In the name of God,who is the merciful

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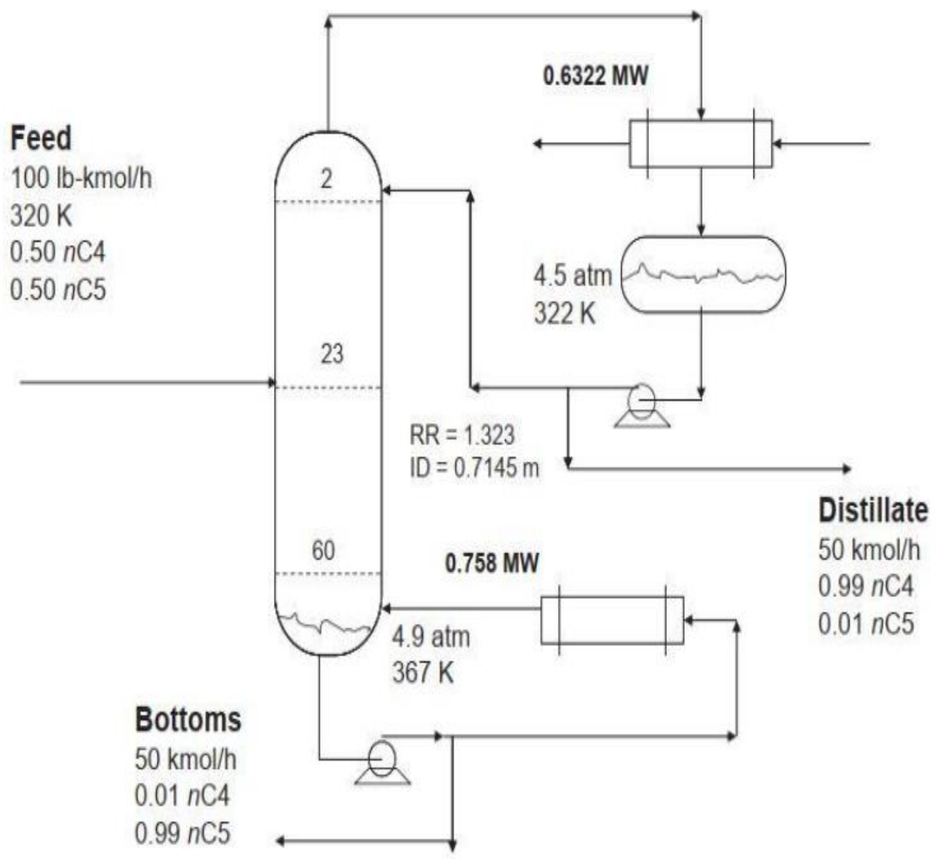
Distillation is a common separation technique for liquid streams containing several components and is one of the most important unit operations in chemical manufacturing processes. Distillation is designed and controlled to produce a product stream of the required purity, whether for sale or for use in other chemical processes. Distillation is based on the separation of the components of a liquid mixture by the difference in their boiling points. The pure component that boils at a lower temperature is the light component and the pure component that boils at a higher temperature is the heavy component. For example, in a mixture of benzene and toluene, benzene is the light component and toluene is the heavy component. A saturated liquid mixture of the two components at a certain concentration is in equilibrium with the vapor phase where the concentration of the light component is highest relative to the liquid phase. Let x be the mole fraction of the light component in the liquid phase and y be the mole fraction of the light component in the vapor phase. For ideal mixtures, the phase equilibrium relationship is modeled based on relative

Evapotranspiration by the following equation:

$$y = \frac{\alpha x}{1 + (\alpha - 1)x}$$

where alpha represents the relative volatility. If we consider a conceptual design of the operation of a two-component distillation tower, the feed usually enters near the middle of the tower. The vapor flows from one stage to the next from the bottom up in the tower, while the liquid flows from one stage to the next from the top down in the tower. The vapor is condensed in the top tray and a portion of that liquid is refluxed back into the tower. The remaining liquid is removed as the product stream. The liquid leaving the bottom of the tower, which contains components with lower relative volatility, is also considered the bottom product of the tower, and the remaining liquid stream is vaporized through a reboiler and re-enters the tower. The liquid passing through each initial tray overflows and flows through a chute to the next tray. When the liquid moves in the cylinder, it comes into direct contact with the vapor passing through the holes of the cylinder and mass transfer occurs between the two phases. Do your nomenclature in such a way that the mole fraction of liquid and vapor leaving the first cylinder are considered as xi and yi, respectively. Also, represent the molar flow rate of liquid and vapor leaving the same cylinder as Li and Vi in the equations, respectively. Since the liquid entering this cylinder comes from the previous cylinder (the naming of the cylinders of the tower is considered from top to bottom), use xi−1 and Li−1 for the liquid mole fraction and its molar flow rate, respectively. Using a similar argument, this time for the next cylinder, which is the source of the vapor to the current cylinder, use yi+1 and Vi+1 for its molar fraction and molar flow rate, respectively. Now, let's proceed to modeling the normal butane and normal pentane distillation towers. First, you should review the problem specification and the governing assumptions and equations. A butanizer column is considered as a sample. A mixture of 50 mol% n-butane (4nC) and 50 mol% n-pentane (5nC) is separated in a column with 61 equilibrium stages. The feed molar flow rate is 100 km/h and the feed enters the equilibrium stage 23 (the condenser is stage 1). The design specifications are 1 mol% pure 5nC in the distillate and 1 mol% pure 4nC in the bottoms of the tower, which are considered as the desired specifications. The reflux drum pressure is set at 4.5 atmospheres to obtain a reflux drum temperature of 322 K so that cooling water can be used in the condenser. Figure 1 shows the flowsheet with its design conditions. The column diameter is 0.7145 m, the reflux ratio is 1.323, and the boiler heat load is 0.758 MW. The tray pressure drop is specified as 0.1 psi at each stage. With a reflux-drum pressure of 4.5 atm and 60 p in the column, the bottom pressure of the tower is also 4.9 atm.

