



RADMAN SANA'T CO.
CONSULTING ENGINEERS



Instructions manual
Vapor-Liquid Equilibrium

**Aim:**

In this unit we study the liquid-vapor equilibrium of the mixture of ethanol and water the present experiments were conducted at various temperature at 1 atm and the experimental data were collected and some were compared with theoretical results.

Vapor–liquid equilibrium

In thermodynamics and chemical engineering, the vapor–liquid equilibrium (VLE) describes the distribution of a chemical species between the vapor phase and a liquid phase. The concentration of a vapor in contact with its liquid, especially at equilibrium, is often expressed in terms of vapor pressure, which will be a partial pressure (a part of the total gas pressure) if any other gas(es) are present with the vapor. The equilibrium vapor pressure of a liquid is in general strongly dependent on temperature. At vapor–liquid equilibrium, a liquid with individual components in certain concentrations will have an equilibrium vapor in which the concentrations or partial pressures of the vapor components have certain values depending on all of the liquid component concentrations and the temperature. The converse is also true: if a vapor with components at certain concentrations or partial pressures is in vapor–liquid equilibrium with its liquid, then the component concentrations in the liquid will be determined dependent on the vapor concentrations and on the temperature. The equilibrium concentration of each component in the liquid phase is often different from its concentration (or vapor pressure) in the vapor phase, but there is a relationship. The VLE concentration data can be determined experimentally, approximated with the help of theories such as Raoult's law, Dalton's law, and Henry's law. Such vapor–liquid equilibrium information is useful in designing columns for distillation, especially fractional distillation,



which is a particular specialty of chemical engineers. In mixtures containing two or more components, the concentrations of each component are often expressed as mole fractions. The mole fraction of a given component of a mixture in a particular phase (either the vapor or the liquid phase) is the number of moles of that component in that phase divided by the total number of moles of all components in that phase. Binary mixtures are those having two components. Three-component mixtures are called ternary mixtures. There can be VLE data for mixtures with even more components, but such data is often hard to show graphically. VLE data is a function of the total pressure, such as 1 atm or at the pressure the process is conducted at. When a temperature is reached such that the sum of the equilibrium vapor pressures of the liquid components becomes equal to the total pressure of the system (it is otherwise smaller), then vapor bubbles generated from the liquid begin to displace the gas that was maintaining the overall pressure, and the mixture is said to boil. This temperature is called the boiling point of the liquid mixture at the given pressure. (It is assumed that the total pressure is held steady by adjusting the total volume of the system to accommodate the specific volume changes that accompany boiling.) The boiling point at an overall pressure of 1 atm is called the normal boiling point of the liquid mixture.

Thermodynamic description of vapor–liquid equilibrium

The field of thermodynamics describes when vapor–liquid equilibrium is possible, and its properties. Many of the analysis depends on whether the vapor and liquid consist of a single component, or if they are mixtures.

