

Distillation. Separation of water and ethanol in Raschig-Ring Packed Column

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Abstract

This experiment was performed as part of the Felles lab, in the course TKP4105 Separation Technology. A mixture of water and ethanol was distilled in a Raschig Ring Packed Column. The purpose of the experiment was to understand operation of a distillation column, and the parameters which determine it's condition. It was found that the column reached steady state after 25 minutes, and that column efficiency increases with reboiler power duty.

Contents

1	Theory	3
1.1	Packed Column	3
1.2	Column efficiency	3
1.3	McCabe-Thiele	3
1.4	Flooding	5
1.5	Reflux	6
1.6	GC-Analysis	6
2	Experimental	6
2.1	Startup	6
2.2	Exercise 1	7
2.3	Exercise 2	7
2.4	Shutdown	7
3	Results	7
3.1	Time to reach Steady State	7
3.2	Varying reboiler power levels	7
3.3	Efficiency vs Vapor Velocity	8
3.4	Flooding	8
4	Discussion	14
5	Conclusion	14
	List of Symbols	15
A	Measurements & Calculations	17
A.1	Calculating required amount of ethanol	17
A.2	Vapor velocity	19
B	Risk Assessment	20
C	Copy of journal	23
D	McCabe-Thiele Matlab-script	25

1 Theory

Theory for this experiment is mainly found from DistInstruct.pdf.¹

1.1 Packed Column

A packed distillation does not, contrary to i.e. a sieve-tray column or an Oldershaw column, have a set number of trays. Instead it is filled with a packing that gives a high surface area for vapor and liquid to react, thus increasing efficiency.

In a Raschig-Ring packed column, which was used in this experiment, the packing consists of hollow glass cylinders.

1.2 Column efficiency

Overall column efficiency for a packed distillation column is defined as the ratio of total number of ideal equilibrium stages to the height equivalent of a theoretical plate (HETP). HETP is the height of packing which does the same separation as a theoretical step. HETP can be calculated by (1.1),

$$\text{HETP} = \frac{\text{Packing Height}}{N_t - 1} \quad (1.1)$$

where N_t is the theoretical number of steps, calculated from a McCabe-Thiele diagram. A lower HETP indicates more theoretical "steps" in the column, thus higher efficiency.

Column efficiency can be determined by plotting HETP against vapor velocity, which is defined as (1.2)¹

$$\nu = \frac{V_{gas}}{A} \quad (1.2)$$

where V_{gas} is volume rate of gas, and A is the cross-sectional area of the column. The diameter of the packed column is given as $D = 0.05$ m.

1.3 McCabe-Thiele

The McCabe-Thiele method is a method to graphically determine the ideal amount of steps for a binary distillation process.² The method assumes constant molar overflow. This implies constant molar flow rates of both vapor and liquid leaving every stage. To construct a McCabe-Thiele diagram one needs to determine an operating line and a vapor-liquid equilibrium line. To make the operating line, one needs the enriched operating line and the

stripping line. Both the enriched operating line and the stripping operating line can be derived from the mass balance of light component. To make the vapor-liquid equilibrium line one construct a plot by plotting the vapor-liquid equilibrium data.

Equation for finding the enriched operating line is given by (1.3);

$$y_{n+1} = \left(\frac{R}{R+1} \right) x_n + \frac{x_D}{R+1} \quad (1.3)$$

where y_{n+1} is the mole fraction of light component in the gas phase in tray $n + 1$. x_n is the mole fraction of light component in the liquid phase in tray n , and x_D is the mole fraction of light component in the distillate. R is the reflux ratio.

Equation for the stripping operating line is given by (1.4);

$$y_{m+1} = \left(\frac{L_m}{V_{m+1}} \right) x_m + \frac{Wx_w}{V_{m+1}} \quad (1.4)$$

where y_{m+1} is the mole fraction of light component in the gas phase in tray $m+1$ with vapor flow V_{m+1} , x_m is the mole fraction of light component in the liquid phase in tray m with liquid flow L_m . x_w is the mole fraction of light component in the bottom flow with bottom flow W . When reflux ratio increases the slope of the enriched operating line increases and the slope of the stripping operating line decreases.

The condition of the feed, q , is defined as (1.5);

$$q = \frac{\text{heat needed to vaporize 1 mole of feed at entering conditions}}{\text{molar latent heat of vaporization of feed}} \quad (1.5)$$

Equation (1.5) is used to plot the q -line in the diagram. The q -line has slope $\frac{q}{q-1}$, which is crossing the crossing-point of the operating lines and the $x=y$ line.

