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Optimal Operation of Kaibel Columns

Maryam GHADRDAN

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Thesis Contributions

Chapter 1 Introduction

Chapter 2 a short review on Thermally coupled columns, with focus on Kaibel columns, their design, optimal operation and control.

Chapter 3 Two operation modes

- maximizing the purities in the products with fixed boilup
- minimizing energy with specified product purities

Chapter 4 shortcut design of a Kaibel column using V_{min} diagram.

Chapter 5 Vapour split as a degree of freedom. Two methods are used to study the effect of vapour split manipulation, namely a shortcut method and rigorous simulations.

Chapter 6 short review of self-optimizing methods.

Thesis Contributions

Chapter 7 Control of Kaibel columnfor the case of maximizing purities of products with fixed boilup.

Chapter 8 Short review on static estimators.

Chapter 9 A new class of static estimators for four different scenarios:

- open
- primary variables are controlled
- secondary variables are controlled
- estimation of primary variables are controlled.

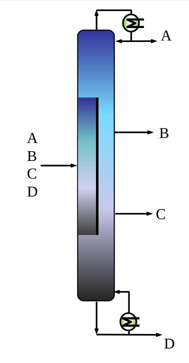
Chapter 10 Control of Kaibel column for specified product composition

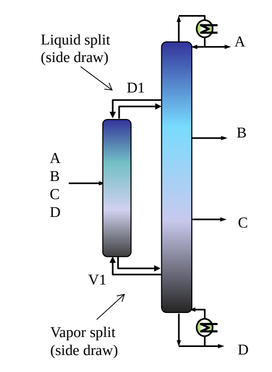
Chapter 11 Dynamic compensation for static estimators

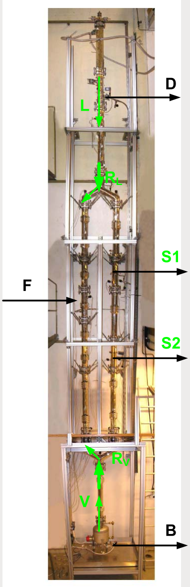
Contents

DoF

$$u = \begin{bmatrix} R_L & R_V & L & V & S_1 & S_2 \end{bmatrix}$$







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V_{min} diagram

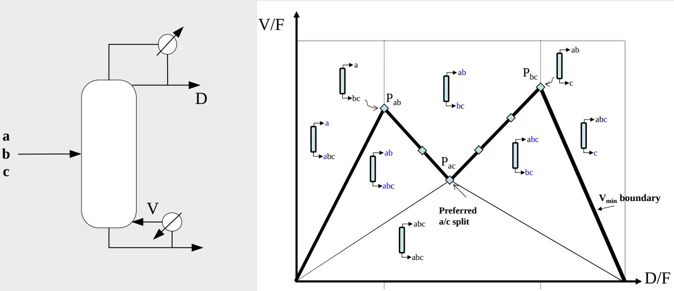


Figure: V_{min} diagram for a ternary feed

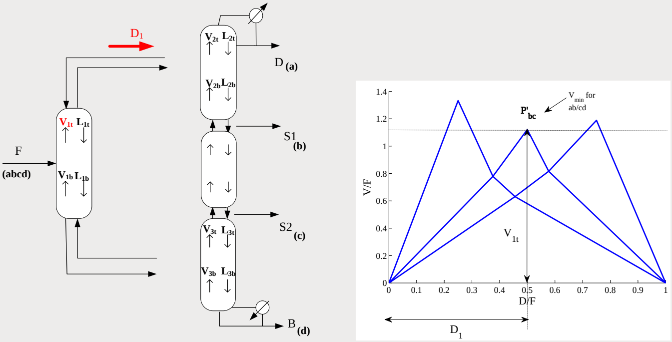
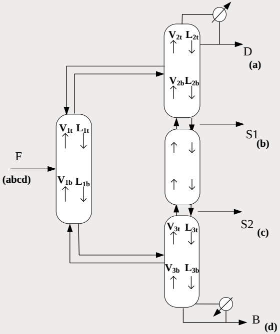


Figure: V_{min} diagram for the prefractionator of Kaibel distillation column (b/c split)

V_{min} diagram for Kaibel distillation column



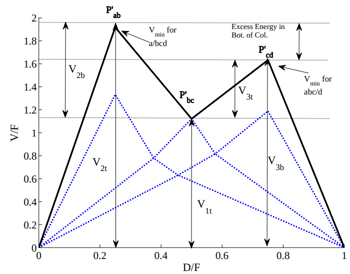


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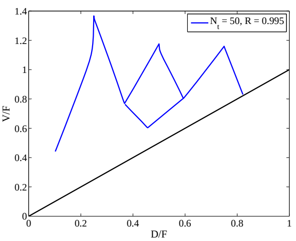
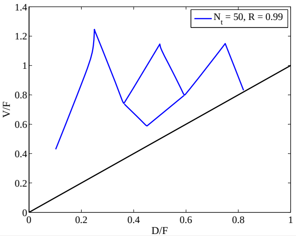
Table: Procedure of making the V_{min} diagrams from rigorous simulations

Line	Specifications
0 - a/b	$R_{C2,bot} = UB$, Increase D while $R_{C1,top} < UB$,
a/b - a/c	$R_{C1,top} = UB$, Increase D while $R_{C3,top} < LB$,
a/c - b/c	$R_{C3,bot} = UB$, Increase D while $R_{C2,top} < UB$
b/c - b/d	$R_{C2,top} = UB$, Increase D while $R_{C4,top} < LB$
b/d - c/d	$R_{C4,top} = UB$, Increase D while $R_{C3,top} < UB$
c/d - end	$R_{C3,top} = LB$, Increase D while $R_{C1,bot} < LB$
a/c - a/d	$R_{C1,top} = UB$, Increase D while $R_{C4,top} < LB$
a/d - b/d	$R_{C4,bot} = UB$, Increase D while $R_{C2,top} < UB$

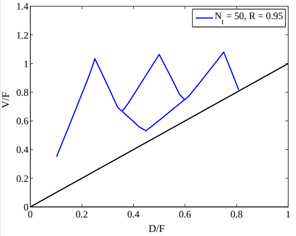
V_{min} from rigorous simulation



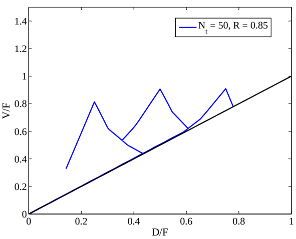
(a)



