RADMAN SANA'T CO.
CONSULTING ENGINEERS

Instructions manual

Continuous tray Distillation Tower

Distillation

A distillation column is an essential part used in the distillation of liquid mixtures to separate the mixture into its components, based on the differences in volatilities. Fractionating columns are used in small scale laboratory distillations as well as large scale industrial distillations. Fractional distillation is one of the unit operations of chemical engineering Fractionating columns are widely used in the chemical process industries where large quantities of liquids have to be distilled Such industries are the petroleum processing, petrochemical production, natural gas processing, coal tar processing, brewing, liquefied air separation, and hydrocarbon solvents production and similar industries but it finds its widest application in petroleum refineries. In such refineries, the crude oil feedstock is a complex, multicomponent mixture that must be separated, and yields of pure chemical compounds are not expected, only groups of compounds within a relatively small range of boiling points, also called fraction That is the origin of the name fractional distillation or fractionation. It is often not worthwhile separating the components in these fractions any further based on product requirements and economics.

Distillation is one of the most important and most commonly methods of separation and is based on the distribution of components between two liquid and gas phases. In fact, distillation is one of the most common ways of separating materials from one another due to the difference in boiling point. Distillation is a physical process for the separation of objects with boiling temperature.

In general, the distillation tower consists of four main parts:

1.Tower

2.Reboiler

3.Condensor

4.Auxiliary equipment includes: a variety of control systems, waste heat exchanger, pumps and product collection tanks, waste tank, feed tank, trays and sample valves.

Tower

Generally towers used in the industry for distillation are divided into two basic categories :

1.tray Towers

2.Packed Towers

Tray towers are divided into 4 categories based on the types of trays used in it:

1.Jet Tray Towers

2.Sieve Tray Towers

3.Bubble Cap Towers

4.Valve Tray Towers

Performance of a tray tower

Generally, the process that occurs in a tray tower is the process of separating the mixtures As mentioned above, the process is carried out directly or indirectly. In the process of distillation of the heat source, it provides the heat necessary for distillation and separation of the material of a solution. The rising steam from the tower moves through the top of the tower to the bottom of the tower, causing direct contact with the trays. This contact causes a rise in the temperature of the liquid on the tray and eventually causes the temperature of the liquid to approach the bubble temperature. As the liquid reaches the bubble temperature, the first steam particles are gradually produced, which is a vapor that is rich in volatile matter (a substance that has a lower boiling point or a higher pressure). On the other hand, in the vapor phase, materials that have a lower boiling point are subjected to liquefy and move in the

liquid phase towards the bottom of the tower. The most important function of a tower is to create an appropriate contact point between the vapor and liquid phases. The higher the level of contact. Of course, the fluid flow regime on the tray is also one of the important factors on the performance of a tower.

Industrial distillation towers are usually operated at a continuous steady state. Unless disturbed by changes in feed, heat ambient temperature, or condensing, the amount of feed being added normally equals to the amount of product being removed. The heat entering a distillation column is a crucial operating parameter, addition of excess or insufficient heat to the column can lead to foaming, weeping, entrainment, or flooding.

Figure 1 depicts an industrial fractionating column separating a feed stream into one distillate fraction and one bottoms fraction. However, many industrial fractionating columns have outlets at intervals up the column so that multiple products having different boiling ranges may be withdrawn from a column distilling a multi-component feed stream. The "lightest" products with the lowest boiling points exit from the top of the columns and the "heaviest" products with the highest boiling points exit from the bottom.

