Chemical Engineering Thermodynamics

Vapor/Liquid Equilibrium:

Introduction and Application

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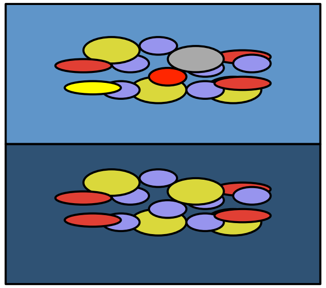
Consider a multicomponent system in a VLE condition, the fugacity (to be defined in Chapter 11) of species *i* for each phase is given by,

For vapor mixture $\hat{f}_i^v = \hat{\phi}_i y_i P$

For liquid solution $\hat{f}_i^l = \gamma_i x_i f_i$

VLE criteria (to be shown/derived in chapter 11),



$$\hat{f}_i^l = \hat{f}_i^v$$

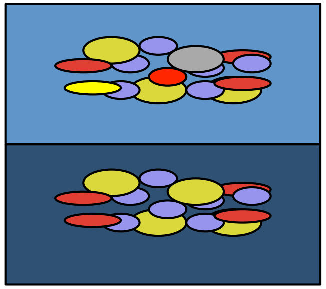
so $$\hat{\phi}_i y_i P = \gamma_i x_i f_i$$

where,

$\hat{\phi}_i$ fugacity coefficient species i in gas mixture

f_i fugacity of pure species i

γ_i *activity* coefficient of species i in liquid solution



Raoult’s Law

$\hat{\phi}_i = 1$

For ideal gas vapor mixture in equilibrium with ideal liquid solution

$\gamma_i = 1$

equation becomes $\quad y_i P = x_i f_i$

and also for pure species in equlibrium and ideal gas vapor,

$$f_i = f_i^l = f_i^v = P = P_i^{sat}$$

we get, $\quad y_i P = x_i P_i^{sat} \quad$ Raoult's Law $\quad$ (10.1)

Modified Raoult’s Law

$\hat{\phi}_i = 1$

For ideal-gas mixture in equilibrium with non-ideal liquid solution

$$\cancel{\hat{\phi}_i} y_i P = \gamma_i x_i f_i$$

$$y_i P = \gamma_i x_i P_i^{\text{sat}} \quad \text{Modified Raoult's Law} \qquad (10.5)$$

where γ_i is a function of T and x_i.

K-value (K_i)

$$K_i = \frac{y_i}{x_i} \qquad (10.10)$$

If Raoult's Law is valid,

$$y_i P = x_i P_i^{sat}$$

$$K_i = \frac{P_i^{sat}}{P} \qquad (10.11)$$

If Modified Raoult's Law is valid,

$$y_i P = x_i \gamma_i P_i^{sat}$$

$$K_i = \frac{\gamma_i P_i^{sat}}{P} \qquad (10.12)$$

K-value Using DePriester Chart

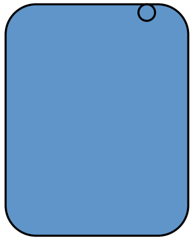
For light hydrocarbon mixture (commonly found in industry),

K_i is essentially function of T and P only.

K_i are tabulated in a chart called the DePriester chart.

Bubblepoint & Dewpoint Calculations

BUBL P: Calculate $\{y_i\}$ and P, given $\{x_i\}$ and T



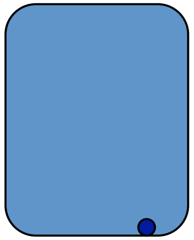
To calculate the P when the 1st bubble appear as a result of decrease in P at constant T. Also calculate the bubble’s composition $\{y_i\}$.

or

To calculate the P when the last bubble disappear as a result of increase in P at constant T. Also calculate the composition $\{y_i\}$ of this bubble.

DEW P: Calculate $\{x_i\}$ and P, given $\{y_i\}$ and T

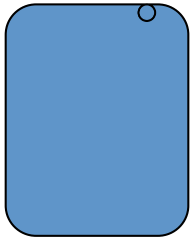
To calculate the P when the 1st dew (a drop of liquid) appear as a result of increase in P at constant T. Also calculate the composition $\{x_i\}$ of this dew.



or

To calculate the P when the last dew disappear as a result of decrease in P at constant T. Also calculate the composition $\{x_i\}$ of this dew.

BUBL T: Calculate $\{y_i\}$ and T, given $\{x_i\}$ and P

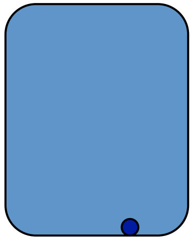


To calculate the T when the 1st bubble appear as a result of increase in T at constant P. Also calculate the composition $\{y_i\}$ of this bubble.

or

To calculate the T when the last bubble disappear as a result of decrease in T at constant P. Also calculate the composition $\{y_i\}$ of this bubble.

DEW T: Calculate $\{x_i\}$ and T, given $\{y_i\}$ and P

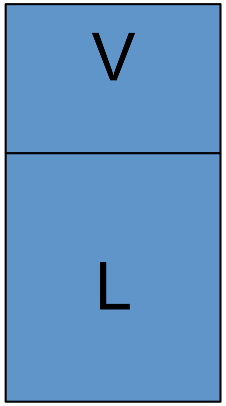


To calculate the T when the 1st dew (a drop of liquid) appear as a result of decrease in T at constant P. Also calculate the composition $\{x_i\}$ of this dew.

or

To calculate the T when the last dew disappear as a result of increase in T at constant P. Also calculate the composition $\{x_i\}$ of this dew.

Derivation



Overall mole balance

$$T = L + V$$

Component mole balance,

$$Tz_i = Lx_i + Vy_i$$

Let T=1 mol, so V and L are mole fractions,

$$z_i = Lx_i + Vy_i$$

$$z_i = (1 - V)x_i + Vy_i \qquad \text{(A)}$$

Note: z_i is overall composition.