(b)



(c)



(d)

Definition of the Objective Function

Two different ways to operate a column:

Mode 1 Specify the product purities and use the remaining DOF for minimizing the vapor consumption (motivation to introduce thermally-coupled columns)

Mode 2 Fix the column boilup at the maximum and try to get the most out of the column (when energy is relatively cheap)

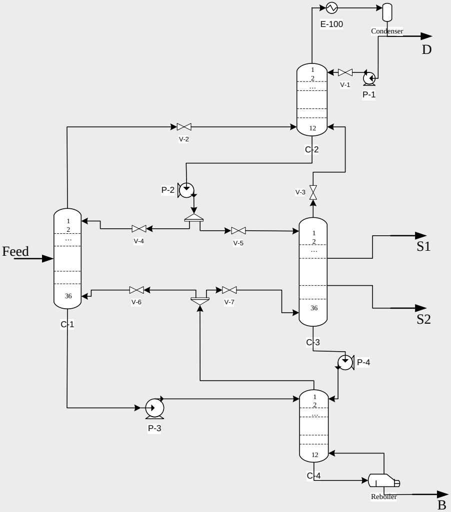


Figure: Simulation flowsheet of Kaibel distillation column

Mode 1

The optimal values are obtained by plotting the contours manually.

DoF

$$u = \begin{bmatrix} R_L & R_V \end{bmatrix}$$

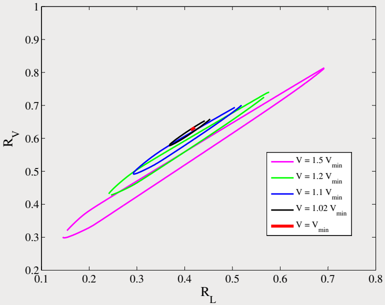


Figure: Contours of constant boilup as a function of vapour and liquid splits at constant product purities

Mode 1

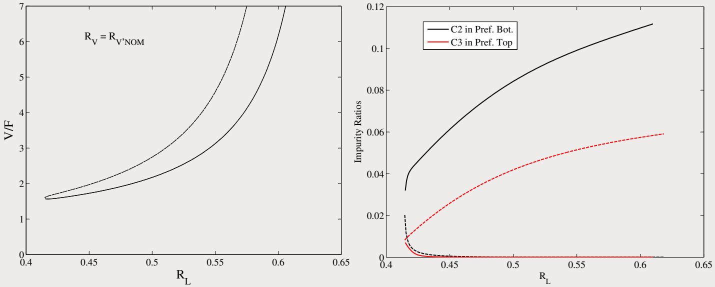


Figure: (Left) Boilup rate as a function of liquid split at constant vapour split and product purities, (Right) Impurities in the top and bottom of prefractionator

Obs!

Multiplicity is seen in the solution

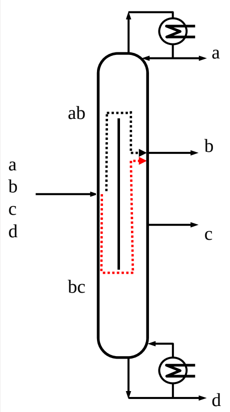
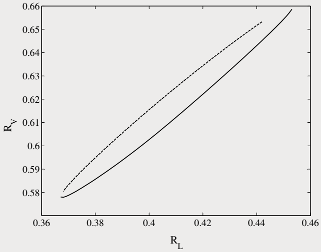
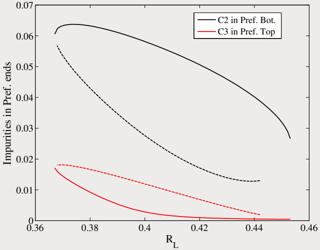


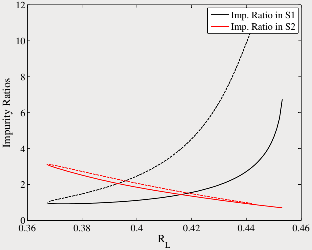
Figure: Paths of impurity flow to side streams

Mode 1: Impurities along a boilup contour

$$V = 1.02\,V_{min}$$







Mode 2:

Objective J is to minimize the loss compared to the ideal profit (pure products).

$$J = D(1 - x_D) + S_1(1 - x_{S1}) + S_2(1 - x_{S2}) + B(1 - x_B)$$

DoF

$$u = \begin{bmatrix} R_L & R_V & L & S_1 & S_2 \end{bmatrix}$$

Optimization is done in MATLAB using GA method

Mode 2

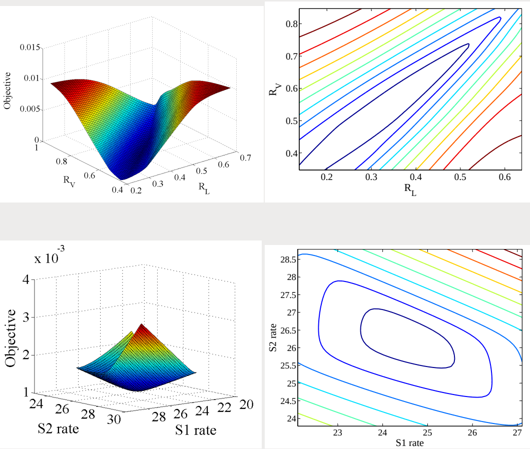


Figure: Mode 2 with fixed boilup: 3-D surfaces and contour plot of impurity sum (cost J) as a function of degrees of freedom with the other variables fixed at their optimal values.

$R_V = R_{V,nom}$?

