Optimal Model-Based Production Planning for Refinery Operation

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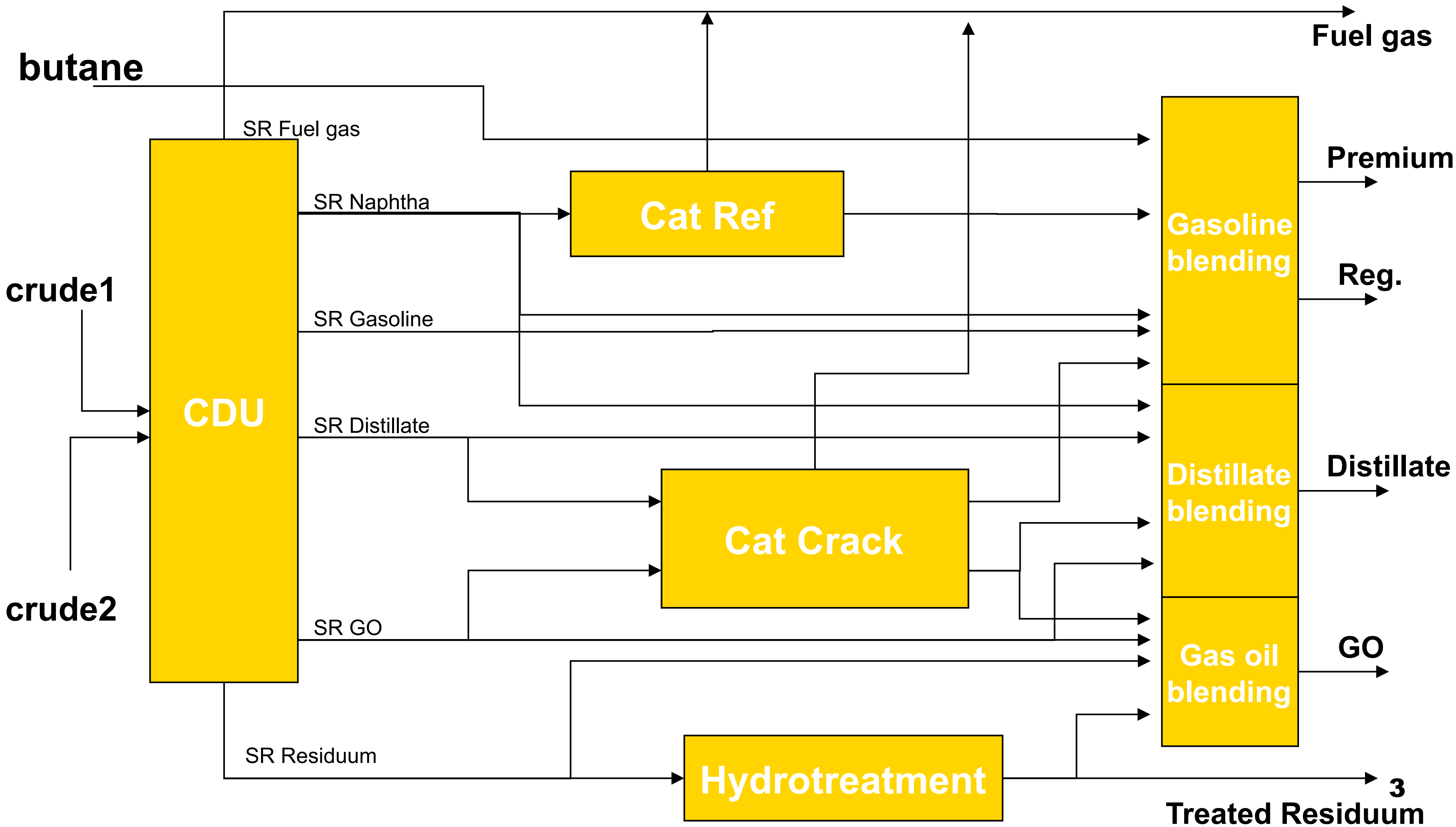
Introduction

