Optimal Model-Based Production Planning for Refinery Operation

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Outline

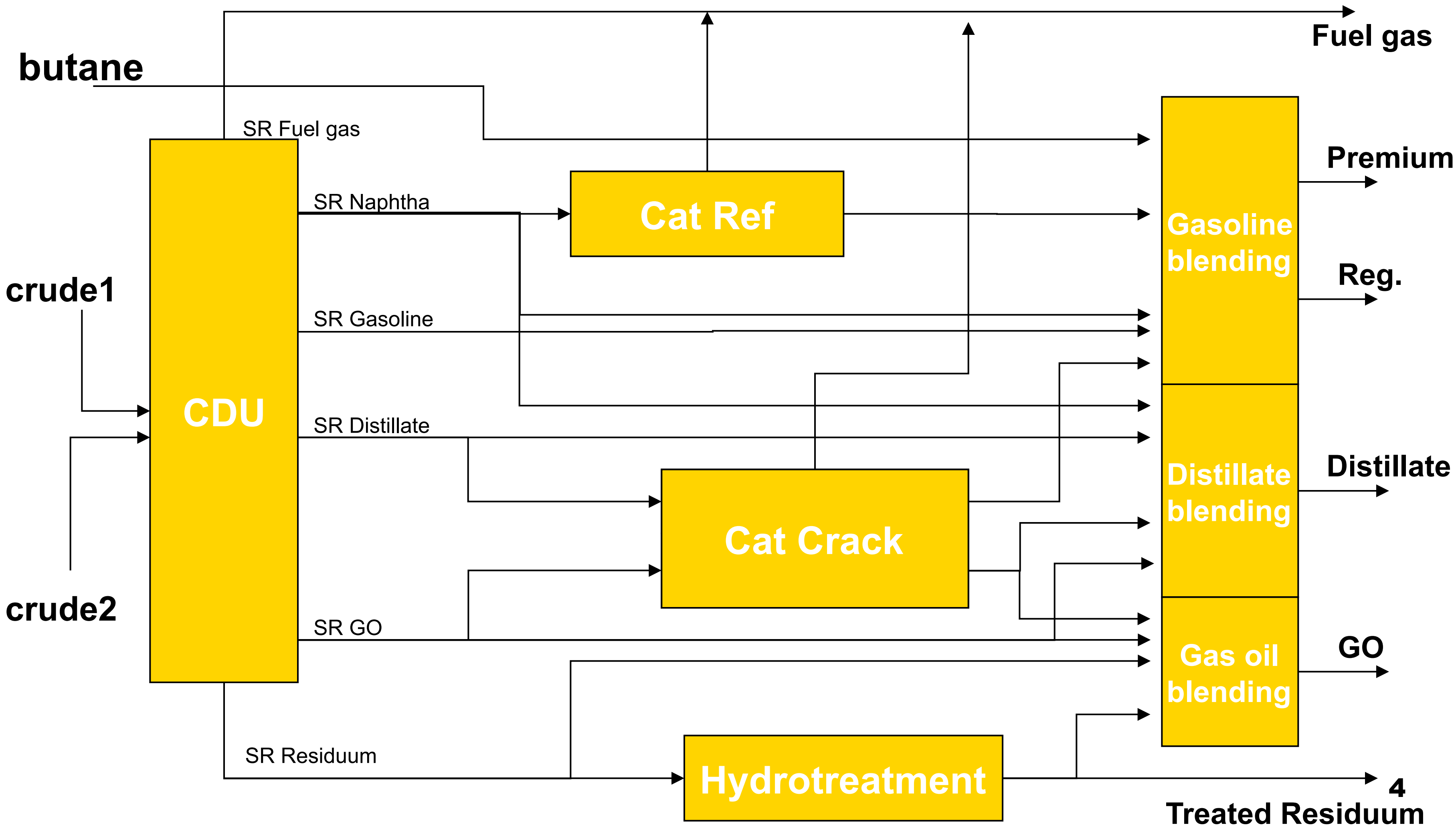
- Introduction
- Problem Statement
- CDU
  - Modeling
  - Conventional Distillation Columns
  - Steam Distillation Column
  - FI Model
- Conclusion