The number of theoretical stages required in the column is determined by plotting the vapor-liquid equilibrium line and the operating line in a diagram with the mole fraction of light component. The mole fraction of the gas phase should be on the y -axis and the mole fraction of the liquid phase should be on the x -axis. Steps are being drawn between the operating line and the equilibrium line from the top tray (distillate); $x = x_D$ to the bottom $x = x_B$ and the number of steps drawn is equivalent to the number of theoretical steps needed.

At total reflux the reflux ratio goes to infinity large. Because of this the operating line can be found by taking the limit of equation (1.3) when R

approaches infinity:

$$y = \lim_{R \rightarrow \infty} \frac{R}{R+1}x + \frac{x_D}{R+1}$$

$$y = x \quad (1.6)$$

The result of this can be used as a new operating line, and the operating line at total reflux will be equal to the line $y = x$, where x and y are the mole fraction of light component in liquid and vapor phase.

Using a matlab-script, figure 1.1 was produced. From the plot, it is found that five steps are needed. The script is included in the appendix.

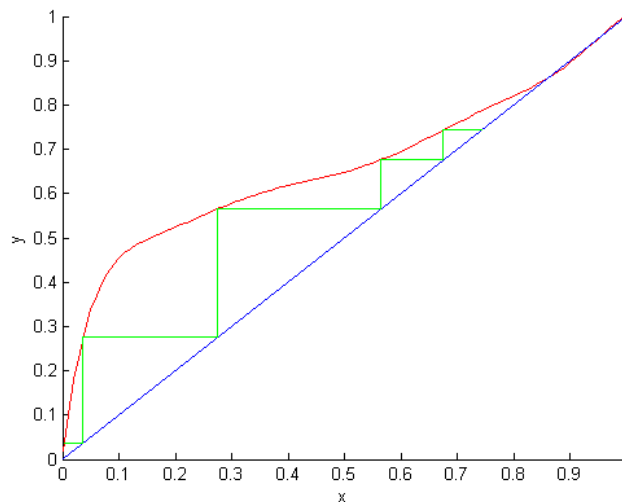


Figure 1.1: The McCabe-Thiele diagram used for calculating the number of theoretical steps. The y-axis shows the mole fraction of ethanol in the vapor phase, the x-axis shows the mole fraction in liquid phase. The upper curved line is the equilibrium line, while the straight line $y=x$ is the operating line. The horizontal and vertical lines in between count the theoretical steps

1.4 Flooding

The flooding point is a condition caused by high vapor velocity. At the flooding point, the vapor velocity is so high that liquid accumulates in the top of the column. This causes a sudden increase in the pressure drop

1.5 Reflux

Reflux is the portion of the vapor that condenses and returns to the distillation column. This particular experiment will work with total reflux, that is, all vapor is condensed back in to the column.

1.6 GC-Analysis

Gas chromatography is a common type of chromatography used in analytical chemistry. It is used for separation and detection of compounds that can be vaporized without decomposition.³

In gas chromatography there is a moving phase, also called the mobile phase, and a stationary phase. The moving phase is usually an inert gas, and the stationary phase, called column, usually consist of a polymer or glass. The compounds that are being analysed will interact with the walls of the stationary state. Each compound will start to elute at different times. The retention time of each compound will vary, and comparing retention times can identify compounds in the sample. The quantity of a compound in the sample can be found by plotting a chromatogram, which is a plot of the measured signal against time. By integrating the area under this curve, the quantities can be calculated.

The samples were analysed with Gas Chromatography. The output of this analysis are given in mass fractions. Equation (1.7) was then used to convert the data to mole fractions.

$$x_{\text{EtOH}} = \frac{\frac{w_{\text{EtOH}}}{M_{\text{EtOH}}}}{\frac{w_{\text{EtOH}}}{M_{\text{EtOH}}} + \frac{(1-w_{\text{EtOH}})}{M_{\text{H}_2\text{O}}}} \quad (1.7)$$

2 Experimental

2.1 Startup

The PC and cooling water was turned on, and it was ensured that the taps for top and bottom samples were properly closed. The column was charged with 5800 mL of water-ethanol mixture, with a mole fraction of ethanol (x_{EtOH}) of 0.1. The experiment required 1596 mL of ethanol and 4202 mL of water. Calculation can be found in appendix. (A.5)

The reboiler was set to 50 % power, and the column was monitored until the first drop of distillate was made. This was marked as Time Zero. The column was now run on the same power level for an hour, while exercise 1 was performed.

2.2 Exercise 1

In the first exercise, the time required for reaching Steady-State was determined. Samples of the distillate was taken every five minutes, and the composition of these were measured with GC. 12 samples were collected, plus one final sample of the bottom for use later in the experiment. The samples' composition can be found in A.1.

