An Overview of Chemical Process Technology

Making Sense of Process Technology

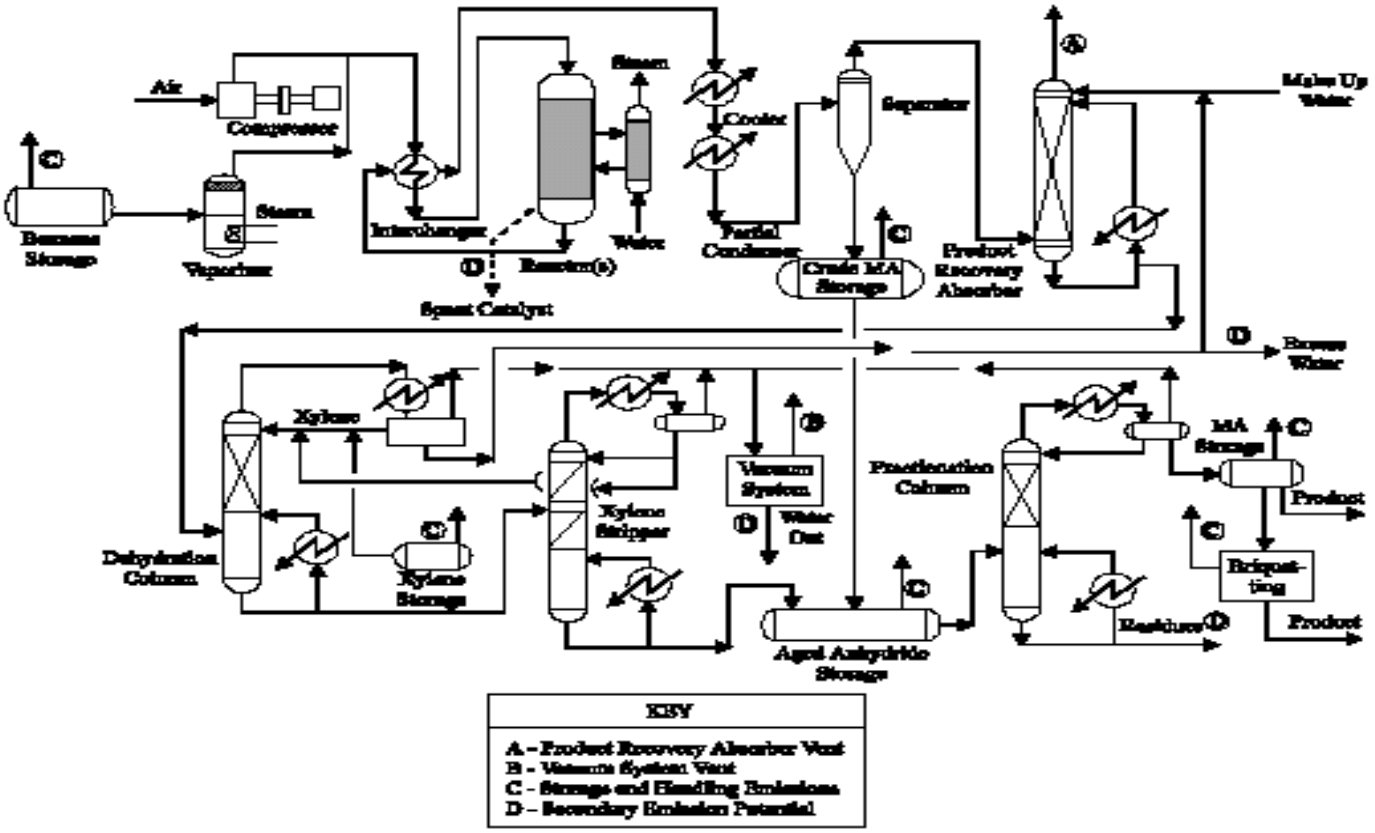


Figure 6.14-1. Process flow diagram for uncontrolled model plant.

