Optimal Model-Based Production Planning for Refinery Operation

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Outline

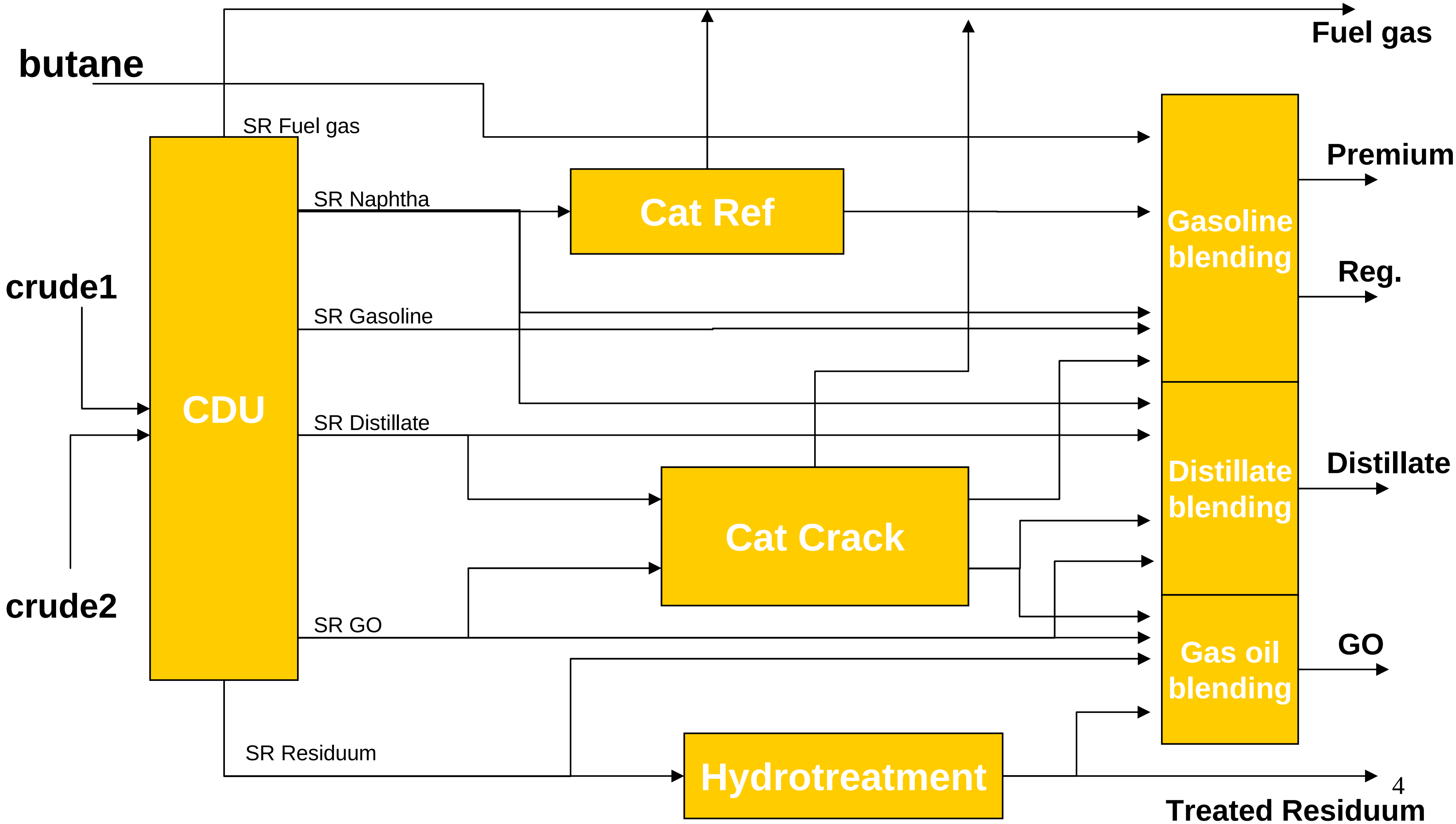
- Introduction
- Problem Statement
- Refinery Planning Model Development
  - LP Planning Models
  - NLP Planning Models
- Conclusion