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

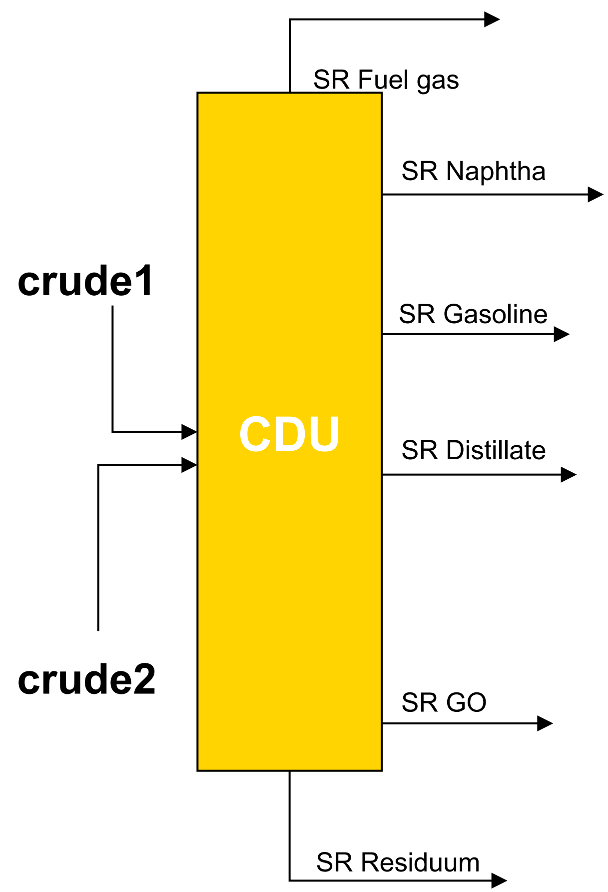
CDU Models

- 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:

$$F_{outlet} = a_{unit,feed,outlet} * F_{feed}$$

    - Swing cut equation:

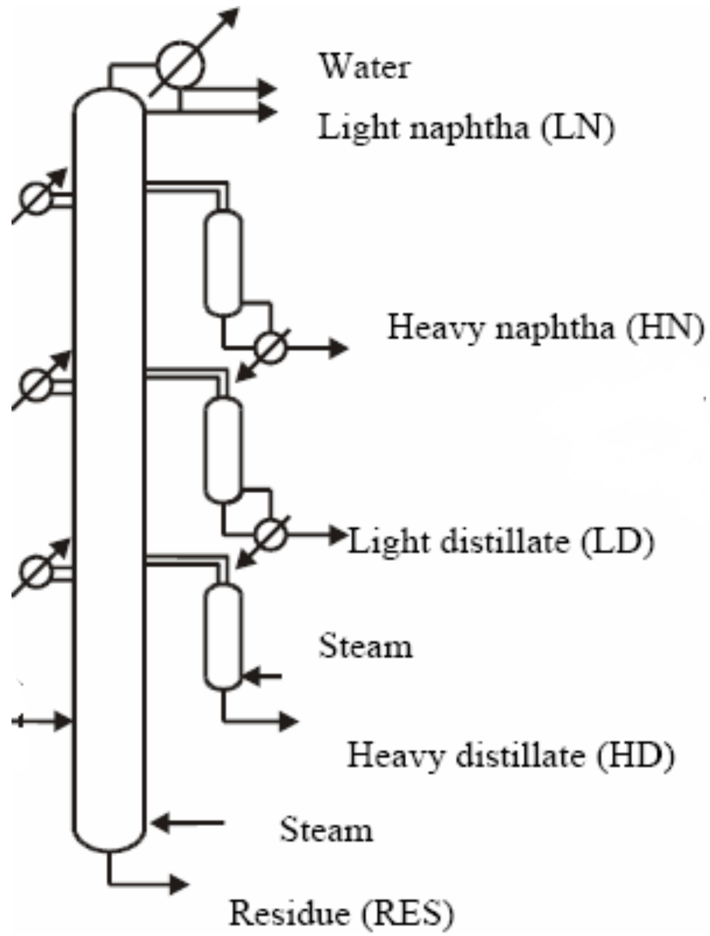
$$F_{outlet} = a_{CDU,feed} * F_{feed} + b_{CDU,outlet,front} + b_{CDU,outlet,back}$$