2.3 Exercise 2

In the second exercise, the column efficiency as a function of vapor velocity was determined.

Reboiler power was set to 35%, and the column was left to reach steady state. As the column had reached steady-state, samples of the top and bottom of the column was taken and analyzed with GC. The reflux rate at the time of sampling was noted. The reboiler was set to a new power level, and the procedure was repeated for a total of five different power levels. The power levels used in this experiment was 35 %, 40 %, 45 %, 50 % and 55 %.

2.4 Shutdown

When all samples were taken, the heater was turned off and the column was set to cool down. When the column was cold, it was emptied, and cooling water and the computer were turned off.

3 Results

3.1 Time to reach Steady State

Figure 3.1 shows top samples taken during the first hour of the experiment. From this plot, it can be seen that the column reaches a steady state at approximately 25 minutes. It was assumed that the time required to reach steady state was constant throughout the experiment.

3.2 Varying reboiler power levels

The reboiler power levels used, and the corresponding molar fractions of the top and bottom samples can be found in Table A.2. After the reboiler power was adjusted, the column was run for 25 minutes and allowed to reach steady-state before samples from top and bottom were taken.

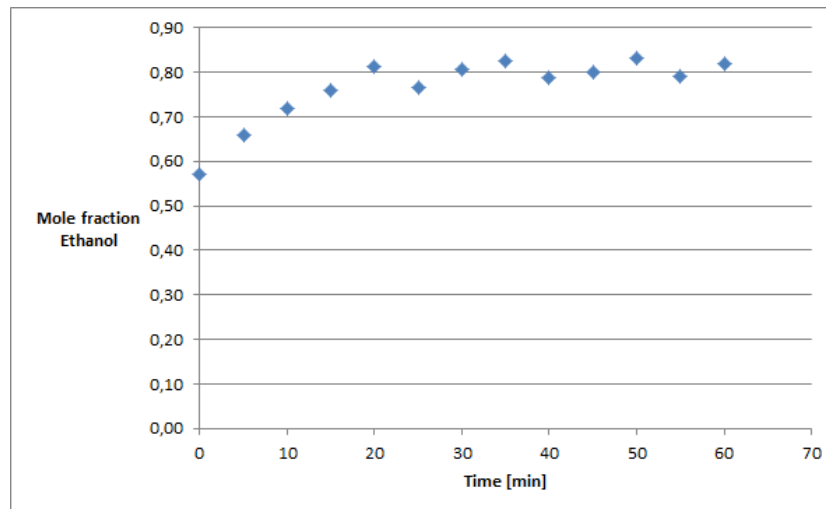


Figure 3.1: The graph shows molar fraction of ethanol against time. 12 samples were taken during one hour, in order to determine when the column reaches steady state. The reboiler level were 50 % for all samples. Data for the diagram are given in table A.1.

Figure 3.2 to 3.6 show McCabe-Thiele plots for the five different reboiler levels. The plots were made in Matlab, using the script that can be found in appendix D.

3.3 Efficiency vs Vapor Velocity

By plotting HETP against vapor velocity, it can be seen how column efficiency varies with different power levels. A plot of this for the experiment can be found in figure 3.7. A low HETP indicates higher efficiency, as this implies more theoretical steps of equilibrium in the column.¹ Values for vapor velocity can be found in table A.3.

3.4 Flooding

The reboiler power was increased gradually up to 60%. Accumulation of liquid in the top of the column was observed, but the actual flooding point was not reached in the experiment.

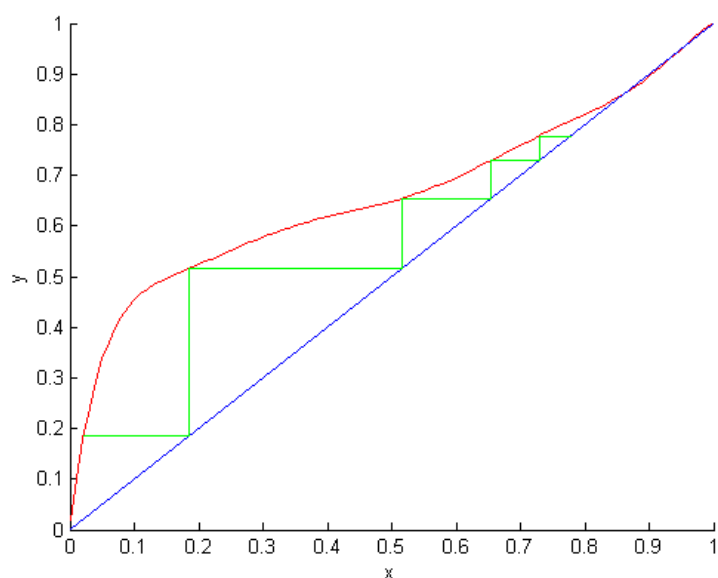


Figure 3.2: McCabe-Thiele plot for the column at 35 % reboiler level. The y-axis shows the mole fraction of ethanol in the vapor phase, the x-axis shows the mole fraction in liquid phase. The upper curved line is the equilibrium line, while the straight line $y=x$ is the operating line. The horizontal and vertical lines in between count the theoretical steps