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

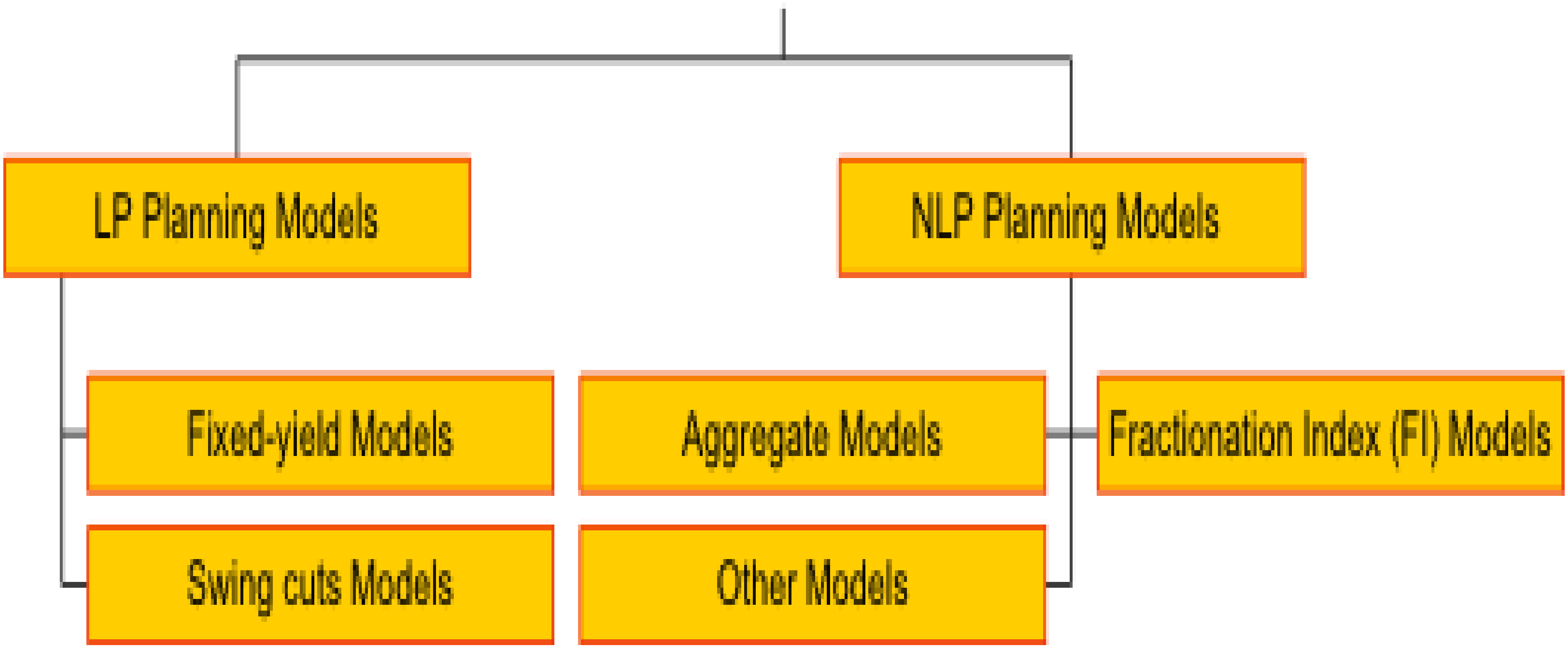
Typical Refinery Configuration *(Adapted from Aronofsky, 1978)*



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

Refinery Planning Model



LP Refinery Planning Models

- **Fixed yield models**:
  - Simplest planning models
  - Linear equation for calculating process unit yield

