Distillation Column Design

Assignment 2

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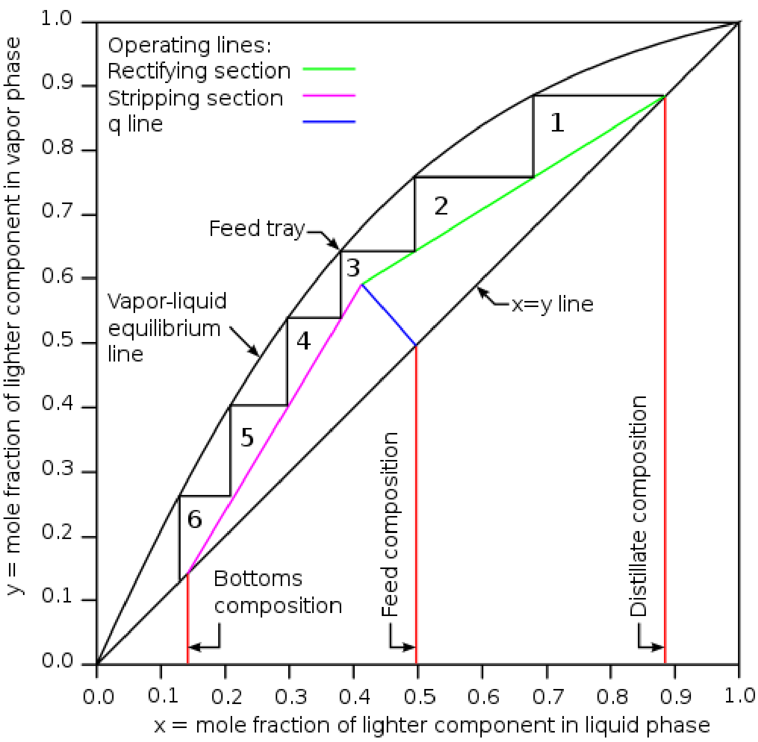
System: Ethanol and Water

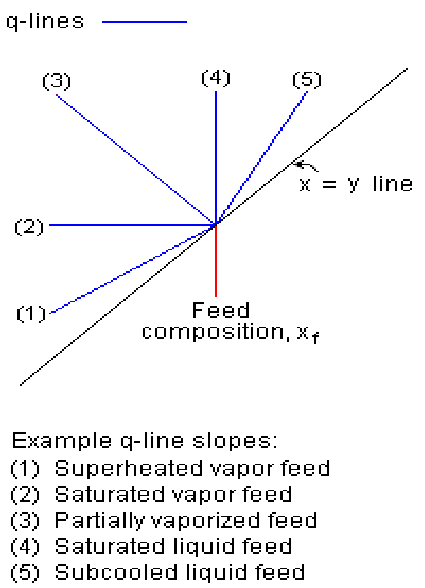
Q1.
From your previous assignment, you have drawn a Y Vs X (vapour equilibrium)curve assuming the system to be non-ideal. Now for the same selected system, you have to find the following with the help of MATLAB.
1.**Actual number of stages(trays)** required to achieve separation(with graph) in a Distillation column with the help of the McCabe-Thiele method.
2.**Minimum number of stages(trays)** required to achieve their separation (with graph)
3.**Minimum Reflux Ratio**

McCabe thiele Method for the Distillation of Binary Solutions

The **McCabe–Thiele method** is a technique used in chemical engineering for the analysis of ***binary distillation***.It is based on the fact that the composition at each theoretical tray (or equilibrium stage) is completely determined by the mole fraction of one of the two components and the assumption of constant molar overflow, which necessitates that:
•Equal molar heats of vaporisation for all feed components.
•For each mole of liquid that evaporates, one mole of vapour condenses.
•The effects of heat including heat of solution negligible



Typical McCabe–Thiele diagram for binary feed distillation



slope examples for q-lines

Determination of the Actual number of Stages

1.Determination of the Actual number of Stages involves following steps:

1.Analyze the enriching section and and draw enriching section Top product composition and Reflux Ratio

2.Analyze the Feed section and determine the draw q-line using q.

3.Determine the point of intersection between the enriching section and q-line.