Typical Crude Distillation Unit (CDU)

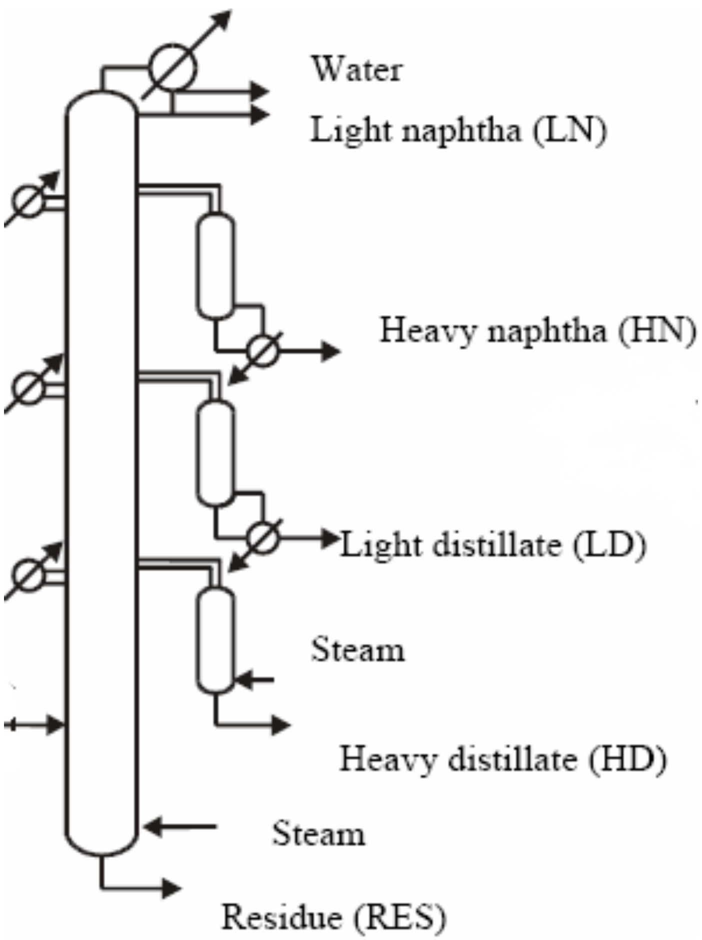
Complexity of CDU

- 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
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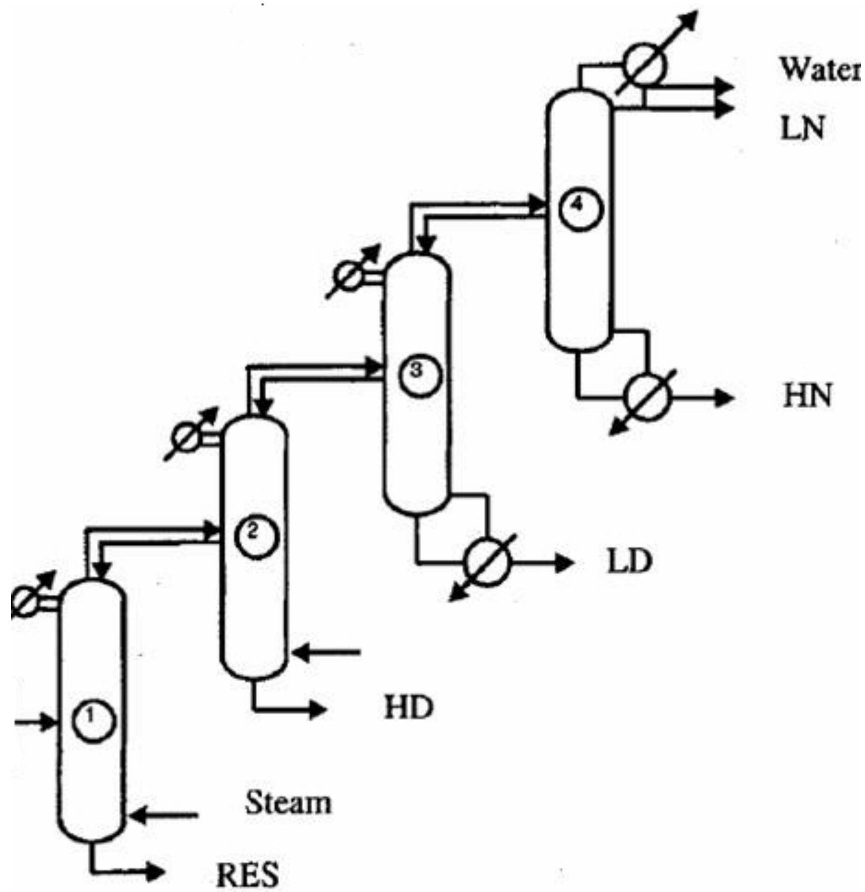


Cascaded Columns Representation of a Crude Distillation Column
(Gadalla et al, 2003)

CDU Aggregate Model

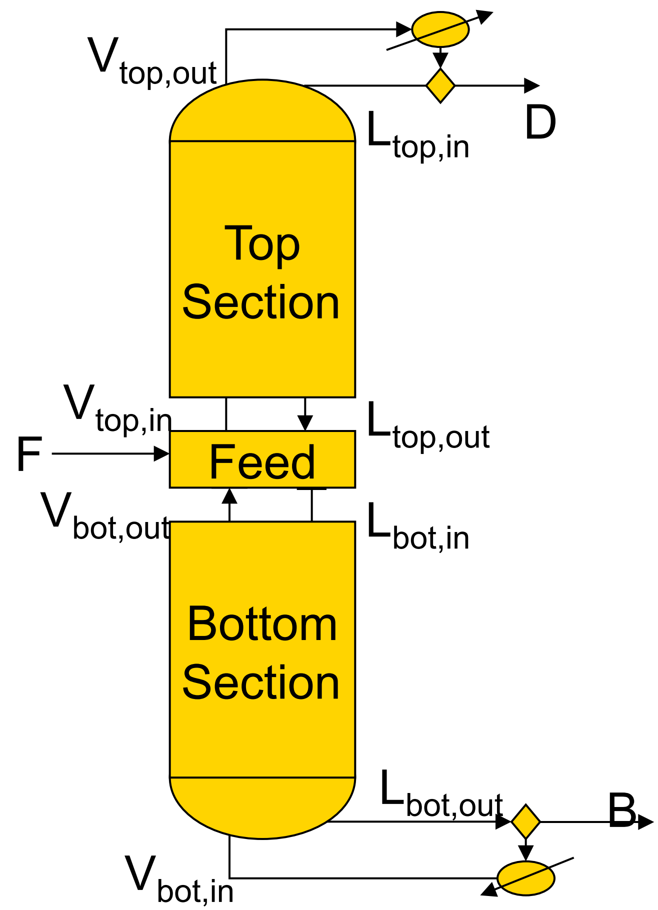
- Original Aggregate Distillation Column Model
  - Based on work of Caballero & Grossmann, 1999
  - Principle
    - Top and bottom integrated heat and mass exchangers around the feed location
    - Constant flow in each section
    - Pinch location is at the feed section
    - Feasibility criteria

$$\frac{V_{j,i}}{V_{j,total}} \leq K_{j,i}\frac{L_{j,i}}{L_{j,total}} \qquad i \in comp, i \leq \text{LK}, j \in loc$$

$$\frac{V_{j,i}}{V_{j,total}} \geq K_{j,i}\frac{L_{j,i}}{L_{j,total}} \qquad i \in comp, i \geq \text{HK}, j \in loc$$