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

  - Models are robust and simple
    - Do not represent the process non-linearity
  - Different coefficients for different operating modes and feedstock

LP Refinery Planning Model

- **Swing cut models**:
  - Improvement from the fixed-yield approach
  - Crude oil cuts are allowed to change
    - Front and back of each cut is optimized

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

    - Better representation for the operating modes
    - Uses existing LP tools
    - Different coefficients for different crude oils
    - Models do not represent the process non-linearity

LP Refinery Planning Model Example

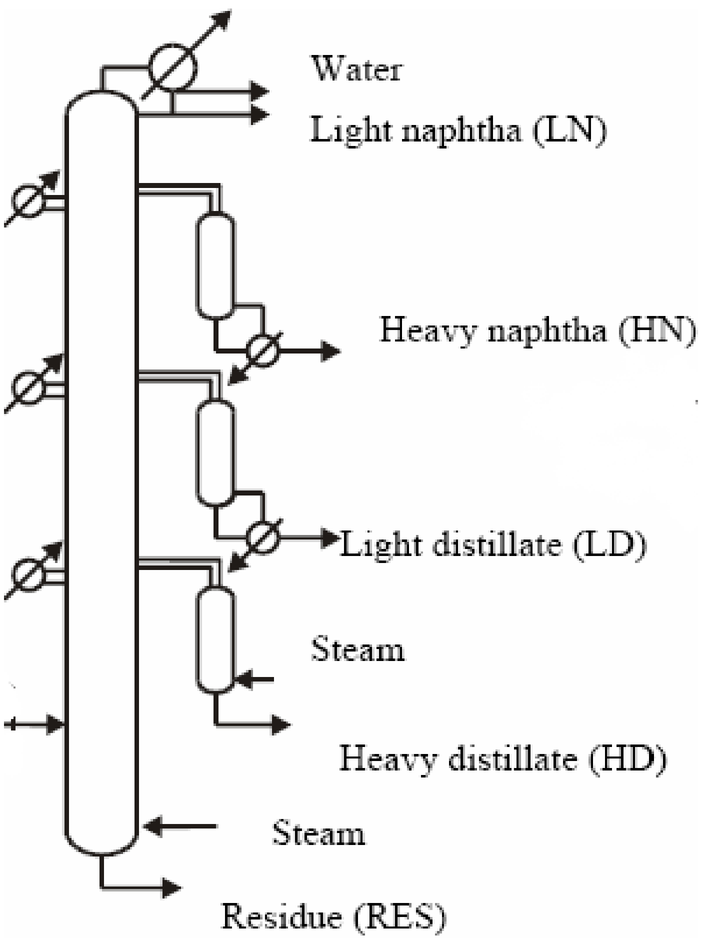
- **Example**
  - Complex refinery configuration
    - Processing 2 crude oils & importing heavy naphtha
  - Swing cut model
    - Offers lower net cost & different feed quantities
    - Shows benefits of better equations

		Fixed yield	Swing cut
Crude Feedstock	**Crude1 (lighter)**	**142**	**0**
	Crude2 (heavier)	**289**	**469**
Other Feedstock	**Heavy Naphtha**	13	9
Refinery Production	**Fuel Gas**	13	17
	LPG	18	20
	Light Naphtha	6	6
	Premium Gasoline	20	20
	Reg. Gasoline	80	92
	Gas Oil	163	170
	Fuel Oil	148	160
	Net Cost	**89663**	**85714**