V_{min} diagram for the nominal feed properties (black) and new feed composition with optimal (blue) and fixed R_V (red)

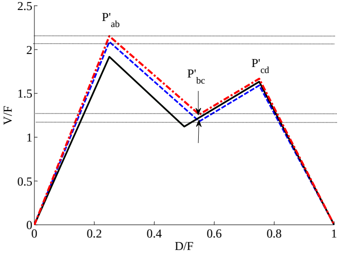
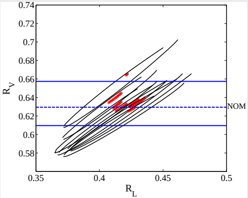
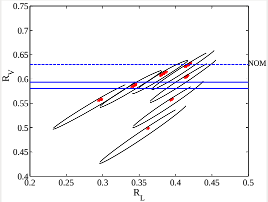


Figure: b/c composition change from 0.25/0.25 to 0.30/0.20 with optimal $R_V = 0.5649$ and fixed $R_V = 0.5846$

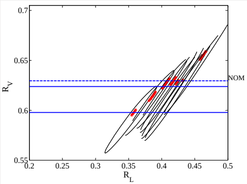
$R_V = R_{V,nom}$?



Change in a/b composition



Change in b/c composition



Change in c/d composition

Contours of boilups up to 2% more than minimum energy for different feed composition changes in A/B, B/C and C/D

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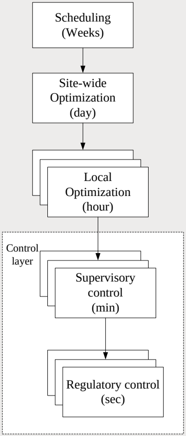
Comparison of energy saving for two different vapour split values

Compositions	(x_a/x_b)		(x_b/x_c)		(x_c/x_d)	
	$R_{V,nom}$	$R_{V,lower}$	$R_{V,nom}$	$R_{V,lower}$	$R_{V,nom}$	$R_{V,lower}$
0.1 / 0.4	0.8%	2.7%	14.2%	8.67%	2.7%	-0.02%
0.15 / 0.35	0.07%	1.41%	6.96%	2%	0.65%	0.5%
0.2 / 0.3	0%	0.96%	0.8%	0.05%	0%	0.97%
0.3 / 0.2	0%	1.1%	0.85%	0.33%	0%	0.67%
0.35 / 0.15	0%	1.12%	3.58%	0.16%	0%	0.68%
0.4 / 0.1	0%	0.8%	6.54%	6.98%	0.5%	1.9%

General procedure for control structure design

I Top-down (focus on steady-state economics)

1. Define operational objectives (optimal operation):
   - Cost function J (to be minimized)
   - Constraints
2. Objective: Find regions of active constraints
   - Identify steady-state DOF
   - expected disturbances.
   - Optimize the operation wrt the DOF for the expected disturbances (off-line analysis)
   - Select primary controlled variables CV1s (Self-optimizing)
3. Select location of throughput manipulator



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II Bottom-up (focus on dynamics) [1]

4. Select structure of regulatory control layer (including inventory control):
   - Select 'stabilizing' controlled variables CV2
   - Select inputs (valves) and 'pairings' for controlling CV2 (Decision 4)
     1. Stabilizes the process and avoids drift
     2. If possible, use same regulatory layer for all regions
5. Select structure of supervisory control
   - Controls primary CV1's
   - Supervises regulatory layer
   - Performs switching between CV1s for different regions
6. Select structure of (or need for) optimization layer (RTO)
   - Updates setpoints for CV1 (if necessary)

[1] Skogestad, S., 2004, Control Structure Design for Complete Chemical Plants, Computers and Chemical Engineering, 28, 219-234

Loss Method

OBJECTIVE

Self-optimizing control is when we can achieve an acceptable loss with constant setpoint values, for the controlled variables in the presence of disturbance and noise.

[2]

$$\mathbf{L}(\mathbf{H}, \mathrm{d}, \mathrm{e}) = \mathbf{J}(\mathrm{u}, \mathrm{d}, \mathrm{e}^{x})_{\mathrm{c}=\mathrm{c}^{*}} - \mathbf{J}(\mathrm{u}^{opt}(\mathrm{d}), \mathrm{d})$$

where d and e are constrained to satisfy the following inequality

$$\| \begin{bmatrix} \mathrm{d}' & \mathrm{n}^{x} \end{bmatrix}^{T} \|_2 \leq 1$$

and $\mathrm{d} = \mathbf{W}_d \mathrm{d}'$ and $\mathrm{n}^{x} = \mathbf{W}_{\mathrm{n}^x} \mathrm{n}^{x\prime}$.

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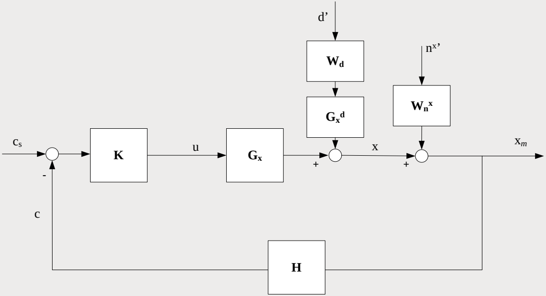
[2] Skogestad, S. (2000). Plantwide control: The search for the self-optimizing control structure. Journal of Process Control 10, 487-507



Assumption: Linear steady-state measurement model,

$$x = \mathbf{G}_x u + \mathbf{G}_x^d d$$

The actual measurements x_m, containing noise n^x is

$$x_m = x + n^x$$

The CVs of the form $c = \mathbf{H} x_m$

H is found by solving

$$\min_{\mathbf{H}} \| \mathbf{J}_{uu}^{1/2} (\mathbf{H}\mathbf{G}_x)^{-1} \mathbf{H}\tilde{\mathbf{F}} \|_F^2$$

where $\tilde{\mathbf{F}} = \begin{bmatrix} \mathbf{F}\mathbf{W}_d & \mathbf{W}_{\mathrm{n}^x} \end{bmatrix}$.

F: optimal sensitivity matrix. It can be found

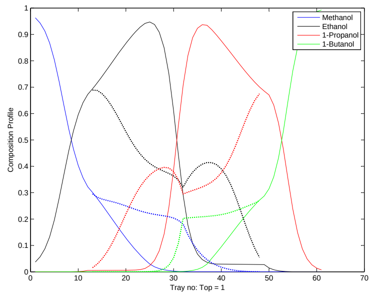
- using $\mathbf{F} = -\mathbf{G}_x \mathbf{J}_{uu}^{-1} \mathbf{J}_{ud} + \mathbf{G}_x^d$
- numerically from its definition $\mathbf{F} = \frac{d\mathrm{y}_{opt}}{d\mathrm{d}}$ ✓

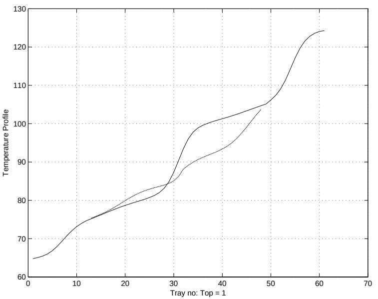
$\mathbf{J}_{uu}$ can be difficult to obtain, especially if one relies on numerical methods, and also taking the difference can introduce numerical inaccuracy.