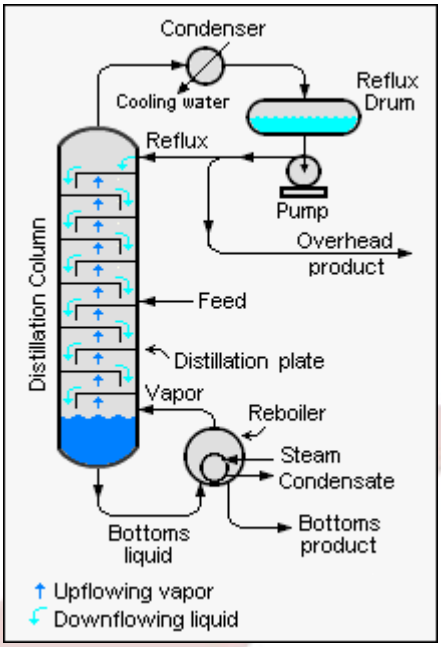

Fig1. Continuous tray distillation

Industrial fractionating columns use external reflux to achieve better separation of products Reflux refers to the portion of the condensed overhead liquid product that returns to the upper part of the fractionating column as shown in Figure. Inside the column, the down flowing reflux liquid provides cooling and condensation of up flowing vapors thereby increasing the efficacy of the distillation tower. The more reflux and or more trays provided, the better is the tower's separation of lower boiling materials from higher boiling materials. The design and operation of a fractionating column depends on the composition of the feed and as well as the composition of the desired products. Given a simple, binary component feed, analytical methods such as the McCabe–Thiele method or the Fenske equation can be used.

Bubble-cap "trays" or "plates" are one of the types of physical devices, which are used to provide good contact between the up flowing vapor and the down flowing liquid inside an industrial fractionating column. Such trays are shown in below Figures

