Conceptual Process Design: An Hierarchical Approach

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HDA Process

Toluene + H\textsubscript{2} \rightarrow Benzene + CH\textsubscript{4}
2 Benzene \leftrightarrow Diphenyl + H\textsubscript{2}

\[ \Delta H = -21530 \text{ Btu/mol} \]

Basic information:

1. Reactions take place between 1150-1300 F.
2. Pressure is about 500 psi.
3. Excess hydrogen (5/1 ratio) prevents coking.
4. Effluent gas must be quenched to 1150 F in order to prevent coking.
Synthesis versus Analysis

Figure 2: Synthesis vs. Analysis
Hierarchical Structure

Hierarchy of decisions

1. Batch versus continuous
2. Input-output structure of the flowsheet
3. Recycle structure of the flowsheet
4. General structure of the separation system
   a. Vapor recover system
   b. Liquid recovery system
5. Heat-exchanger network
FIGURE 8.10-7
Figure 10.2  HDA process control strategy.
Figure 5.18  HDA process Alternative 6 with complete heat management control system using auxiliary coolers and reboilers.
Level 2 - Input-output structure

FIGURE 5.1-2
Level 3 - recycle structure

H₂ feed
95% H₂, 5% CH₄

F₆

R₆, y₆H

P₆

MR

Reactor

Separator system

P₆

Benzene, P₆

Diphenyl

FIGURE 6.2-4
HDA, gas recycle.
Level 3 - reactor

CS1 - Big Furnace/Small Heat Exchanger

Figure 5.23 HDA process basic heat management control system.
Level 4 - separation system

*FIGURE 7.2-2*
Separation system recycle loop.
Level 4 - separator sequence

FIGURE 7.3-4
Sequence selection changes recycle costs.
Level 4 - alternative separator sequence

FIGURE 1.2-4
Alternate distillation trains.

FIGURE 1.2-3
Alternate distillation trains.
Level 4- Flowsheet

H₂, CH₄

Heat

Compressor

Purge

Reactor

Coolant

Flash

H₂, CH₄

Benzene

Recycle

Product

Stabilizer

Diphenyl

Toluene

FIGURE 1.2-1
Level 4- PFD

FIGURE 8.10-2
HDA process with a feed-effluent heat exchanger. (Note: The quench stream following the reactor is not shown on these graphs.) [From D. L. Terrill and J. M. Douglas, I&EC Research, 26: 685 (1987), with permission of the American Chemical Society.]
Level 5- HENS

Alternative 6

FIGURE 8.10-7
Different Perspective: Onion Diagram

The hierarchy of process design can be viewed as an onion model (R. Smith).

*Figure 1.6* The “onion model” of process design. A reactor design is needed before the separation and recycle system can be designed, and so on. (*From Smith and Linhoff, Trans. IChemE, Ch.ERD, 66:195, 1988; reproduced by permission of the Institution of Chemical Engineers.*)
1st layer- inside out

Process design starts with the reactor
2nd layer

Once we know the reactor design, we need to specify the separation system
Once we know reactor and separator design, we know material and energy balance $\Rightarrow$ Heat Exchanger Network
4th layer

Once we have the process and HEN design

Utilities
Utilities

The process requires external heating and cooling utilities
Water management

Water and effluent treatment system
Complete onion

A complex problem with many facets!