- 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

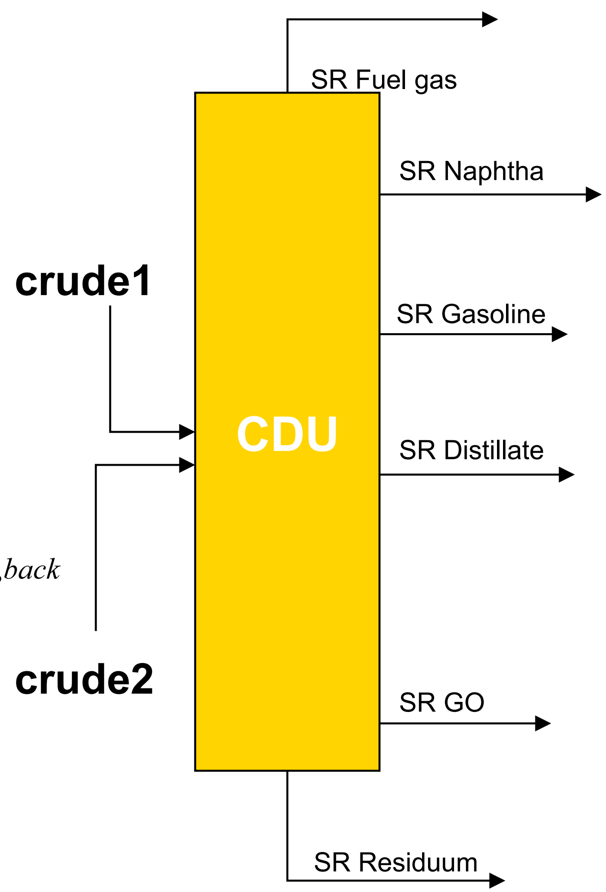
CDU Models

- Initial Focus on CDU
  - Front end of the every refinery
  - LP models
    - Fixed-yield equation:

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

    - Swing cut equation:

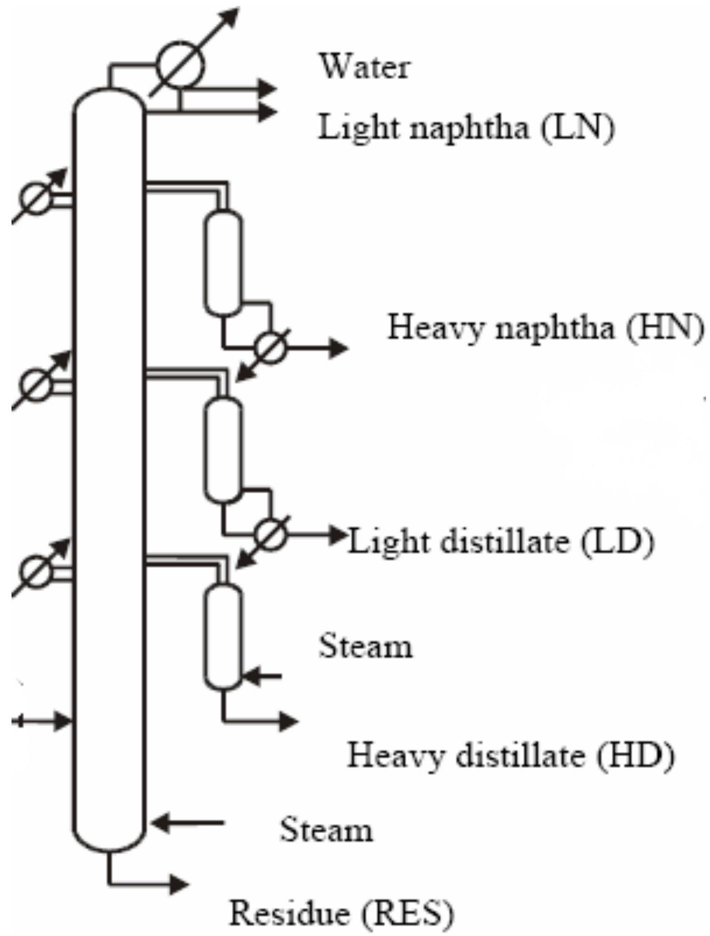
$$F_{outlet} = a_{CDU,feed} * F_{feed} + b_{CDU,outlet,front} + b_{CDU,outlet,back}$$



Typical Crude Distillation Unit (CDU)