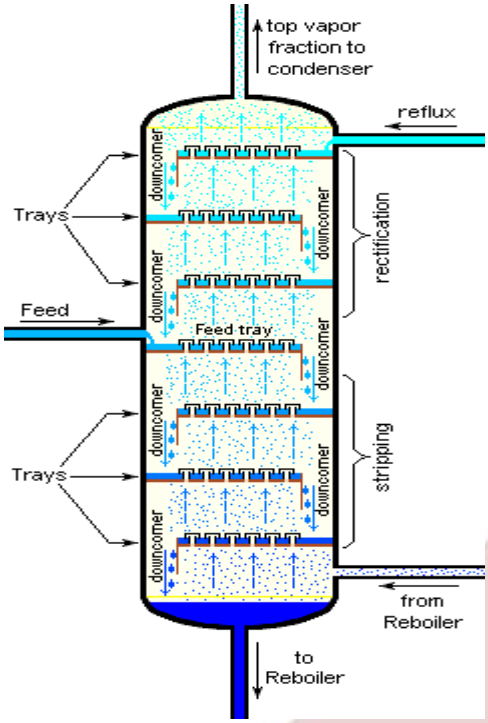

Fig3. Tray of tower

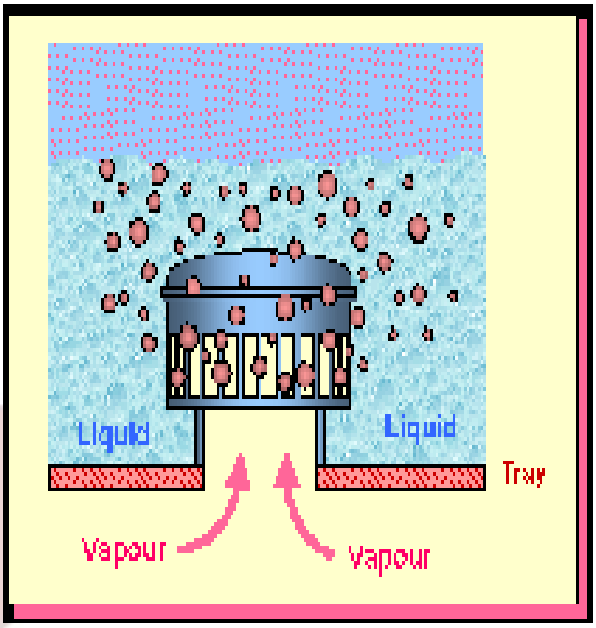

Fig2. Bubble cap

Bubble caps are used to provide proper contact between gas and liquid inside the distillation column. These cap trays are shown in the figure above .The efficiency of a tray or plate is typically lower than that of a theoretical 100% efficient equilibrium stage. Hence, a fractionating column almost always needs more actual, physical plates than the required number of theoretical vapor–liquid equilibrium stages In industrial uses, sometimes a packing material is used in the column instead of trays, especially when low pressure drops across the column are required, as when operating under vacuum. This packing material can either be random dumped packing (1–3 in or 2.5– 7.6 cm wide) such as Raschig rings or structured sheet metal. Liquids tend to wet the surface of the packing, and the vapors pass across this wetted surface, where mass transfer takes place. Differently shaped packings have different surface areas and void space between packings. Both of these factors affect packing performance.

Fenske Equation

The Fenske equation in continuous fractional distillation is an equation used for calculating the minimum number of theoretical plates required for the separation of a binary feed stream by a fractionation column that is being operated at total reflux When designing large-scale, continuous industrial distillation towers, it is very useful to first calculate the minimum number of theoretical plates required to obtain the desired overhead product composition.

$$N = \frac{\log[\left(\frac{xd}{1-xd}\right)\left(\frac{1-xb}{xb}\right)]}{log\alpha av}$$

N is the minimum number of theoretical plates required at total reflux (of which the reboiler is one)

xd is the mole fraction of high volatile component in the overhead distillate,

xb is the mole fraction of high volatile component in the bottoms

αav is the average relative volatility of the high volatile component to the low volatile component

Distillation Columns

The concept of theoretical plates in designing distillation processes has been discussed in many reference texts Any physical device that provides good contact between the vapor and liquid phases present in industrial-scale distillation columns or laboratory-scale glassware distillation columns constitutes a "plate" or "tray". Since an actual, physical plate can never be a 100% efficient equilibrium stage, the number of actual plates is more than the required theoretical plates.

$$Na = \frac{Nt}{\mathrm{E}}$$

where Na is the number of actual, physical plates or trays. Nt is the number of theoretical plates or trays and E is the plate or tray efficiency. The trays or plates used in industrial distillation columns are fabricated of circular steel plates and usually installed inside the column at intervals of about 60 to 75 cm (24 to 30inches) up the height of the column. That spacing is chosen primarily for ease of installation and ease of access for future repair or maintenance An example of a very simple tray is a perforated tray. The desired contacting between vapor and liquid occurs as the vapor flowing upwards through the perforations, comes into contact with the liquid flowing downwards through the perforations.

To design a distillation unit or a similar chemical process, the number of theoretical trays or plates (that is, hypothetical equilibrium stages), Nt, required in the process should be determined, taking into account a likely range of feedstock composition and the desired degree of separation of the components in the output fractions. In industrial continuous fractionating columns, Nt is determined by starting at either the top or bottom of the column and calculating material. balances, heat balances and equilibrium flash vaporizations for each of the succession of equilibrium stages until the desired end product composition is achieved. The calculation process requires the availability of a great deal of vapor–liquid equilibrium data for the components present in the distillation feed, and the calculation procedure is very complex. In an industrial distillation column the Nt required to achieve a given separation also depends upon the amount of reflux used. Using more reflux decreases the number of plates required and using less reflux increases the number of plates required. Hence, the calculation of Nt is usually repeated at various reflux rates. Nt is then divided by the tray efficiency, E to determine the actual number of trays or physical plates, Na needed in the separating column. The final design choice of the number of trays to be installed in an industrial distillation column is then selected based upon an economic balance between the cost of additional trays and the cost of using a higher reflux rate.

There is a very important distinction between the theoretical plate terminology used in discussing conventional distillation trays and the theoretical plate terminology used in the

discussions below of packed bed distillation or absorption or in chromatography or other applications. The theoretical plate in conventional distillation trays has no "height". It is simply a hypothetical equilibrium stage. However, the theoretical plate in packed beds, chromatography and other applications is defined as having a height.