Substitute $y_i = K_i x_i$ into (A),

$$z_i = (1-V)x_i + K_i x_i V = x_i(1-V+VK_i) = x_i(1+V(K_i-1))$$

$$x_i = \frac{z_i}{1+V(K_i-1)}$$

Substitute $x_i = \dfrac{y_i}{K_i}$ into (A),

$$z_i = (1-V)\frac{y_i}{K_i} + y_i V \qquad z_i K_i = (1-V)y_i + y_i V K_i$$

$$y_i = \frac{z_i K_i}{1+V(K_i-1)} \qquad (10.16)$$

Also,

$$\sum x_i - \sum y_i = 0$$

$$\sum \frac{z_i}{1+V(K_i-1)} - \sum \frac{z_i K_i}{1+V(K_i-1)} = 0$$

$$\sum \frac{z_i - z_i K_i}{1+V(K_i-1)} = 0$$

Bubblepoint Calculation

At bubble point (practically all liquid) L=1, V=0 and $z_i = x_i$

$$\sum \frac{z_i - z_i K_i}{1 + V(K_i - 1)} = 0$$ becomes,

$$\sum (x_i - x_i K_i) = 0$$

$$\sum x_i = \sum x_i K_i$$

$$\sum x_i K_i = 1 \qquad (10.13)$$ Bubblepoint criteria

If Raoult's Law valid,

$$\sum x_i K_i = \sum x_i \frac{P_i^{sat}}{P} = 1 \qquad \text{so,} \quad P = \sum x_i P_i^{sat} \qquad (10.2)$$

see example 10.1

If Modified Raoult's Law valid,

$$\sum x_i K_i = \sum x_i \frac{\gamma_i P_i^{sat}}{P} = 1 \qquad \text{so,} \quad P = \sum x_i \gamma_i P_i^{sat} \qquad (10.6)$$

see example 10.3

Dewpoint Calculation

At dewpoint (practically all vapor): L=0, V=1 and $z_i = y_i$

$$\sum \frac{z_i - z_i K_i}{1 + V(K_i - 1)} = 0$$ becomes,

$$\sum \frac{y_i - y_i K_i}{K_i} = 0$$

$$\sum \frac{y_i}{K_i} - \sum y_i = 0$$

$$\sum \frac{y_i}{K_i} = 1 \qquad (10.14)$$

Dewpoint criteria

If Raoult's Law valid,

$$\sum \frac{y_i}{K_i} = \sum \frac{y_i}{\frac{P_i^{sat}}{P}} = 1 \qquad P = \frac{1}{\sum \frac{y_i}{P_i^{sat}}} \qquad (10.3),$$

see example 10.1

If Modified Raoult's Law valid,

$$\sum \frac{y_i}{K_i} = \sum \frac{y_i}{\frac{\gamma_i P_i^{sat}}{P}} = 1 \qquad P = \frac{1}{\sum \frac{y_i}{\gamma_i P_i^{sat}}} \qquad (10.7),$$

see example 10.3

Relative Volatility

$$\alpha_{ik} = \frac{y_i / x_i}{y_k / x_k} = \frac{K_i}{K_k}$$

at azeotrope $\alpha_{ik} = \frac{1}{1} = 1$

$\alpha_{ik} > 1$ Species i is relatively more volatile

$\alpha_{ik} < 1$ Species k is relatively more volatile

If Raoult's Law valid,

$$\alpha_{12} = \frac{P_1^{sat} / P}{P_2^{sat} / P} = \frac{P_1^{sat}}{P_2^{sat}}$$

Note: for higher vapor pressure means more volatile $\alpha_{12} > 1$

If Modified Raoult's Law valid,

$$\alpha_{12} = \frac{\gamma_1 P_1^{sat} / P}{\gamma_2 P_2^{sat} / P} = \frac{\gamma_1 P_1^{sat}}{\gamma_2 P_2^{sat}}$$

Example 10.1

Plot Px_1y_1 at $T=75^oC$

Mixture: Acetonitrile(1)/Nitromethane(2)

Antoine Eqn,

$$\ln P_1^{sat} / kPa = 14.2724 - \frac{2945.47}{T/{}^oC + 224.00}$$

$$\ln P_2^{sat} / kPa = 14.2043 - \frac{2972.64}{T/{}^oC + 209.00}$$

calculate at 75^oC,

$$P_1^{sat} = 83.21 kPa \qquad P_2^{sat} = 41.98 kPa$$

Note: Acetonitrile(1) is more volatile.

Calculate P and y_1, given a set of x_1 and T=75^{o}C.
This is BUBL P calculation.

$$\sum x_i K_i = 1 \quad (10.13) \ .$$

Let us assume Raoult's Law is valid , $P = P_b = \sum x_i P_i^{sat} \qquad (10.2)$

$$P = x_1 P_1^{sat} + x_2 P_2^{sat} = x_1 P_1^{sat} + (1 - x_1) P_2^{sat}$$

$$P = (P_1^{sat} - P_2^{sat}) x_1 + P_2^{sat} \qquad \text{Eqn A} \qquad \text{note: a linear line (y=mx+c)}$$

$$\text{also,} \quad y_1 = \frac{x_1 P_1^{sat}}{P} \qquad \text{Eqn B}$$

So,
Calculate P for a set of x_1 (Eqn A) and then calculate y_1 (Eqn B)

Given or Set

Calculate

$$P = P_b = (P_1^{sat} - P_2^{sat})x_1 + P_2^{sat}$$

$$y_1 = \frac{x_1 P_1^{sat}}{P}$$

T (°C)	x_1	$P=P_b$(kPa)	y_1
75	0	41.98 P_2^{sat}	0
75	0.2	50.23	0.3313
75	0.4	58.47	0.5692
75	0.6	66.72	0.7483
75	0.8	74.96	0.8880
75	1	83.21 P_1^{sat}	1

Point b

So now plot Px_1 and Py_1 on Pxy diagram!!

Ex: Calculate P_d and x_1, given y_1=0.6 and T=75^{o}C

(i.e. what is the dew P for gas mixture at 75^{o}C and 60% acetonitrile)

This is point c in previous Px_1y_1 diagram.
Dew P calculation (Note: z_1=y_1).

$$\sum \frac{y_i}{K_i} = 1 \quad (10.14), \quad \text{If Raoult's Law valid,} \quad P_d = \frac{1}{\sum \frac{y_i}{P_i^{sat}}} \qquad (10.3)$$

$$P_d = \frac{1}{\frac{0.6}{83.21} + \frac{0.4}{41.98}} = 59.74 kPa$$

Compare with values from Pxy diagram.