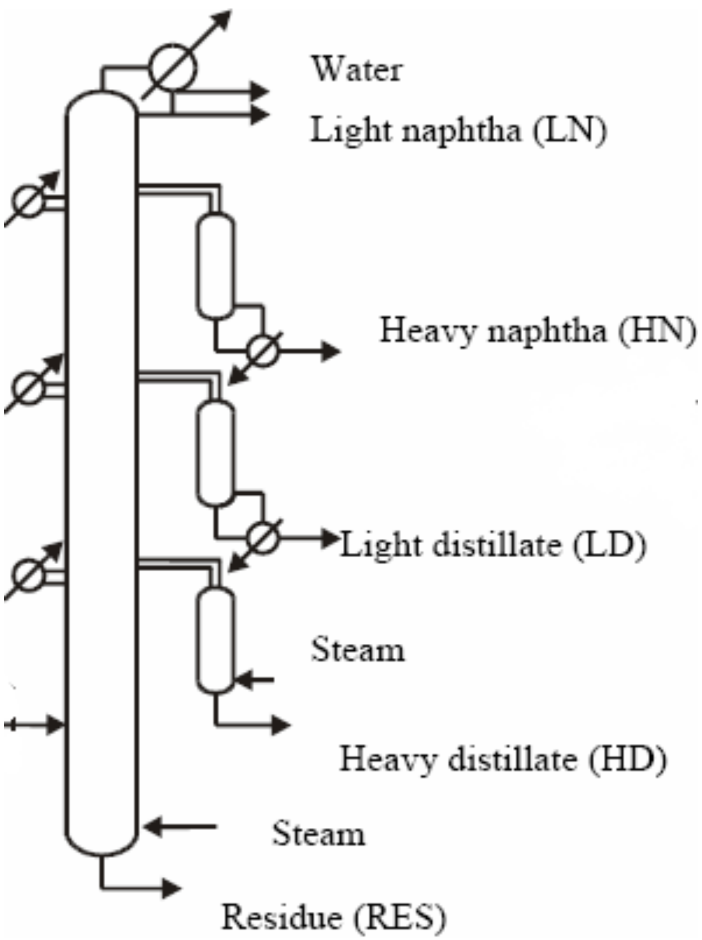
Complexity of CDU

- 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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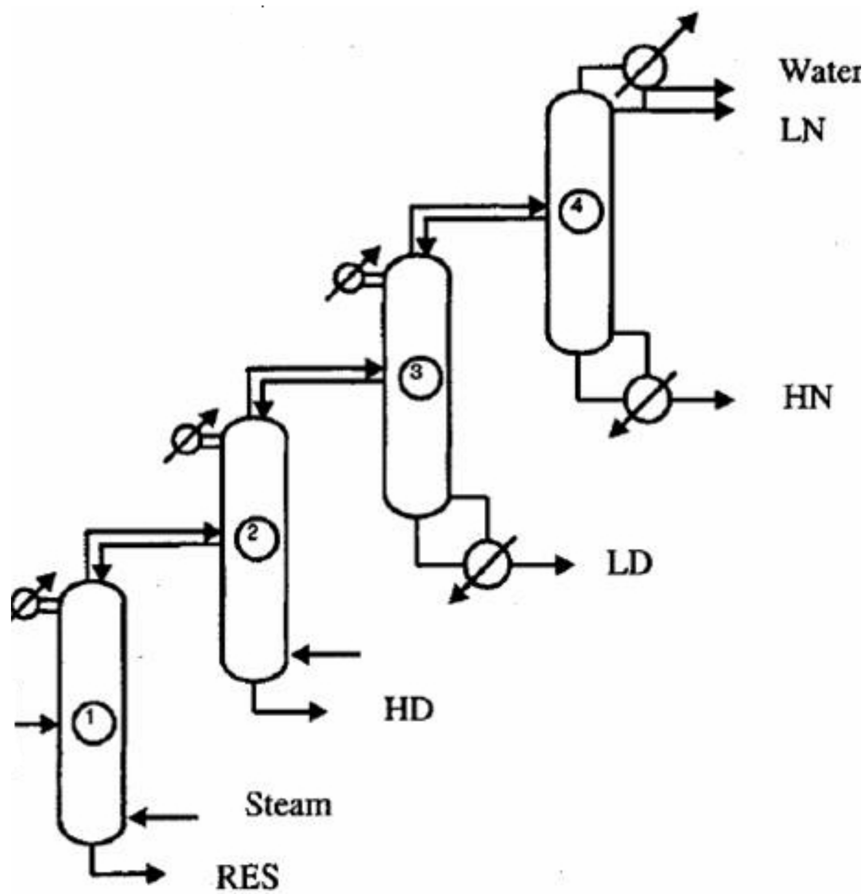