    - Temperature constraint

$$T_{reb} > T_{bot} > T_{botfeed} > T_{topfeed} > T_{top} > T_{cond}$$

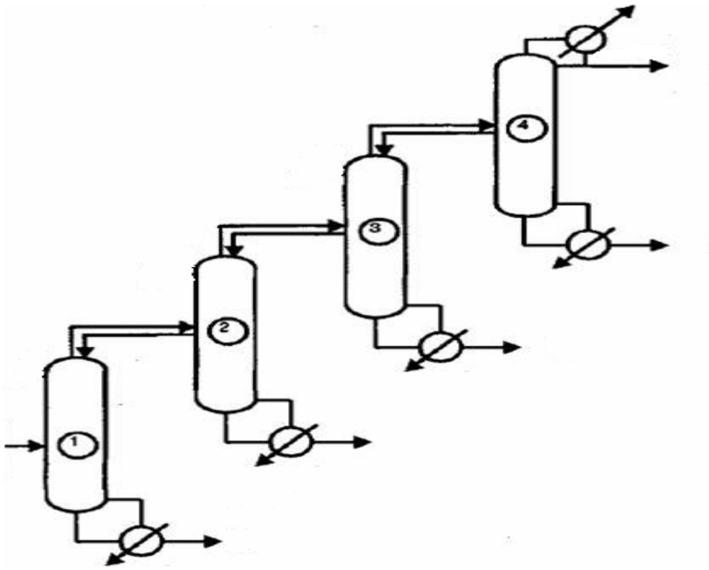


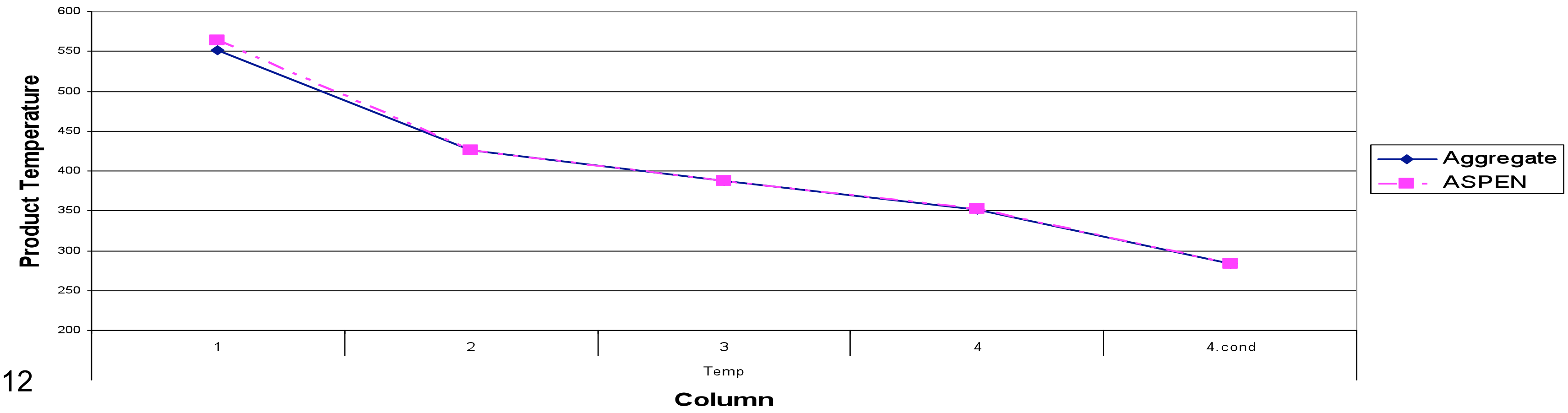
Aggregate Model – Conventional Distillation Column