Mode 2; Control Structure design

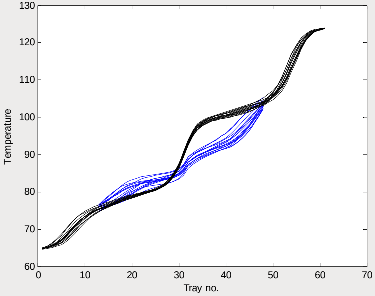
- 5 steady-state DOF: reflux rate, side stream flows, liquid split and vapor split
- Need to find 5 CVs: Single temperatures
- Throughput Manipulator (TPM): column feed
- Assumed that the temperature loops in the upper layer are used for stabilization too
- Disturbances: feed flow rate (F), feed composition (z_F) and feed liquid fraction (q), setpoints of controllers.

Optimal Profiles in Kaibel Arrangement





Optimal composition (left) and temperature (right) profiles



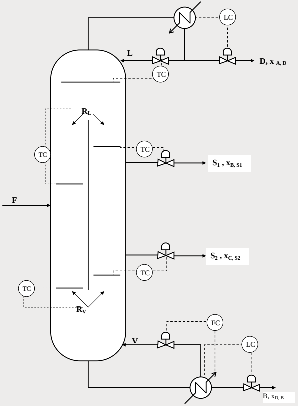


Figure: Optimal temperature profiles for disturbances in feed compositions, liquid fraction and boilup flow setpoint

Pairings

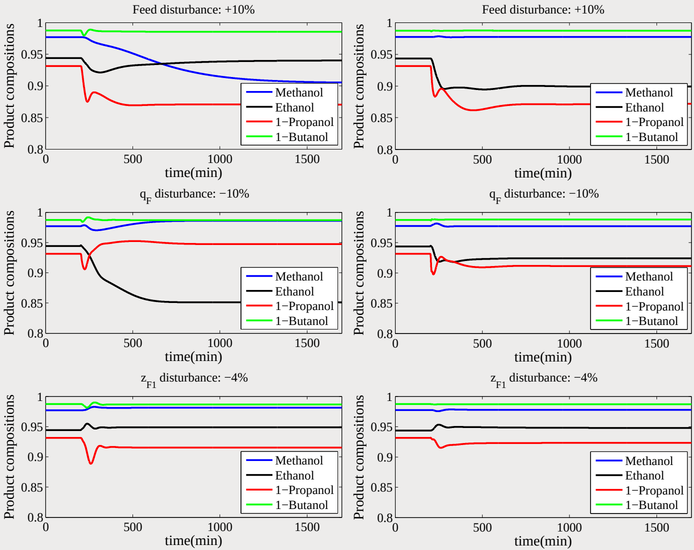
- Avoid pairing on negative steady-state RGA
- Choose pairings corresponding to RGA-elements close to 1
- Prefer pairing on variables with good controllability (=small effective delay).

$$RGA(\mathbf{G}) = \mathbf{G} \times (\mathbf{G}^{-1})^T$$

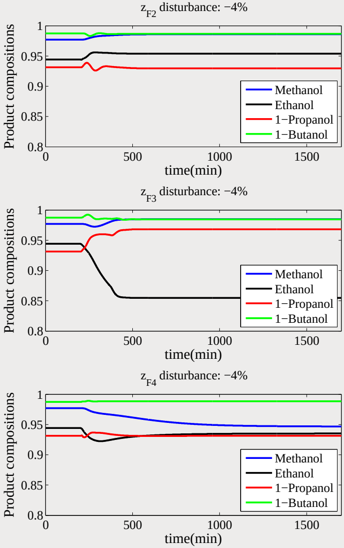
	R_l	R_v	RR	$Side_1$	$Side_2$
$T15$	0.31	0.72	0.49	−0.06	−0.47
$T36$	−0.74	0.42	10.37	0.33	−9.38
$T39$	2.18	−0.78	4.16	−1.50	−3.07
$T54$	−1.13	0.77	−4.22	2.31	3.27
$T75$	0.38	−0.13	−9.81	−0.08	10.64