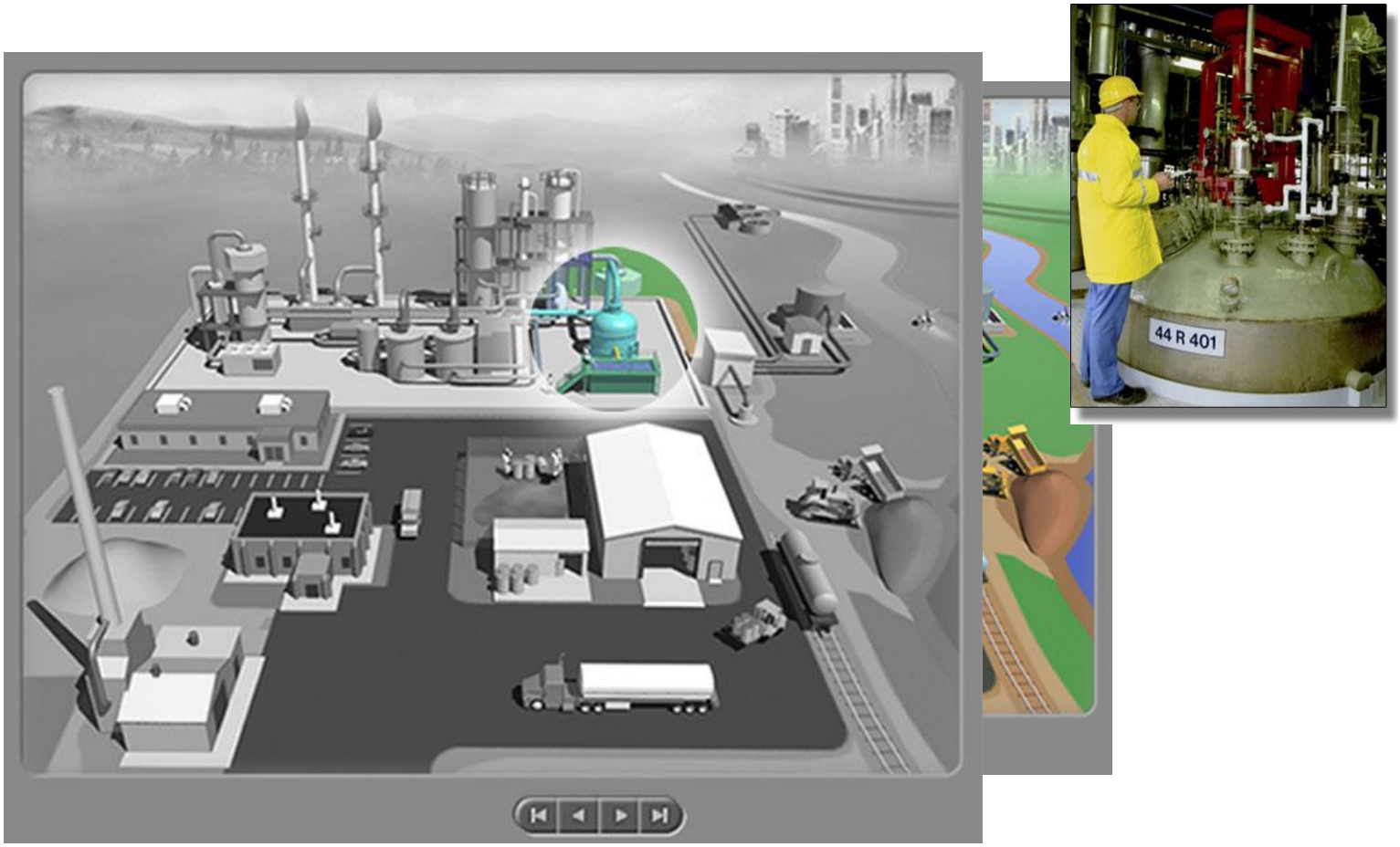
Unit Operations or “Unit ops” Concept

- Each chemical process can be broken down into a series of steps (operations)
- Individual operations have common techniques – based on the same scientific principles
- Underscores the common features of diverse processes
- Crosses industry and process lines

Behind the Complex Appearance, Chemical Manufacturing is Simple…

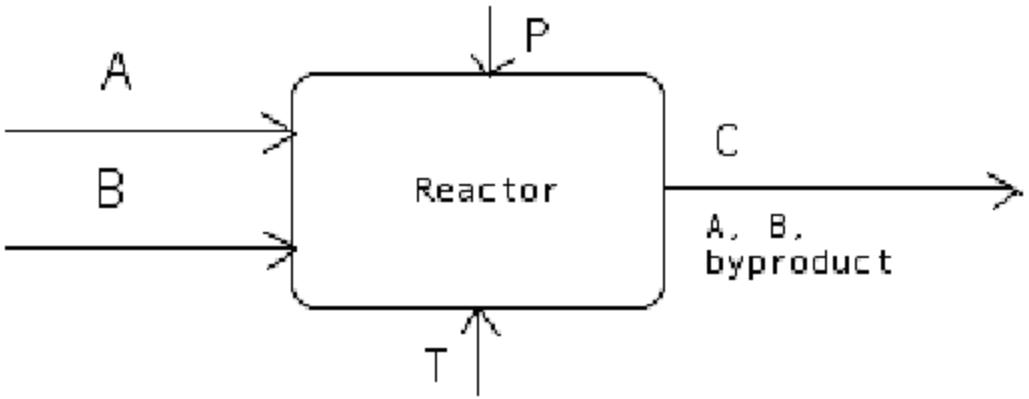
- Raw materials are mixed and/or **reacted** to create useful products
- These products are **separated** in one or more steps
- Between each step, process streams may be **heated** or **cooled** to optimum temperatures
- In some cases, products may be **mechanically processed** to convenient form for transport and use

