# Introduction to Chemical Engineering

## Problem Sheet 2 – Week 3 – September 27 2024

**Goals:** Consolidating Your Foundations on Non-Reactive Systems

This week's exercise is designed to strengthen your understanding of material balances on non-reactive systems, whether using mass balances or mole balances.

**Remarks:**

- A splitter/splitting point does not alter the composition of the input and output streams; it only divides the total flow rate of the input stream into several output streams with different flow rates (see Problem 2)

# Problem 1: Pure Ethanol (Material Balance – Single Unit – Non-reactive)

Suppose you want to make 1000 kg/h of pure ethanol by separating a mixture that contains 60% water and 40% ethanol. To help with the separation, you add a pure benzene stream to the distillation column. This helps remove the water from the ethanol.

The distillate that comes out of the top of the distillation column has 75% benzene, 24% water, and the rest is ethanol. As mentionned above, the process also produces pure ethanol.

Start by drawing a labeled flowchart of the process and then determine how much benzene needs to be fed into the distillation column.

## Problem 2: Distillation with Reflux (Material Balance – Multiple Units – Non-reactive)

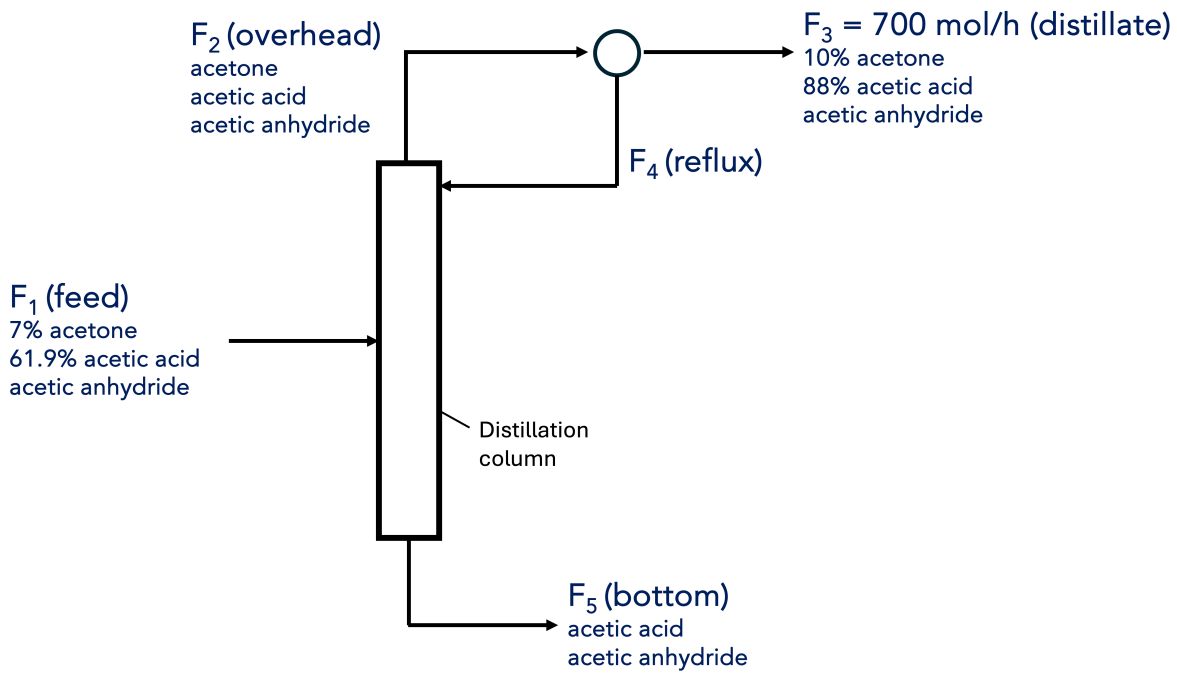
You are tasked with calculating all the flow rates in a distillation system, where a three-component mixture is separated. The feed mixture consists of 7% acetone, 61.9% acetic acid, and 31.1% acetic anhydride (all percentages are in mol %).

The overall system is designed to produce:

- A **bottoms stream** with **no acetone**
- A **distillate stream** of **700 mol/h**, containing **10% acetone** and **88% acetic acid** (in mol %).

Additionally, **60% of the overhead** is returned as **reflux** to the column.

You are required to calculate all the flows within the system (in mol/h), assuming that all compositions are given in mol %



# Problem 3: Orange juice (Material Balance – Multiple Units – Non-reactive)

Fresh orange juice contains **12.0 wt% solids** (the solids include sugars, fibers, and other non-water components) and **88% water**. Concentrated orange juice contains **42.0 wt% solids** and **58% water**. Initially, the juice was concentrated using a single evaporation process, but this caused many of the **volatile flavor compounds** to escape with the water, resulting in a flat-tasting concentrate.

A new process is introduced to solve this issue. In this process, a fraction of the **fresh juice** (containing **12% solids** and **88% water**) **bypasses the evaporator**, while the remaining juice enters the evaporator and is concentrated to **58 wt% solids** and **42% water**. The concentrated stream from the evaporator is then mixed with the bypassed fresh juice to achieve a final concentration of **42% solids** and **58% water**.

**Tasks:**

1. **Draw and Label a Flowchart:**
    - You are asked to draw and label a flowchart for this process. Assume that only water is evaporated, meaning the solids and flavor compounds remain unaffected.
    - The species involved include:
        - **Fresh juice** (12% solids, 88% water)
        - **Evaporated juice** (58% solids, 42% water)
        - **Final product** (42% solids, 58% water)
        - **Water vapor** (the water removed by the evaporator)
    - Prove that the subsystem, where the bypass stream splits off from the evaporator feed, has **one degree of freedom** (i.e., one variable that can be controlled independently).
    - Perform a **degree-of-freedom analysis** for:
        - The **overall system**
        - The **evaporator**
        - The **bypass**
        - The **mixing point**
    - List the equations you would need to solve to determine all unknown stream variables. **Circle the variable** for which each equation would solve, but **do not perform any calculations**.

2. **Calculate the Amount of Product and Fraction of Bypassed Feed:**
    - Calculate the amount of **42% concentrate orange juice** produced per **100 kg of fresh juice** fed to the process.
    - Determine the **fraction of the fresh juice** that bypasses the evaporator.

3. **Consider a Different Concentration and Suggest Drawbacks:**
    - The **volatile flavor compounds** are primarily retained in the portion of the fresh juice that **bypasses the evaporator**.
    - Consider how you could improve flavor retention by increasing the solids concentration to **90%** in the evaporator, instead of 58%. This would result in bypassing a larger fraction of the fresh juice.
    - Suggest potential **drawbacks** of this approach