Temperature Control

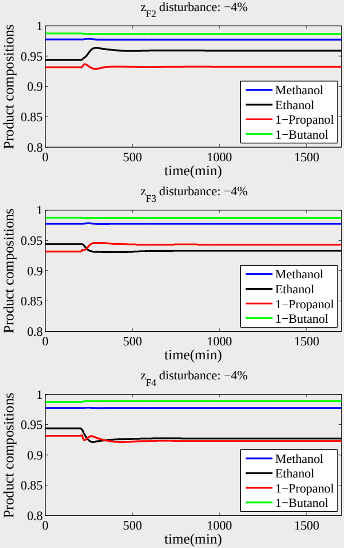
Composition Control



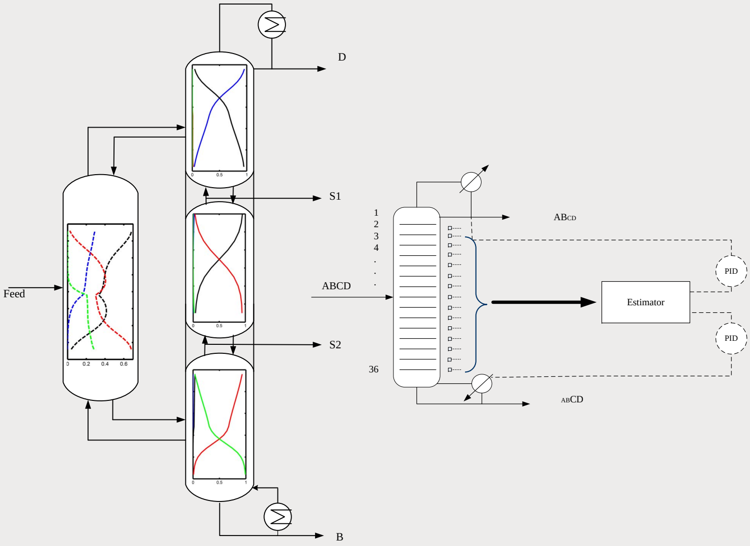
Temperature Control



Composition Control



Controlling compositions



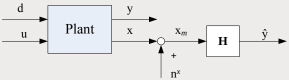
Our Static Estimator

OBJECTIVE

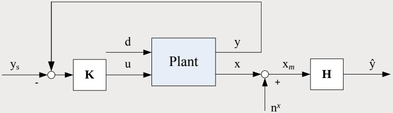
The main objective is to find a linear combination of measurements such that keeping these constant indirectly leads to nearly accurate estimation with a small loss L in spite of unknown disturbances, d, and measurement noise, n^x.

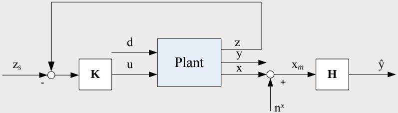
$$\min_{\mathbf{H}} \|e\|_2 = \|\mathrm{y} - \hat{\mathrm{y}}\|_2$$

Our Static Estimator

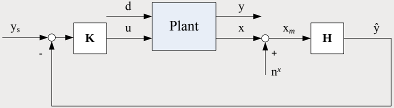


- "Open-loop" (for Monitoring of $\hat{y}$)
  1. No control (u is a free variable)
  2. Primary variables y are controlled (u is used to keep $y = y_s$).
  3. Secondary variables z are controlled (u is used to keep $z = z_s$).

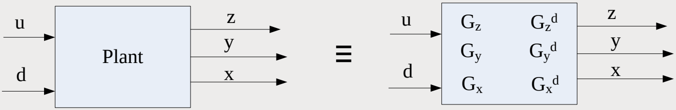




- "Closed-loop" (for Control of $\hat{y}$)



Our Static Estimator



1. Assumption: Linear models for the primary variables y, measurements x, and secondary variables z

$$\mathrm{y} = \mathbf{G}_y \mathrm{u} + \mathbf{G}_y^d \mathrm{d} \qquad \mathrm{x} = \mathbf{G}_x \mathrm{u} + \mathbf{G}_x^d \mathrm{d} \qquad \mathrm{z} = \mathbf{G}_z \mathrm{u} + \mathbf{G}_z^d \mathrm{d}$$

$$\mathbf{G}_y = \left(\frac{\partial \mathrm{y}}{\partial \mathrm{u}}\right)_{\mathrm{d}}, \mathbf{G}_y^d = \left(\frac{\partial \mathrm{y}}{\partial \mathrm{d}}\right)_{\mathrm{u}}, \cdots$$

2. The actual measurements x_m, containing measurement noise n^x is $\mathrm{x}_m = \mathrm{x} + \mathrm{n}^x$
3. The linear estimator is of the form $\hat{\mathrm{y}} = \mathbf{H}\mathrm{x}_m$

Optimal estimators for different scenarios

"Open-loop" 1

$$\mathbf{H}_1 = \mathbf{Y}_1 \mathbf{X}_1^{\dagger}$$

$$\mathbf{Y}_1 = \begin{bmatrix} \mathbf{G}_y \mathbf{W}_u & \mathbf{G}_y^d \mathbf{W}_d & 0 \end{bmatrix}$$

$$\mathbf{X}_1 = \begin{bmatrix} \mathbf{G}_x \mathbf{W}_u & \mathbf{G}_x^d \mathbf{W}_d & \mathbf{W}_{n^x} \end{bmatrix}$$

"Open-loop" 2

$$\mathbf{H}_2 = \mathbf{Y}_2 \mathbf{X}_2^{\dagger}$$

$$\mathbf{Y}_2 = \begin{bmatrix} \mathbf{W}_{y_s} & 0 & 0 \end{bmatrix}$$

$$\mathbf{X}_2 = \begin{bmatrix} \mathbf{G}_x^{cl} \mathbf{W}_{y_s} & \mathbf{F}\mathbf{W}_d & \mathbf{W}_{n^x} \end{bmatrix}$$

"Open-loop" 3

$$\mathbf{H}_3 = \mathbf{Y}_3 \mathbf{X}_3^{\dagger}$$

$$\mathbf{Y}_3 = \begin{bmatrix} \mathbf{G}_y^{cl} \mathbf{W}_{z_s} & \mathbf{F}'_y \mathbf{W}_d & 0 \end{bmatrix}$$

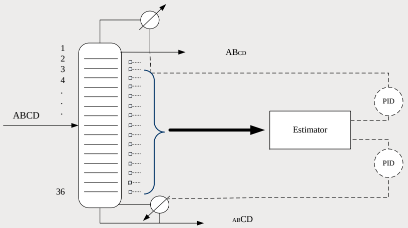
$$\mathbf{X}_3 = \begin{bmatrix} \mathbf{G}_x^{cl} \mathbf{W}_{z_s} & \mathbf{F}'_x \mathbf{W}_d & \mathbf{W}_{n^x} \end{bmatrix}$$

"Closed-loop"

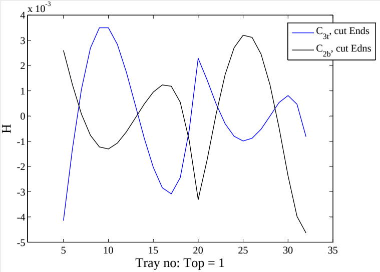
$$\min_{\mathbf{H}} \left\| \mathbf{H} \begin{bmatrix} \mathbf{F}\mathbf{W}_d & \mathbf{W}_{n^x} \end{bmatrix} \right\|_F$$

$$\text{s.t. } \mathbf{H}\mathbf{G}_x = \mathbf{G}_y$$

H values



$$\begin{bmatrix}\Delta\hat{y}_1\\ \Delta\hat{y}_2\end{bmatrix} =$$



$$\times \begin{bmatrix}\Delta T_5\\ \Delta T_6\\ \Delta T_7\\ \Delta T_8\\ \vdots\\ \Delta T_{32}\end{bmatrix}$$