Cascaded Columns Representation of a Crude Distillation Column
(Gadalla et al, 2003)

CDU Aggregate Model

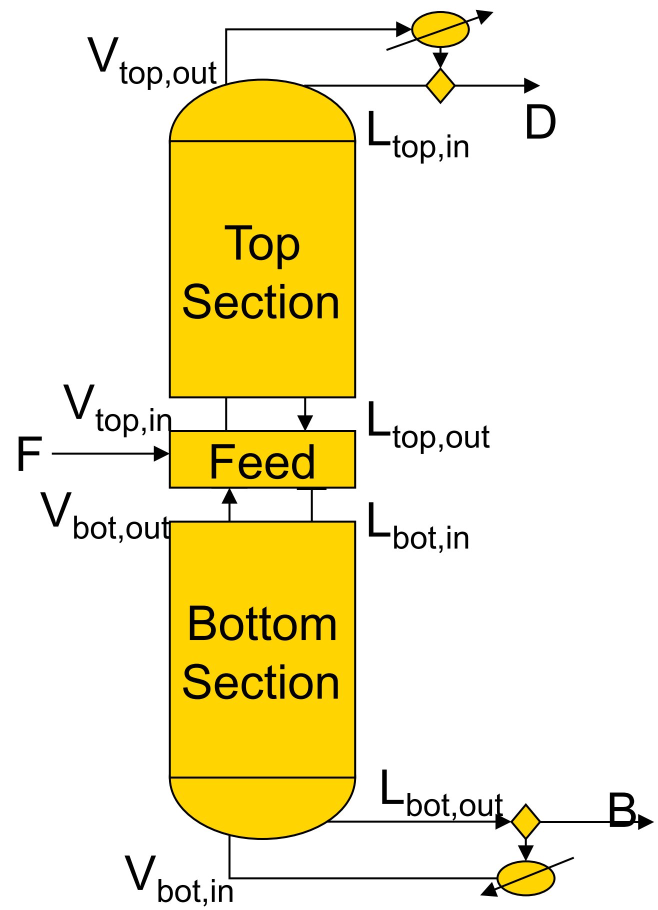
- Original Aggregate Distillation Column Model
  - Based on work of Caballero & Grossmann, 1999
  - Principle
    - Top and bottom integrated heat and mass exchangers around the feed location
    - Constant flow in each section
    - Pinch location is at the feed section
    - Feasibility criteria