- 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)
  - $F_1 = D_j + \sum_{k=1}^{j} B_k$
- Successful model
  - Example: 4 cascaded conventional columns, with 18-component feed (C3-C20)

Aggregate Model Example

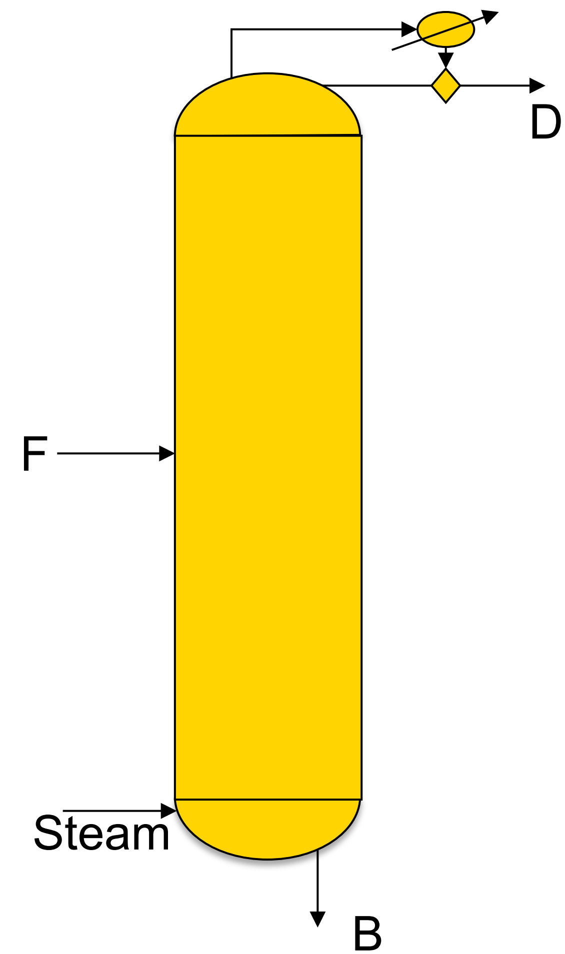
- Conventional cascaded columns example
  - 4 columns
    - Indirect sequence
  - Feed
    - 18 components (C3-C20)





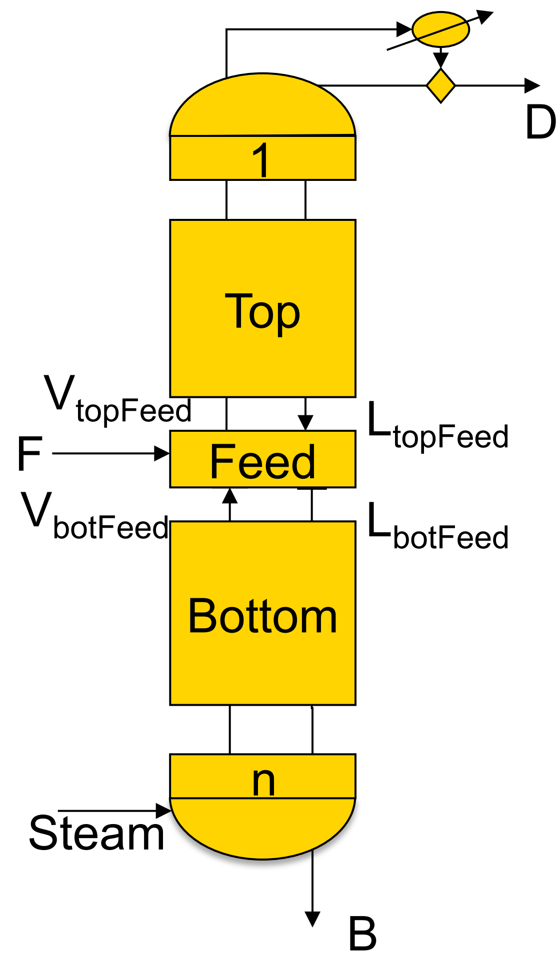
Aggregate Model – Steam Distillation Column