Open-loop estimation (S1)

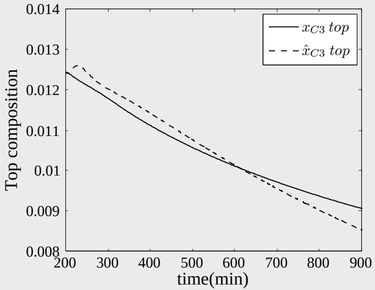


Figure: Top estimate with -1 percent change in boilup

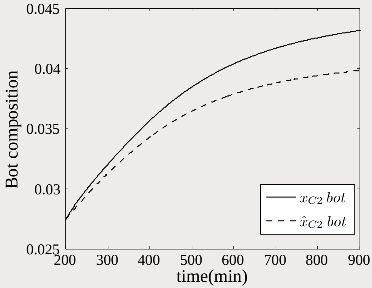


Figure: Bot estimate with -1 percent change in boilup

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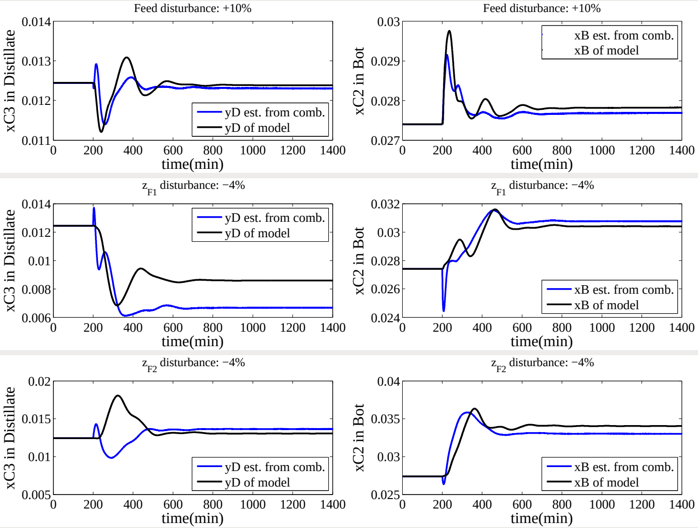
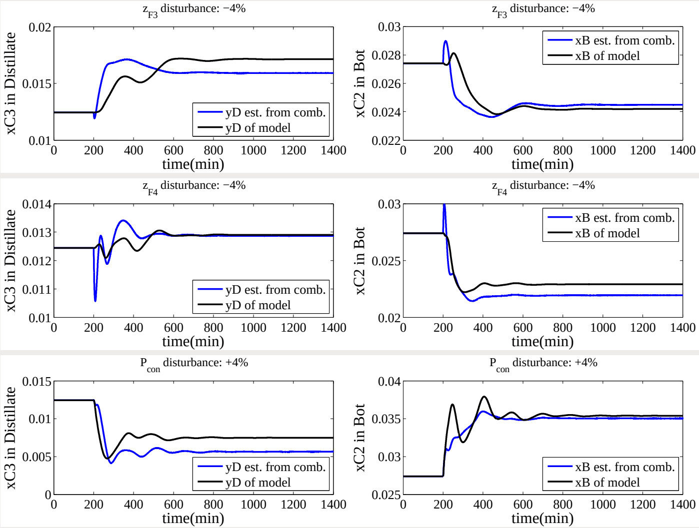
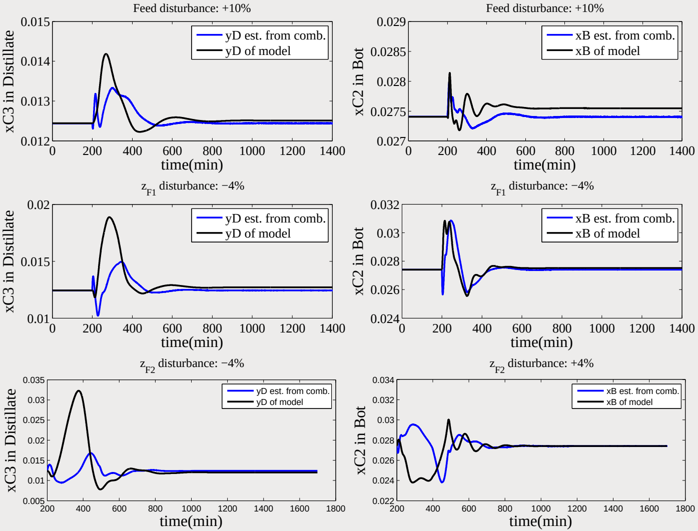
Open-loop estimation (S3)



OL estimation (S3) (contd.)



Closed-loop estimation (S4)



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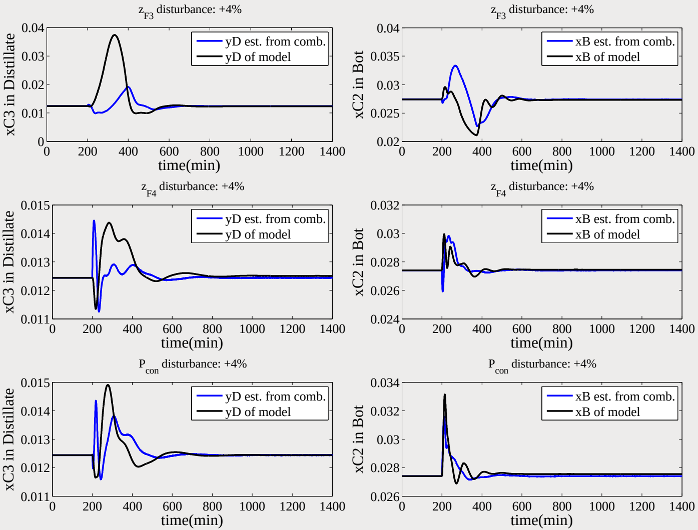
Closed-loop estimation (S4)



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Improving dynamic performance

The fast dynamics of measurements with negative contributions may lead to inverse response (RHP zero in the transfer function from u to CV)

- Cascade Control:
  Close a fast inner loop and adjust the setpoint on a time scale which is slower than the RHP-zero.
- Use of measurements from the same section of the process:
  Selected measurements are similar, then it is less likely to get RHP-zero. However, this gives a larger steady-state error.
- Filters:
  The Low-pass filters will keep the system optimal at steady state.