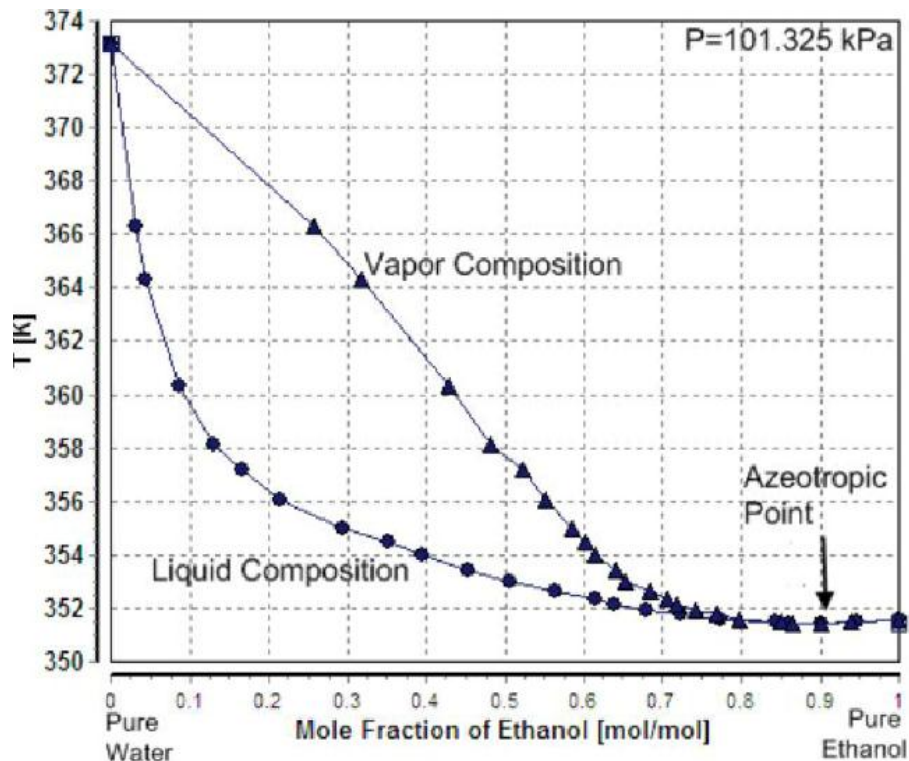


Fig1. Mole fraction of Ethanol

Boiling-point diagrams

Binary mixture VLE data at a certain overall pressure, such as 1 atm, showing mole fraction vapor and liquid concentrations when boiling at various temperatures can be shown as a two-dimensional graph called a boiling-point diagram. The mole fraction of component 1 in the mixture can be represented by the symbol x_1 . The mole fraction of component 2, represented by x_2 , is related to x_1 in a binary mixture as follows:

$$x_1 + x_2 = 1$$

In multi-component mixtures in general with n components, this becomes:

$$x_1 + x_2 + \dots + x_n = 1$$

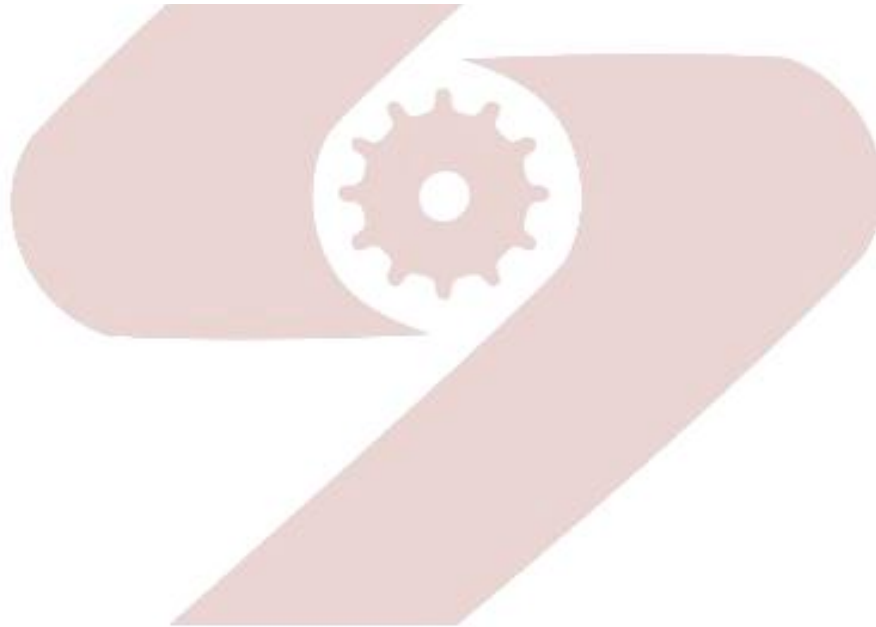


The preceding equilibrium equations are typically applied for each phase (liquid or vapor) individually, but the result can be plotted in a single diagram. In a binary boiling-point diagram, temperature (T) is graphed vs x_1 . At any given temperature where both phases are present, vapor with a certain mole fraction is in equilibrium with liquid with a certain mole fraction. The two mole fractions often differ. These vapor and liquid mole fractions are represented by two points on the same horizontal isotherm (constant T) line. When an entire range temperatures vs. vapor and liquid mole fractions is graphed, two (usually curved) lines result. The lower one, representing the mole fraction of the boiling liquid at various temperatures, is called the bubble point curve. The upper one, representing the mole fraction of the vapor at various temperatures, is called the dew point curve. These two curves necessarily meet where the mixture becomes purely one component, namely where $x_1 = 0$ (and $x_2 = 1$, pure component 2) or $x_1 = 1$ (and $x_2 = 0$, pure component 1). The temperatures at those two points correspond to the boiling points of each of the two pure components. For certain pairs of substances, the two curves also coincide at some point strictly between $x_1 = 0$ and $x_1 = 1$. the dew-point temperature always lies above the boiling-point temperature for a given composition when they are not equal. The meeting point is called an Azeotrope for that particular pair of substances. It is characterized by an azeotrope temperature and an azeotropic composition, often expressed as a mole fraction. There can be maximum-boiling azeotropes, where the azeotrope temperature is at a maximum in the boiling curves, or minimum-boiling azeotropes, where the azeotrope temperature is at a minimum in the boiling curves

If one wants to represent a VLE data for a three-component mixture as a boiling point "diagram", a three dimensional graph can be used. Two of the dimensions would be used to represent the composition mole fractions, and the third dimension would be the temperature. Using two dimensions, the composition can be represented as an equilateral triangle in which each corner represents one of the pure components. The edges of the triangle represent a mixture of the two components at each end of the edge. Any point inside the triangle



represents the composition of a mixture of all three components. The mole fraction of each component would correspond to where a point lies along a line starting at that component's corner and perpendicular to the opposite edge. The bubble point and dew point data would become curved surfaces inside a triangular prism, which connect the three boiling points on the vertical temperature "axes". Each face of this triangular prism would represent a two-dimensional boiling-point diagram for the corresponding binary mixture. Due to their three-dimensional complexity, such boiling-point diagrams are rarely seen. Alternatively, the three-dimensional curved surfaces can be represented on a two-dimensional graph by the use of curved isotherm lines at graduated intervals. Two sets of such isotherm lines are needed on such a two-dimensional graph: one set for the bubble point surface and another set for the dew point surface



