Data Article

Differential temperature control in heat-integrated pressure-swing distillation for separating azeotropes to deal with operating pressure fluctuations: Basic and explanatory data

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A B S T R A C T

This data article contains basic and explanatory data of “Differential temperature control in heat-integrated pressure-swing distillation for separating azeotropes to deal with operating pressure fluctuations” [1], including thermodynamic models, vapor-liquid equilibrium diagrams, steady-state flowsheets, temperature profiles of columns, description and setpoint units of the abbreviation of inventory control loops, description of control loops of control flowsheet with DTC, control flowsheets of PCTC and DTC, temperature and composition tuning constants, faceplates and flowsheet equations, dynamic performances and integral absolute errors. It also contains other important information.

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**Specifications Table**

| Subject                     | Chemical Engineering (General) |
|-----------------------------|--------------------------------|
| Specific subject area       | Control of distillation processes for separating azeotropes |
| Type of data                | Table                          |
|                             | Image                          |
|                             | Graph                          |
|                             | Figure                         |
| How data were acquired      | Aspen Plus and Aspen Dynamics   |
| Data format                 | Raw                            |
|                             | Processed                      |
| Parameters for data collection | To make an overall assessment, the selected cases covered different important elements of HI-PSD, including minimum/maximum-boiling azeotropes, PHI/FHI-PSD, LPC->HPC/HPC->LPC sequence and conventional/entrainer-assisted PSD. |
| Description of data collection | The data were collected by simulations with Aspen Plus and Aspen Dynamics. |
| Data source location        |                                |

**Value of the Data**

- The data provide the insights on simulations of steady-state design and dynamic control of the investigated processes, including full information of thermodynamic models, vapor-liquid equilibrium diagrams, steady-state flowsheets, temperature profiles of columns, description and setpoint units of the abbreviation of inventory control loops, description of control loops of control flowsheet with DTC, control flowsheets of PCTC and DTC, temperature and composition tuning constants, faceplates and flowsheet equations, dynamic performances and integral absolute errors.
- The data will be useful for the related researchers to understand how the simulations are established.
- The data provide a baseline for exploring other potential aspects of DTC in future.

**1. Data description**

Table 1 shows thermodynamic models of all the mixtures.

Table 2 shows the description and setpoint units of the abbreviation of inventory control loops of the control faceplate.
Table 1
Thermodynamic models of all the mixtures.

| mixture                        | thermodynamic model\(^a\) |
|-------------------------------|---------------------------|
| toluene/ethanol               | NRTL                     |
| acetone/methanol              | UNIQUAC                  |
| methanol/chloroform           | NRTL                     |
| ethanol/ethyl acetate         | UNIQUAC                  |
| toluene/pyridine              | NRTL                     |
| methanol/trimethoxysilane     | UNIFAC                   |

\(^a\) The default parameters for the chosen thermodynamic models are used.

Table 2
The description and setpoint units of the abbreviation of inventory control loops of the control faceplate.

| abbreviation | description\(^a\)                                    | unit of set point       |
|--------------|-------------------------------------------------------|-------------------------|
| FC           | fresh feed flow rate controller                       | kmol/h or kg/h          |
| DC (if it has)| 1st column distillate flow rate controller            | kmol/h                  |
| D2C (if it has)| 2nd column distillate flow rate controller            | kmol/h                  |
| B1C (if it has)| 1st column bottom flow rate controller                | kmol/h                  |
| B2C (if it has)| 2nd column bottom flow rate controller                | kmol/h                  |
| PC1          | 1st column pressure controller                        | bar                     |
| PC2          | 2nd column pressure controller                        | bar                     |
| LC1          | 1st column reflux drum level controller                | m                      |
| LC2          | 1st column sump level controller                       | m                      |
| LC3          | 2nd column reflux drum level controller                | m                      |
| LC4          | 2nd column sump level controller                       | m                      |

\(^a\) The 1st column represents the left column in the process flowsheet and the 2nd column represents the right column in the process flowsheet.

