DESIGN OF METAL SEPARATION USING HIGH TEMPERATURE DISTILLATION

Principles of Extractive metallurgy

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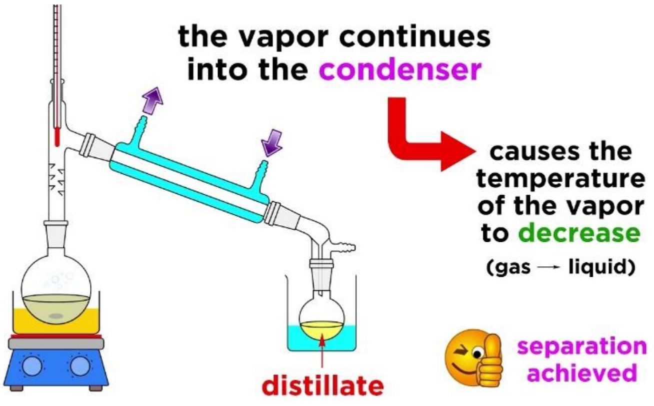
Distillation:

The word distillation derives from the Latin verb destillare, meaning to drop down or to trickle down. Distillation had a broader meaning in ancient and medieval times because nearly all purification and separation operations were subsumed under the term distillation, such as filtration, crystallization, extraction, sublimation, or mechanical pressing of oil. This becomes evident because in earlier times there was no clear understanding of heat or the consistency of materials.



Distillation is a well-defined separation unit consisting of the partial evaporation of a liquid mixture and successive condensation, with a composition that differs from that of evaporation. It is the process of separating the components or substances from a liquid mixture by using selective boiling and condensation.

Principle:

In heating a mixture of substances, the most volatile or the lowest boiling distils first, and the others subsequently or not at all.

Working:

This basic operation requires the use of a still or retort in which a liquid is heated, a condenser to cool the vapour, and a receiver to collect the distillate.

Types of distillation:

There are several types of distillation processes. Most methods of distillation used by industry and in laboratory research are variations of simple distillation.

A method called fractional distillation, or differential distillation, has been developed for certain applications, such as petroleum refining, because simple distillation is not efficient for separating liquids whose boiling points lie close to one another.

Multiple-effect distillation, often called multistage-flash evaporation, is another elaboration of simple distillation. This operation, used primarily by large commercial desalting plants, does not require heating to convert a liquid into vapour. The liquid is simply passed from a container under high atmospheric pressure to one under lower pressure. The reduced pressure causes the liquid to vaporize rapidly; the resulting vapour is then condensed into distillate.

A variation of the reduced-pressure process uses a vacuum pump to produce a very high vacuum. This method, called vacuum distillation, is sometimes employed when dealing with substances that normally boil at inconveniently high temperatures or that decompose when boiling under atmospheric pressure.

Steam distillation is an alternative method of achieving distillation at temperatures lower than the normal boiling point. It is applicable when the material to be distilled is immiscible (incapable of mixing) and chemically nonreactive with water. Examples of such materials include fatty acids and soybean oils. The usual procedure is to pass steam into the liquid in the still to supply heat and cause evaporation of the liquid.

Metal Refining:

In metallurgy refining of metals is the final process. Once the extraction process is complete, we must ensure that the metal is free of any impurities. If you remember we have done a similar process before of removing impurities during concentration of ores. However, in the refining process, the chemical composition of the metal will remain unchanged. There are various ways to make a metal pure. The refining method to be chosen will depend on the physical and chemical properties of a particular metal.
It is to be distinguished from other processes such as smelting and calcining in that those two involve a chemical change to the raw material, whereas in refining, the final material is usually identical chemically to the original one, only it is purer.

Role of distillation in metal refining:

Certain metals such as Zinc and Mercury have a very low boiling point. So on heating them they very readily vaporize. And of course, they leave behind their impurities. The impure metal is heated beyond its melting point in a furnace and the vapours are reconverted to metals once the impurities are separated.

Metal distillation utilizes the difference in boiling point and vapor pressure between various metal elements, and is distilled under a certain temperature. The metal with a low boiling point and low vapor pressure volatilizes into the gas phase and then condensed into ingot again, while the impurity metal element with a low boiling point and low vapor pressure does not volatilize and left in the residue. In this way, the metals are separated.

Principal of distillation in metal refining:

From the kinetic theory of gases, Langmuir derived an expression for the mass of vapor molecules, ω_i, of a species, i, striking unit area of surface in unit time.

$$\omega_i = p_i\sqrt{(M_i/2\pi RT)}$$

where Mi is the atomic or molecular weight of the species in the gas phase and p_i is the vapour pressure.

Assuming ideal behaviour of the gas, the activity of an element in a liquid solution(a_m), relative to the pure substance standard state, is defined by the relation:

$$a_m = p_m/p_m^\circ$$

Where p°_m is the vapor pressure of the pure element at the temperature considered.

