Optimal Model-Based Production Planning for Refinery Operation

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Outline

- Introduction
- Problem Statement
- CDU Aggregate Model
  - Conventional distillation column
  - Steam distillation column
- Conclusion
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

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

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

Typical Crude Distillation Unit (CDU)
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)
Distillation Columns

Conventional Distillation Column (Energy separating agent)

Stripping Distillation Column (Mass separating agent)
Aggregate Model – Conventional Distillation Column

- Base model for the more complicated CDU model
- Successful initialization
  - Initial values are generated using series of optimized column material balances
- Additional constraints are identified to ensure convergence of the model
  - $R_j \geq R_{j-1} + B_j$ (R_i reflux of column j)
  - $F_1 = D_j + \sum B_k$
- Successful model
  - Example: 4 cascaded conventional columns, with 18-component feed (C3-C20)
Aggregate Model Results

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

- Example run using GAMS
- Solver: CONOPT
- Model is robust
  - Different feed and column arrangements

<table>
<thead>
<tr>
<th></th>
<th>18 component, 4 columns</th>
<th>8 components, 3 columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>SINGLE EQUATIONS</td>
<td>1696</td>
<td>935</td>
</tr>
<tr>
<td>SINGLE VARIABLES</td>
<td>1666</td>
<td>779</td>
</tr>
<tr>
<td>Time, sec</td>
<td>1.484</td>
<td>1.28</td>
</tr>
</tbody>
</table>
Aggregate Model – Steam Stripping Distillation Column

- Building on the successful conventional distillation column
- Lack of reboiler and addition of live steam
  - Requires modified constraints in the model
  - Consideration for the column reflux should be accounted for in the feed
  - Different temperature profile and pressure calculation
Summary

- Preliminary research to build a nonlinear refinery planning & scheduling model
  - Current focus on CDU
- CDU Aggregate Model
  - NLP model
  - Used cascaded column approach to address complexity of the CDU
  - Built base model for conventional distillation column
    - Model proved robust
  - Upgraded the base model for steam distillation column
    - Modified original aggregate model
    - Identified additional constraints
Future work

- Integrating the CDU aggregate model into the production planning model
- Explore other nonlinear models
  - Rigorous simulation models and packages
  - Assessing the benefit in terms of accuracy, robustness & simplicity
- Upgrade process model for other important units
  - Cat. Cracking unit
  - Cat. Reforming Unit
- Extend the model to multi-period
- Add scheduling elements