Optimal Model-Based Production Planning for Refinery Operation

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Introduction

- Refinery production planning models
  - Operation optimization
    - Crude selection
  - Maximizing profit; minimizing cost
  - LP-based, linear process unit equations
  - Comprise accuracy for robustness and simplicity

- 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

- Process Models in Refinery Planning Model
  - Linear yield calculation assumption: LP requirement
  - Tradeoff: accuracy vs. robustness & simplicity
  - Area for nonlinear upgrade

- Initial Focus on CDU
  - Front end of the every refinery
  - Dictates final products and their quality
  - Fixed-yield equation:
    \[ F_{\text{outlet}} = a_{\text{unit,feed,outlet}} \times F_{\text{feed}} \]
  - Swing cut equation:
    \[ F_{\text{outlet}} = a_{\text{CDU,feed}} \times F_{\text{feed}} + b_{\text{CDU, outlet, front}} + b_{\text{CDU, outlet, back}} \]
CDU Aggregate Model

- **Aggregate Distillation Column Model**
  - Proposed nonlinear implementation
  - Adds simplest process modeling to planning
  - 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
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)
Aggregate Model Initialization & Constraints

- Proper initialization is important for convergence
- Initial values are generated using optimized column material balance
  1. Overall material balance around the column: using LP equations only
  2. Material balance for the column internal streams: using NLP equations.
     - No energy balance or equilibrium equation
- Additional constraints are identified to ensure convergence of the model
  - \( R_j \geq R_{j-1} + B_j \) \((R_i \text{ reflux of column } j)\)
  - \( F_1 = D_j + \sum_{k=1}^{j} B_k \)
Aggregate Model Results

- Conventional cascaded columns example
  - 4 columns
    - Indirect sequence
  - Feed
    - 18 components (C3-C20)
  - Aggregate model vs. Aspen

Cascaded Conventional Columns
(based on Gadalla et al, 2003)
Aggregate Model Example

![Graph showing product temperature across different columns. The graph demonstrates a decreasing trend in product temperature as you move from column 1 to column 4 and 4.cond. The lines represent the Aggregate and ASPEN models.]
Distillation Columns

Conventional Distillation Column (Energy separating agent)

Stripping Distillation Column (Mass separating agent)
Distillation Column with Mass Separating Agent

- Focus on refluxed stripper
- Steam (common in refineries) used as the separating agent, instead of reboilers
- Stripping stream reduces liquid partial pressure, thus creating the vapor phase
- Benefit: restriction on bottom temperature
Comparison of Distillation Columns
Conventional & Steam Stripping

- Differences from conventional columns
  - Temperature in the column
    - Rectifying section the same
    - Stripping section: no reboiler
      - Cooling effect: from liquid to vapor
    - Profile: peak at the feed stage

(Suphanit 1999)
Shortcut Method

- Shortcut calculations
  - Fenske-Underwood-Gilliland method
    - Using light key (LK) & heavy key (HK) components
    - Minimum reflux condition: Underwood equation
      - Minimum vapor flow and reflux ratio
    - Total reflux condition: Fenske equation
      - Minimum number of stages:
    - Finite reflux condition
      - Linear interpolation between minimum and total reflux conditions
  - Theoretical stages: Gilliland correlation
    - Feed location: Kirkbride equation
Shortcut Calculation

- FUG cannot be applied directly
- Shortcut calculation
  - Inert stripping agent
    - Focus on CDU with steam being inert, immiscible and safe
  - Separate treatment for the rectifying section & the stripping section
    - Stripping section requires stage-by-stage flash calculation

Stripping section vapor flow
(Suphanit 1999)
Summary

- Preliminary research to build a nonlinear refinery planning & scheduling model
  - Current focus on CDU

- CDU Aggregate Model
  - NLP model for cascaded columns with indirect sequence coupling
  - Proposed an initialization scheme with additional constraints
  - Model results are in good agreement with Aspen results

- Shortcut method
  - Differences between conventional & steam stripping distillation columns
  - FUG cannot be applied directly to columns with steam stripping
Future work

- Integrating the CDU aggregate model into the production planning model
- Explore nonlinear process models for other important units
  - Cat. Cracking unit
  - Cat. Reforming Unit
- Extend the model to multi-period
- Add scheduling elements