

## MATERIAL BALANCE

Material balance calculations are employed in tracing the inflow and outflow of material in a process and thus establish quantities of components or the whole process stream. The procedures are useful in formulating products to specified compositions from available raw materials, evaluating final compositions after blending, evaluating processing yields, and evaluating separation efficiencies in mechanical separation systems.

### Law of Conservation of Mass

Material balances are based on the principle that matter is neither created nor destroyed. Thus, in any process, a mass balance can be made as follows:

$$\text{Inflow} = \text{Outflow} + \text{Accumulation}$$

Inflow may include formation of material by chemical reaction or microbial growth processes, and outflow may include material depletion by chemical or biological reactions.

If accumulation is 0, inflow = outflow and the process is at steady state. If the accumulation term is not 0, then the quantity and concentration of components in the system could change with time and the process is an unsteady state.

### Process Flow Diagrams

Before formulating a material balance equation, visualize the process and determine the boundary of the system for which the material balance is to be made. It is essential that everything about the process that affects the distribution of components is known. The problem statement should be adequate to enable the reader to draw a flow diagram. However, in some cases, basic physical principles associated with a process may affect the distribution of components in the system but may not be stated in the problem. It is essential that a student remembers the physical principles applied in the processes used as examples. Knowing these principles not only allows the student to solve similar material balance problems but also provides information that may be used later as a basis for the design of a new process or for evaluation of parameters affecting efficiency of a process



For example, consider a problem in crystallization. The problem may be simply stated: Determine the amount of sugar (water-free basis) that can be produced from 100 kg of sugar solution that contains 20% by weight of sugar and 1% of a water-soluble uncrystallizable impurity. The solution is concentrated to 75% sugar, cooled to 20°C, centrifuged, and the crystals dried.

The problem statement is indeed adequate to draw a process flow diagram. This is shown in above Fig.

However, this flow diagram does not give a complete picture of where various streams separate and leave the system. below Figure is a flowdiagram of the same process, but after taking into consideration howcomponents partition in various steps in the process, additional streams leaving the system are drawn in the diagram.

To concentrate a 20% solution to 75% requires the removal of water. Thus, water leaves the system at the evaporator. The process of cooling does not alter the mass, therefore, the same process stream enters and leaves the crystallizer. Centrifugation separates most of the liquid

phase from the solid phase, and the crystals, the solid phase containing a small amount of retained solution, enter the drier.

A liquid phase leaves the system at the centrifuge. Water leaves the system at the drier.

Three physical principles involved in this problem are not stated: (1) Crystals will crystallize out of a solution when solute concentration exceeds the saturation concentration. The solute concentration in the liquid phase is forced toward the saturation concentration as crystals are formed. Given enough time to reach equilibrium, the liquid phase that leaves the system at the centrifuge is a saturated sugar solution. (2) The crystals consist of pure solute and the only impurities are those adhering to the crystals from the solution. (3) It is not possible to completely eliminate the liquid from the solid phase by centrifugation. The amount of impurities that will be retained with the sugar crystals depends on how efficiently the centrifuge separates the solid from the liquid phase. This principle of solids purity being dependent on the degree of separation of the solid from the liquid phase applies not only in crystallization but also in solvent extraction. In order to solve this problem, the saturation concentration of sugar in water at 20°C, and the water content of the crystals fraction after centrifugation must be known.

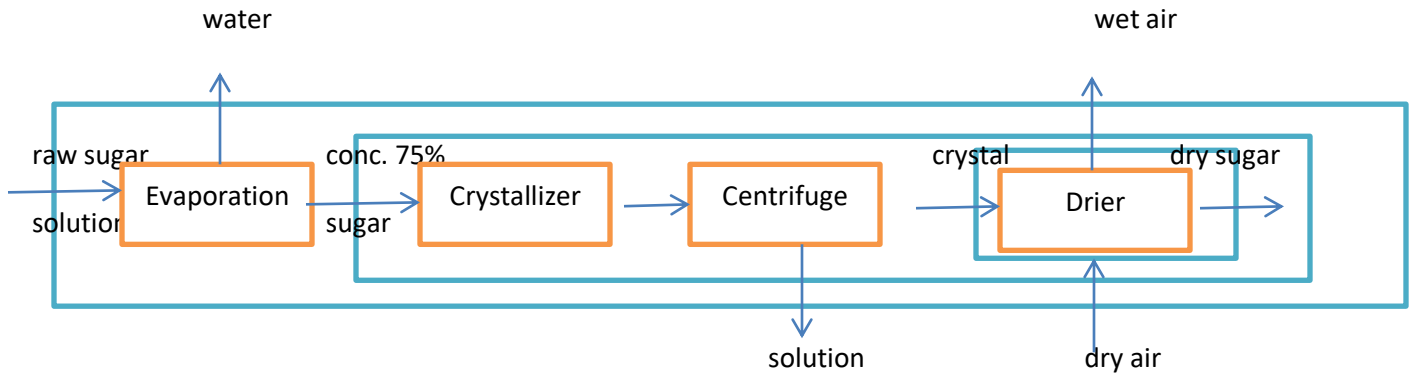


Figure: Process flow diagram for a crystallization problem showing input and exit streams and boundaries enclosing subsystems for analyzing sections of the process