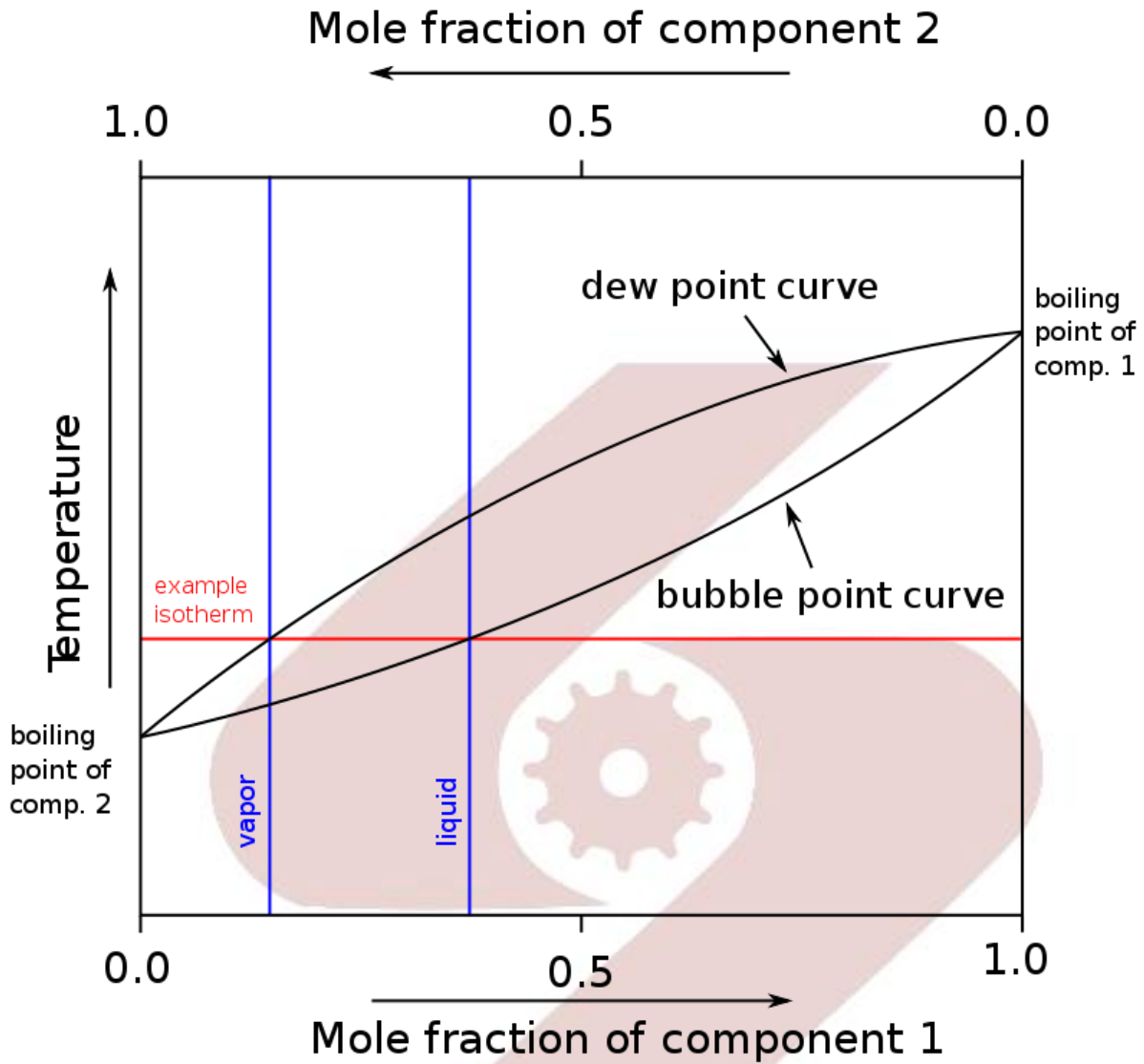


Fig2. Boiling Point diagram



K values and relative volatility values

The tendency of a given chemical species to partition itself preferentially between liquid and vapor phases is the Henry's law constant. There can be VLE data for mixtures of four or more components, but such a boiling-point diagram is hard to show in either tabular or graphical form. For such multi-component mixtures, as well as binary mixtures, the vapor-liquid equilibrium data are represented in terms of K values defined by:

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

where y_i and x_i are the mole fractions of component i in the phases y and x respectively

For Raoult's law:

$$K_i = \frac{P^*}{P}$$

The values of the ratio K_i are correlated empirically or theoretically in terms of temperature, pressure and phase compositions in the form of equations, tables or graph such as the DePriester charts For binary mixtures, the ratio of the K values for the two components is called the relative volatility denoted by α :

$$\alpha = \frac{K_i}{K_j}$$



which is a measure of the relative ease or difficulty of separating the two components. Large-scale industrial distillation is rarely undertaken if the relative volatility is less than 1.05 with the volatile component being i and the less volatile component being j . K values are widely used in the design calculations of continuous distillation columns for distilling multicomponent mixtures

Vapor–liquid equilibrium diagrams

For each component in a binary mixture, one could make a vapor–liquid equilibrium diagram. Such a diagram would graph liquid mole fraction on a horizontal axis and vapor mole fraction on a vertical axis. In such VLE diagrams, liquid mole fractions for components 1 and 2 can be represented as x_1 and x_2 respectively, and vapor mole fractions of the corresponding components are commonly represented as y_1 and y_2 . Similarly for binary mixtures in these VLE diagrams

$$x_1 + x_2 = 1 \text{ and } y_1 + y_2 = 1$$

Such VLE diagrams are square with a diagonal line running from the $(x_1 = 0, y_1 = 0)$ corner to the $(x_1 = 1, y_1 = 1)$ corner for reference. These types of VLE diagrams are used in the McCabe–Thiele method to determine the number of equilibrium stages (or theoretical plates) needed to distill a given composition binary feed mixture into one distillate fraction and one bottoms fraction. Corrections can also be made to take into account the incomplete efficiency of each tray in a distillation column when compared to a theoretical plate.