Then calculate x_1 using,

$$x_1 = \frac{y_1 P_d}{P_1^{sat}} = \frac{0.6(59.74)}{83.21} = 0.43$$

- We could also plot Pxy diagram using DEW pressure calculation.
- Set y_i, calculate P_d and x_i.
- Plot Pxy using $P_d x_i y_i$
- DIY…..

Plot Tx_1y_1 at P=70kPa

Mixture: Acetonitrile(1)/Nitromethane(2)

Antoine Eqn,

$$T_1^{sat} / {}^oC = \frac{2945.47}{14.2724 - \ln P / kPa} - 224.00$$

$$T_2^{sat} / {}^oC = \frac{2972.64}{14.2043 - \ln P / kPa} - 209.00$$

so at 70kPa,

$$T_1^{sat} = 69.84^o C \qquad \mathrm{T}_2^{sat} = 89.58^o C$$

As expected Acetonitrile(1) is more volatile

$$\sum x_i K_i = 1 \quad (10.13)$$

For Raoult's Law, $P = P_b = \sum x_i P_i^{sat} \qquad (10.2)$

$$P = x_1 P_1^{sat} + x_2 P_2^{sat} = x_1 P_1^{sat} + (1 - x_1) P_2^{sat}$$

$$x_1 = \frac{P - P_2^{sat}}{P_1^{sat} - P_2^{sat}} \qquad \text{Eqn C}$$

Note: Since we used BUBL point calculation, $T = T_b$

Choose T between T_1^{sat} and T_2^{sat} , then using Antoine eqns calculate P_1^{sat} and P_2^{sat} at the chosen T and then calculate x_1 by Eqn C.

Then calculate y_1 using,

$$y_1 = \frac{x_1 P_1^{sat}}{P}$$

Plot Tx_1y_1 at P=70 kPa

Given or Set

$$x_1 = \frac{P - P_2^{sat}}{P_1^{sat} - P_2^{sat}}$$

$$y_1 = \frac{x_1 P_1^{sat}}{P}$$

P (kPa)	$T=T_b(^oC)$	x_1	y_1
70	69.84 T_1^{sat}	1 $(x_2=0)$	1 $(y_2=0)$
70	74	0.7378	0.8484
70	78	0.5156	0.6759
70	82	0.3184	0.4742
70	86	0.1424	0.2401
70	89.58 T_2^{sat}	0 $(x_2=1)$	0 $(y_2=1)$

So now plot Tx_1 and Ty_1 on a Txy diagram!!

Ex: Calculate T_b and y_1, given x_1=0.6 and P=70kPa.
(i.e. calculate the bubble temperature at 70kPa and 60% acetonitrile)

This is point b in previous Tx_1y_1 diagram. Note: z_1=x_1
Bubble temperature calculation!!

$$\sum_i x_i K_i = 1 \quad (10.13),$$

The solution is not straightforward as T is unknown. Let's see how to solve mathematically,

$$\text{For Raoult's Law, } P_b = \sum_i x_i P_i^{sat} \qquad (10.2)$$

$$P_b = \frac{P_k^{sat}}{P_k^{sat}} \sum_i x_i P_i^{sat} = P_k^{sat} \sum_i x_i \frac{P_i^{sat}}{P_k^{sat}} = P_k^{sat} \sum_i x_i \alpha_{ik}$$

where k is a component that arbitrarily chosen.

$$P_b = P_k^{sat} \sum x_i \alpha_{ik}$$

$$\text{where } \alpha_{ik} = \frac{P_i^{sat}}{P_k^{sat}} \quad \text{is relative volatility of } i \text{ wrt } k.$$

$$P_k^{sat} = \frac{P_b}{\sum x_i \alpha_{ik}} \qquad \text{(A)}$$

$$Also,$$

$$\ln \alpha_{ik} = \ln \frac{P_i^{sat}}{P_k^{sat}} = \ln P_i^{sat} - \ln P_k^{sat} = \left(A_i - \frac{B_i}{T + C_i} \right) - \left(A_k + \frac{B_k}{T + C_k} \right)$$

Solution is through iteration,

1. Start with an initial guess of T as follows,

$$T = \sum x_i T_i^{sat} \qquad T = 0.6(69.84) + 0.4(89.58) = 77.74^o C$$

2. Arbitrarily pick a component, e.g. Nitromethane so, k=2

3. Calculate α_{ik},
(note: Number of α_{ik} is equal to total number of component)

$$\ln \alpha_{ik} = \left(A_i - \frac{B_i}{T + C_i} \right) - \left(A_k + \frac{B_k}{T + C_k} \right)$$

we get,

$$\alpha_{12} = 1.9611$$

$$\alpha_{22} = 1$$

4. Calculate P_k^{sat} using eqn A, $P_k^{sat} = \dfrac{P}{\sum x_i \alpha_{ik}}$

$$P_2^{sat} = \frac{P}{x_1\alpha_{12} + x_2\alpha_{22}} = \frac{70}{0.6(1.9611)+0.4(1)} = 44.3977\text{kPa}$$

5. Calculate a new value of T using the Antoine eqn,

$$T = \frac{B_k}{A_k - \ln P_k^{sat}} - C_k \qquad T = \frac{2972.64}{14.2043 - \ln 44.3977} - 209 = 76.53^o C$$

6. Stop if this T is equal or close to earlier value of T, else use this value as a new guess. Repeat steps 3, 4 & 5 until converge.

T	α_{12}	P_2^{sat}	T
77.74	1.9611	44.39	76.53
76.53	1.9703	44.24	76.43
76.43	1.9717	44.22	76.42

Answer (point b)

7. Finally, calculate y_i using Raoult's law (Use the Antoine Eqn for P_i^{sat})

y_1=0.7472

DEW T calculation

Calculate T_d and x_1, given y_1 and P.