- 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



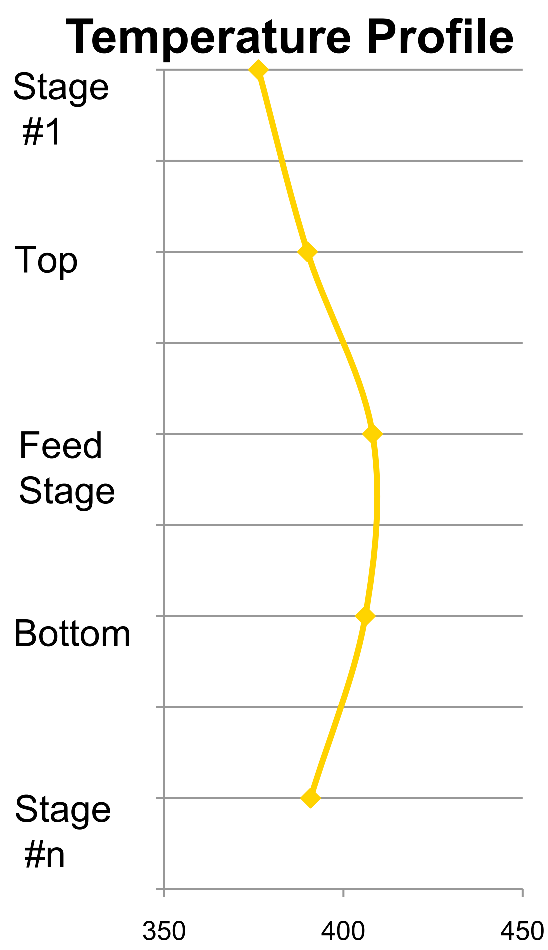
Aggregate Model – Steam Distillation Column

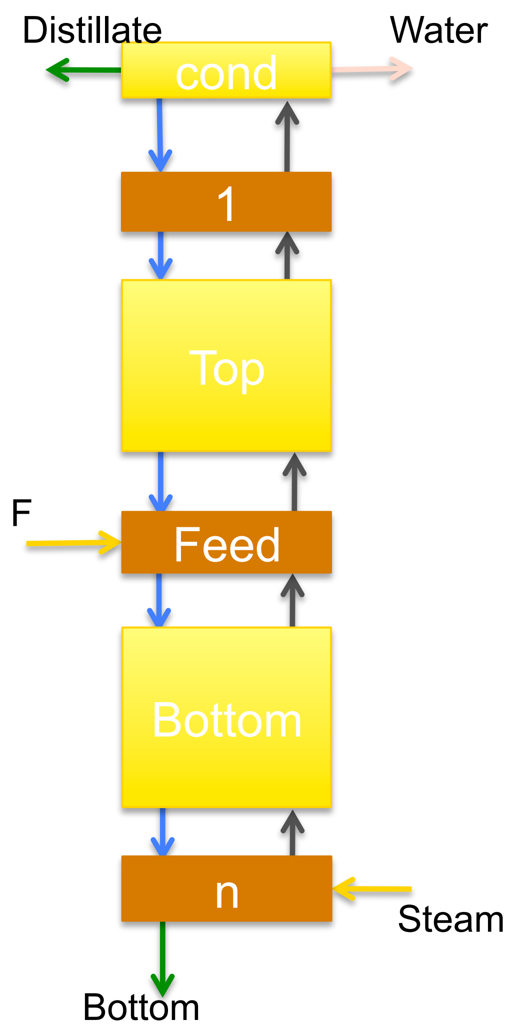
- New model
  - Column split into 5 sections
    - Condenser, stage #1, top section, feed stage, bottom section, stage n
  - Equilibrium equations applied to stage #1, feed stage and stage #n, excluding steam
  - Mass & energy balances applied to all stages and sections
  - Top product at the bubble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





