Optimal Model-Based Production Planning for Refinery Operation

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Introduction

Refinery production planning models
- Optimizing refinery operation
  - Crude selection
- Maximizing profit; minimizing cost
- LP-based, linear process unit equations

Current Project
- Collaboration with BP Refining Technology
- Goal: develop a refinery planning model with nonlinear process unit equations, and integrated scheduling elements
Problem Statement

Typical Refinery Configuration

(Adapted from Aronofsky, 1978)
Problem Statement

- **Information Given**
  - Refinery configuration: Process units
  - Feedstock & Final Product

- **Objective**
  - Select crude oils and quantities to process
    - Maximizing profit
    - single period time horizon
CDU Models

- Initial Focus on CDU
  - Front end of the every refinery
  - LP models
    - Fixed-yield equation:
      \[ F_{\text{outlet}} = a_{\text{unit,feed,outlet}} \times F_{\text{feed}} \]
    - Swing cut equation:
      \[ F_{\text{outlet}} = a_{\text{CDU,feed}} \times F_{\text{feed}} + b_{\text{CDU,outlet,front}} + b_{\text{CDU,outlet,back}} \]
Complexity of CDU

- CDU depends on steam stripping for fractionation, not reboilers
  - Crude stability
- Multiple side streams
  - Single column configuration
- Side strippers with steam stripping and reboilers
- Side condensers

Typical Crude Distillation Column (Gadalla et al, 2003)
CDU & Cascaded Columns

Typical Crude Distillation Column
(Gadalla et al, 2003)

Cascaded Columns Representation
of a Crude Distillation Column
(Gadalla et al, 2003)
CDU Aggregate Model

- Original Aggregate Distillation Column Model
  - Based on work of Caballero & Grossmann, 1999
  - Principle
    - Top and bottom integrated heat and mass exchangers around the feed location
    - Constant flow in each section
    - Pinch location is at the feed section
  - Feasibility criteria
    - \[
      \frac{V_{j,i}}{V_{j,total}} \leq J_{j,i} \frac{L_{j,i}}{L_{j,total}} \quad \text{i} \in \text{comp}, \ i \leq \text{LK}, \ j \in \text{loc}
    \]
    - \[
      \frac{V_{j,i}}{V_{j,total}} \geq J_{j,i} \frac{L_{j,i}}{L_{j,total}} \quad \text{i} \in \text{comp}, \ i \geq \text{HK}, \ j \in \text{loc}
    \]
  - Temperature constraint
    - \[ T_{\text{reb}} > T_{\text{bot}} > T_{\text{botfeed}} > T_{\text{topfeed}} > T_{\text{top}} > T_{\text{cond}} \]
Aggregate Model Example

- Conventional cascaded columns example
  - 4 columns
    - Indirect sequence
  - Feed
    - 18 components (C3-C20)
Aggregate Model – Steam Distillation Column

- Complexity of adding steam stripping
  - Lack of the reboiler and return to the column
  - Steam does not participate in the equilibrium calculations
    - Suitability of the section equimolal flowrate assumption
  - Temperature profile is different
  - Column pressure and equilibrium constant calculations
Aggregate Model – Steam Distillation Column

- New model
  - Column split into 5 sections
    - Condenser, stage #1, top section, feed stage, bottom section, stage #n
  - Equilibrium equations applied to stage #1, feed stage and stage #n, excluding steam
  - Mass & energy balances applied to all stages and sections
  - Top product at the bubble point
Modified Aggregate Model Example

- **Feed**
  - C08, C10, C12 & C14
  - Recovery
    - LK: C10, 74%
    - HK: C12, 80%

- **Results**
  - Correct temperature profile
    - Peak at the feed stage

- Temperature Profile

- Diagram:
  - Distillate
  - Water
  - Cond
  - Top
  - Feed
  - Bottom
  - Stage #1
  - Top
  - Feed Stage
  - Bottom
  - Stage #n
  - 350
  - 400
  - 450
  - Steam
  - Bottom
Steam distillation cascaded columns

- Extension of the previous example
  - Using 2 cascaded columns
  - Model predicted the feed-stage peak of the temperature profile
Steam distillation cascaded columns

- Further studies
  - Impact of adding steam to the equilibrium equation
  - Additional equilibrium constraints for the top and bottom sections
  - Compare the results against simulation runs
Multi-period Planning Model

- Next phase in the development & key to the project
- Utilize available models
  - Swing cuts, aggregate & FI models
- Preliminary development
  - Addition of weekly demand and scheduled crude availability
  - Handling refinery operation
    - Crude change-overs
    - Crude inventory & product inventory
  - Identifying time resolution
Summary

- Research aims to build a nonlinear refinery planning & scheduling model
  - Current focus on CDU
- CDU complexity
  - Requires decomposition into cascaded columns
  - Aggregate model approach
    - conventional distillation columns
    - steam-stripping distillation columns
  - CDU fractionation index (FI) model
- Multi-period planning model
  - Preliminary work started
  - Key to scheduling & planning integration