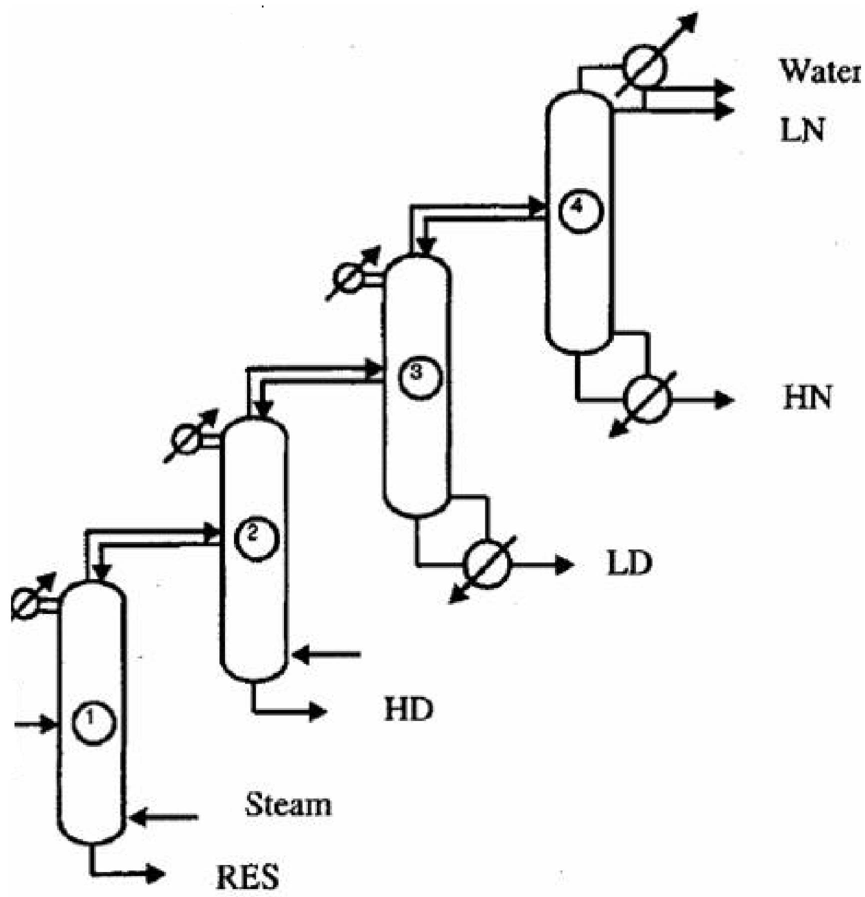
NLP Refinery Planning Models

- Focus on the front end of the refinery
  - Crude distillation unit (CDU)
- Types
  - Aggregate model
  - Fractionation index (FI) model
  - Other models

CDU & Cascaded Columns



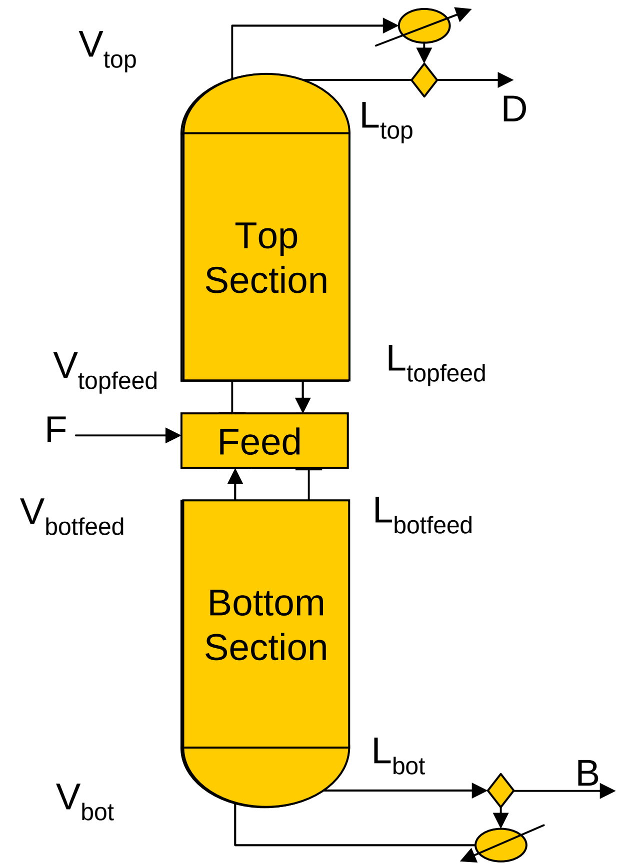
Typical Crude Distillation Column
(Gadalla et al, 2003)