Using this relation, we can write,

$$\omega_i = a_i p_i^\circ\sqrt{(M_i/2\pi RT)}$$

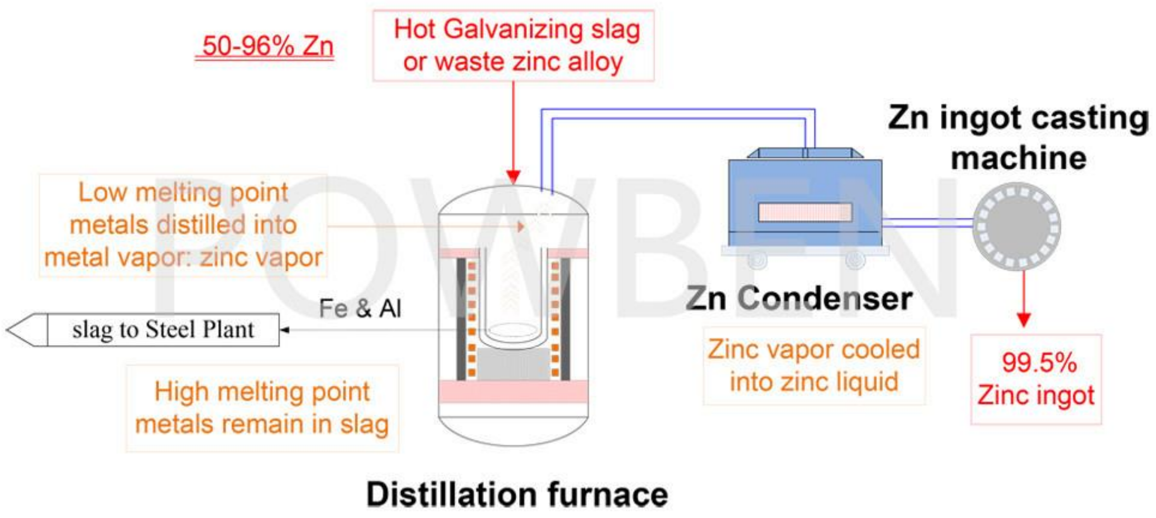
At equilibrium, the rate of condensation is equal to the rate of evaporation, so that this equation also gives the rate at which atoms or molecules are transferred from the melt to the gas. Hence, if two species, A and B, can volatilize at a given temperature, the relative rates of volatilization are given by:

$$\frac{\omega_A}{\omega_B} = \frac{a_A p_A^\circ\sqrt{(M_A/2\pi RT)}}{a_B p_B^\circ\sqrt{(M_B/2\pi RT)}}$$

If A and B represent the solute and the solvent, respectively, the extent to which the solute can be removed without excessive loss of the solvent increases as the ratio ω_A/ω_B is increased. This is the basis of refining by distillation.

Why pressure lower than atmospheric pressure is used in Distillation Plant?

The use of distillation is very widespread in the chemical industries and many different types and methods of distillation are in use. It is possible to carry out distillation processes at atmospheric pressure or at pressures that are higher or lower than atmospheric. Vacuum distillation is distillation performed under reduced pressure, which allows the purification of compounds not readily distilled at ambient pressures or simply to save time or energy. This technique separates compounds based on differences in boiling points. This technique is used when the boiling point of the desired compound is difficult to achieve or will cause the compound to decompose. A reduced pressure decreases the boiling point of compounds. The reduction in boiling point can be calculated using a temperature-pressure nomograph using the Clausius–Clapeyron relation



The figure above shows the vacuum distillation of zinc.

Applications:

1. The most common refining method for mercury is triple distillation, in which the temperature of the liquid mercury is carefully raised until the impurities either evaporate or the mercury itself evaporates, leaving the impurities behind. This distillation process is performed three times, with the purity increasing each time.
2. Vacuum distillation is one of the techniques used for removal of major impurities at ppm level in cadmium from 3N+ to 5N+. Although the zone refining and allied techniques are used to remove the impurities from 5N and above, the vacuum distillation is used (Kovelevski *et al* 1996) as a preceding supportive to remove the high melting point impurities.
3. Pb–Sn alloys were separated successfully by the vacuum distillation in small- scale and continuous industrialized experiments, and lead content in refined tin decreased to less than 0.01%.
4. An interesting alternative for recycling all types of scrap magnesium is vacuum distillation. This method aims at refining magnesium scrap into very high-purity magnesium (99.999%) to be used in the semiconductor industry.
5. The impurities in crude tin were effectively removed at 1473 K for 35 min and material weight of 80 g under 5 Pa. Under this condition, 98.67 mass% of tin in the residue can be recovered, and 84 mass% of arsenic in crude tin was removed by vacuum distillation. Arsenic can be removed effectively from crude tin by using vacuum distillation.
6. High purity zinc is also obtained by vacuum distillation.

Advantages of using Distillation:

1. Simple process and easy to operate.
2. Low loss of valuable metals and high metal recovery metals.
3. Low processing cost and investment & good economic returns.
4. Environmentally friendly.
5. Various choice for end products: alloy, pure metal ingot, and metal powder.