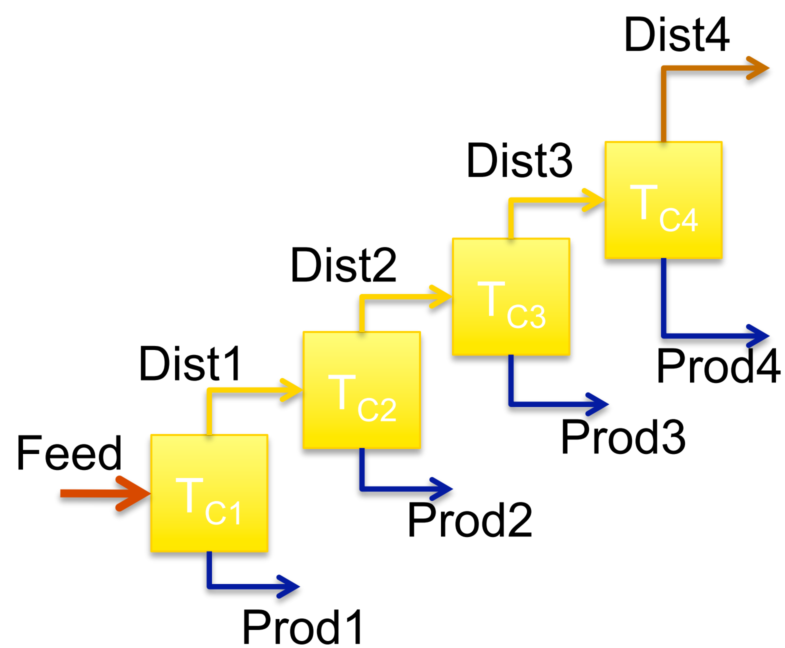
CDU FI Model

- Separation is modeled as a sequence of separation stages

- Based on Geddes' fractionation index (FI) and Fenske equation

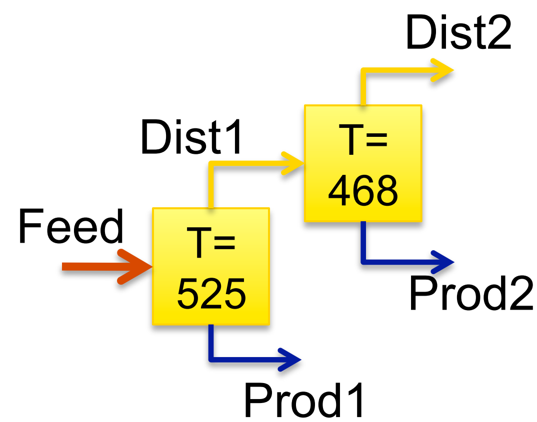
$$\left(\frac{Dist}{Prod}\right)_{i,j} = \left(\alpha_{i/ref}\right)_j^{FI} \left(\frac{Dist}{Prod}\right)_{ref,j}, i \in comp, j \in stage$$

- T_c is the stage temperature and the crude cut point temperature



FI Model Example

- Two-stage separation
  - Feed: 6 components (C8, C10, C12, C14, C15 & C16)
  - Objective
    - Maximum recovery of C12 from heavier component stream



Component	Feed	Prod1	Prod2	Dist2
C08	5	0.0	0.0	5.0
C10	10	0.0	0.9	9.1
C12	21	0.2	20.4	0.4
C14	20	11.7	8.3	0.0
C15	22	20.7	1.3	0.0
C16	22	22.0	0.0	0.0
total	*100*	*54.4*	*31.1*	*14.4*

Summary

- Research aims to build a nonlinear refinery planning & scheduling model
  - Current focus on CDU
- CDU complexity
  - Requires decomposition into cascaded columns
  - Involves conventional & steam-stripping distillation columns
- Aggregate distillation column model
  - Suitable for conventional distillation columns
- Modified aggregate distillation model
  - Designed for steam-stripping distillation columns
- CDU fractionation index (FI) model
  - Builds on Fenske equation
  - Used for sequenced separations of multi-component feed

Future work

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