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

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

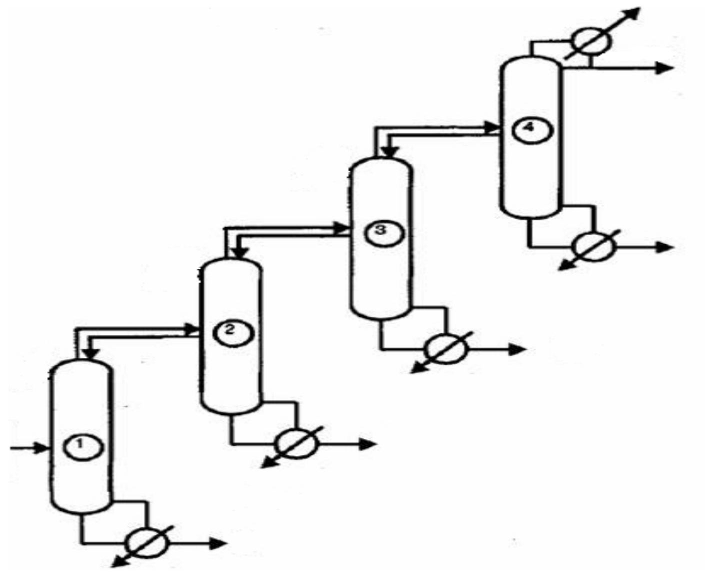
    - Temperature constraint

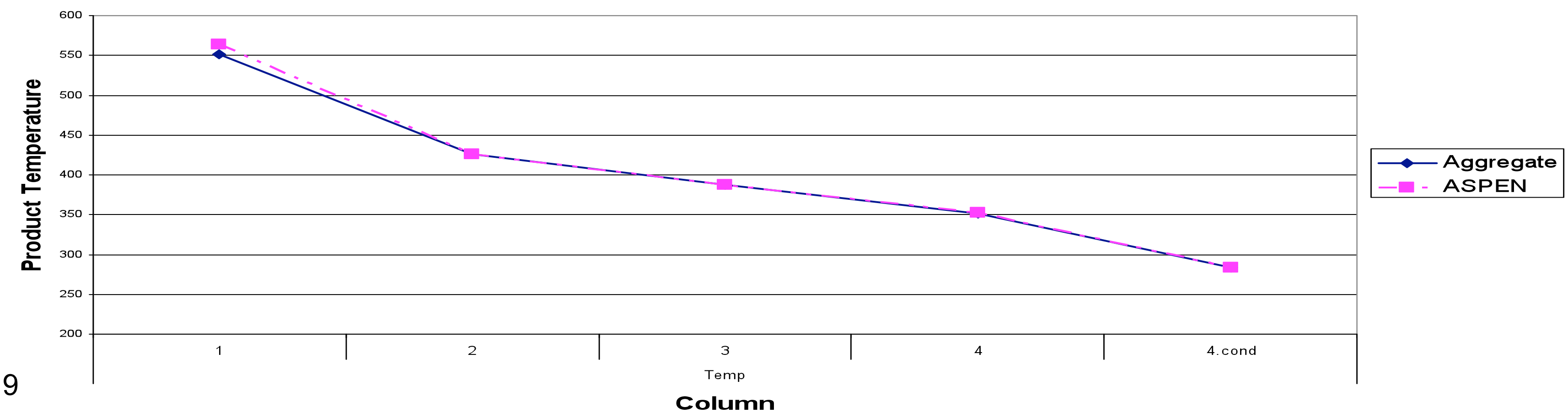
$$T_{reb} > T_{bot} > T_{botfeed} > T_{topfeed} > T_{top} > T_{cond}$$



Aggregate Model Example

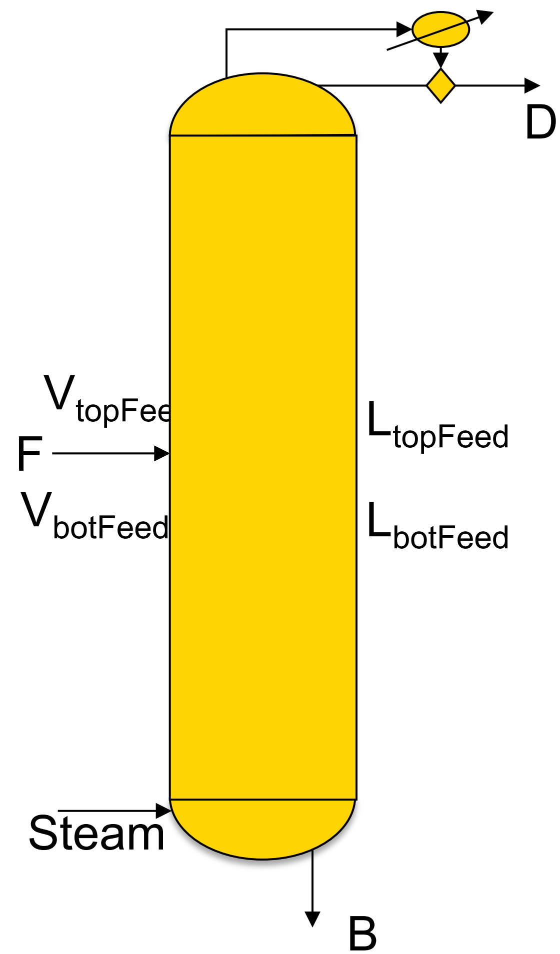
- Conventional cascaded columns example
  - 4 columns
    - Indirect sequence
  - Feed
    - 18 components (C3-C20)