Device Description

The set-up has a distillation tower (a) that has 5 trays and 1 cap on each tray with a diameter of 1.25 inches (3.175 cm) It is installed that the distance between two trays is 20 cm and the inner diameter of the tower 7 cm (b) A thermometer is installed on the trays to measure the temperature of the liquid on the tray. On each tray there is a valve for sampling liquid on the tower (c). The boiler is heated by a heater with a capacity of 2 kW. A thermometer (T_v1) is installed on the evaporator boiler, which shows the steam temperature inside the boiler. At the beginning of the work the pressure of the boiler is atmospheric. But during work, because there is liquid on all trays And the set-up enters the atmosphere through the condenser (g). The pressure inside the boiler is a little more than atmospheric util to compensate for the pressure drop that the steam has as it passes through the tower.
feed include mixture of ethanol, mixture flow in feed tank adjusted by peristaltic pump p1, mixture pumped towards the preheater tank. There is a 300 watt heater in the preheater tank After the temperature rises, mixture pumped in to the middle of the distillation tower. The condenser at the top of the tower has an effective surface area of about 200 cm2 square centimeters.

And is cooled with cold water. Cold water flow rate can be adjusted with a rotameter Inlet and outlet water temperature is measured by two thermometers (T in and Tout). The steram in this condenser are counter-current and the reflux rate for the tower can be adjusted by a

peristaltic pump (p2). Peristaltic pump is used to adjust the reflux flow rate and the product. The product is collected in the product tank on the right side of the device. Adjacent to the reboiler tank, sight glass is considered Which shows the remaining mixture to the heat exchanger and finally to the waste tank after condensing process.

According to the device PID below, we have:

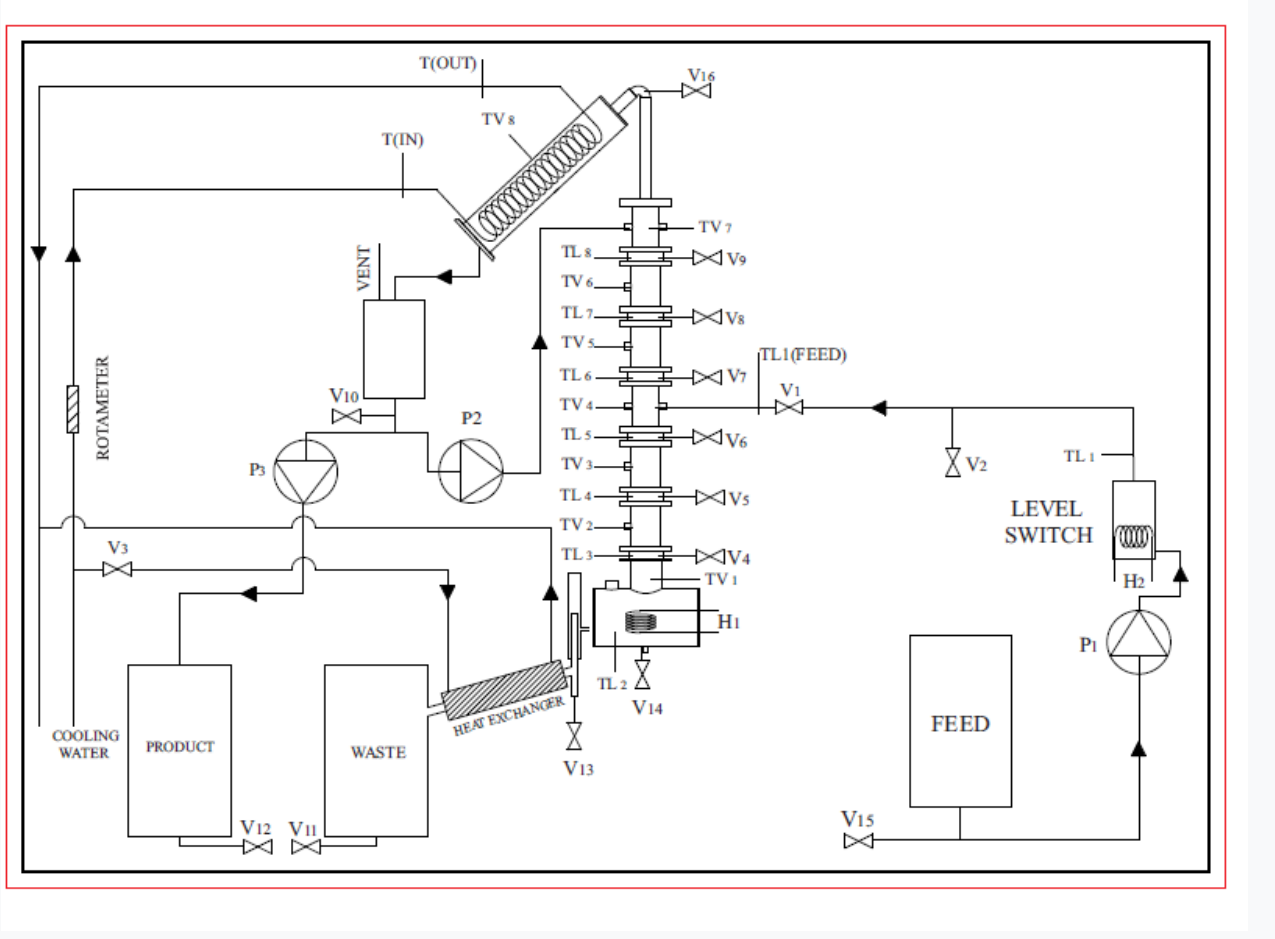

Fig4. PID Unit

TL2 : boiler temperature

TL3 to TL8 : Liquid temperature on trays

TV01: Steam temperature inside the boiler tank

TV02 to TV07: Steam temperature in the distillation tower

T08: Condensed product temperature in the condenser

Tin and Tout: inlet and outlet temperature of condenser water

V4 to V9: sampling valve on trays

Touch Panel

First, turn on the heater related to the boiler tank (heater 2) and set its to the desired temperature (set point) . First, the tower works at total reflux, after the tower reaches a steady state and we get sample from the tower, then Turn on the Metering pump and Set flow of pump to a certain value so that the process is continuous throughout the tower.
To turn on the heater preheating tank for the feed (heater 1), as shown in the figure below, then set its to the desired temperature (set point) .
To record data in the Set up -in part on the device, put the flash memory and at the end of the work for record data press TRANSFER DATA on the touch panel then the data is available as an Excel file.