Introduction to Chemical Reactors



Reactor basics

- A + B → C (+ byproducts) (+ unreacted A & B)
- Every reaction is governed by:
  - **reaction stoichiometry**
  - **reaction equilibrium (maximum conversion)**
  - **rate of reaction**



Trade-offs in Reactor Design

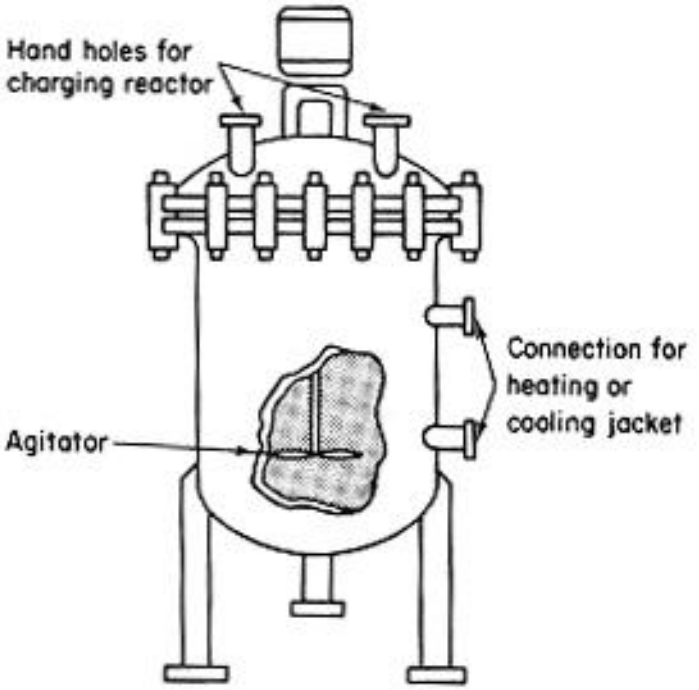
- **Want to maximize…**
  - product throughput
  - conversion efficiency
  - selectivity
  - flexibility
  - process safety
  - “controllability”
- **Want to minimize**
  - byproduct formation
  - energy use
  - downstream separations
  - physical complexity
  - capital cost

Some Common Reactor Types

- Batch
- Semi-batch
- Continuous
  - **Stirred tank**
  - **Packed bed**
  - **Fluidized bed**
- Electrolytic “cells”
- Bioreactors

Batch Reactor

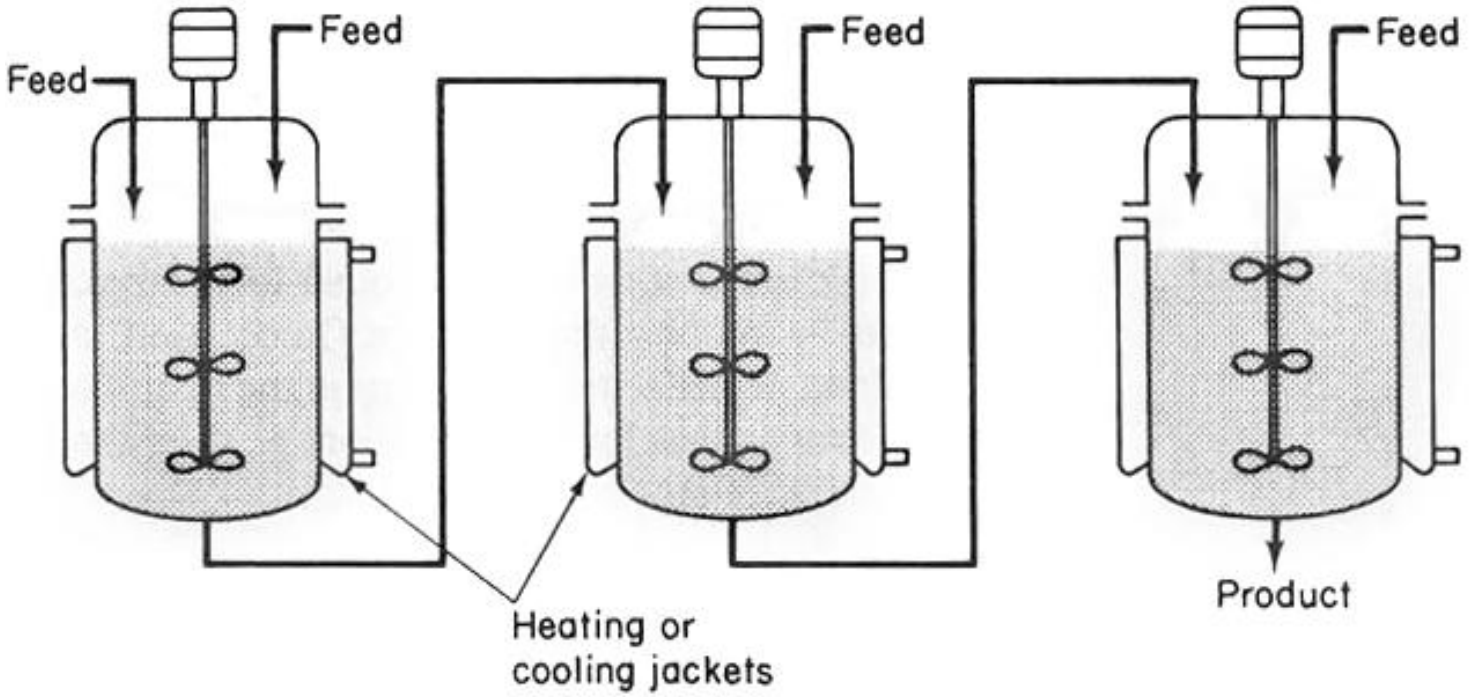
- Reactants added to vessel and products emptied after completion of reaction
  - some reactants may be added continuously ("semi-batch")
- often referred to as "stirred tank reactor"
  - Agitator mechanism
  - Insulating jacket
  - Pipes & valves to control conditions
- Primarily small-scale (e.g. specialty chem) and experimental processes