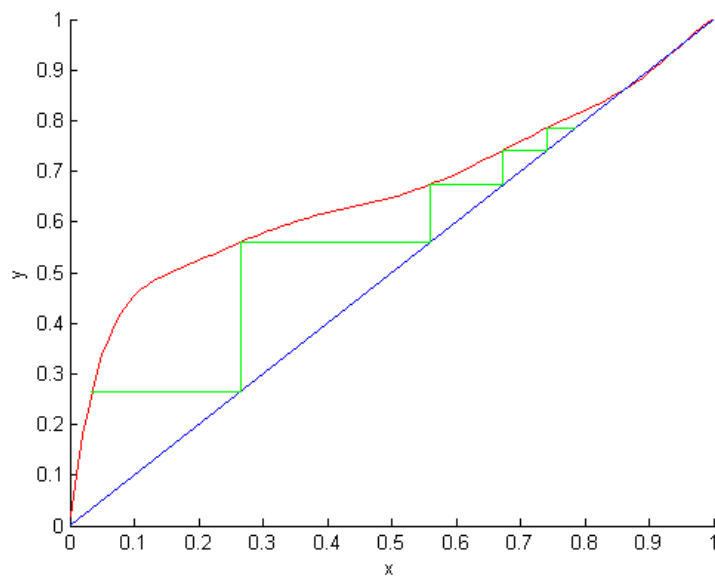


Figure 3.3: McCabe-Thiele plot for the column at 40 % reboiler level. The y-axis shows the mole fraction of ethanol in the vapor phase, the x-axis shows the mole fraction in liquid phase. The upper curved line is the equilibrium line, while the straight line $y=x$ is the operating line. The horizontal and vertical lines in between count the theoretical steps

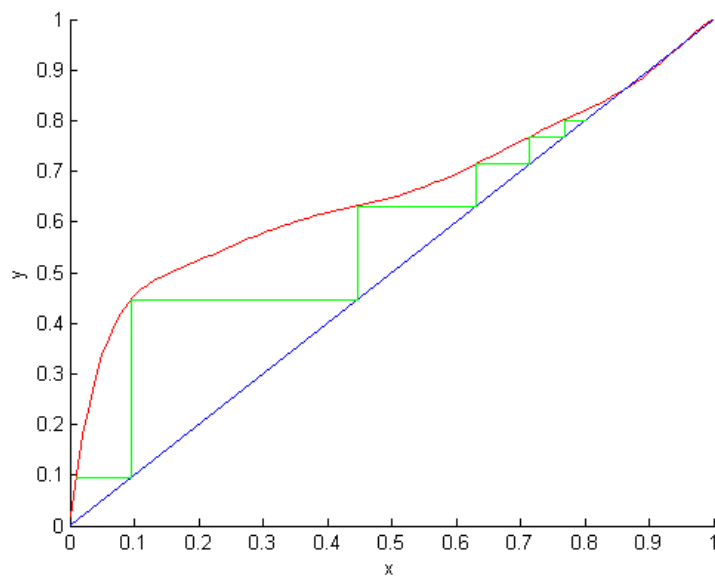


Figure 3.4: McCabe-Thiele plot for the column at 45 % reboiler level. The y-axis shows the mole fraction of ethanol in the vapor phase, the x-axis shows the mole fraction in liquid phase. The upper curved line is the equilibrium line, while the straight line $y=x$ is the operating line. The horizontal and vertical lines in between count the theoretical steps