Table 3
Controller tuning constants of the proposed control structure with DTC of PHI-PSD for separating the toluene/ethanol mixture.

| Controlled Variable | Manipulated Variable | Gain \(K_C\) (\%/%) | Integral Time \(\tau_I\) (min) | Derivative Time \(\tau_D\) (min) |
|---------------------|----------------------|----------------------|-------------------------------|-------------------------------|
| T21                 | \(Q_{Aux}\)          | 37.45                | 7.92                          | –                             |
| CC                  | T21                  | 29.35                | 75.24                         | –                             |
| DT                  | \(Q_{R2}\)           | 0.44                 | 7.92                          | –                             |

Table 4
Controller tuning constants of the proposed control structure with PCTC of PHI-PSD for separating the toluene/ethanol mixture.

| Controlled Variable | Manipulated Variable | Gain \(K_C\) (\%/%) | Integral Time \(\tau_I\) (min) | Derivative Time \(\tau_D\) (min) |
|---------------------|----------------------|----------------------|-------------------------------|-------------------------------|
| T21                 | \(Q_{Aux}\)          | 37.45                | 7.92                          | –                             |
| CC                  | T21                  | 29.35                | 75.24                         | –                             |
| T20                 | \(Q_{R2}\)           | 1.39                 | 10.56                         | –                             |

Table 3 shows controller tuning constants of the proposed control structure with DTC of PHI-PSD for separating the toluene/ethanol mixture.

Table 4 shows controller tuning constants of the proposed control structure with PCTC of PHI-PSD for separating the toluene/ethanol mixture.

Table 5 shows controller tuning constants of the proposed control structure with DTC of PHI-PSD for separating the acetone/methanol mixture.

Table 6 shows controller tuning constants of the proposed control structure with PCTC of PHI-PSD for separating the acetone/methanol mixture.

Table 7 shows controller tuning constants of the proposed control structure with DTC of PHI-PSD for separating the toluene/ethanol mixture.
Table 5
Controller tuning constants of the proposed control structure with DTC of PHI-PSD for separating the acetone/methanol mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%) | Integral Time $\tau_1$ (min) | Derivative Time $\tau_D$ (min) |
|---------------------|----------------------|----------------|-----------------------------|-------------------------------|
| T47                 | $Q_{aux}$            | 11.94          | 7.92                        | –                             |
| DT                  | $Q_{x2}$             | 0.80           | 9.24                        | –                             |

Table 6
Controller tuning constants of the proposed control structure with PCTC of PHI-PSD for separating the acetone/methanol mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%) | Integral Time $\tau_1$ (min) | Derivative Time $\tau_D$ (min) |
|---------------------|----------------------|----------------|-----------------------------|-------------------------------|
| T47                 | $Q_{aux}$            | 11.94          | 7.92                        | –                             |
| T55                 | $Q_{x2}$             | 30.95          | 9.24                        | –                             |

Table 7
Controller tuning constants of the proposed control structure with DTC of FHI-PSD for separating the toluene/ethanol mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%) | Integral Time $\tau_1$ (min) | Derivative Time $\tau_D$ (min) |
|---------------------|----------------------|----------------|-----------------------------|-------------------------------|
| T11                 | $RR_1$               | 53.45          | 25.08                       | –                             |
| DT                  | $Q_{x2}$             | 0.45           | 7.92                        | –                             |

Table 8
Controller tuning constants of the proposed control structure with PCTC of FHI-PSD for separating the toluene/ethanol mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%) | Integral Time $\tau_1$ (min) | Derivative Time $\tau_D$ (min) |
|---------------------|----------------------|----------------|-----------------------------|-------------------------------|
| T11                 | $RR_1$               | 53.45          | 25.08                       | –                             |
| T19                 | $Q_{x2}$             | 1.39           | 10.56                       | –                             |

Table 9
Controller tuning constants of the proposed control structure with DTC of FHI-PSD for separating the methanol/chloroform mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%) | Integral Time $\tau_1$ (min) | Derivative Time $\tau_D$ (min) |
|---------------------|----------------------|----------------|-----------------------------|-------------------------------|
| T19                 | $RR_1$               | 7.22           | 25.08                       | –                             |
| DT                  | $Q_{x2}$             | 0.35           | 7.92                        | –                             |

Table 10
Controller tuning constants of the proposed control structure with PCTC of FHI-PSD for separating the methanol/chloroform mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%) | Integral Time $\tau_1$ (min) | Derivative Time $\tau_D$ (min) |
|---------------------|----------------------|----------------|-----------------------------|-------------------------------|
| T19                 | $RR_1$               | 7.22           | 25.08                       | –                             |
| T23                 | $Q_{x2}$             | 2.47           | 9.24                        | –                             |

Table 8 shows controller tuning constants of the proposed control structure with PCTC of FHI-PSD for separating the toluene/ethanol mixture.

Table 9 shows controller tuning constants of the proposed control structure with DTC of FHI-PSD for separating the methanol/chloroform mixture.

Table 10 shows controller tuning constants of the proposed control structure with PCTC of FHI-PSD for separating the toluene/ethanol mixture.