Example: Calculate T_d and x_1 for $z_1 = y_1 = 0.6$ and P=70kPa. See page 356 for the solution (also by iteration) of DEW T calculation.

Answer: $T_d = 79.58^oC$

$x_1 = 0.4351$

Example 10.4

Calculation of dew pressure and bubble pressure using K-value from DePriester chart.

Note: Why the solution is by trial and error?

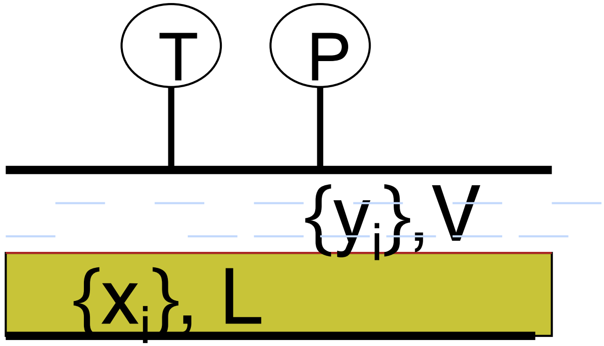
Flash Calculation

Flash Calculation

An important application of VLE!

Liquid at pressure equal or higher than P_b "flashes" or partially evaporates when the P is reduced, thus producing a vapor and liquid.

Flash calculation is to determine V , L, $\{x_i\}$, and $\{y_i\}$ at T and P by assuming VLE.



Note: $\{x_i\}$ composition of liquid and $\{y_i\}$ composition of vapor

As derived for VLE system,

$$y_i = \frac{z_i K_i}{1 + V(K_i - 1)} \qquad (10.16)$$

$$\sum y_i = 1, \quad \text{so:}$$

$$\sum \frac{z_i K_i}{1 + V(K_i - 1)} = 1 \qquad (10.17)$$

Solution is by trial and error.

Guess V until the summation term equal to 1.
But………

………first we need to know whether the system is actually two-phase.

In general ……

If $P_d < P < P_b$, two phase

or

If $T_b < T < T_d$, two phase

Examples of Flash Calculation

Example 10.5:
Flash calculation for system where
Raoult's Law valid

Example 10.6:
Flash calculation using K-value from
DePriester Chart

Dewpoint T of Mixture of Water Vapor and Non-condensable Gases

This is a special case of dew T calculation.

Solution is straightforward by the application of Raoult's Law to the condensable component H_2O (here identified as component 2).

The system contains a dew (liquid water) in VLE with mixture of water vapor and non-condensable gases (such as N_2, CO_2, O_2 etc.).

$$y_2 P = x_2 P_2^{sat}$$

The dew is 100% H_2O, so $x_2=1$

$$\text{so} \quad P_2^{sat} = y_2 P$$

Example

Dewpoint T of Combustion Products

For stoichiometric combustion of methane, calculate dew point T of the combustion products.

$CH_4 + 2O_2 + 2(79/21)N_2 \text{ ------> } CO_2 + 2H_2O + 2(79/21)N_2$

Mole fraction of H_2O is $2/(1+2+2(79/21)) = 0.19$

$$P_2^{sat} = y_2 P \qquad P_2^{sat} = 0.19(101.325\text{kPa}) = 19.25\text{kPa}$$

From steam table*, $T_d = T_2^{sat} = 59.5^oC$

*You could also use Antoine Eqn.

Henry’s Law

Henry's Law is VLE relation that is valid for ideal-gas mixture in equilibrium with a dilute solution, where we want to know the composition of dissolve gas *i* in the dilute solution.

For example,

a) CO_2 and H_2O system.

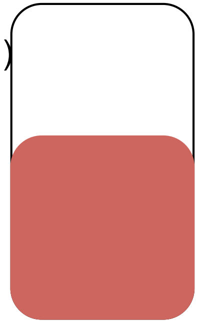
b) Air and H_2O system.

$$\overset{1}{\cancel{\hat{\phi}_i}}\, y_i P = \gamma_i x_i f_i$$

$$y_i P = x_i \gamma_i f_i = x_i \gamma_i P_i^{sat}$$

no value for dissolved (supercritical) gas at VLE conditions

$$\text{let } H_i = \gamma_i f_i = \gamma_i P_i^{sat}$$



H_i is Henry's constant (in bar) for dissolved gas (i).

so $y_i P = x_i H_i$ Henry's Law

$y_i P = x_i H_\mathrm{i}$

So at dilute solution,
$y_i = (H_\mathrm{i}/\mathrm{P})\ x_i$

For constant system pressure P,
$y_i = (Constant) x_i$

If we plot y_i vs x_i , we get a straight line through the origin.

So Henry's constant for dissolved gas (*i*) can be easily determined from experiment.

In previous example of dewpoint for combustion product, we assume the liquid is all H_2O (x_2=1).

What if we want to know the mole fraction of dissolved CO_2 (component 1) in the dew (liquid)?

We could solve this using Henry's Law for dissolved gases (CO_2).

Apply Henry's law for component 1.

Use H_1 data from Table 10.1 (note: this actually valid at 25°C).

$$x_1 = \frac{y_1 P}{\mathrm{H}_1} = \frac{(1/(1+2+7.52))(1.013bar)}{1670bar} = 3.4622\mathrm{x}10^{-5} \approx 0$$

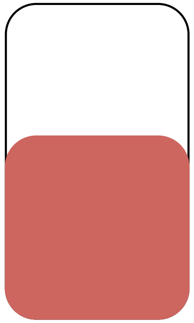
As expected, only small amount of CO_2 present in liquid water.