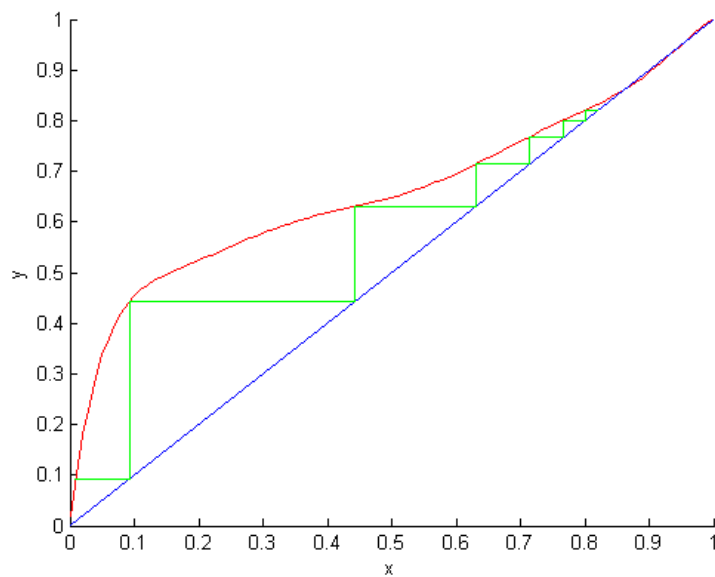


Figure 3.5: McCabe-Thiele plot for the column at 50 % reboiler level. The y-axis shows the mole fraction of ethanol in the vapor phase, the x-axis shows the mole fraction in liquid phase. The upper curved line is the equilibrium line, while the straight line $y=x$ is the operating line. The horizontal and vertical lines in between count the theoretical steps

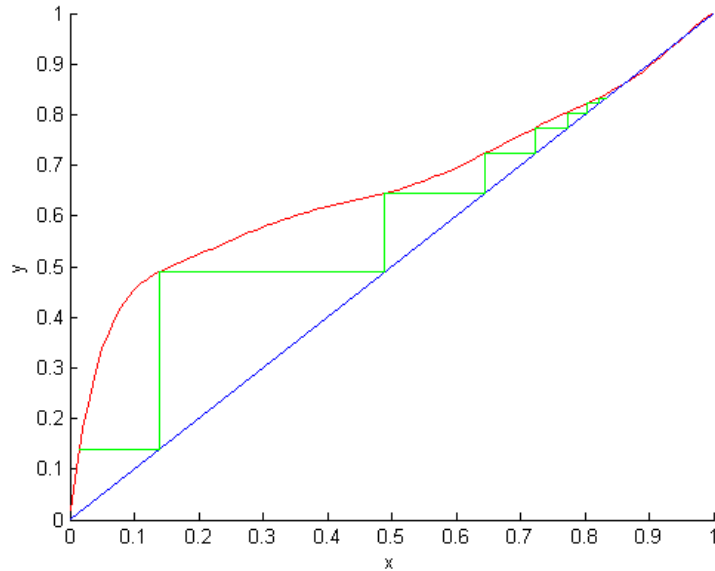


Figure 3.6: McCabe-Thiele plot for the column at 55 % reboiler level. The y-axis shows the mole fraction of ethanol in the vapor phase, the x-axis shows the mole fraction in liquid phase. The upper curved line is the equilibrium line, while the straight line $y=x$ is the operating line. The horizontal and vertical lines in between count the theoretical steps

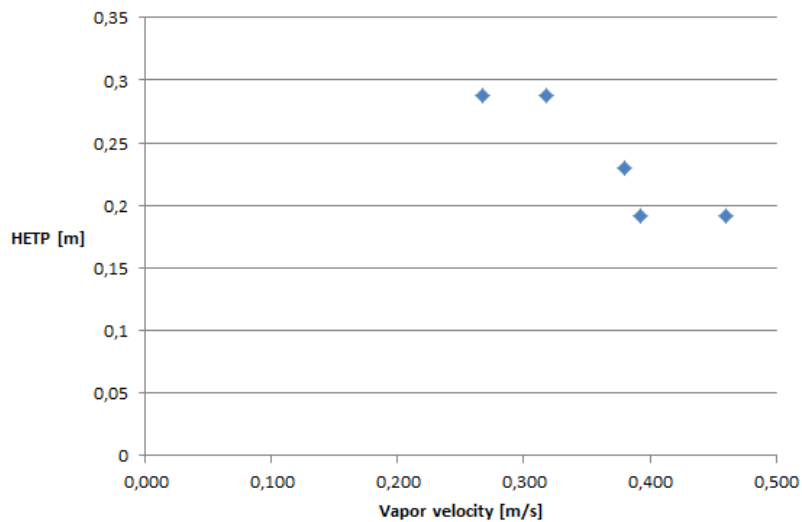


Figure 3.7: The figure shows a plot of HETP against vapor velocity for five different power duties.

4 Discussion

From figure 3.1, it can be seen that the molar fractions of ethanol are stable, with some variation. This variation may come from uncertainty in the GC-analysis. It was assumed that the time needed to reach steady state was constant for all power duties, and the measurements from exercise 2 seem to support this assumption.

For the calculation of vapor velocity assumptions of ideal gas and a column pressure of 1 bar was made. As the vapor is condensed continuously during steady state, it is very unlikely that gas will accumulate in the top and increase column pressure significantly.