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

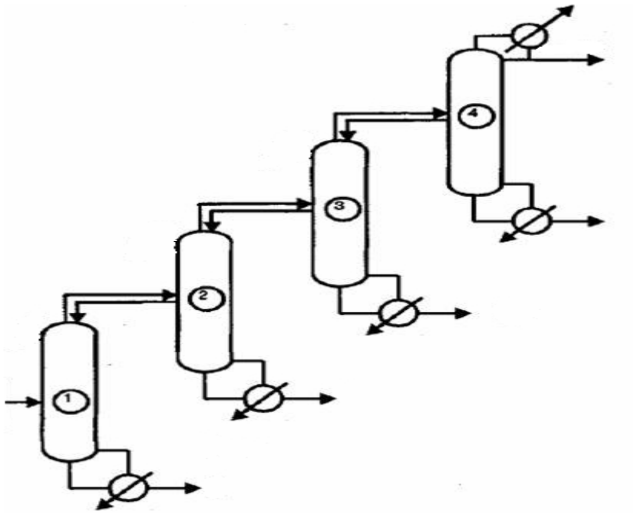
NLP Refinery Planning Models

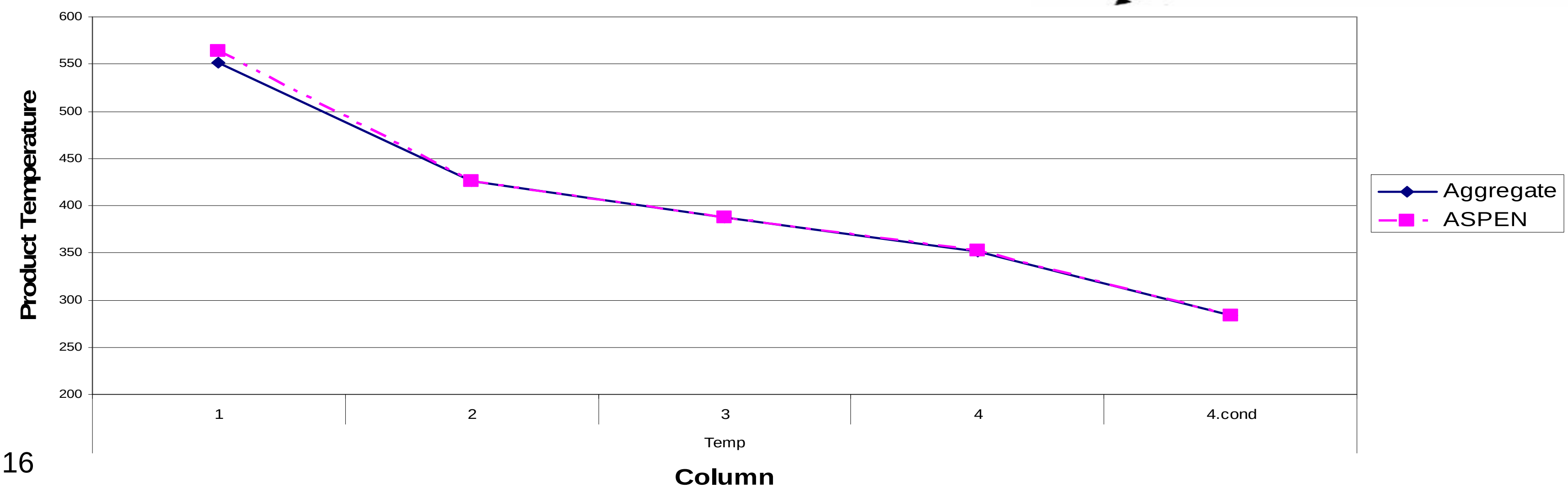
- **Aggregate model**
  - Conventional distillation
  - Based on work of Caballero & Grossmann, 1999
  - integrated heat and mass exchangers
  - sections around the feed location
    - Assuming equimolal flow in each section
  - Nonlinearity in equilibrium constant
  - Single & cascaded columns arrangements
    - Model is robust
    - Results in good agreement with rigorous calculation