Example

$$\mathbf{G}_x = \begin{bmatrix} \frac{1}{3s+1} \\ \frac{1}{s+1} \end{bmatrix}$$

and the optimal matrix **H** is

$$\mathbf{H} = \begin{bmatrix} 2 & -1 \end{bmatrix}$$

the transfer function from u to ŷ is

$$\mathbf{G} = \mathbf{H}\mathbf{G}_x = \frac{2}{3s+1} - \frac{1}{s+1} = \frac{1-s}{(3s+1)(s+1)} \approx \frac{e^{-1.5s}}{3.5s+1}$$

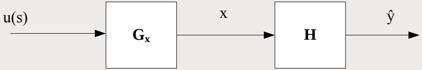
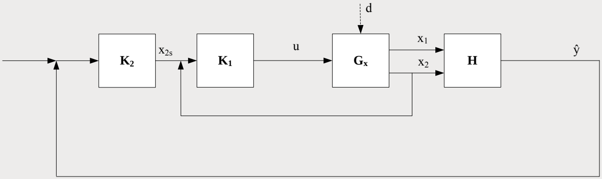


Figure: Block diagram of the estimation

Theorem

Cascade (inner-loop) can not move the zero of $\mathbf{HG}_x$

Proof.



By performing the loop calculations, the transfer function from x_{2s} to $\hat{y}$ is

$$\hat{y} = \left(h_2 + h_1 \frac{g_1}{g_2}\right) \frac{kg_2}{1 + kg_2} x_{2s} \tag{1}$$

The term $(h_1 g_1 + h_2 g_2)$, which includes the RHP zero, is unchanged.

Filtering

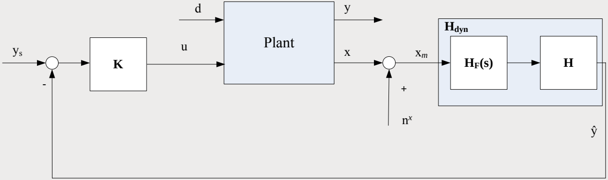


Figure: Block diagram of the estimation system including filter ($\mathbf{H_F}$)

$$\mathbf{H}_F = \begin{bmatrix} \frac{1}{\tau_{F1}s+1} & 0 \\ 0 & \frac{1}{\tau_{F2}s+1} \end{bmatrix}$$

$$\mathbf{H}_F(0) = I$$

Some Filters:

$$\mathbf{H}_{F1} = \begin{bmatrix} \frac{1}{s+1} & 0 \\ 0 & \frac{1}{3s+1} \end{bmatrix}$$

$$\mathbf{H}_{F2} = \begin{bmatrix} 1 & 0 \\ 0 & \frac{s+1}{3s+1} \end{bmatrix}$$

$$\mathbf{H}_{F3} = \begin{bmatrix} \frac{3s+1}{s+1} & 0 \\ 0 & 1 \end{bmatrix}$$

$$\mathbf{H}_{F4} = \begin{bmatrix} 1 & 0 \\ 0 & \frac{1}{3s+1} \end{bmatrix}$$

The filtered transfer function will be

$$\mathbf{H}_{dyn1}\mathbf{G}_x = \frac{1}{(3s+1)(s+1)}$$

$$\mathbf{H}_{dyn2}\mathbf{G}_x = \frac{1}{3s+1}$$

$$\mathbf{H}_{dyn3}\mathbf{G}_x = \frac{1}{s+1}$$

$$\mathbf{H}_{dyn4}\mathbf{G}_x = \frac{2s+1}{(3s+1)(s+1)}$$

Using Lead-lag compensators, we can make the response as fast as we want.

Distillation case-study

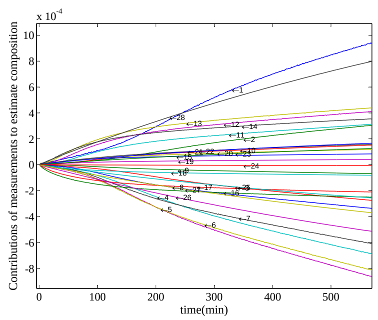


Figure: $\mathbf{HG}_x(t)$ with -1% change in boilup and constant Reflux ratio

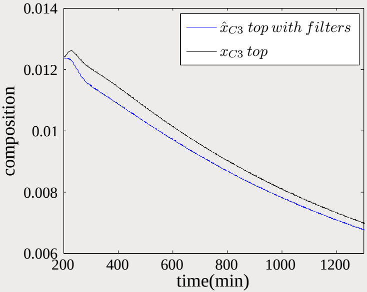


Figure: Estimated composition (tf = $\mathbf{HG}_x$) and filtered estimated composition (tf = $\mathbf{HH}_F\mathbf{G}_x$) where there are filters only on 6th, 16th and 17th measurements

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Optimizing filters

$$\min_{\mathbf{H_F}} \left\| \mathbf{H}\mathbf{H}_F \mathbf{G}_x - \mathbf{G}_{ref} \right\|$$

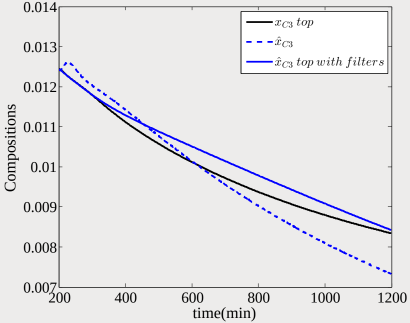

Figure: Real composition, Estimated composition (tf = $\mathbf{HG}_x$) and filtered estimated composition (tf = $\mathbf{HH}_F\mathbf{G}_x$) where filters are optimized for first 100 min. assuming $G_{ref} = G_{u \to y_1}$

Explicit solution for the filter problem

Approach:

Convert the model matching problem to Nehari problem

$$\|\mathbf{T}_1 - \mathbf{T}_2\mathbf{Q}\mathbf{T}_3\|_\infty \Rightarrow \|\mathbf{R} - \mathbf{X}\|_\infty = \|\Gamma_R\|$$

- In our case we have $\mathbf{T}_3 = \mathbf{I}$
- An optimal $\mathbf{Q}$ exists if the ranks of the two matrices $\mathbf{T}_2(j\omega)$ and $\mathbf{T}_3(j\omega)$ are constant for all $0 < \omega < \infty$[3].