Water and ethanol are rather small molecules and in the scale of this experiment it is very unlikely that intermolecular forces will have any significance.

The flooding point was never reached, but at 60% power duty it was observed accumulation of liquid at the very top of the column. If power duty were to be increased further, the flooding point would most likely be reached.

From figure 3.7, it can be seen that HETP decreases with increasing vapor velocity. This indicates a higher column efficiency with higher power duties.

5 Conclusion

From the measurements of the first hour of the experiment, it was found that the column reaches steady state after 25 minutes. These measurements was made with a power duty of 50 %.

At 60 % power duty tendencies of flooding was observed, as liquid accumulated in the top of the column. The actual flooding was not reached.

By plotting HETP against vapor velocity it was found that column efficiency increases with higher vapor velocity and thus power level.

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List of symbols

Symbol	Dimension	Description
A	m^2	cross-sectional area of column
D	m	Diameter of packed column
L_m	V	liquid flow in tray m
M_{EtOH}	g/mol	Molar mass ethanol
M_{H_2O}	g mol^{-1}	Molar mass H ₂ O
n_i	mol	moles of component i
n_{tot}	mol	mole total of ethanol and water
\dot{n}	mol s^{-1}	molar flow
p_i	bar	Partial pressure of component i
q	no dimension	condition of feed
R_i	mL s^{-1}	Reflux rate
R	$\text{J mol}^{-1} \text{K}$	Universal gas constant
T	K	Temperature
ν	m s^{-1}	vapor velocity
V	mL	Volume
V_i	L	Volume of component i
V_{tot}	L	total volume of water and ethanol
$V_{EtOH,96\%}$	L	Volume of 96% ethanol
V_i	L	Measured pump flow rate
V_{m+1}	L	Vapor flow
\dot{V}_{gas}	L	volume rate gas
W	L s^{-1}	Bottom flow
W_{EtOH}		
x	no dimension	mole fraction of ethanol in column top
x_D		Volume
x_{EtOH}	L	Volume
x_n	L	Volume
x_m	L	Volume
x_W	L	Volume
y_{n+1}	L	Volume
y_{m+1}	L	Volume
ρ_i	g cm^{-3}	Density of component i

References

- [1] *Felles Lab: Distillation Columns*, September, 2012, read 7th Oct. 2013. Available at http://www.nt.ntnu.no/users/preisig/Repository/TKP_4110_Felles_Lab/experiment%20descriptions/DistInstruct.pdf
- [2] Geankoplis, C.J *Transport Processes and Separation Process Principles*, 4th ed.; Pearson Education, Inc, 2003
- [3] Rebecca Carrier and Julie Bordonaro *Intro to Gas Chromatography*, 1994, read 29th Oct. 2013. Available at <http://www.rpi.edu/dept/chem-eng/Biotech-Environ/CHROMO/chromgram.html>
- [4] Aylward, G. Findlay, T. *SI Chemical Data*, 6th ed.; John Wiley & Sons Ltd., 2008

A Measurements & Calculations

Table A.1 shows mass fractions and corresponding mole fractions of EtOH from the twelve top samples taken during the first hour of the experiment. Mass fractions of ethanol were measured using GC-analysis, the corresponding mole fractions were calculated using (A.4). Table A.2 show measured

Table A.1: The table show mass fractions and corresponding mole fractions measured as the column approached steady state.

Time [min]	Mass Fraction EtOH	Mole Fraction EtOH
0	0,77	0,57
5	0,83	0,66
10	0,87	0,72
15	0,89	0,76
20	0,92	0,81
25	0,89	0,77
30	0,91	0,81
35	0,92	0,83
40	0,91	0,79
45	0,91	0,80
50	0,93	0,83
55	0,91	0,79
60	0,92	0,82

mass fractions and corresponding mole fractions of ethanol from top and bottom samples taken for different reboiler power levels.

A.1 Calculating required amount of ethanol

The mole fraction of ethanol, x_{EtOH} , is given by (A.1);

$$x_{EtOH} = \frac{n_{EtOH}}{n_{tot}} = \frac{n_{EtOH}}{n_{EtOH} + n_{H_2O}} \quad (A.1)$$

Where n_{EtOH} is moles of ethanol and n_{tot} is the total numbers of moles in the mixture and n_{H_2O} is moles of water. Moles of ethanol is given by (A.2);

$$n_{EtOH} = \frac{V_{EtOH}\rho_{EtOH}}{M_{EtOH}} \quad (A.2)$$

Where V_{EtOH} is the volume of pure ethanol, ρ_{EtOH} is the density of pure ethanol and M_{EtOH} is the molecular weight of ethanol. In a mixture of only

Table A.2: The table shows measured mole fractions from the top and bottom of the column for different reboiler power levels. The column had reached steady state for all measurements.