See also example 10.2

If the fugacity of *i* in liquid phase is given by Henry's Law,

$$\hat{f}_i = \gamma_i x_i f_i = x_i \mathrm{H}_i$$

If the gas is ideal solution (Lewis/Randall is valid),



$$\hat{f}_i^{id} = \phi_i y_i P$$

So we get the following version of Henry's Law if gas mixture is ideal solution ,

$$\phi_i y_i P = x_i \mathrm{H}_i$$

Extension of Example 10.3

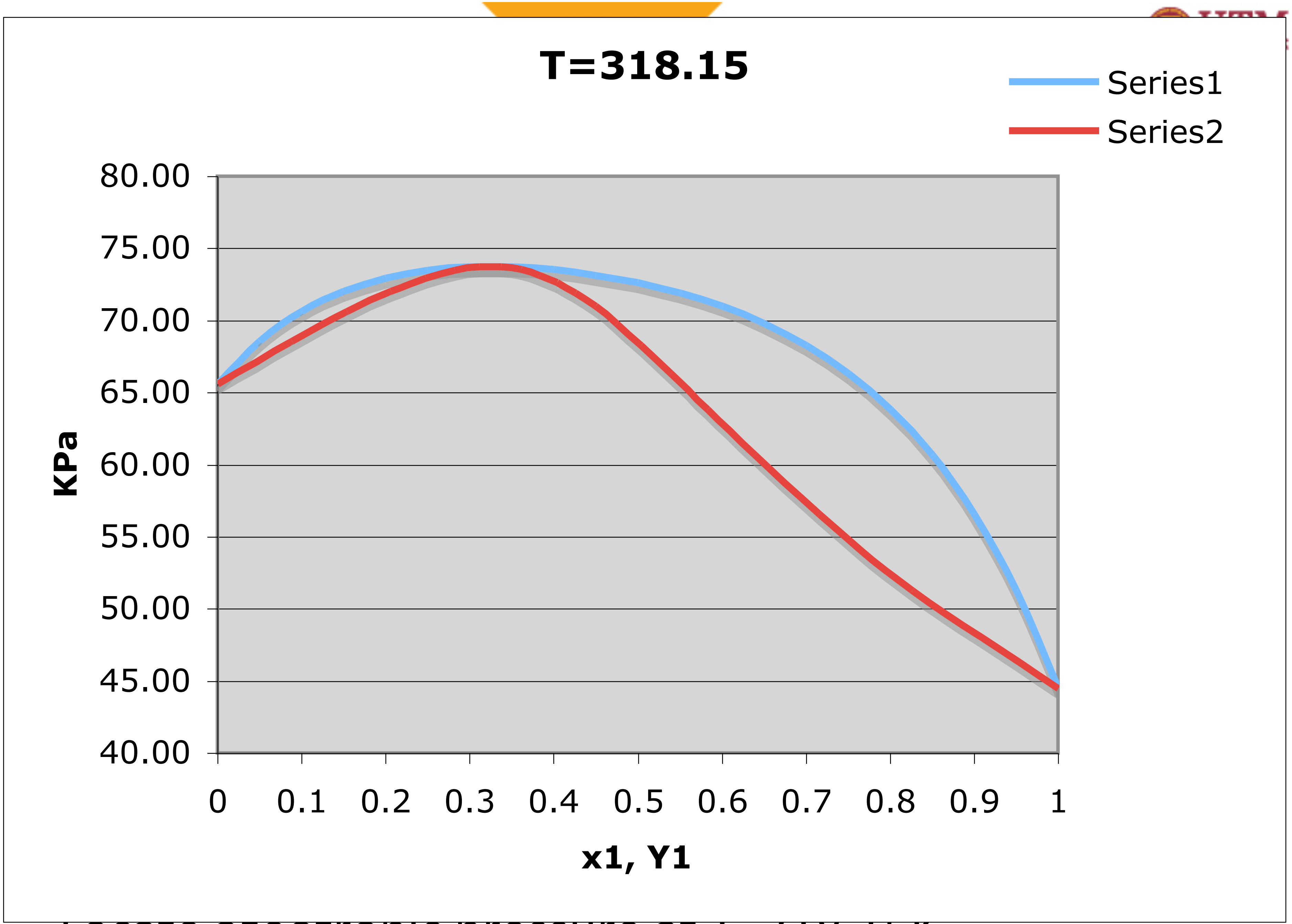
Plot Px_1y_1 and x_1y_1 diagrams at T=318.15K