Batch process characteristics

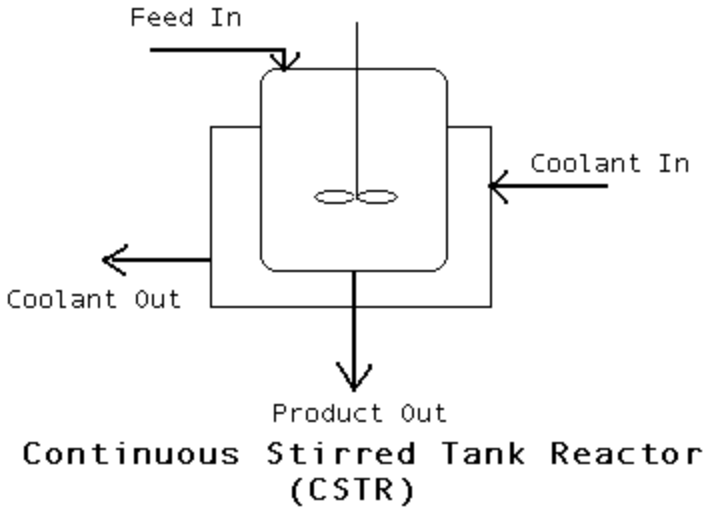
- Not enough product demand to make continuously
- More practical and feasible for multi-step synthesis
- Can reduce overall process complexity
- Allows chemists to maximize yield of desired compound, which can reduce waste
- Easier to operate, maintain and repair
- Can be adapted to multiple uses – important for facilities producing many different products (e.g. specialty)

Reactors in Series: A Battery of Stirred Tanks



Continuous Reactor

- Reactants added and products removed at constant rate – constant volume in reactor
- Continuous stirred tank – "CSTR" equipment similar to batch reactor
- Pipe (tubular) reactor – tubing arranged in coil, jacketed in heat transfer fluid



Continuous Stirred Tank Reactor (CSTR)

Continuous Reactor Characteristics

- Good for high production – used primarily for large-scale operations (>20 million pounds/yr product)
- Usually dedicated to single product
- Requires significant automation and capital expenditures

Other Continuous Reactor Types

- Packed bed
  - Tubular reactor packed with solid catalyst particles
  - Catalyst increases reaction rate and conversion
- Fluidized bed
  - Combination of continuous stirred-tank and packed-bed