Power level	Mass Fraction EtOH	Mole Fraction EtOH
35% top	0,90	0,78
35% btm	0,15	0,06
40% top	0,90	0,78
40% btm	0,13	0,06
45% top	0,91	0,80
45% btm	0,11	0,05
50% top	0,92	0,82
50 % btm	0,14	0,06
55% top	0,93	0,83
55 % btm	0,09	0,04
55% top2	0,91	0,80

water and ethanol the moles of water, n_{H_2O} , is given by (A.3);

$$n_{H_2O} = \frac{\rho_{H_2O}(V_{tot} - V_{EtOH})}{M_{H_2O}} \quad (A.3)$$

Where ρ_{H_2O} is the density of water, V_{tot} is the total volum in the mixture and M_{H_2O} is the molecular weight of water. By rearranging the equations (A.1), (A.2) and (A.3):

$$x_{EtOH} = \frac{\frac{V_{EtOH} \rho_{EtOH}}{M_{EtOH}}}{\frac{V_{EtOH} \rho_{EtOH}}{M_{EtOH}} + \frac{\rho_{H_2O}(V_{tot}-V_{EtOH})}{M_{H_2O}}} \quad (A.4)$$

Solving this for values $x_{EtOH} = 0,1$, $\rho_{EtOH} = 0,791g/cm^3$, $M_{EtOH} = 46,0g/mole$, $M_{H_2O} = 18,02g/mole$ and $V_{tot} = 5800mL$, the volume of pure ethanol is $V_{EtOH} = 1532mL$. In 96 % ethanol, the volume of ethanol needed is;

$$V_{EtOH,96\%} = \frac{V_{EtOH}}{0.96} = \frac{1532mL}{0.96} = 1596ml \quad (A.5)$$

The amount of water needed is then:

$$v_{H_2O} = V_{tot} - V_{EtOH,96\%} = 5800mL - 1596ml = 4202ml \quad (A.6)$$

A.2 Vapor velocity

The vapor velocity was calculated based on the measured pump flow rates. When the column has reached steady-state, the flow of liquid reflux will be equal to the vapor flow. By calculating the total number of moles in the vapor flow, the volume flow rate can be determined by assuming ideal gas. Vapor velocity is then given as

Total number of moles in the vapor was calculated by (A.7),

$$\dot{n} = xV \frac{\rho_{\text{EtOH}}}{M_{\text{EtOH}}} + (1 - x)V \frac{\rho_{\text{H}_2\text{O}}}{M_{\text{H}_2\text{O}}} \quad (\text{A.7})$$

where V is the measured pump flow rate, x the molar fraction of ethanol in the top of the column and ρ and M are density and Molar weights of water and ethanol.⁴ In the instructions, the vapor velocity, ν , is defined as

$$\nu = \frac{\dot{V}}{A} \quad (\text{A.8})$$

Further the ideal gas law is given in (A.9),

$$V = \frac{nRT}{P} \quad (\text{A.9})$$

where P is pressure, R the universal gas constant n the number of moles and T the temperature in Kelvin. A pressure of 1 bar was assumed for the calculations.

By combining (A.7), (A.8) and (A.9), an expression for the vapor velocity is found as (A.10).

$$\nu = \frac{\dot{n}RT}{AP} \quad (\text{A.10})$$

The vapor velocities for the different power levels are given in table A.3.

Table A.3: The table shows calculated vapor velocities for five different reboiler power levels. Ideal gas and a pressure of 1 bar is assumed. For the calculations made, a constant temperature of 78,3 °C was assumed based on measurements in the column.

Boiler level [%]	Mole fraction Top	Pump flow rate [ml/s]	Total molar flow [mol/s]	Vapor velocity [m/s]
35	0,78	0,700	0,018	0,267
40	0,78	0,844	0,021	0,318
45	0,80	1,033	0,026	0,380
50	0,82	1,100	0,026	0,392
55	0,83	1,317	0,031	0,460

B Risk Assessment

Potential undesirable incident/strain

Identify possible incidents and conditions that may lead to situations that pose a hazard to people, the environment and any materiel/equipment involved.