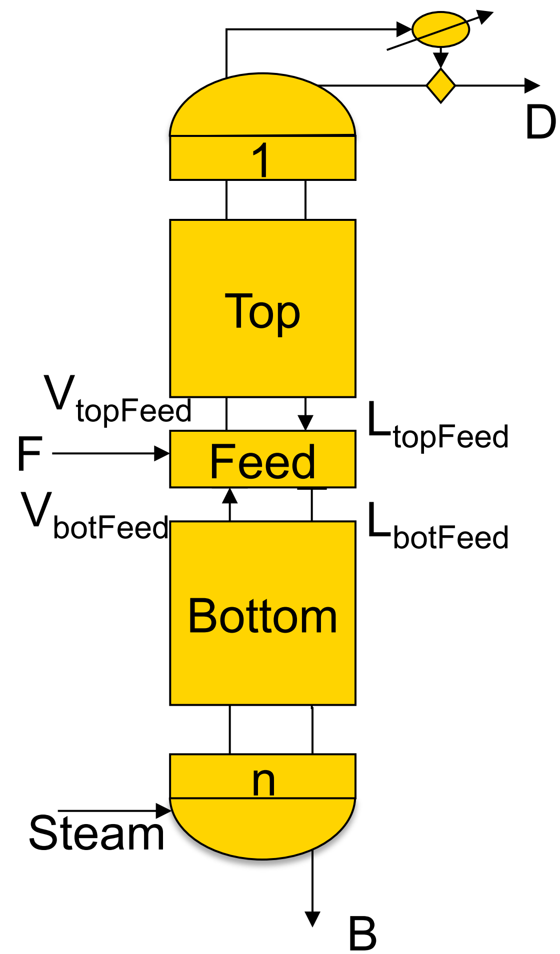
Aggregate Model – Steam Distillation Column

- 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



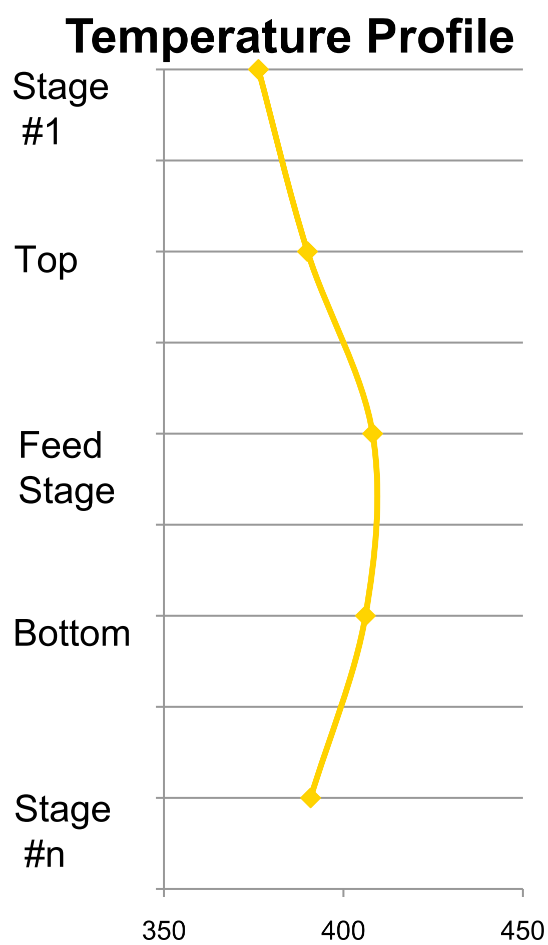
Aggregate Model – Steam Distillation Column

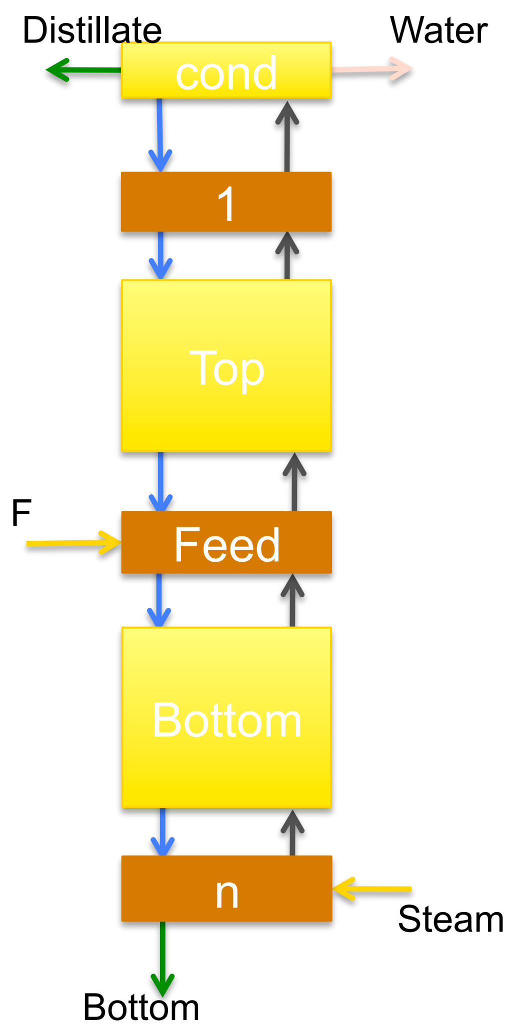
- New model
  - Column split into 5 sections
    - Condenser, stage #1, top section, feed stage, bottom section, stage n
  - Equilibrium equations applied to stage #1, feed stage and stage #n, excluding steam
  - Mass & energy balances applied to all stages and sections
  - Top product at the bubble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