NLP Refinery Planning Models

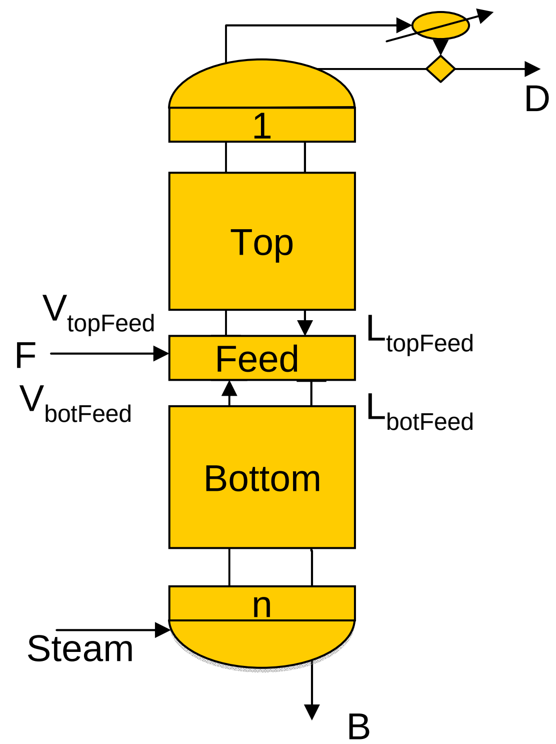
- **Aggregate model**
  - Conventional distillation example
    - 4 columns
    - Feed: 18 components (C3-C20)
    - Results: product temperature matching simulation results