Criteria for the assessment of likelihood and consequence in relation to fieldwork

Each activity is assessed according to a worst-case scenario. Likelihood and consequence are to be assessed separately for each potential undesirable incident. Before starting on the quantification, the participants should agree what they understand by the assessment criteria:

Likelihood	Minimal 1	Low 2	Medium 3	High 4	Very high 5
	Once every 50 years or less	Once every 10 years or less	Once a year or less	Once a month or less	Once a week
Consequence	Grading	Human	Environment	Financial/material	
	E Very critical	May produce fatality/ies	Very prolonged, non-reversible damage	Shutdown of work > 1 year.	
	D Critical	Permanent injury, may produce serious serious health damage/sickness	Prolonged damage. Long recovery time.	Shutdown of work 0.5-1 year.	
	C Dangerous	Serious personal injury	Minor damage. Long recovery time	Shutdown of work < 1 month	
	B Relatively safe	Injury that requires medical treatment	Minor damage. Short recovery time	Shutdown of work < 1 week	
A Safe	Injury that requires first aid	Insignificant damage. Short recovery time	Shutdown of work < 1 day		

The unit makes its own decision as to whether opting to fill in or not consequences for economy/materiel, for example if the unit is going to use particularly valuable equipment

It is up to the individual unit to choose the assessment criteria for this column.

Risk = Likelihood x Consequence

Please calculate the risk value for "Human", "Environment" and, if chosen, "Economy/materiel", separately.

About the column "Comments/status, suggested preventative and corrective measures": Measures can impact on both likelihood and consequences. Prioritise measures

that can prevent the incident from occurring; in other words, likelihood-reducing measures are to be prioritised above greater emergency preparedness, i.e. vonsequence-reducing measures.

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Distillation 10 October 10.15 lab:

- 1596 mL ethanol + 4202 mL diwater

at 50%

Sample	Time	mole fraction	pump flow rate
1	0 min	0,7727	66 mL/min
2	5 min	0,83125	
3	10 min	0,86737	
4	15 min	0,88933	
5	20 min	0,91699	
6	25 min	0,89321	
7	30 min	0,91411	
8	35 min	0,92438	
9	40 min	0,90546	
10	45 min	0,91196	
11	50 min	0,92642	
12	55 min	0,90696	
13	60 min	0,92105	
14	60 min BEM	0,13704	

Farit: 89,69

tests X

tests	X
test1	0,86257
test2	0,87967
test3	0,870267

at 35%

sample	mole frac
top (15)	0,89937
bottom (16)	0,1455

pump flow rate: 42 mL/min

at 40%

sample	mole frac
top (17)	0,9033
btm (18)	0,13244

pump flow rate: 50,65

at 45%

sample	mole frac
top 19	0,91147
blm 20	

pump flow rate: 62

at 56%

sample	mole frac
top (21)	
wtm (22)	

pump flow rate 79

top2 (23)

(24) → Finish

D McCabe-Thiele Matlab-script

```

clear all
clc

% Eq. data, row 1: x_et, row 2: y_et
% Mass fractions from Geankoplis Appendix A, A.3-23
EDm = [0 0.02 0.05 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.94 0.96 0.98 1; 0 0.192 0.377
0.527 0.656 0.713 0.746 0.771 0.794 0.822 0.858 0.912 0.942 0.959 0.978 1];
[r,c]=size(EDm);
ED = ones(r,c);
%Converting to mole fractions
Met = 46.068; %Molar weights for ethanol and water
Mw = 18.016;

for i = 1:r
    for j = 1:c
        ED(i,j)=(EDm(i,j)/Met)/((EDm(i,j)/Met)+((1-EDm(i,j))/Mw));
    end
end

y = ED(2,1:length(ED));
x = ED(1,1:length(ED));
%Finding 8th order polynom for eq. line
c = polyfit(x,y,8);
%Plotting eq.line and operating line
figure('Name','McCabe-Thiele');
hold on
eq = plot(0:0.01:1,polyval(c,0:0.01:1));
op = line([0 1],[0 1]);
set(eq,'color','r');
set(op,'color','b');
xlabel('x');
ylabel('y');
%Calculation and plot of theoretical stages
xd = 0.7433; %Top
xb = 0.0329; %Bottom
xs = [];
ys = [];
%Starting at the top of op-line y=x
xs(1) = xd;
ys(1) = xd;
f = @(x,y) (c(1)*x^8+c(2)*x^7+c(3)*x^6+c(4)*x^5+c(5)*x^4+c(6)*x^3+c(7)*x^2+c(8)*x+c(9)-
y);
%Solve equation
i=1;
while xs(i)>xb
    xs(i+1)=fzero(f,0.5,[],ys(i));
    line([xs(i) xs(i+1)],[ys(i) ys(i)], 'color', 'g');
    ys(i+1) = xs(i+1);
    if xs(i+1)>xb
        line([xs(i+1) xs(i+1)],[ys(i) ys(i+1)], 'color', 'g');
    end
    i=i+1;
end
disp(i)

```