Table 11 shows controller tuning constants of the proposed control structure with DTC of FHI-PSD for separating the ethyl acetate/ethanol mixture.
Table 11
Controller tuning constants of the proposed control structure with DTC of FHI-PSD for separating the ethyl acetate/ethanol mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%/%) | Integral Time $\tau_1$ (min) | Derivative Time $\tau_0$ (min) |
|---------------------|----------------------|------------------|-----------------------------|-------------------------------|
| T25                 | RR_2                 | 3.96             | 27.72                       | –                             |
| DT                  | Q_{R1}               | 0.39             | 10.56                       | –                             |

Table 12
Controller tuning constants of the proposed control structure with PCTC of FHI-PSD for separating the ethyl acetate/ethanol mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%/%) | Integral Time $\tau_1$ (min) | Derivative Time $\tau_0$ (min) |
|---------------------|----------------------|------------------|-----------------------------|-------------------------------|
| T25                 | RR_2                 | 3.96             | 27.72                       | –                             |
| T50                 | Q_{R1}               | 9.01             | 9.24                        | –                             |

Table 13
Controller tuning constants of the proposed control structure with DTC of EA-PSD for separating the toluene/pyridine mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%/%) | Integral Time $\tau_1$ (min) | Derivative Time $\tau_0$ (min) |
|---------------------|----------------------|------------------|-----------------------------|-------------------------------|
| T16                 | Q_{Aux}              | 28.30            | 10.56                       | –                             |
| DT                  | Q_{R2}               | 0.53             | 7.92                        | –                             |
| CC                  | DF                   | 50.73            | 432.96                      | –                             |

Table 14
Controller tuning constants of the proposed control structure with PCTC of EA-PSD for separating the toluene/pyridine mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%/%) | Integral Time $\tau_1$ (min) | Derivative Time $\tau_0$ (min) |
|---------------------|----------------------|------------------|-----------------------------|-------------------------------|
| T16                 | Q_{Aux}              | 28.30            | 10.56                       | –                             |
| T18                 | Q_{R2}               | 7.69             | 9.24                        | –                             |
| CC                  | DF                   | 50.73            | 432.96                      | –                             |

Table 15
Controller tuning constants of the proposed control structure with DTC of the HPC->LPC of PHI-PSD for separating the methanol/trimethoxysilane mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%/%) | Integral Time $\tau_1$ (min) | Derivative Time $\tau_0$ (min) |
|---------------------|----------------------|------------------|-----------------------------|-------------------------------|
| DT                  | RR_3                 | 0.23             | 11.88                       | –                             |
| T5                  | 1/RR_2               | 14.13            | 50.16                       | –                             |

Table 12 shows controller tuning constants of the proposed control structure with PCTC of FHI-PSD for separating the ethyl acetate/ethanol mixture.

Table 13 shows controller tuning constants of the proposed control structure with DTC of EA-PSD for separating the toluene/pyridine mixture.

Table 14 shows controller tuning constants of the proposed control structure with PCTC of EA-PSD for separating the toluene/pyridine mixture.

Table 15 shows controller tuning constants of the proposed control structure with DTC of the HPC->LPC of PHI-PSD for separating the methanol/trimethoxysilane mixture.
Table 16
Controller tuning constants of the proposed control structure with PCTC of the HPC–>LPC of PHI-PSD for separating the methanol/trimethoxysilane mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%/%) | Integral Time $\tau_I$ (min) | Derivative Time $\tau_D$ (min) |
|---------------------|----------------------|------------------|-----------------------------|-------------------------------|
| T3                  | $RR_1$               | 2.23             | 13.20                       | –                             |
| T5                  | $1/RR_2$             | 13.96            | 50.16                       | –                             |

Table 17
Controller tuning constants of the proposed control structure with DTC of the LPC–>HPC of PHI-PSD for separating the methanol/trimethoxysilane mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%/%) | Integral Time $\tau_I$ (min) | Derivative Time $\tau_D$ (min) |
|---------------------|----------------------|------------------|-----------------------------|-------------------------------|
| DT                  | $RR_1$               | 1.99             | 11.88                       | –                             |
| CC                  | DT                   | 14.88            | 34.32                       |                                |
| DT2                 | $1/RR_2$             | 0.33             | 50.16                       | –                             |

Table 18
Controller tuning constants of the proposed control structure with PCTC of the LPC–>HPC of PHI-PSD for separating the methanol/trimethoxysilane mixture.

| Controlled Variable | Manipulated Variable | Gain $K_C$ (%/%) | Integral Time $\tau_I$ (min) | Derivative Time $\tau_D$ (min) |
|---------------------|----------------------|------------------|-----------------------------|-------------------------------|
| DT                  | $RR_1$               | 1.99             | 11.88                       | –                             |
| CC                  | DT                   | 14.69            | 34.32                       |                                |
| T3                  | $1/RR_2$             | 3.16             | 48.84                       | –                             |

Fig. 1. T-xy diagram of toluene/ethanol.