Reactors – potential wastes

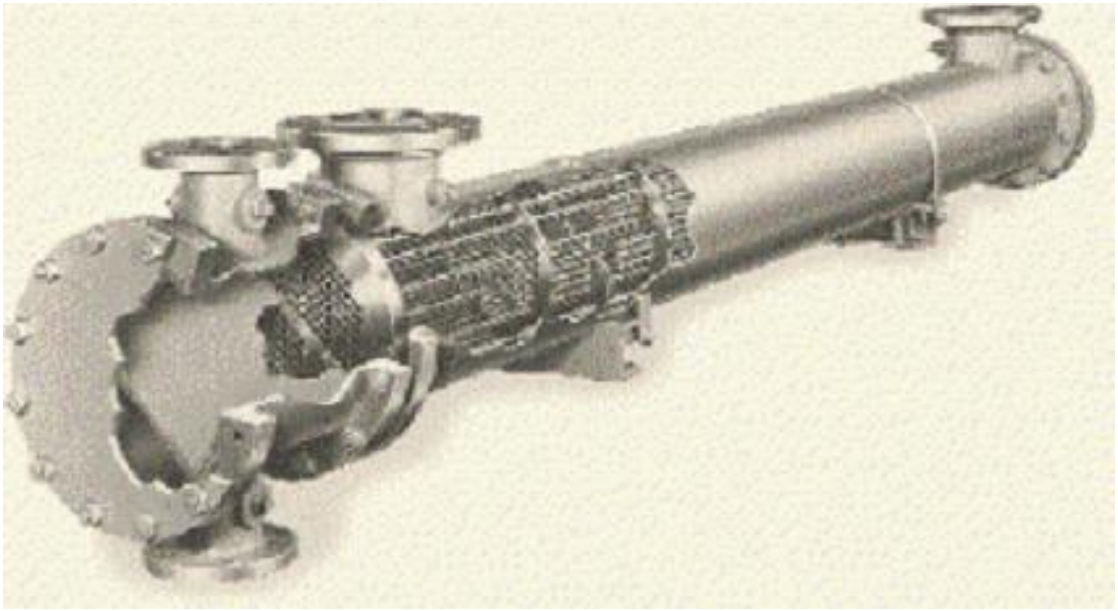
- Byproducts
- Spent catalysts, salts, filter aids,etc
- Waste (gas, liquid, solid) from reactivation of catalyst in fluidized bed
- Discharge of fluidizing gas
- Off-spec product
- Cleaning waste
- Vent gases from reactor charging
- Contaminated cooling water

Heat Transfer Equipment

Heat Transfer Operations

- Needed to heat or cool reactants and/or products
  - **control of process conditions**
  - **recovery of process heat**
  - **cooling (“quenching”) of reactants**
  - **to effect phase change**
- Can be stand-alone or integrated with other unit operation
  - **reactor heat/cooling**
  - **distillation reboiler/condenser**
- May use either radiative or convective heat exchange

Shell and tube heat exchanger



Separations Equipment

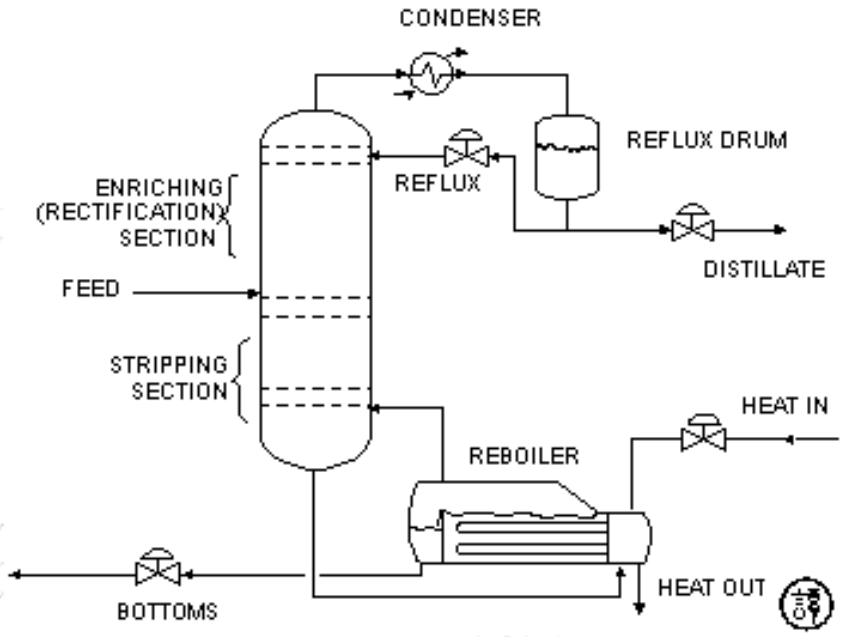
Separations

- Most chemical reactions are not complete (some unreacted inputs remain)
- Side reactions may result in one or more unwanted (or desired) byproducts
- Separations needed to obtain purified product to be used by customers or downstream manufacturers