You can see the overal picture of this system in the next page.



Debotanizer Tower Flowsheet

First, check how many degrees of freedom this distillation tower has, by setting it to zero, we can solve the equations governing the tower and control the tower in steady state conditions (the answer is 5). Now that the degrees of freedom of the distillation tower are equal to 5, 5 control loops are required to set it to zero. The control loops of the tower are:

Reboiler heat load control

Condenser heat load control

Distillate product control

Tower downflow control

Tower return flow control

The distillate controller regulates the composition and quality of the product. In many systems, this controller adjusts the reflux ratio to maintain the desired product purity. If the controller determines that the top product meets specifications or needs to reach a desired purity, it can increase the reflux ratio and return more liquid to the tower, which will separate more of the lighter components from the heavier ones. Similarly, the bottom product controller is responsible for the purity of the bottom product. This loop often adjusts the reboiler rate, which is the energy input to the boiler, to control the concentration of the heavier component in the lower sections. If the product is to be purer, the reboiler steam velocity is increased, providing more steam to carry the heavier components from the bottom of the tower up to the top of the tower where they can be effectively separated. The reflux control loop regulates the flow of the reboiler to the condenser. The reflux ratio, which is the rate of reflux of liquid to distillate, is a key variable in determining the efficiency and effectiveness of a tower. The reflux rate control loop is often tied closely to the distillation controller to meet the tower separation specifications. Each control loop is critical to the distillation process. They are usually integrated in such a way that changes in one loop can affect the others and require careful balancing and tuning by process control engineers. Advanced control strategies, such as multivariable control, cascade control, or model predictive control, may be implemented to optimize the performance of these loops. It is important to note that a valve must be considered on the feed to the tower and for the outlet streams, and its pressure-flow relationship must be included in your calculations. In distillation towers, a temperature control strategy is usually used to control the quality of the products, rather than directly measuring the concentration of the main light and heavy components at the bottom and top of the tower, respectively (two-point control approach1). This is because not only are online concentration measurement equipment usually very expensive, but the measurement signal is also delayed. On the other hand, due to the large interaction between the control loops in the decentralized two-point control approach (whether based on temperature measurement or concentration measurement), the single-point temperature control approach is usually used. For this purpose, the temperature of one of the trays of the tower is selected and controlled. Various methods have been proposed for selecting the appropriate tray, the most common of which is selecting the tray at the location where the greatest change in the temperature profile of the tower occurs. Considering the dependence of concentration on the Temperature,by measuring the tray temperature,Inferring the concentration and, in the event of disturbances, maintaining the concentration distribution and product quality close to the desired value. For this reason, this method is called the inferential control strategy.

1. First, write all the assumptions, equations and equilibrium relations related to the vapor and liquid phases for modeling, and then write the total and partial mass balance and energy balance for the condenser, reboiler, trays of the Rectifying and Stripping sections, and the feed tray.

2. First, check in the open circuit mode whether the system reaches the steady state of the process or is always unstable. If it is not stable, consider at least the control loops to stabilize its state and calculate the steady values of all state variables and output variables and explain how to calculate them.

3. According to the investigations carried out and the sensitivity analysis of the temperature profile along the tower, it has been determined that the highest temperature change slope is related to the equilibrium stage 55. Now apply the mentioned control loops and check the system in closed circuit. Note that the controlled variables are the top pressure of the tower, the liquid height of the reflux drum, the liquid height of the sump tower, the equilibrium stage temperature of the 55th stage, and the feed entering the tower.

4. Initially, identify the system by applying a step change and then design a PI controller using the ITSE and IAE methods to control the pressure and temperature. Then simulate the closed-loop system in Simulink and examine the dynamic response of the process to a ±10% change in the setpoint of each controller and compare it with each other.

5. Consider the system simulated in the previous step and this time compare the performance of the controllers to the disturbance rejection with a ±10% change in the feed molar flow rate, the normalized mole fraction of butane in the feed, and the inlet flow temperature, and obtain the stability limits of the controllers.

6. As explained in the project form, one of the control approaches is the output control. Now, the goal is to control the normal butane concentration of the output in the distillate product with this approach. In this way, by controlling the temperature of the equilibrium stage, you should keep the normal butane concentration of the output at 98% molar.

Resources

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