Table 19 shows Comparison of IAE of important variables between PCTC and DTC under large feed disturbances.

Table 20 shows ratio of reboiler duty to feed flow rate.

Fig. 1 shows T-xy diagram of toluene/ethanol.

Fig. 2 shows flowsheet of PHI-PSD for separating the toluene/ethanol mixture.

Fig. 3 shows temperature profiles of PHI-PSD for separating the toluene/ethanol mixture: (a) the LPC and (b) the HPC.

Fig. 4 shows the proposed control structure with DTC of PHI-PSD for separating the toluene/ethanol mixture: (a) control faceplate and (b) flowsheet equations.

Fig. 5 shows the proposed control structure with PCTC of PHI-PSD for separating the toluene/ethanol mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.
| Process       | Control type | Item            | Unit          | F+ 20 % | F− 20 % | C+ 20 % | C− 20 % | Sum  |
|---------------|--------------|-----------------|---------------|---------|---------|---------|---------|------|
| toluene       | PCTC         | ethanol         | 10⁻⁴ kg/kg   | 4.26    | 0.74*   | 0.27    | 5.28    |      |
| and           |              | toluene         | 10⁻⁴ kg/kg   | 53.12   | 8.14*   | 7.06    | 68.32   |      |
| ethanol       |              | QR (HPC)       | kW           | 6236.7  | 2310.7* | 71.3    | 8618.8  |      |
| Min Azeotrope | T 20         | °C              | -            | 349.3   | 122.6*  | 29.7    | 501.6   |      |
| PHI           | DTC          | ethanol         | 10⁻⁴ kg/kg   | 4.27    | 0.74*   | 0.27    | 5.28    |      |
| LPC→HPC       |              | toluene         | 10⁻⁴ kg/kg   | 52.05   | 5.23*   | 10.83   | 68.11   |      |
| acetone       | PCTC         | methanol        | 10⁻³ mol/mol | 41.22   | 1.12    | -       | 42.34   |      |
| and           |              | acetone         | 10⁻³ mol/mol | 24.55   | 30.06   | -       | 54.61   |      |
| methanol      |              | QR (HPC)       | kW           | 28,928.4 | 18.540.1 | 14.47   | 47.468.4 |      |
| Min Azeotrope | T 55         | °C              | -            | 210.6   | 146.6   | -       | 357.2   |      |
| PHI           | DTC          | methanol        | 10⁻³ mol/mol | 41.58   | 1.13    | -       | 42.71   |      |
| LPC→HPC       |              | acetone         | 10⁻³ mol/mol | 75.27   | 32.34   | -       | 107.61  |      |
| toluene       | PCTC         | ethanol         | 10⁻³ kg/kg   | 22.58   | 19.00*  | 133.00  | 174.58  |      |
| and           |              | toluene         | 10⁻³ kg/kg   | 3.99    | 0.78*   | 1.39    | 6.16    |      |
| Min Azeotrope | T 19         | °C              | -            | 273.4   | 106.9*  | 108.8   | 489.11  |      |
| PHI           | DTC          | ethanol         | 10⁻³ kg/kg   | 22.59   | 19.00*  | 132.72  | 178.37  |      |
| LPC→HPC       |              | toluene         | 10⁻³ kg/kg   | 3.68    | 0.42*   | 0.34    | 4.44    |      |
| methanol      | PCTC         | methanol        | 10⁻³ mol/mol | -       | 29.77   | 26.68   | 56.46   |      |
| and           |              | chloroform      | 10⁻³ mol/mol | -       | 11.12   | 4.02    | 15.14   |      |
| chloroform    |              | QR (HPC)       | kW           | -       | 792.2   | 3019.2  | 3811.4  |      |
| Min Azeotrope | T 23         | °C              | -            | -       | 18.9    | 7.11    | 90.0    |      |
| PHI           | DTC          | methanol        | 10⁻³ mol/mol | -       | 29.83   | 26.63   | 56.46   |      |
| LPC→HPC       |              | chloroform      | 10⁻³ mol/mol | -       | 15.28   | 3.52    | 18.80   |      |
| ethanol       | PCTC         | ethyl acetate   | 10⁻³ mol/mol | 15.14   | 15.37   | 15.42   | 15.26   | 61.20 |