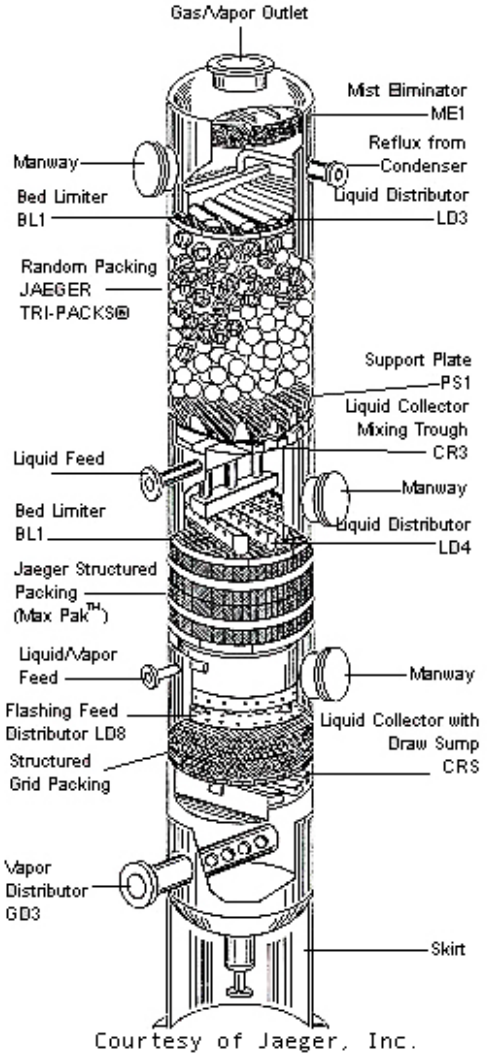
Distillation

- Separates liquids having differing boiling points
- Can separate solutions where all components are appreciably volatile (fractionation)
- Mixture heated to boiling of most volatile component (i.e. lowest boiling point), compound becomes gaseous, then condensed again in attached vessel.
- Additional compounds can be isolated from mixture by increasing temperature to appropriate boiling point(s)

Distillation Column



M.T. Tham, Distillation website, R.C. Costello and Association, Oct. 1997

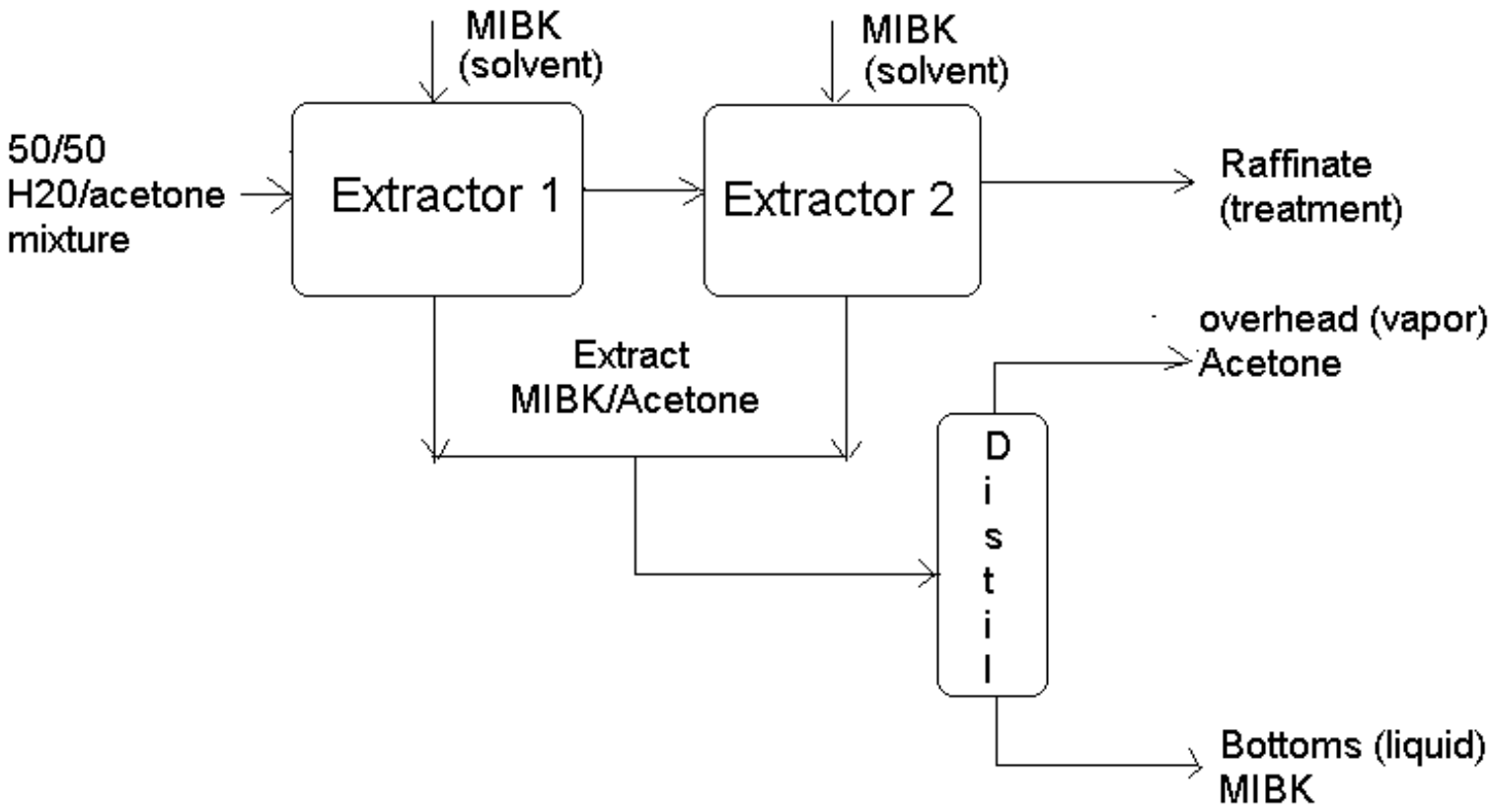


Courtesy of Jaeger, Inc.