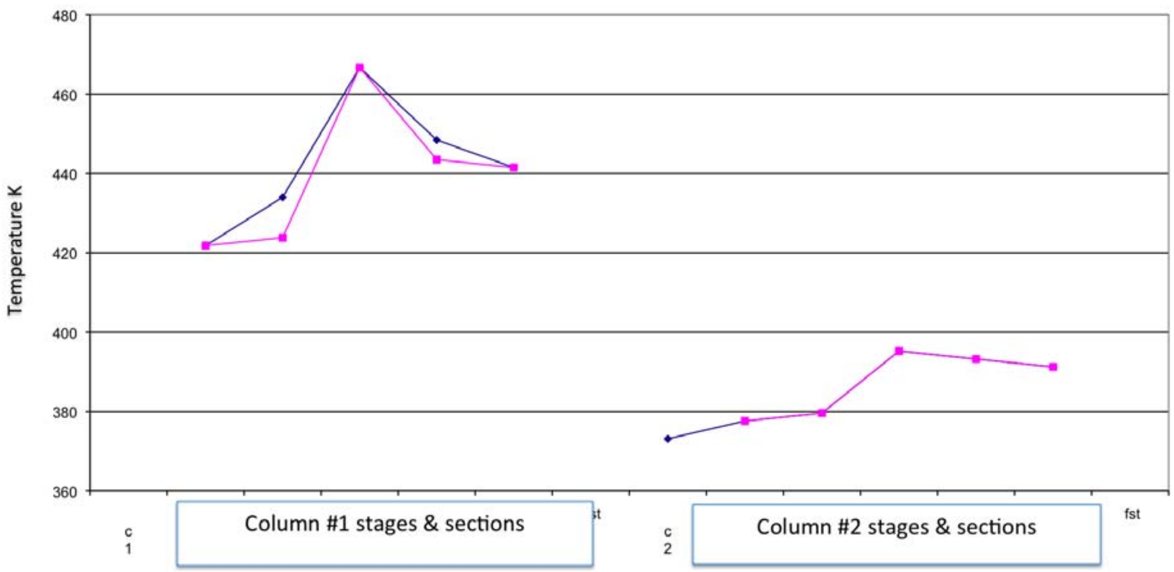
NLP Refinery Planning Models

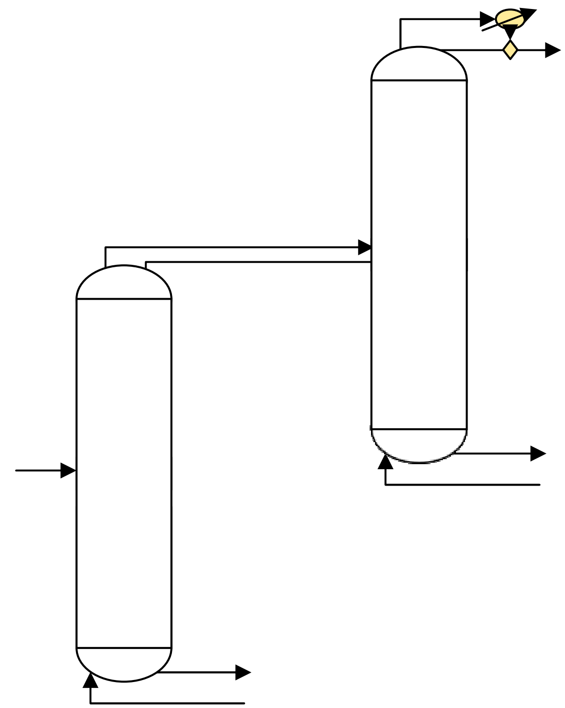
- **Aggregate model**
  - Steam distillation
  - Modified aggregate model
    - 3 Equilibrium stages
    - 2 multi-stage sections
    - Assuming non-equimolal flow in each section
  - Nonlinearity in equilibrium constant
  - Single & cascaded columns arrangements
    - Model is robust
    - Results show predicted temperature peak at the feed stage



NLP Refinery Planning Models

- **Aggregate model**
  - Steam distillation example
    - 2 columns, both with steam distillation
    - Feed: 4 components
    - Results: temperature trend successfully predicted for both columns





NLP Refinery Planning Models

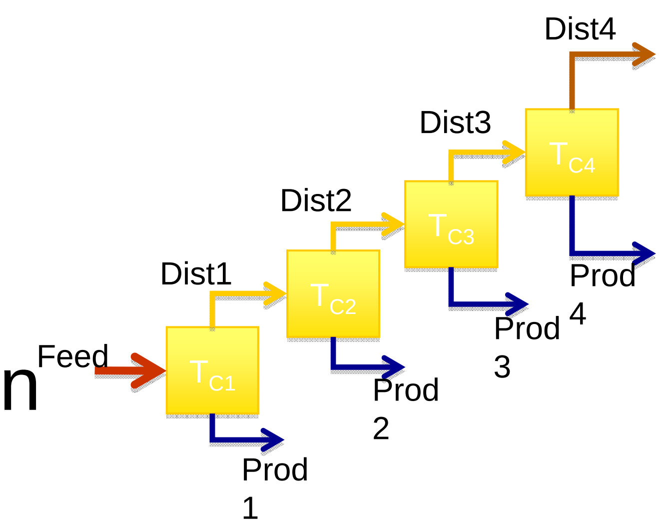
- **Aggregate model**
  - Mixed-type distillation
    - Combines conventional and steam distillation
    - Can be solved for a limited number of cascaded columns
    - Initialization

NLP Refinery Planning Models

- **FI model**
  - CDU is a series of binary separations
    - Cut point temperature is the separation temperature
  - Based on Geddes' fractionation index method (Geddes 1958)
    - FI replaces N_{min} in Fenske equation