4.Using Xw, analyse the Stripping Section and determine the Stripping section line

The number of theoretical stages required for a particular separation is equal to the number of triangles that can be drawn between these operating lines(**enriching section line r,q-line, stripping section line**) and the **equilibrium curve.**

Actual no of stages=No. Of Triangles formed between operating lines and the equilibrium curve

------------------------MATLAB--------------------------

```
>> Q1_Simutech
Enter Reflux Ratio : 2.4
Enter bottom product composition : 0.14
Enter Feed composition : 0.45
Enter Top product composition : 0.89
Enter The value of q : 0.65
```

Inputs like **Reflux ratio,bottom product composition,feed composition**,etc taken from the user Then calculating the actual number of stages required for the distillation of binary solution are performed as per the above steps using **MATLAB code.**

--------------------CODE------------------------

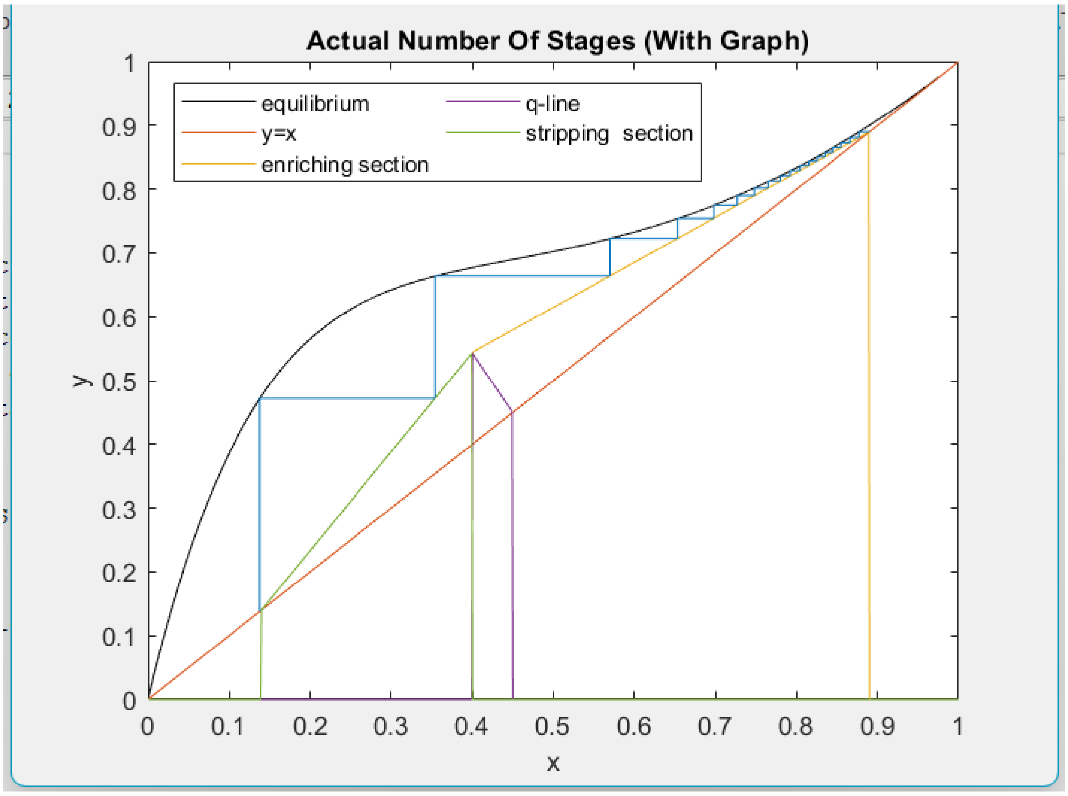
```
%%%%%%%%%%%%%%%%%%%%%  Taking Input From The User  %%%%%%%%%%%%%%%%%%%%%%%%

R=input("Enter Reflux Ratio : ");
Xw=input("Enter bottom product composition : ");
Xf=input("Enter Feed composition : ");
Xd=input("Enter Top product composition : ");
q=input("Enter The value of q : ");

%%%%%%%%%%%%%%%%  Actual Number Of Stages (With Graph)  %%%%%%%%%%%%%%%%%%%

Xint=((Xd*(q-1)/(R+1)+Xf)/(q-R*(q-1)/(R+1)));  % Point Of Intersection Of
Yint=(R/(R+1))*Xint+(Xd/(R+1));                 % q-line and enriching
Xint=round(Xint,3);                             % section line
mn1=min([Xint Xd]);
mx1=max([Xint Xd]);
mn2=min([Xint Xf]);
mx2=max([Xint Xf]);
mn3=min([Xint Xw]);
mx3=max([Xint Xw]);
m=(Yint-Xw)/(Xint-Xw);
i1=1000*mn1;i2=1000*mn2;i3=1000*mn3;
x=zeros([1 1000]);
x(1)=0.001;
for i=2:1000
    x(i)=x(i-1)+0.001;
end
y=zeros([1 1000]);                              % Equilibrium Curve
for i=1:1000