From bubblepoint calculation,

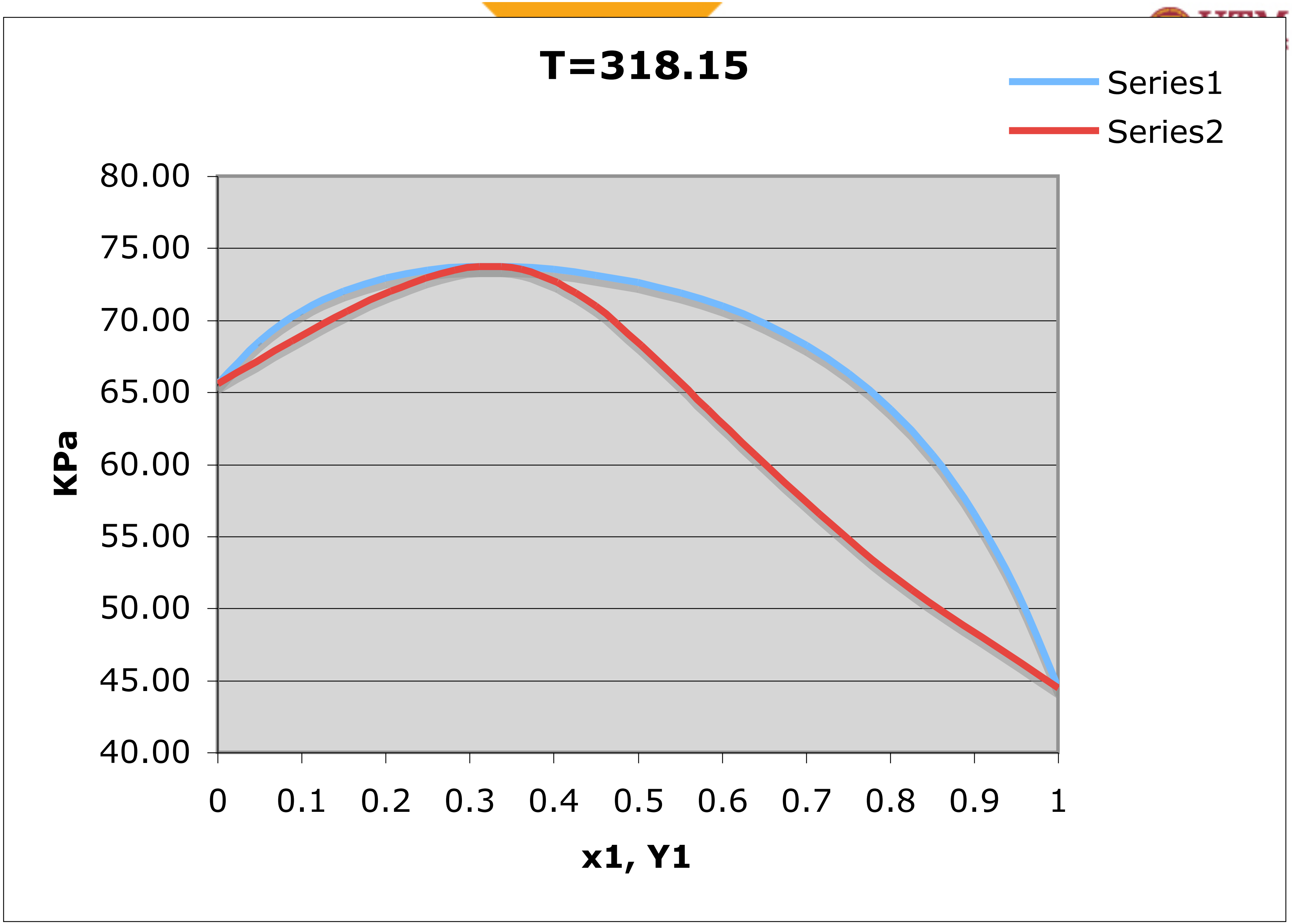
Set x_1
Calculate P_b
Calculate y_1

x1	G1	G2	P	y1
0.00	3.03	1.00	65.64	0.00
0.05	2.72	1.00	68.57	0.09
0.10	2.45	1.01	70.64	0.15
0.15	2.23	1.03	72.06	0.21
0.20	2.03	1.05	72.97	0.25
0.25	1.86	1.07	73.50	0.28
0.30	1.72	1.10	73.73	0.31
0.35	1.60	1.15	73.73	0.34
0.40	1.49	1.19	73.54	0.36
0.45	1.40	1.25	73.17	0.38
0.50	1.32	1.32	72.63	0.40
0.55	1.25	1.40	71.92	0.43
0.60	1.19	1.49	70.99	0.45
0.65	1.15	1.60	69.81	0.47
0.70	1.10	1.72	68.29	0.50
0.75	1.07	1.86	66.36	0.54
0.80	1.05	2.03	63.88	0.58
0.85	1.03	2.23	60.70	0.64
0.90	1.01	2.45	56.60	0.72
0.95	1.00	2.72	51.31	0.83
1.00	1.00	3.03	44.51	1.00