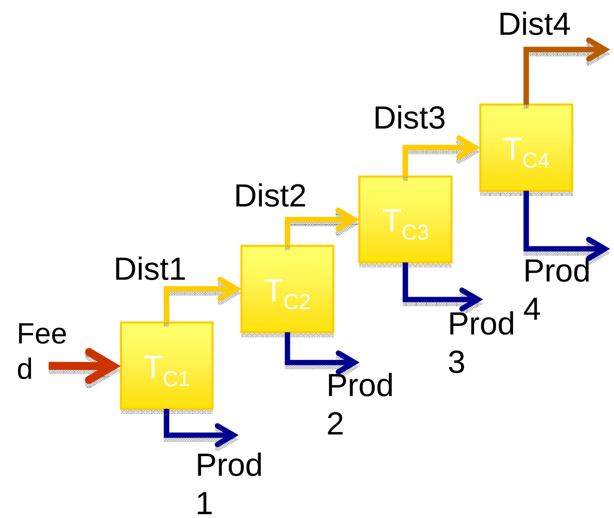
$$\left(\frac{Dist}{Prod}\right)_{i,j} = \left(\alpha_{i/ref}\right)_j^{FI}\left(\frac{Dist}{Prod}\right)_{ref,j}, i \in comp, j \in stage$$

    - Model is crude-independent



NLP Refinery Planning Models

- **FI model**
  - FI model example
    - Venezuelan crude (Watkin 79)
    - 40 Pseudo-components, 4 cuts
    - 4 runs: Maximizing naphtha (N), heavy naphtha (HN), light distillate (LD), heavy distillate (HD)
    - Cut-point temperature and product quantities reflect the different business objectives
    - Stats
      - Equations: 562
      - Variables: 568
      - Solver: CONOPT



	Cut point temperature					
Run	**Gas OH**	**Naphtha**	**H Naphtha**	**L Dist.**	**H Dist;**	**B. Residue**
Max Naphtha		272.7	417.0	426.4	526.8	595.3
Max H Naph.		272.7	386.2	487.8	526.8	595.3
Max L Dist.		272.7	386.2	398.3	606.0	631.1
Max H Dist.		272.7	386.2	398.3	526.8	650.5
	Product					
Max Naphtha	6.2	112.9	35.1	68.6	16.5	60.7
Max H Naph.	6.2	107.4	53.0	56.1	16.6	60.7
Max L Dist.	6.2	111.5	10.7	95.0	16.0	60.5
Max H Dist.	6.2	111.5	10.7	94.0	16.9	60.5

NLP Refinery Planning Models

- **FI Model**
  - ***FI model in the planning model***
    - Venezuelan crude only (Watkin 79)
    - Model calculates feed quantity and final products for maximum profits at the given prices
    - Model also generates the cut point temperature settings
      - Stats
        - Equations: 686
        - Variables: 707
        - Solver: CONOPT

Feedstock	
Crude oil	100.0
Final product	
Fuel gas	13.4
Prem. Gasoline	12.2
Reg. Gasoline	52.0
Distilate	0.0
Fuel oil	6.8
HT Residue	16.4
Economics	
income	701
OpCost	30
purchases	651
Profit	20

Cut	**Cut point Temp**
Naphtha	287
H Naph.	398
L Dist.	462
H Dist.	552
B Residue	628

NLP Refinery Planning Models

- **Other Models**
  - All limited to empirical approaches
    - Alhajeri & Elkamel (2008):
      - Empirical correlation
    - Dua & Gueddar
      - Artificial neural networks

Future work

- NLP Aggregate model
  - Investigate better initialization scheme and additional constraints
- NLP FI model
  - More runs using the FI model
    - Additional FI parameters
    - Manage property blending for the intermediate streams
- NLP models
  - Assess the benefit of the different modeling approaches in terms of accuracy, robustness & simplicity
  - Upgrade process model for other important units
- Extend the model to multi-period
- Add scheduling elements