    y(i)=x(i)*exp(1.6798/(1+(1.6798*x(i))/(0.9227*(1-x(i))))^2));
    y(i)=round(y(i),3);
end
y1=zeros([1 1000]);                             % Y=X line
for i=1:1000
```

```
    y1(i)=x(i);
end
y2=zeros([1 1000]);                    % Enriching Section Line
while x(i1)<=mx1
    y2(i1)=(R/(R+1))*x(i1)+(Xd/(R+1));
    i1=i1+1;
end
y3=zeros([1 1000]);                    % q-line
while x(i2)<=mx2
    y3(i2)=(q/(q-1))*x(i2)-Xf/(q-1);
    i2=i2+1;
end
y4=zeros([1 1000]);                    %Stripping Section Line
while x(i3)<=mx3
    y4(i3)=m*(x(i3)-Xw)+Xw;
    i3=i3+1;
end
l1=zeros([1 1000]);                    % Y-coordinate of stages
l2=zeros([1 1000]);                    % X-coordinate of stages
l1(1)=Xd;l2(1)=Xd;i=1;
while l2(i)>Xint
    [~,num]=(min(abs(y-l1(i))));
    l2(i+1)=num/1000;
    l1(i+1)=(R/(R+1))*(num/1000)+(Xd/(R+1));
    i=i+1;
end
if l2(i)<Xint
```

```
if l2(i)<Xint
    l1(i)=m*((l2(i))-Xw)+Xw;
end
while l2(i)>Xw
    [~,num]=(min(abs(y-l1(i))));
    l2(i+1)=num/1000;
    l1(i+1)=m*((num/1000)-Xw)+Xw;
    i=i+1;
end
if l2(i)<Xw
    l1(i)=l2(i);
end
i=1;
figure(1)
grid on
plot(x,y,"black",'DisplayName','equilibrium');
xlabel("x");
ylabel("y");
title(" Actual Number Of Stages (With Graph)");
xlim([0 1]);
ylim([0 1]);
hold on
plot(x,y1,'DisplayName','y=x');
hold on
plot(x,y2,'DisplayName','enriching section');
hold on
plot(x,y3,'DisplayName','q-line');
hold on
```

```
plot(x,y4,'DisplayName','stripping  section');
hold on
lg=legend;
lg.NumColumns=2;
hold off
legend('AutoUpdate','off');
while l2(i)>Xw
    line([l2(i+1),l2(i)],[l1(i),l1(i)]);
    line([l2(i+1) l2(i+1)],[l1(i),l1(i+1)]);
    i=i+1;
end
hold off
disp("Actual Number Of Stages(Trays) : ")
disp(i-1);
```

OUTPUT



McCabe thiele diagram for showing actual no. of stages.

```
Actual Number Of Stages(Trays) :
    18
```

Determination minimum number of stages

Determining minimum number of stages involves following steps:

1. Analyse enriching section and draw vertical line connecting equilibrium curve and **Xd.**

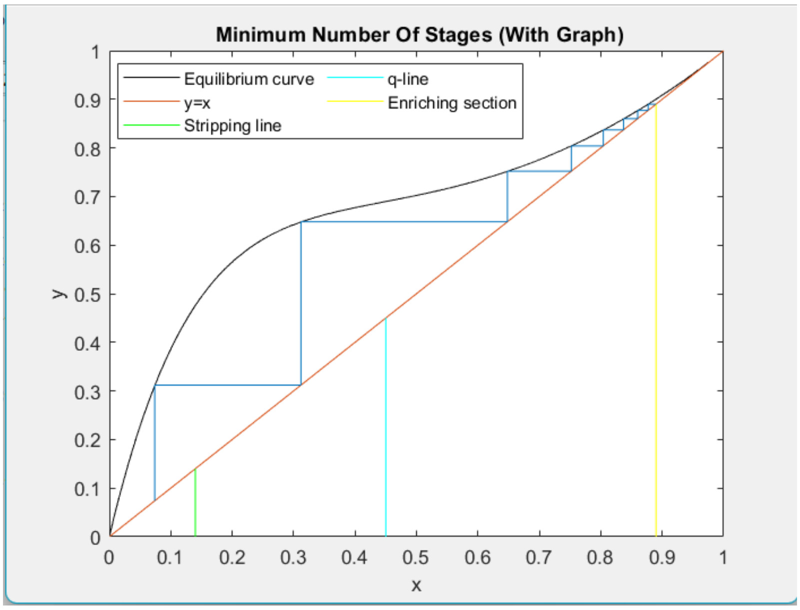
2. Analyse the stripping section and draw a vertical line connecting the equilibrium curve and **Xw.**

3. Draw triangles starting from **Xd** till **Xw** between the curve and straight line **y=x.**

Minimum of stages(tray)=No. Of triangle formed between these lines and equilibrium curve

```
%%%%%%%%%%%%%%%%%  Minimum Number Of Stages (With Graph)  %%%%%%%%%%%%%%%%%

q1=zeros([1 1000]);                             % Y-coordinate of stages
q2=zeros([1 1000]);                             % X-coordinate of stages
q1(1)=Xd;q2(1)=Xd;i=1;
legend('AutoUpdate','off');
while q2(i)>Xw
    [~,num]=(min(abs(y-q1(i))));
    q2(i+1)=num/1000;
    q1(i+1)=num/1000;
    i=i+1;
end
i=1;
figure(2)
plot(x,y,'black','DisplayName','Equilibrium curve');
xlabel("x");
ylabel("y");
title(" Minimum Number Of Stages (With Graph)");
xlim([0 1]);
ylim([0 1]);
hold on
plot(x,y1,'DisplayName','y=x');
hold on
line([Xw,Xw],[0,Xw],'DisplayName','Stripping line','Color','green');
line([Xf,Xf],[0,Xf],'DisplayName','q-line','Color','cyan');
line([Xd,Xd],[0,Xd],'DisplayName','Enriching section','Color','yellow');
lgd=legend;
lgd.NumColumns=2;
hold off
legend('AutoUpdate','off');
while q2(i)>Xw
    line([q2(i+1),q2(i)],[q1(i),q1(i)]);
    line([q2(i+1),q2(i+1)],[q1(i),q1(i+1)]);
```

OUTPUT



McCabe thiele diagram for showing Minimum no. of stages.

```
Minimum Number Of Stages(Trays) :
     8
```

Determination Minimum Reflux Ratio

Determine minimum reflux ratio involves following steps:

1.Reflux ratio is minimum when top(enriching section) section line intersects the equilibrium curve.

2. We located the intersection of the **q line** and the equilibrium curve and then drew a line from that point **(xd,xd)**. The line's y intercept is equal to **xd/(Rmin+1).**

3. We know **Xd** hence we can find **Rmin.**

```
%%%%%%%%%%%%%%%%%%%%%%  Minimum Reflux Ratio  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%

syms f1(x)
f1(x)=x*exp(1.6798/(1+(1.6798*x)/(0.9227*(1-x)))^2);
syms f2(x)
f2(x)=(q/(q-1))*x-Xf/(q-1);
nump=vpasolve(f1(x)-f2(x)==0,x);
numx=max(nump);
numx=round(numx,3);
numy=f1(numx);
Rm=(numy-Xd)/(numx-numy);
Rm=round(Rm,3);
Rm=abs(Rm);
disp("Minimum Reflux Ratio : ")
disp(Rm);
```

Output of code:

```
Minimum Reflux Ratio :
1.974
```

Q2.