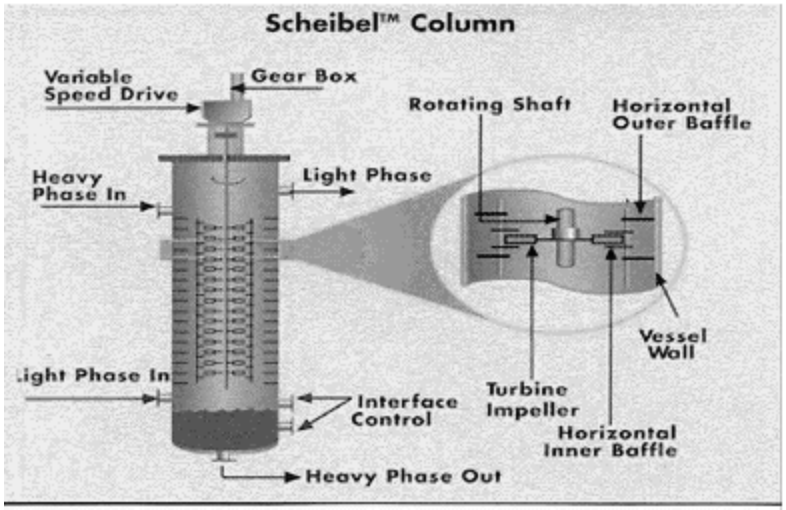
Extraction

- **Separation of compounds based on differential solubilities in fluids such as water or organic solvents.**
  - may also be done using supercritical fluids
- **requires that at least two distinct liquid phases be present**
- **often requires that a second downstream separation be performed to recover the extraction solvent**