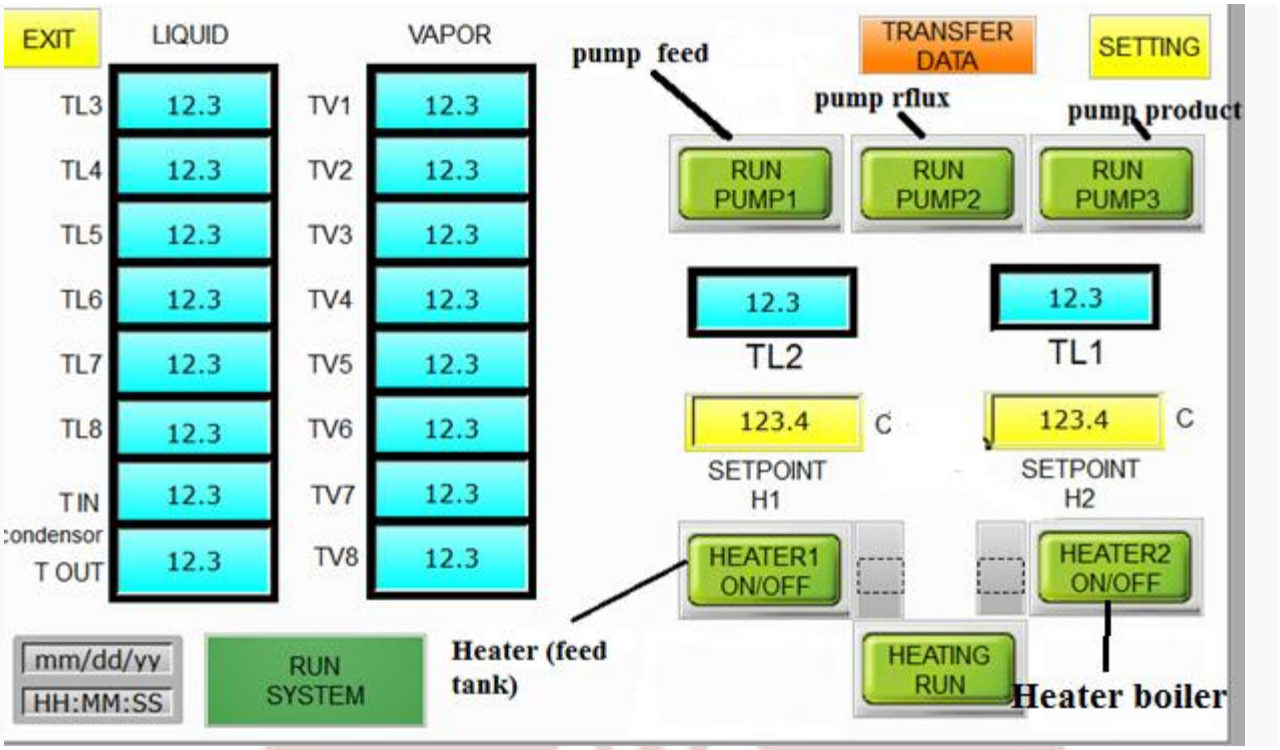

Fig5. Touch Panel Unit

How to do experiment

1. Prepare solution of 10% (volume of ethanol) and fill it in the boiler tank. the alcohol content of the sample measure with a hydrometer.
2. Prepare solution of 10% ethanol and water and fill the feed tank until it is relatively full. (Do not use distilled water)
3. Turn on the heater inside the reboiler allow for the distillation tower to warm up(25 minutes) and the temperature of TV1 reaches to the 90℃
4. Turn on preheater. Give the system some time to Keep the temperature of outlet solution the preheater at about 58 ° C. **Make sure that valve V1 on the preheating tank is open.** The temperature of the preheater heater is set the temperature range of the feed tray (to prevent heat shock)

5. Adjusting rotameter of condenser on appropriate flow rate of water.
6. Using the sampling valve, sampling the product and the WASTE tank and determine the percentage of alcohol with hydrometer.
7. Using the P2 peristaltic pump, adjust the reflux to a specified value (2.4 Lit / min). On these pumps, an adjusting screw is installed, which is pumped by placing a certain flow mark on each line.
8. Note that the set-up must operate in total reflux conditions.
9. Wait for the steam to enter the condenser and liquefy.
10. Write down the necessary information about the condition of the tower and the condenser in three steps, 5 minutes apart.
11. Then turn on the metering pump P1 for the feed Adjust the feed pump flow to a specified value so that the process is continuous throughout the tower.
12. After reaching steady state, read the temperature values along the tower
13. By adjusting rate of condenser, the rate of separation can be changed.
14. Now the ratio of liquid returned to the system can be changed as desired and sampled after the system is steady state
15. Allow the system 4 or 5 minutes to raeches steady state.
16. Write down the necessary information about the condition of the tower and the condenser
17. Be careful not to fill the WASTE tank. It is better to connect to the sewage after sampling
18. Finally close all valves and turn off the heater.
19. After cooling the set-up , turn off the cold water of condenser
20. Washing the tower by using water.