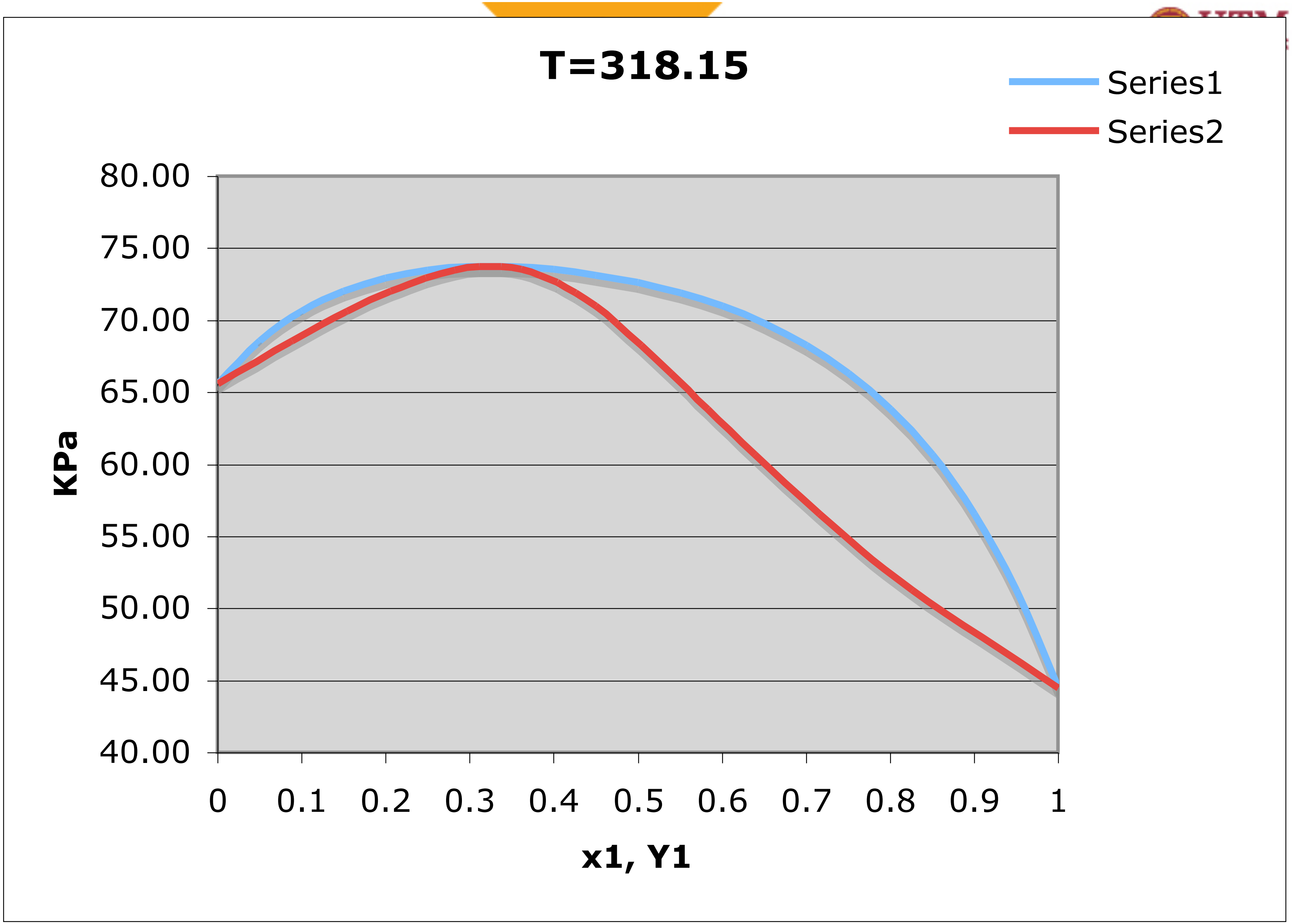
G1 is gamma1



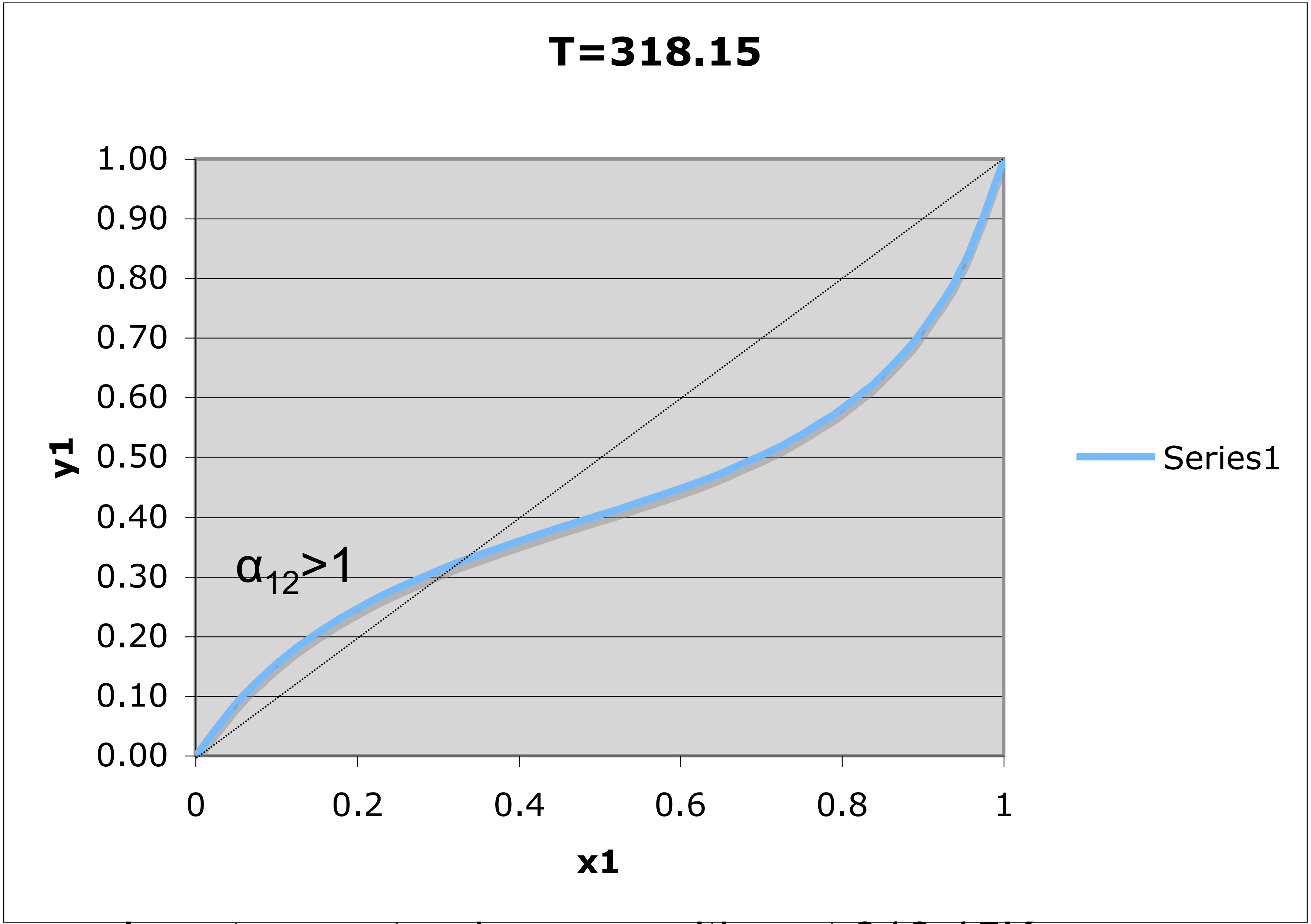
Locate azeotropic pressure at T=318.15K and its composition



Locate BUBL P at T=318.15K, x_1=0.25



Locate DEW P at T=318.15K, y_1=0.6



Locate azeotropic composition at 318.15K

A stream of mixture of methanol(1)/methyl acetate(2) is inside a pipeline where the T is 318.15K and P is 66kPa. The stream contains (60 mole percent methanol). What is the phase of the stream?

Let's check bubble pressure and dew pressure.

