 10403/110 = 94.6

Side-Draw Temperature:

1) The method of calculating side-draw temperature is much the same as the calculation of the top temperature except that complications arise because of the presence of the low boiling materials that pass the draw plate.

2) Making heat balance upon the drawn plate.

3) In practice, steam and vapor of lighter products are usually present, and hence the effect of these vapors on the final condensation temperature must be estimated. The lighter vapors extended from materials boiling at almost the same temperature as the side-draw product to materials that are substantially **fixed gases**.

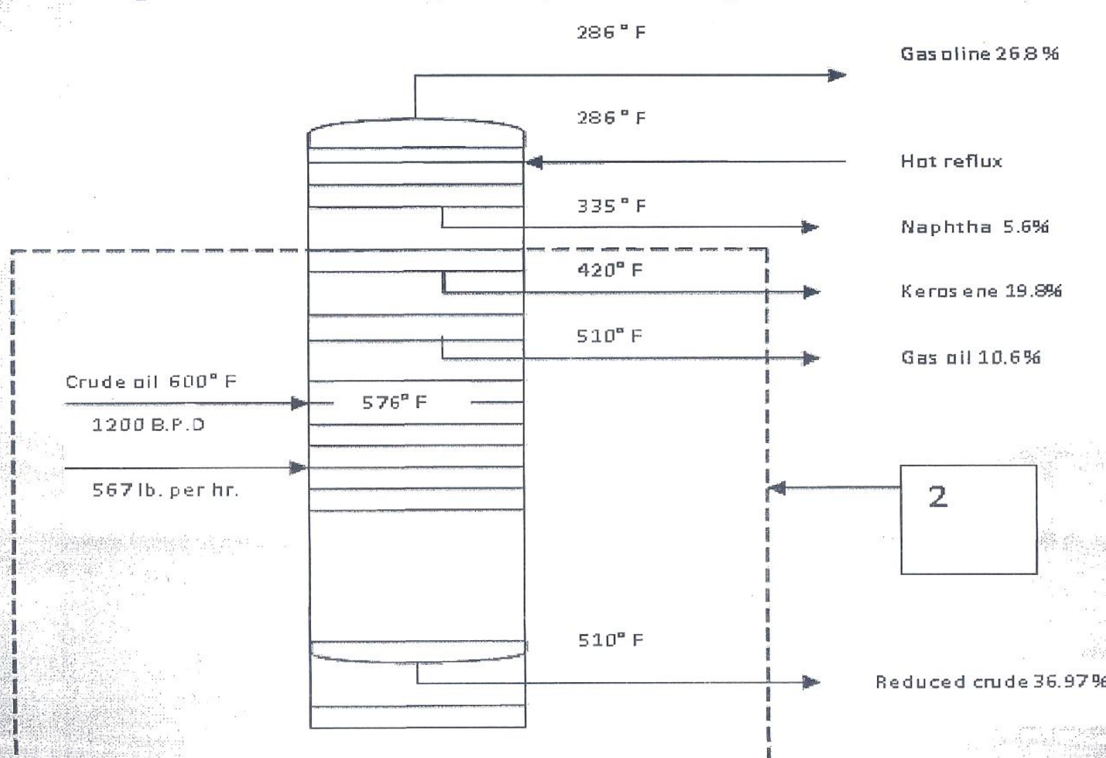
4) Those vapor materials which are far above their boiling point behave as fixed gases and lower condensation point by **Dalton's law of partial pressures**, just as steam does, but those vapor materials which are at or near their boiling point are not effective in reducing the partial pressure.

5) Arbitrarily, **the vapors materials that will be condensed at the second or higher draw plate above the plate under consideration may be considered to act as fixed gases.**

6) Also, **the vapor constituting the materials that is withdrawn from the draw plate above the one under consideration are assumed to have no effect at all on the partial pressure.**

7) thus in a tower producing, **gasoline, naphtha, kerosene, and gas oil , at the kerosene draw plate the gasoline vapor would be considered as a fixed gas , whereas naphtha vapor would assumed to have no effect on the condensation point.**

Example (3) : (Calculation of Side Temperature)
This example is a continuation of examples (1) and (2). The temperature of the kerosene plate will be computed.(actual temperature = 420°F)



Solution :

Heat balance on kerosene plate, quantity of reflux and reflux (or vapor reflux) must be determined.