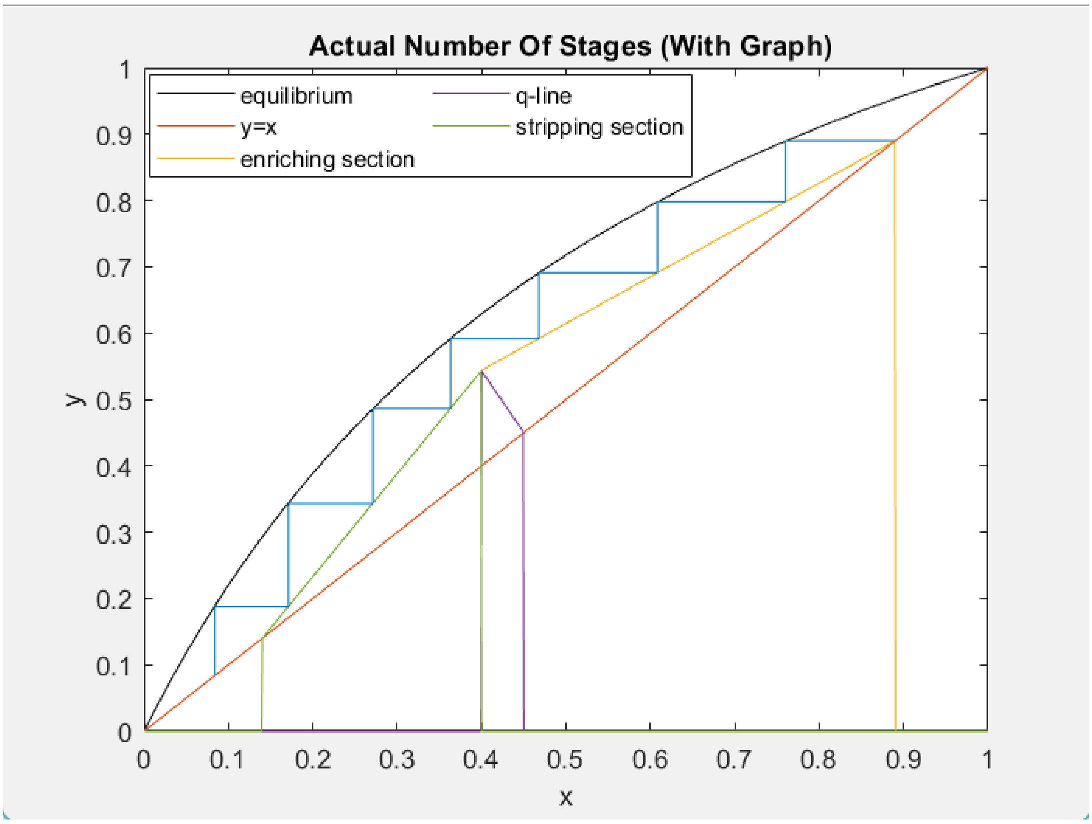
Repeat Q1 assuming that the system is ideal (system following Raoult's law). Compare the graphs, no. of trays obtained in both the cases for each sub-problems and **mention the reasons for differences.**

Assuming the system to be ideal we did the same calculations of actual no. of stages,Minimum no. of stages and reflux ratio we got following graphs and output.