Example of extraction process- 50/50 acetone/water mixture



Liquid-Liquid Extraction Unit

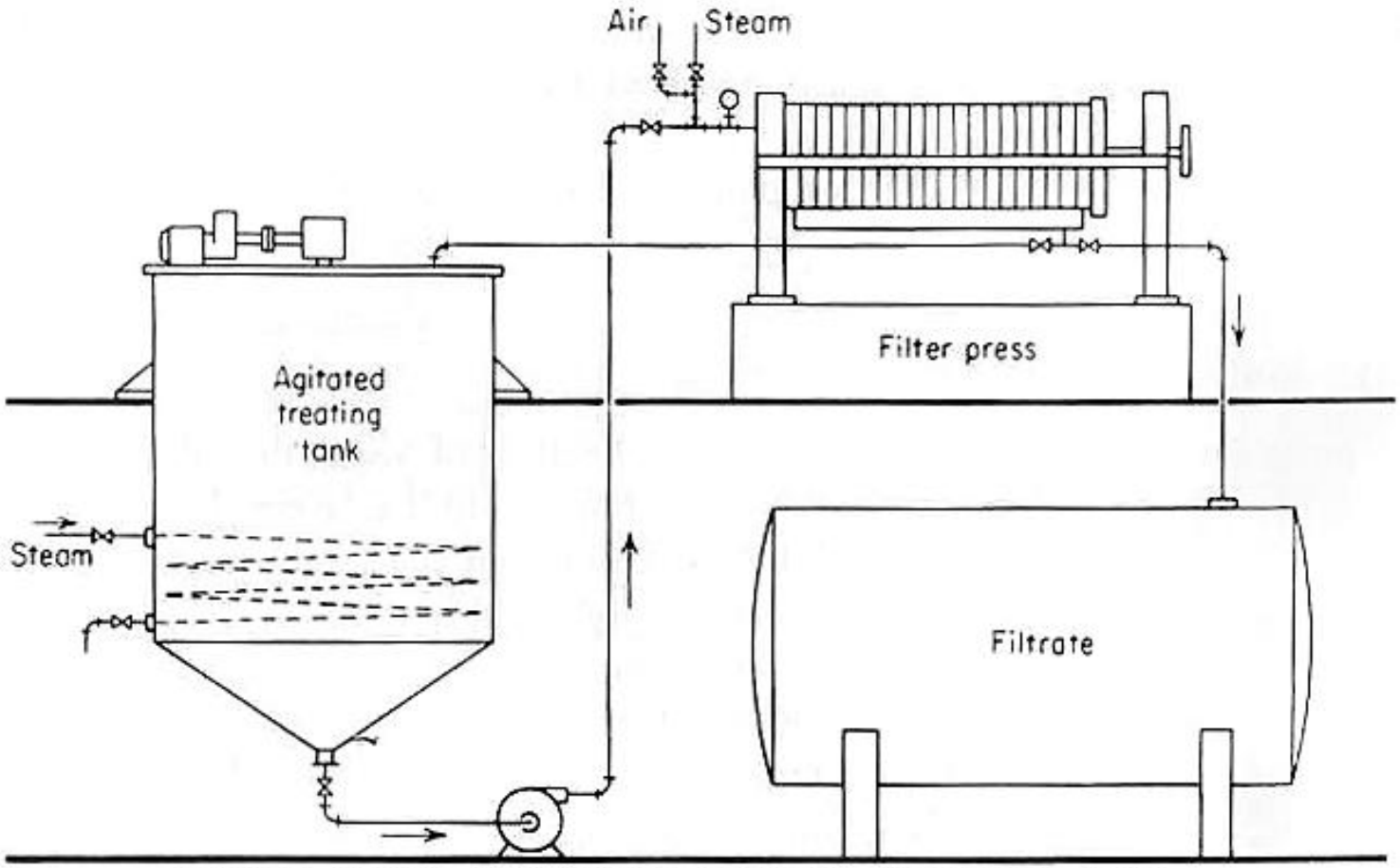


Courtesy Pressure Chemical Co.
Pressure Chemical Co.
3419 Smallman Street
Pittsburgh, PA 15201-1997
412 682-5882
www.pressurechemical.com

Filtration

- **Separates solids from liquids or gases**
  - feedstock preparation
  - product or catalyst recovery
- **Slurry or mixture of liquid and suspended particles passed through porous barrier**
- **Alternative form is centrifugation**
  - Slurry placed in porous basket, spun rapidly and outward force pushes liquid through filter
  - Fluid reclaimed on outside of basket

Filtration Process



(from R.E. Treybal, Mass-Transfer Operations, Mc-Graw Hill, 1980)

Other Separations Processes

- **Gas-Liquid**
  - *Distillation* (single stage="flash")
  - Evaporation
  - Gas Absorption
- **Liquid-Liquid**
  - *Liquid extraction*
  - Product washing
- **Solid-fluid**
  - *Filtration*
  - Adsorption and ion exchange
  - Crystallization
  - Drying
  - Leaching

Separations - potential wastes

- Distillation:
  - **Overhead vapor contamination of contact or non-contact cooling water, steam jet condensate, etc… in distillation operations**
  - **Still bottoms**
  - **non-condensable gases**
- Filtration:
  - **Filtrate, filter cake and filter presses from filtration processes**
- Extraction:
  - **Vapor loss from headspace over extraction**
  - **Liquid or solid non-product phase**

Materials Handling Equipment

Materials Handling

- Pipes, Valves and Connection
- Pumps, compressors and steam jet ejectors
- Storage tanks, containers, and vessels
- Blending and milling (e.g., mix tanks, grinders)
- Product preparation (e.g. Packaging stations)

Materials Handling – Potential Wastes

- Leaks and spills
  - **Airborne emissions through controlled vents (reactor)**
  - **Fugitives around seals, stirrer glands, pump and valve packing, piping flanges, joints, etc…**
  - **Contaminated exchange fluid from leaks into non-contact heating or cooling coils/pipes**
  - **Seal flushes**
- Maintenance Operations
  - **Contaminated gas, steam or water from equipment flushing (cleaning)**
  - **Contaminated gaskets, packing, piping, filters, etc.**
  - **Paint stripping, welding, lubrication, etc…**

Ancillary Equipment and Processes

Ancillary Equipment and Processes

- **Chemical loading and transportation**
- **Maintenance activities (e.g., equipment cleaning)**
- **Waste management**
  - Vents/flares
  - Wastewater treatment/pretreatment
  - Hazardous and solid waste management
- **Laboratory activities**
- **Office activities**

Other Sources of Waste

- **Chemical loading and transportation**
  - vent gases
  - spills
- **Maintenance activities (e.g., equipment cleaning)**
  - cleaning fluids/solvent
  - drained material
- **Waste management**
- **Vents/flares**
- **Process water treatment/pretreatment**
  - blowdown
  - treatment chemicals
- **Laboratory activities**
  - sample wastes
  - lab reagents
- **Office activities**

Unit Summary

- Despite diversity of processes, underlying equipment and phenomenology is relatively simple
- “Unit Ops” paradigm helps provide unifying framework for understanding process technology
- Each process unit has characteristic waste and emission sources/causes
- Emissions stem from both intrinsic and extrinsic causes