From example 10.3b), Dew P is 62.89kPa

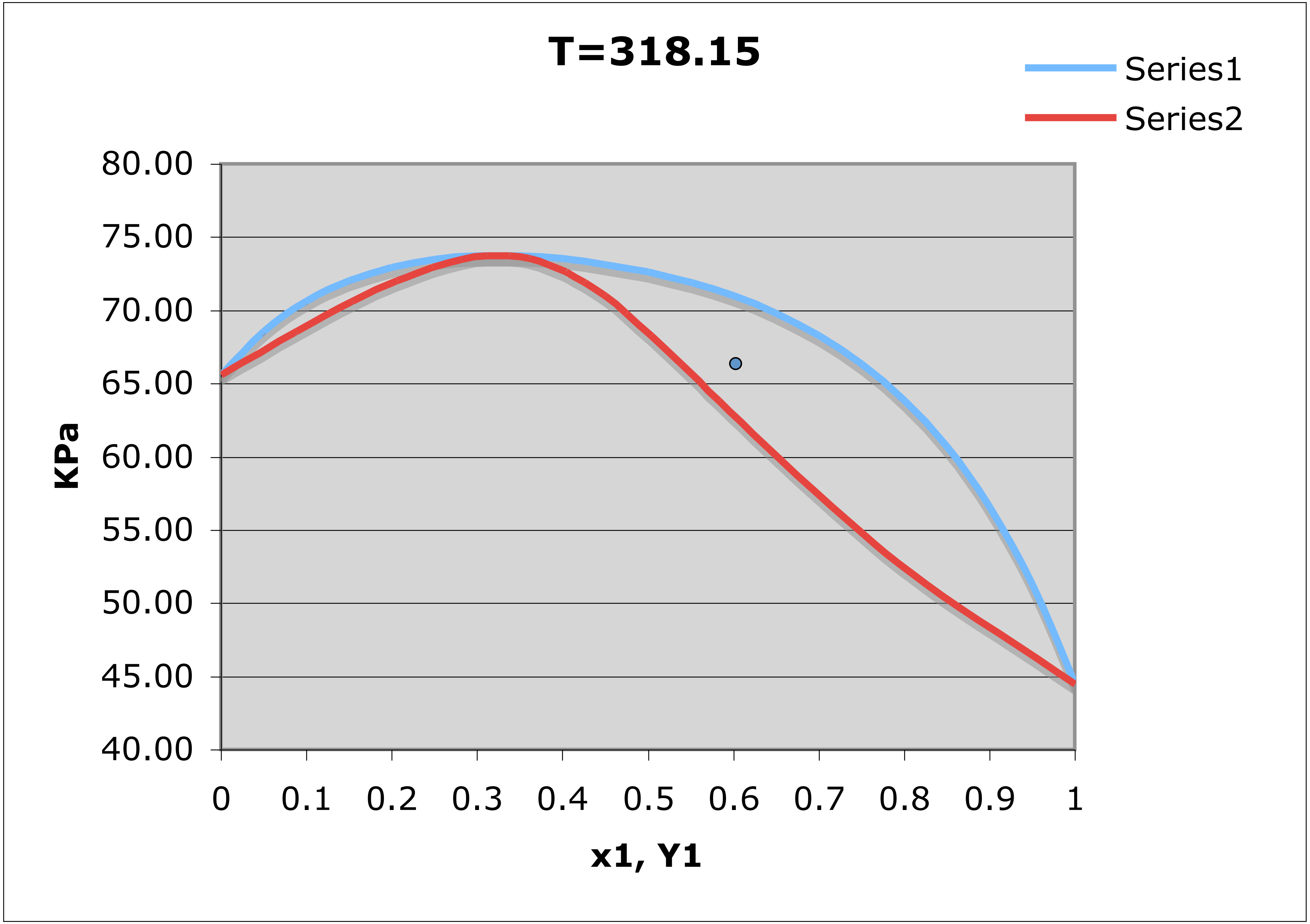
Now calculate bubble P,

$$P_b = x_1\gamma_1 P_1^{sat} + x_2\gamma_2 P_2^{sat} = 71kPa$$

$P_d < P < P_b$ hence **two phases**!

Locate the conditions on the following Px_1y_1 diagram.

Determine V, L, $\{x_i\}$ and $\{y_i\}$ using flash calculation.


T=318.15
Series1
Series2
KPa
80.00
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
x1, Y1

$$K_1 = \frac{P_1^{sat}\gamma_1}{P} = \frac{P_1^{sat}\exp(A(x_2)^2)}{P}$$

$$K_2 = \frac{P_2^{sat}\exp(A(x_1)^2)}{P}$$

We need x_1!! Lets us do bubble point calculation at P=66kPa, T=318.15K and x_1

$$P_b = 66kPa = x_1\gamma_1 P_1^{sat} + x_2\gamma_2 P_2^{sat} \qquad \text{(a)}$$

$$K_1 = \frac{P_1^{sat}\gamma_1}{P} = \frac{P_1^{sat}\exp(A(x_2)^2)}{P}$$

$$K_2 = \frac{P_2^{sat}\exp(A(x_1)^2)}{P}$$

so (a) becomes,

$$66 = x_1 P_1^{sat}\exp(A(1-x_1)^2) + \ (1\text{-}x_1)P_2^{sat}\exp(A(x_1)^2)$$

$$66 = x_1(44.51)\exp(1.107)(1 - x_1)^2) + (1\text{-}x_1)(65.64)\exp(1.107(x_1)^2)$$

Guess x_1,

$x_1 = 0.7$ P=68.29

$x_1 = 0.8$ P=63.88

$x_1 = 0.75$ P=66.36

$x_1 = 0.76$ P=65.91……good enough

Now we can calculate K_1 and K_2 for flash calculation,

$$K_1 = \frac{P_1^{sat}\gamma_1}{P} = \frac{44.51\exp(1.107(1-0.76)^2)}{66} = 0.719$$

$$K_2 = \frac{65.64\exp(1.107(0.76)^2)}{66} = 1.885$$

Substitute into eqn (10.17),

$$\sum \frac{z_i(K_i)}{1+V(K_i-1)} = 1$$

$$\frac{0.6(0.719)}{1+V(0.719-1)} + \frac{(1-0.6)(1.885)}{1+V(1.885-1)} = 1 \qquad (10.17)$$

$$\frac{0.431}{1-0.281V} + \frac{0.754}{1+0.885V} = 1$$

$$\frac{0.431}{1-0.281V}+\frac{0.754}{1+0.885V}=1$$

Guess,	$\sum \quad = 1$
V=0.50	1.024
V=0.55	1.017
V=0.70	1.002
V=0.75	0.999
V=0.73	1.000

So V=0.73 L=1-V=0.27

$$y_i = \frac{z_i K_i}{1 + V(K_i - 1)} \qquad (10.16)$$

$y_1 =$ ....

$y_2 =$ ....

$$x_i = \frac{y_i}{K_i}$$

$x_1 =$ ....

$x_2 =$ ....