Introduction to Process Design

- Process design synthesizes knowledge from several disciplines.
  - Thermodynamics
  - Transport Phenomena
  - Reaction Engineering
  - Process Control
- Process design involves a number of issues that are qualitative in nature.
  - Safety
  - Environmental Considerations
  - Ethics

Chemical Plant Design and Construction

- Board of Directors' Design Problem
  - Generation of wealth
  - Core Competency versus diversification
- Discovery of New Projects
  - Long term wealth generation
  - Capital investment needs
- Feedback and Consumer Reaction
  - How well will the product sell?
  - Who is the competition?
- Planning and Organizational Design
  - Development of design team
  - Budget and time line

Preliminary Process Design

- Generation of conceptual flowsheet and design alternatives
- Preliminary process evaluation of alternatives using simplified models
- Detailed process evaluation using commercial simulators
- Economic evaluation
- Safety and environmental issues

- Layout and 3-D Modeling
  - Equipment purchase and installation
  - Control systems design
- Construction
- Startup and Commissioning
- Plant Operation
  - GMP
- Debottlenecking
  - Retrofitting
  - Control systems analysis
- Decommissioning

Preliminary Process Design

- Typically an ill-posed problem is given to you.
- Your objective is to convert this problem to a well posed problem.
- Then, utilize quantitative engineering analysis to solve the problem.
- Utilize engineering judgment to analyze the solution.

Before you do complicated engineering analysis, the first step is to do an ECONOMIC ANALYSIS based on input-output information.

Case Study: Ethanol Production

It is desired to produce 150,000 cubic meters of 190 proof ethanol per year from a feed of 75 million kg/year of ethylene. The ethylene feed is 96 mole % ethylene, 3 mole % propylene and 1 mole % methane. The feed costs $0.18 per pound and it is estimated that ethanol can be sold for $2.55 per gallon.

We first need to make sure that we actually have the POTENTIAL to make money in this process.

Fundamental Rule of Economics:SELLING PRICE SHOULD BE GREATER THAN COST PRICE

Maximum Profit Potential

Step 1:

Price of 190 proof ethanol = \$2.55/gal

150,000 m^3/yr = 39.6 million gal/yr

= \$101 million/yr

Step 2:

190 proof ethanol: 85.44 mole % ethanol + 14.56 mole % water. Thus, 1 kg mole of 190 proof ethanol is:

$(0.8544)(46.07) + (0.1456)(18.02) = 41.99\ kg$

(because mol. wt. of ethanol is 46.07 and mol. wt. of water is 18.02)

Weight fraction of ethanol is: $\frac{(0.8544)(46.07)}{41.99} = 0.937$

Density of 190 proof ethanol is 810 kg/m^3.

Thus, moles of ethanol in 150,000 m^3/yr of 190 proof ethanol is:

$$\frac{(0.937)(150,000)(810)}{46.07} = 2,471,000\ kmol/yr$$

Assuming 100% conversion of ethylene to ethanol, to produce 1 mole of ethanol requires 1 mole of ethylene.

Thus, to produce 2,471,000 $kmol/yr$ of ethanol, we need:

$(2,471,000)(28.05) = 69,310,000\ kg/yr$ of ethylene

The feed is impure. With 96 moles of ethylene, we are also getting 3 moles of propylene and 1 mole of methane.

This amounts to the following:

$$\frac{3}{96}(2,471,000)(42.08) = 3,249,000\ kg/yr \text{ propylene}$$
$$\frac{1}{96}(2,471,000)(16.04) = 412,900\ kg/yr \text{ methane}$$

Total feed = $72,980,000\ kg/yr$
Cost of feed = $\$0.18/lb$ (given)

$$\text{Thus total feed cost} = (72,980,000)(2.2046)(0.18)$$
$$\approx \$29 \text{ million}$$

The reaction to convert ethylene to ethanol requires water. Assuming that the cost of water is negligible:

MAXIMUM PROFIT POTENTIAL is:

$$\begin{aligned} \text{Profit} &= \text{Selling Price} - \text{Cost Price} \\ &= \$101 \text{ million} - \$29 \text{ million} \\ &= \$72 \text{ million} \end{aligned}$$

Thus, we need a process where equipment cost plus operating cost are less than $72 million.

Effect of Price Fluctuation

Ethylene	Ethanol	Max. Profit
$\$0.18/lb$	$\$2.55/gal$	$\$72$ million
$\$0.16/lb$	$\$2.04/gal$	$\$55$ million
$\$0.18/lb$	$\$2.68/gal$	$\$77$ million
$\$0.21/lb$	$\$3.08/gal$	$\$89$ million