Cool gasoline (vapor) = 3415 * (576 – 420) * 0.58 = 327000
Cool naphtha (vapor) = 754 * (576 – 420) * 0.57 = 71000
Cool kerosene(vapor) = 2765 * (576 – 420) * 0.57 = 260000
Cool gas oil (vapor) = 1530 * (576 – 510) * 0.58 = 62000
Reduced crude (liquid) = 5610 * (576 – 510) * 0.72 = 276000

996000

Cool steam	= 567 * (535 – 420) * 0.5 =	44000
Condense kerosene	= 2765 * 100 =	276500
Condense gas oil	= 1530 * 90 =	138000

Reflux heat at kerosene plate		1454000

Moles internal reflux = $\dfrac{Q_T}{(\lambda x M_W)_K} = \dfrac{1454500}{185x100} = 78.6$

Moles fixed gases

Steam	31.5
Gasoline	31
Naphtha no effect	------
	62.5

Total moles vapor = 62.5 + 78.6 = 141.1

Assume tower pressure at kerosene plate = 950 mmHg

$P_i = P_T * y_I$

Partial pressure $= \dfrac{78.6}{141.1} * 950 = 530$ mmHg

$$\ln \frac{p}{p_o} = \frac{\lambda}{R}\left(\frac{1}{T_o} - \frac{1}{T}\right)$$

$$\ln\frac{530}{760}=\frac{100*185}{1.987}\left(\frac{1}{445+460}-\frac{1}{T}\right)$$

T= 414°F

T actual = 420°F

H.W:

Repeat the example above, recalculate the temperature of the naphtha plate, assume a tower pressure of 810 mmHg?

H.W :

A) Calculate the amount of Hot, Cold and circulating reflux if the storage temperature is 100°F and $Cp_v = 0.6$ and $Cp_l = 0.7$ Btu/lb.°F

B) Check the top tower temperature if hot reflux is used. The dew point of gasoline is 296 ° F and the pressure at the top plate is 780 mm Hg.

Fraction	Lb\hr	M.w.	λ	Temperature ° F
Gasoline	33500	101	120	**310**
Kerosene	11800	185	108	**410**
Gas oil	32200	270	95	**510**
R.C	43500	-	-	**510**
Steam	600	18	-	**580**
C.O.	**121000**	-	-	**576**

Calculation of The Diameter of Distillation Column.

Example (4): See examples 1, 2 and 3 the quantities and conditions will be taken from these examples.

Solution:

Density of vapor at top of column (the reflux in the column is always hot reflux)

Mole gasoline	31
Mole hot reflux	141
Mole steam	31.5

Total moles	203.5

P=780 mm Hg

T=286 ° F

$$\text{Volume of vapors} = \frac{nRT}{P} = \frac{203.5 * 379 * (286 + 460) x 760}{780 * 520} = 107600\ ft^3$$

Mass of vapor =

mass of gasoline + mass of hot reflux + mass of steam

= 3415 + 15500 + 567 = 19482 lb/hr

ρ_V =19482 / 107600 = 0.181 lb/ft^3

Assume density of liquid ρ_l = 42.7 lb/ft^3

$$\frac{w}{a} = K\sqrt{\rho_v(\rho_l - \rho_v)}$$

Assume K= 735, K is constant dependent primarily on the tray spacing.

$$\frac{w}{a} = 2040\frac{lb}{hr x ft^2}$$

$$A = \frac{mass}{mass velocity} = \frac{19482}{2040} = 9.55\ ft^2$$

$$D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4x9.55}{\pi}} = 3.5\,ft^3$$

To check the vapor velocity at top (3.5 ft/sec)

$$u = \frac{v}{A} = \frac{107600}{9.55 * 3600} = 3.13\,ft/\sec \quad , u \text{ is ok}$$

H.W:

120000 Lb/hr of 34°API crude oil at 650°F is fed to an atmospheric distillation unit. Steam at a rate of 600 lb/hr and 850°F is used.

The fraction obtained were 34000 lb/hr gasoline (MW=110, λ=120) at 310 °F; 12000 lb/hr kerosene (MW=185, λ=108) at 420 ° F; 30000 lb/hr gas oil (MW=270, λ=95) at 510 °F .

The residue is withdrawn at 510°F. **Assume** C_{PL}= 0.7 ,C_{PV}= 0.6 Btu/lb.°F.

a) Check the top tower temperature if the dew point of gasoline is 296 ° F and the pressure at the top plate is 780 mm Hg.

b) Calculate the diameter of the tower if K=735 and ρ_l= 42.7 lb/ft^3.