Modified Aggregate Model Example

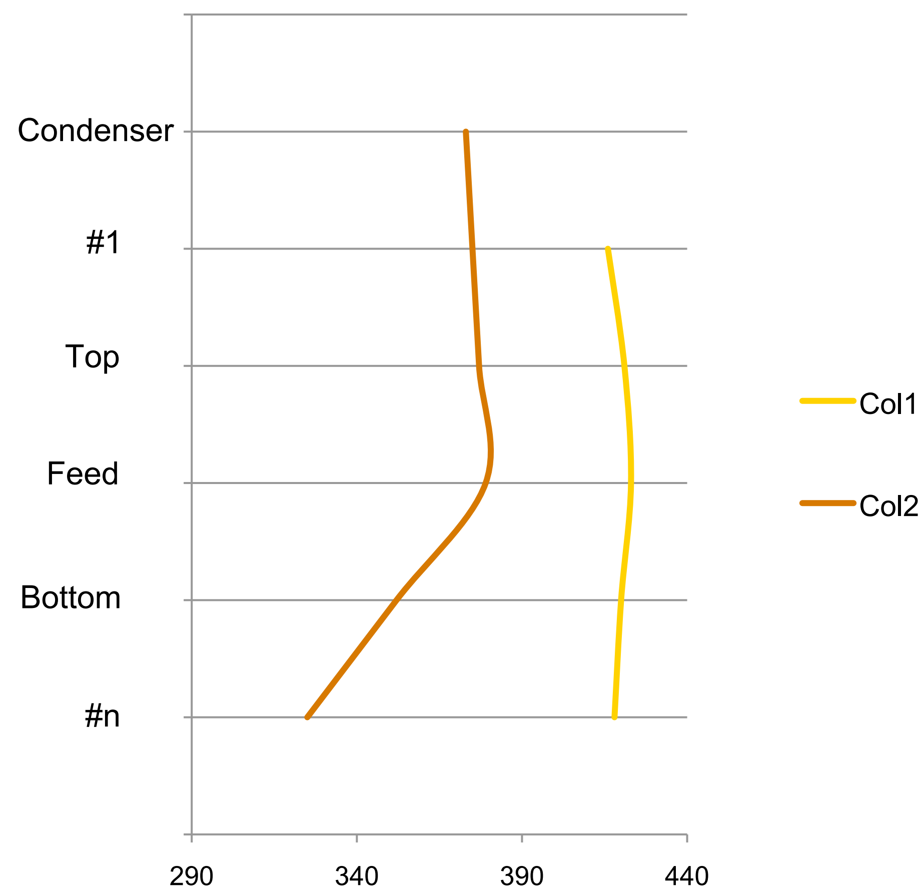
- Feed
  - C08,C10,C12 & C14
  - Recovery
    - LK: C10, 74%
    - HK: C12, 80%
- Results
  - Correct temperature profile
    - Peak at the feed stage

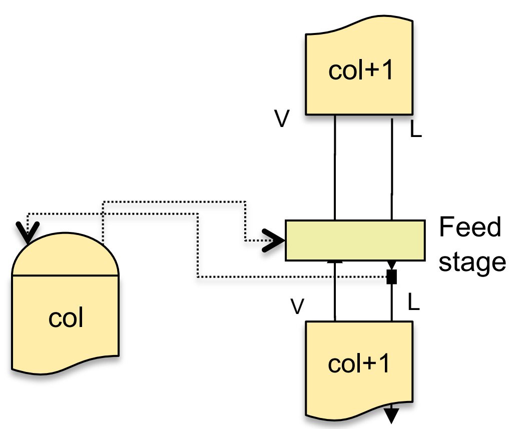




Steam distillation cascaded columns

- 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