Understanding the principles behind distillation

Distillation is one of the most common separation techniques used in laboratories or industries where liquid chemicals are separated based on their volatilities. Distillation is usually done by vaporizing the liquid mixture in one vessel and condensing the vapors into another.

The liquid mixture being distilled is called distilland and the resulting liquid is called distillate. In laboratories, there are several types of distillation used according to the needs such as simple distillation which involves only one vaporization-condensation cycle or vacuum distillation where the process is carried out under reduced pressure. Distillation makes use of the apparent physical property of the liquids: the boiling point. This method will produce an excellent result if the boiling points of the liquids distilled differ significantly from one another.

We need to understand the reason why boiling phenomena occurs. A pure liquid in an open container will boil when its vapor pressure (the pressure of a vapor in its equilibrium with its non-vapor phases) is the same as the ambient pressure. To attain the above condition, a liquid must be heated until it reaches a certain temperature in which the molecules of the liquid have sufficient energy to overcome the attractive forces between them. This specific temperature is called a boiling point/saturation temperature and importantly, it is varied for many different liquids. Moreover, boiling point depends on pressure.

Normal boiling point of liquids occurs at one atm or the standard sea level pressure; for example, water’s normal boiling point is 100 °C. Boiling point will decrease at higher elevations due to the decrease in atmospheric

pressure. Likewise, as the surrounding pressure increases, boiling point will continue to increase and stop at a critical point in which liquid and gas properties become identical; boiling point decreases as the ambient pressure decreases until reaching the triple point (specific temperature and pressure where solid, liquid, and gas coexist in equilibrium). Distillation method is actually not as simple as it first looks.

There is a common misconception that even though two different liquids are mixed together, each of them will still boil at its normal boiling point thus, producing a pure distillate. Nevertheless, this does not occur even in the idealized system (mixture of liquids with similar chemical structure). There are two principles that govern the ideal distillation process: Raoult’s Law and Dalton’s Law. Raoult’s Law states that the partial vapor pressure of a component in a mixture is equal to the vapor pressure of the pure component at that temperature multiplied by its mole fraction in the mixture. Dalton’s Law states that the total vapor pressure is the sum of the vapor pressure of each component in the mixture. Therefore, when an ideal blend of liquids is heated, each component’s vapor pressure will increase causing the total vapor pressure to rise.

As a result, boiling will occur when the total vapor pressure equals the ambient pressure. In a 50: 50 mixture of two mutually soluble liquids, it will boil at the temperature halfway between the boiling points of the pure substances. We unfortunately rarely encounter this type of ideal systems. Most of the time, the liquids have different chemical structure (slightly soluble) causing a change in the volatility. Thus, wide deviations occur from the behaviors that are predicted by Raoult’s Law.

One important example is the mixture of alcohol and water which form azeotrope (the boiling point of the mixture is lower than the boiling temperature of each pure substances) when heated. Distillation technique would be employed in many college-level chemistry classes. There are a few important points to remember. One would be that the vapor of a mixture will always contains a higher amount of the more volatile component.

Additionally, it is not possible to achieve a completely pure distillate, yet a sufficient amount of purification can be attained using distillation.