EXPERIMENTAL SECTION

The unit designed to demonstrate and study the vapor-liquid equilibrium as basic data of any distillation problem is the equilibrium between the liquid and vapor phases of the system subjected to distillation. Hence it is to great important to study the VLE.

The unit consist of distillation tank with a heating element. Shell and tube condenser, reflux distillate section. And pump. flow rate can be adjusted by rotameter.

Instrumentation is done to measure the temperatures at different point. A Thermocouple input at vessel boiler and shown temperature on the vessel boiler. Adjusting temperature of Input gas of condenser T1 to (85-92°C) and start experiment. As table below write the temperature of boiler and condenser after system stability

Table1. Data(Experimental)

T1	T2	T3	TH
temperature Input gas of condenser	temperature Input water of condenser	temperature Out put water of condenser	Boiler temperature

The vapors form the top of column are condensed in the shell and tube type condenser by water. The condensate liquid is collected in reflux tank and return to column

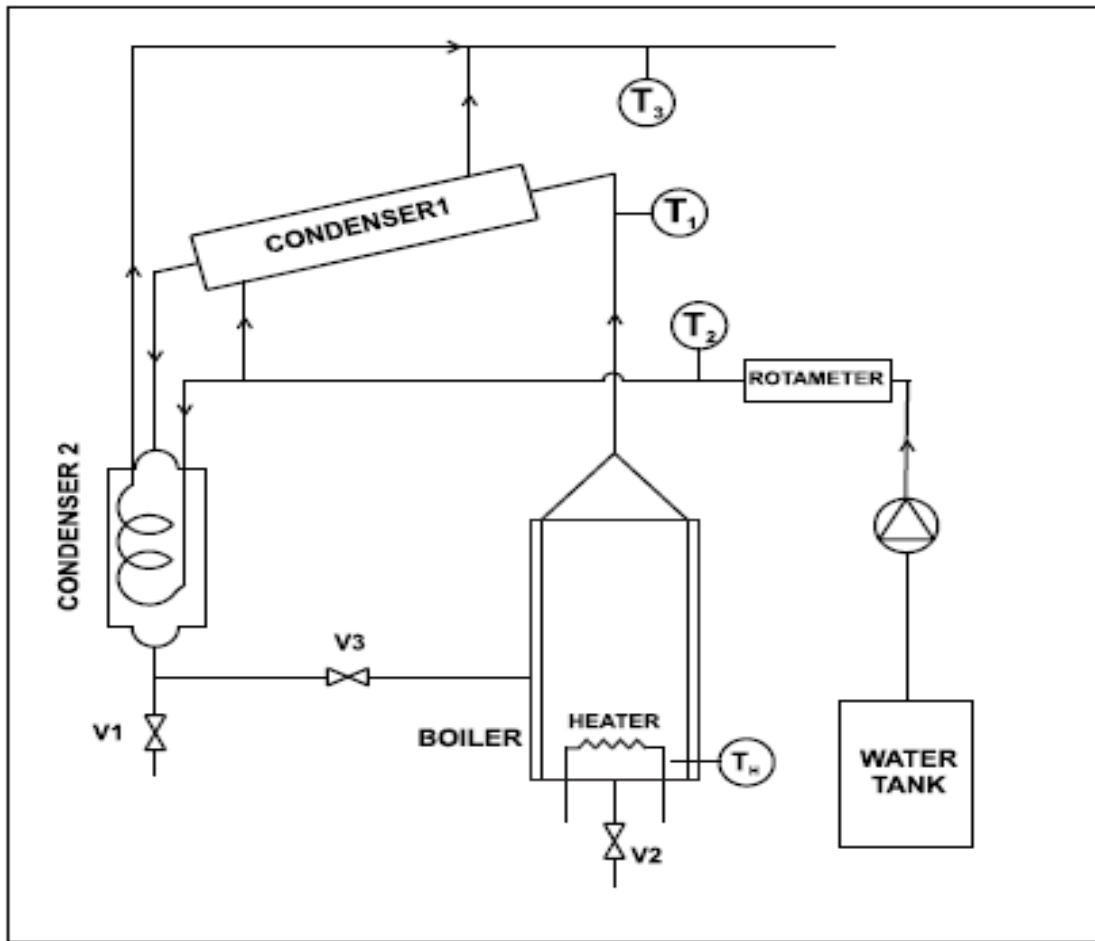


Fig3. PID Unit

The boiler tank of unit is consist of water-ethanol mixture The characteristics of water and ethanol are as follows.

