

Chapter 5: Multi-Stage Distillation

These problems ask you to calculate temperatures, flow rates, and compositions of all streams in a multi-stage distillation column. Assume EMO (equimolal overflow) and equilibrium stages. Typically, a solution can be found if the feed is completely specified (including feed stage) and two more process specifications are made. For example, the reflux ratio and percentage recovery of a chemical in a product stream could be specified. Since we are demonstrating a small number of stages, the “brute force” method will be used – iteratively solving all equations at one time.

5.1 50 mol/s of an equimolar mixture of benzene and toluene is fed to the middle stage of a three-stage distillation column operating at 1 atm. The feed is a saturated liquid at 1 atm such that it all contributes to the liquid flowing down from Stage 2 to Stage 3. The top stage (Stage 1) acts as a partial condenser and the bottom stage (Stage 3) acts as a partial reboiler. The vapor product from Stage 1 has a flow rate of 25 mol/s and the reflux ratio is 1 (meaning that the amount of liquid from Stage 1 returning to Stage 2 is the same as the amount of vapor product). Determine all unknown flow rates, compositions, and temperatures.

5.2 100 mol/h of a liquid containing 5.0 mol% ethanol and 95.0 mol% water is fed to the fourth stage of a five-stage distillation column operating at 1 atm. The feed is a saturated liquid at 1 atm such that it all contributes to the liquid flowing down from Stage 4 to Stage 5. The top stage (Stage 1) acts as a partial condenser and the bottom stage (Stage 5) acts as a partial reboiler. The product vapor is 60.0 mol% ethanol and the reflux ratio is 3.0 (meaning that the amount of liquid from Stage 1 returning to Stage 2 is 3.0 times the amount of vapor product). Determine all unknown flow rates, compositions, and temperatures.

5.3 1,000 kmol/h of a vapor containing 80 mol% water and 20 mol% isopropanol is fed to the second stage of a four-stage distillation column operating at 1 atm. The feed is a saturated vapor at 1 atm such that it all contributes to the vapor flowing up from Stage 2 to Stage 1. The top stage (Stage 1) acts as a partial condenser and the bottom stage (Stage 4) acts as a partial reboiler. 80 mol% of the isopropanol fed to the process is in the liquid product and the reflux ratio is 1.5 (meaning that the amount of liquid from Stage 1 returning to Stage 2 is 1.5 times the amount of vapor product). Determine all unknown flow rates, compositions, and temperatures.

5.4 200 mol/s of an n-hexane (30 mol%) and n-octane (70 mol%) mixture is fed to the middle stage of a three-stage distillation column operating at 1000 mm Hg. The feed is a mixture of vapor and liquid that half contributes to the vapor flowing up from Stage 2 to

Stage 1 and half contributes to the liquid flowing down from Stage 2 to Stage 3. The top stage (Stage 1) acts as a partial condenser and the bottom stage (Stage 3) acts as a partial reboiler. 80 mol% of the n-hexane fed is in the vapor product and the boilup ratio is 2.0 (meaning that the amount of vapor flowing up from Stage 3 to Stage 2 is twice that of the liquid product from Stage 3.) Determine all unknown flow rates, compositions, and temperatures.

5.5 100 mol/s of an equimolar mixture of styrene and ethylbenzene is fed to the middle stage (Stage 3) of a five-stage distillation column operating under vacuum at 100 mm Hg. The feed is slightly subcooled such that the liquid flow rate from Stage 3 to Stage 4 is 125 mol/s greater than the liquid flowing down from Stage 2 to Stage 3. The top stage (Stage 1) acts as a partial condenser and the bottom stage (Stage 5) acts as a partial reboiler. The split of vapor product from Stage 1 and liquid product from Stage 5 is equal. The reflux ratio is 2.0 (meaning that the amount of liquid flowing down from Stage 1 to Stage 2 is twice that of the vapor product from Stage 1.) Determine all unknown flow rates, compositions, and temperatures.

5.6 100 mol/s of a mixture containing water (60 mol%) and methanol (40 mol%) is fed to the middle stage of a three-stage distillation column operating at 1 atm. The feed is a saturated liquid at 1 atm so that it all contributes to the liquid flowing down from Stage 2 to Stage 3. The top stage (Stage 1) acts as a partial condenser and the bottom stage (Stage 3) acts as a partial reboiler. The product liquid from Stage 3 is 90.0 mol% water and the reflux ratio is 1.25 (meaning that the amount of liquid from Stage 1 returning to Stage 2 is 1.25 times the amount of vapor product). Determine all unknown flow rates, compositions, and temperatures.

5.7 10 gal/h of a 20-proof ethanol in water mixture is to be concentrated to 90-proof in a five-stage distillation column operating at 1 atm. The feed to Stage 3 is a slightly subcooled liquid so that the liquid flowing down from the feed stage is 5.0 mol% greater than expected because the feed condenses some of the vapor flowing up into the feed stage. The top stage (Stage 1) acts as a partial condenser and the bottom stage (Stage 5) acts as a partial reboiler. The reflux ratio is 2.0 (meaning that the amount of liquid from Stage 1 returning to Stage 2 is 2.0 times the amount of vapor product). Determine all unknown flow rates, compositions, and temperatures.

5.8 1.0 m^3 (STP)/s of 40 mol% n-butane and balance n-hexane is fed to the third stage (Stage 3) of a four-stage distillation column operating at 2 bar (absolute). The feed is a saturated vapor at 2 bar so that it all contributes to the vapor flowing up from Stage 3 to Stage 2. The top stage (Stage 1) acts as a partial condenser and the bottom stage (Stage 3) acts as a partial reboiler. The liquid product (bottoms) flow rate from Stage 4 is 20.0 mol/s

and 80% of the n-butane fed to the process is in the vapor product. Determine all unknown flow rates, compositions, and temperatures.

5.9 100 mol/s of a vapor containing equimolar amounts of benzene and chlorobenzene is fed to the middle stage (Stage 2) of a three-stage distillation column operating at 1 atm. The feed is a saturated vapor at 1 atm such that it all contributes to the vapor flowing up from Stage 3 to Stage 2. The top stage (Stage 1) acts as a partial condenser and the bottom stage (Stage 3) acts as a partial reboiler. The vapor product flow rate from Stage 1 is 50 mol/s and the reflux ratio is 2.0 (meaning that the amount of liquid from Stage 1 returning to Stage 2 is 2.0 times the amount of vapor product). Determine all unknown flow rates, compositions, and temperatures.

5.10 1000 kmol/day of a 50 mol% acetone - 50 mol% isopropanol mixture is fed to the second stage of a three-stage distillation tower operating at atmospheric pressure. The thermodynamic state of the feed is such that 25 mol% enters the vapor flowing up the column and 75 mol% enters the liquid flowing down the column. The top stage (Stage 1) acts as a partial condenser and the bottom stage (Stage 3) acts as a partial reboiler. 75 mol% of the acetone fed to the column is captured in the vapor product from Stage 1. The vapor product flow rate is 500 kmol/day. Determine all unknown flow rates, compositions, and temperatures.