[3] **Francis1987**.

Scalar-valued case

Step 1 Perform inner-outer factorization for $\mathbf{T}_2$

Step 2 $R = [A, B, C, 0]$ (A *antistable*) $+ R_2$ (*in* RH_∞)

Step 3 The controllability and observability grammians are the solutions of

$$AL_c + L_c A^T = BB^T$$
$$A^T L_o + L_o A = C^T C$$

Step 4 Having λ^2 =largest eigenvalue of $L_c L_o$ and the corresponding eigenvector (ω), define

$$f(s) := [A, \omega, C, 0]$$
$$g(s) := [-A^T, \lambda^{-1} L_o \omega, B^T, 0]$$

Step 5 $X = R - \lambda \frac{f}{g}$

Step 6 $Q = \mathbf{T}_{2o}^{-1} X$

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Example

In our example, we have the following inputs:

$$\mathbf{T}_1 = \frac{1}{0.5s+1} : \text{Desired transfer function } (\mathbf{G}_{ref})$$

$$\mathbf{T}_2 = \frac{-s+1}{3s^2+4s+1} \text{Current transfer function } (\mathbf{HG}_x)$$

Since the rank of $\mathbf{T}_2$ is not constant for all $0 \leq \omega \leq \infty$, a transfer function

$$\mathbf{V} = (s+1)^l$$

$$\mathbf{Q} = \frac{19.82s^2 + 2042s + 678.5}{s^2 + 1002s + 2000}$$

Matrix-valued case

The general algorithm to obtain **Q** is as follows

Step 1 Find a minimal realization of **R**: $\mathbf{R}(s) = [\mathbf{A}, \mathbf{B}, \mathbf{C}, 0]$

Step 2 Solve the Lyapunov equations to find controllability and observability gramians and set $\mathbf{N} = (\mathbf{I} - \mathbf{L}_o \mathbf{L}_c)^{-1}$

Step 3 Set

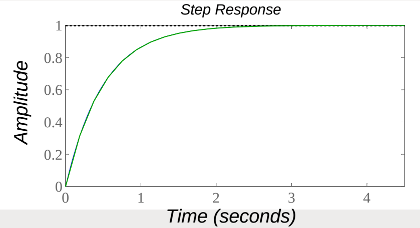
$$\mathbf{L}_1(s) = \left[\begin{array}{cc|cc} \mathbf{A} & -\mathbf{L}_c\mathbf{N}\mathbf{C}^T & \mathbf{C} & \mathbf{I} \end{array}\right]$$
$$\mathbf{L}_2(s) = \left[\begin{array}{cc|cc} \mathbf{A} & \mathbf{N}^T\mathbf{B} & \mathbf{C} & 0 \end{array}\right]$$
$$\mathbf{L}_3(s) = \left[\begin{array}{cc|cc} -\mathbf{A}^T & \mathbf{N}\mathbf{C}^T & -\mathbf{B}^T & 0 \end{array}\right]$$
$$\mathbf{L}_4(s) = \left[\begin{array}{cc|cc} -\mathbf{A}^T & \mathbf{N}\mathbf{L}_o\mathbf{B}^T & \mathbf{B}^T & \mathbf{I} \end{array}\right]$$

Step 4 Select **Y** in RH_∞ with $\|\mathbf{Y}\|_\infty \leq 1$ (for example $\mathbf{Y} = 0$) and set $\mathbf{X} = \mathbf{R} - (\mathbf{L}_1\mathbf{Y} + \mathbf{L}_2)(\mathbf{L}_3\mathbf{Y} + \mathbf{L}_4)$

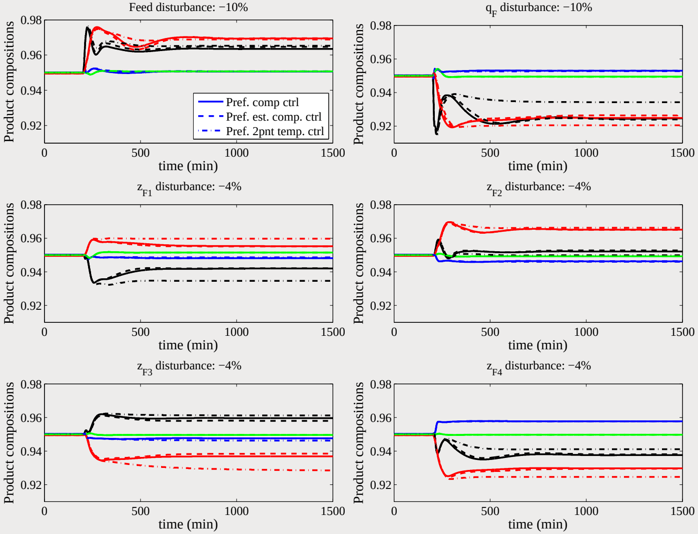
Example

$$\mathbf{T}_1 = \frac{1}{0.5s+1}, \mathbf{T}_2 = \begin{bmatrix} 2 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} \frac{1}{3s+1} \\ \frac{1}{s+1} \end{bmatrix}$$

$$\mathbf{Q} = \begin{bmatrix} \frac{0.92308(s+2)^2(s+0.67)(s+0.3333)(s-0.9431)^2(s-1)}{(s+2)^3(s+0.67)(s+0.6202)(s-0.6202)(s-0.9431)^2} \\ \frac{-1.3846(s+2)^2(s+0.67)(s+0.3333)(s-0.3333)(s-0.9431)^2}{(s+2)^3(s+0.67)(s+0.6202)(s-0.6202)(s-0.9431)^2} \end{bmatrix}$$



Kaibel column control



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Concluding Remarks

- Kaibel distillation columns can save operational costs if operated optimally
- V_{min} diagrams are very useful tools for design, analysis and operation of columns
- It's important to control the key component flows out of the prefractionator
- Combination of measurement will result in lower estimation error compared to using single measurements
- It's possible to have dynamic issues in the estimators which stems from combining measurements from different sections
- Dynamic issues can be alleviated by cascade control, combining subset of measurements or applying filters

Thanks for your attention