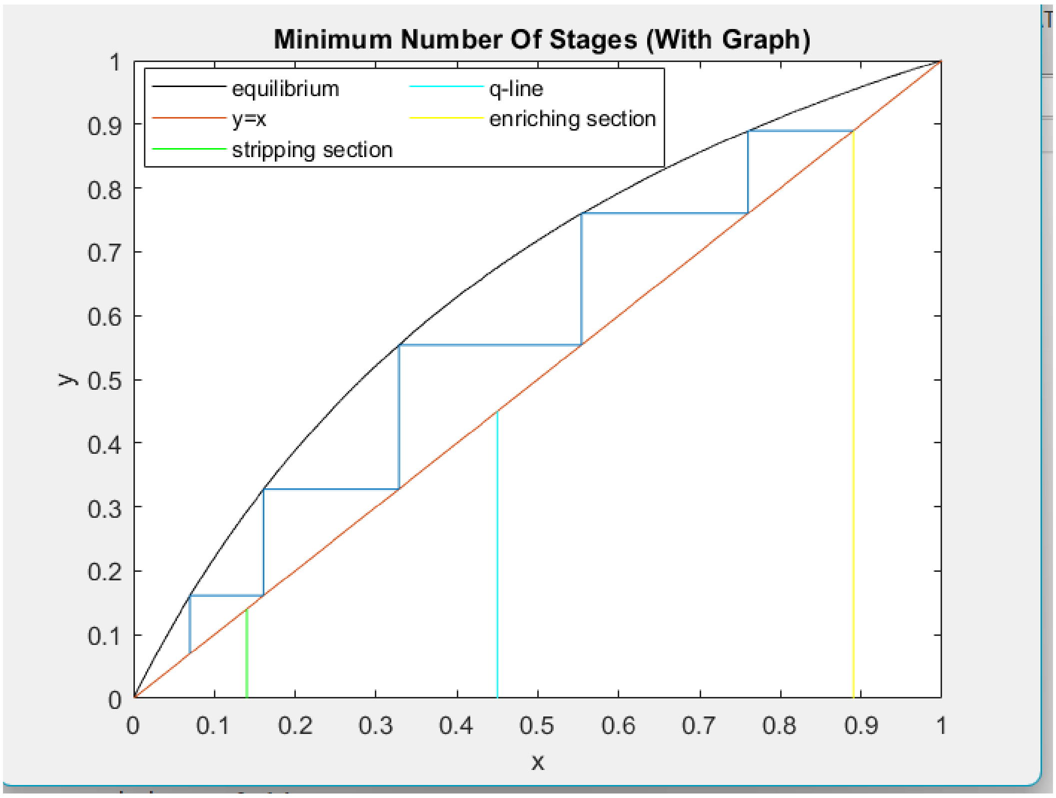
Inputs

```
>> Q2_Simutech
Enter Reflux Ratio : 2.4
Enter bottom product composition : 0.14
Enter Feed composition : 0.45
Enter Top product composition : 0.89
Enter The value of q : 0.65
```

Outputs



McCabe thiele diagram for Actual number of stages when system is ideal



McCabe thiele diagram for Minimum number of stages when system is ideal

```
Actual Number Of Stages(Trays) :
     7

Minimum Number Of Stages(Trays) :
     5

Minimum Reflux Ratio :
1.271

>>
```

Reasons for the differences

1.In the non-ideal binary system, we have decided to go with the activity coefficient model (also known as the Van Laar model), which makes use of the (***γ)*** activity coefficient.

$$\begin{cases} \ln\ \gamma_1 = A_{12}\left(\frac{A_{21}X_2}{A_{12}X_1+A_{21}X_2}\right)^2 \\ \ln\ \gamma_2 = A_{21}\left(\frac{A_{12}X_1}{A_{12}X_1+A_{21}X_2}\right)^2 \end{cases}$$

2.In ideal binary system we apply Raoult's Law and there is no activity coefficient.

$$y_1 P = x_1 P_1^{sat}(T)$$
$$y_2 P = x_2 P_2^{sat}(T)$$

3. The number of triangles formed between the equilibrium curve and operating lines increases in non-ideal systems. Hence,Non-ideal systems have more stages than ideal systems as the curve saturates towards the **y=x** line.

4.Higher reflux ratios increase vapour/liquid contact in distillation columns. Higher reflux ratios mean purer distillate. This slows distillate collecting. Hence non-ideal systems have greater value of **Rmin** as compared to ideal systems.

These are the reasons for the differences in non-ideal and ideal binary system distillation for McCabe thiele Method.

Contribution by Group Members:

SAREN	SUSHMITA
Wrote the MATLAB code for getting the actual number of stages , Reflux ratio , Minimum Reflux Ratio	Looked out for videos and resources for McCabe Thiele process in MATLAB
Wrote the MATLAB code for plotting vapour – liquid equilibrium curve of ethanol-water mixture	Wrote the MATLAB code for getting the minimum number of stages
Help in making report	Help in making report