Peristaltic Pumps

A peristaltic pump is a type of positive displacement pump used for pumping a variety of fluids. The fluid is contained within a flexible tube fitted inside a circular pump casing. As the rotor turns, the part of the tube under compression is pinched closed thus forcing the fluid to be pumped to move through the tube.

point	Flow rate(LPH)
2	0.94
3	1
4	1.5
5	1.8
6	2.4
7	2.9
8	3.2
9	5.5
10	7
11	8
12	9

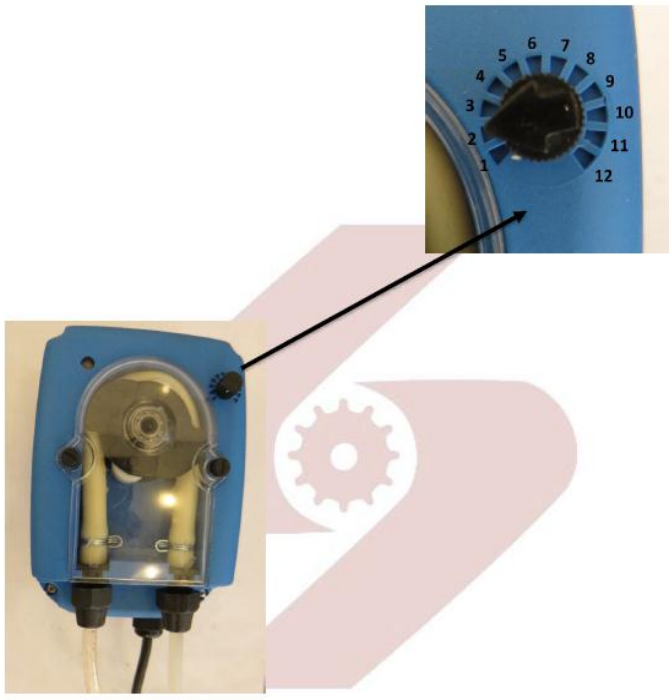

Fig6. Peristaltic pump

calculation mol fraction:

100cc=vol of sample

T=K

V1٪= vol% of ethanol(condenser)

V2%=100- V1%=vol% of water(condenser)

100*V1%= CC volume of alcohol

100*V2%= CC volume of water

volume of alcohol *0.7862= gr mass alcohol

volume of water *0.9965= gr mass water

gr mass alcohol/ 46.07 mol alcohol

gr mass alcohol/ 18.02 mol water

mol water/ (mol water+ mol alcohol) mol fractional of water

mol alcohol/ (mol water+ mol alcohol) mol fractional of alcohol

Heat transfer (QC) in the condenser:

QC=m(H2O)*CP(H2O)*(T8-T7) J/S

T8: Temperature water out of condenser

T7: Temperature water input to condenser

m(H2O)=ρ(H2O)*Q(H2O) Kg/s

Q(H2O)=Flow of water to the condenser

Fenske equation(Nmin)

P* = exp [c1 + (c2 / T) + c3* lnT – c4 *T^0.5]

P1*A=Vapor pressurA top of the tower kpa

P*2A = Vapor pressurA bottom of the tower kpa

P1*B= Vapor pressurB top of the tower kpa

P2* B=Vapor pressurB top of the tower kpa kpa

volatile top of the tower= P1*A/P1*B

volatile bottom of the tower = P2*A/P2*B

Xd=mol fraction condenser Xw =mol fraction boiler

Nm+1 = log(xd / xd – 1) * (1- xw / xw) / log α av

Determine the number of equilibrium stages (McCabe–Thiele method)

equation of Feed line

$$yf = \frac{\mathrm{q}}{\mathrm{q}-1}x - \frac{\mathrm{zf}}{\mathrm{q}-1}$$

We have 5 stages the number of actual plates is more than the required theoretical plates therefor efficiency is:

$$Na = \frac{Nt}{\mathrm{E}}$$