**Table 2. characteristics of water and ethanol**

Materials	Molar mass (g/mol)	formula	Density(g/cm³)
ethanol	46.07	C ₂ H ₆ O	0.789
water	18	H ₂ O	0.9965

Condenser

There are two types of condenser differentiated by the extent of condensation. In a total condenser, all of the vapor leaving the top of the column is condensed. Consequently, the composition of the vapor leaving the top tray y_1 is the same as that of the liquid distillate product and reflux, X_D . In a partial condenser, the liquid product D returns to the column. As liquid and a vapor product stream is removed. The compositions of these three streams (v_1 , D and R) are different. Normally, D (composition y_D) is in equilibrium with R (composition X_D).

Boiler

A boiler or steam generator is a device used to create steam by applying heat energy to water. A boiler or steam generator is used wherever a source of steam is required. The form and size depends on the application. Most reboilers are partial reboilers, that is they only vaporize part of the liquid in the column phase. partial reboilers also provide an ideal separation stage. In large, complex columns, side stream reboilers can be used. These draw liquid off a tray, heat it, and then return the vapor liquid mixture to the same or a similar tray. Reboilers take several forms: they may be "thermosiphon" types that rely on thermal effects on density to draw liquid through the heat exchanger, "force circulation" types that use a pump to force



liquid through, or even stab-in types that come through the side the column into the liquid reservoir.

Experimental

Prepare 3 liters of 10% (volume of ethanol) and fill it in the boiler tank and turn on the heater and pump. And set the temperature of the gas entering to condenser (T1) to 85°C and give the system time to reach the desired temperature, the pressure at this test is the ambient pressure is 101.325 Kpa . After the system reaches the desired temperature. The solution begins to condense Then open the V3 valve and give the system about 20 minutes for the system to reach a steady state. Then close V3 (reflux) for collect the condensed solution in the condenser tank. To obtain the equilibrium data of the two-component system of water and ethanol in the vapor phase, open the valve V1 and take a sample (100cc condensed solution) and determine the volume percentage of alcohol with hydrometer. To obtain the equilibrium data, the two-component system of water and ethanol in the liquid phase open the valve v2 and take a sample from under the boiler (100 cc) and give time it until it reaches 20°C, then determine the volume percentage of alcohol with hydrometer in phase liquid. Accordingly, we obtain the molar fraction of ethanol and measure the validity of the data according to Figure 1. Raise the temperature of T1 (in the range of 85 to 92 ° C) Open the V3 valve again (about 10 to 15 minutes) and allow the system to stabilize at new temperature. Then close the valve V3 and after collecting the sample in the condenser tank, open the valves V1 and V2 again and take a sample from the condenser tank and boiler (100 cc) and allow the sample taken from under the boiler to reach 20°C and then determine the It should be noted that the experiment can volume percentage of alcohol with hydrometer. be repeated with each 1°C increase and the equilibrium data can be obtained at the desired temperature.



Important

Please don't touch Heater when is on

Make sure that the height of the solution inside the boiler tank is not less than half according to sight glass

Calculation :

calculation mol fraction:

100cc=vol of sample

T=K

V1%= vol% of ethanol(condenser)

V2%=100- V1%=vol% of water(condenser)

100*V1%= CC volume of alcohol

100*V2%= CC volume of water

volume of alcohol *0.7862= gr mass alcohol

volume of water *0.9965= gr mass water

gr mass alcohol/ 46.07 mol alcohol

gr mass alcohol/ 18.02 mol water

mol water/ (mol water+ mol alcohol) mol fractional of water

mol alcohol/ (mol water+ mol alcohol) mol fractional of alcohol