| and           |              | ethyl acetate   | 10⁻³ mol/mol | 53.69   | 53.45   | 24.47   | 30.04   | 143.59 |
| Min Azeotrope | T 50         | °C              | -            | 223.0   | 195.4   | 38.8    | 47.66   | 504.7 |
| PHI           | DTC          | ethyl acetate   | 10⁻³ mol/mol | 11.82   | 17.32   | 18.64   | 16.47   | 64.24 |
| HPC→LPC       |              | ethyl acetate   | 10⁻³ mol/mol | 53.12   | 36.96   | 24.63   | 30.11   | 144.82 |
| toluene       | PCTC         | pyridine        | 10⁻³ mol/mol | 4.51*   | 6.96    | 1.16    | 11.39   |      |
| and           |              | pyridine        | 10⁻³ mol/mol | 6.42*   | 4.20    | 5.72    | 5.43    | 20.87 |
| pyridine      |              | QR (HPC)       | kW           | 12,557.5* | 16,806.6 | 800.2   | 808.8   | 30,973.0 |
| Min Azeotrope | T 18         | °C              | -            | 200.8*  | 249.1   | 12.0    | 12.2    | 474.2 |
| EA            | DTC          | pyridine        | 10⁻³ mol/mol | 4.95*   | 6.96    | 1.16    | 11.43   |      |
| and           |              | pyridine        | 10⁻³ mol/mol | 8.22*   | 4.28    | 5.68    | 4.49    | 22.67 |
| methanol      | PCTC         | methanol        | 10⁻² mol/mol | 14.40   | 4.98    | 17.76   | 12.97   | 50.11 |
| and           |              | trimethoxysilane| 10⁻² mol/mol | 11.92   | 9.50    | 8.02    | 11.01   | 40.45 |
| trimethoxysilane|              | RR1             | –            | 2.21    | 8.91    | 33.72   | 62.26   | 107.10 |
| Max Azeotrope | T 3          | °C              | -            | 548.2   | 273.4   | 315.6   | 607.0   | 1744.2 |
| PHI           | DTC          | methanol        | 10⁻² mol/mol | 7.48    | 5.47    | 18.55   | 12.38   | 43.87 |
| HPC→LPC       |              | trimethoxysilane| 10⁻² mol/mol | 12.30   | 9.52    | 8.05    | 11.21   | 41.07 |
| methanol      | PCTC         | methanol        | 10⁻² mol/mol | 1.21    | 1.77    | 6.25    | 10.11   | 19.35 |
| and           |              | trimethoxysilane| 10⁻² mol/mol | 16.20   | 8.41    | 27.54   | 13.50   | 65.65 |
| trimethoxysilane|              | RR1             | –            | 0.17    | 0.24    | 0.59    | 0.37    | 0.84 |
| Max Azeotrope | T 3          | °C              | -            | 539.3   | 312.8   | 771.1   | 376.2   | 2053.8 |
| PHI           | DTC          | methanol        | 10⁻² mol/mol | 7.98    | 9.09    | 9.53    | 11.45   | 38.05 |
| LPC→HPC       |              | trimethoxysilane| 10⁻² mol/mol | 0.85    | 0.67    | 0.59    | 0.37    | 2.49 |
| methanol      | PCTC         | methanol        | 10⁻² mol/mol | 0.26    | 0.24    | 0.52    | 0.54    | 1.05 |
| and           |              | trimethoxysilane| 10⁻² mol/mol | 3.82    | 7.12    | 5.32    | 6.42    | 22.68 |

*These values are the results of the corresponding 15% feed disturbances.
Table 20

| Process                                      | Ratio  | Unit Reboiler duty | Feed flow rate |
|----------------------------------------------|--------|--------------------|---------------|
| PHI-PSD for separating the toluene/ethanol mixture | 0.001404 | MMkcal/hr         | kg/hr         |
| PHI-PSD for separating the acetone/methanol mixture | 0.047812 | MMkcal/hr         | kmol/hr       |
| PHI-PSD for separating the toluene/ethanol mixture | 0.001565 | MMkcal/hr         | kg/hr         |
| PHI-PSD for separating the acetone/methanol mixture | 0.068078 | MMkcal/hr         | kmol/hr       |
| FHI-PSD for separating the methanol/chloroform mixture | 0.106945 | MMkcal/hr         | kmol/hr       |
| PHI-PSD for separating the methanol/trimethoxysilane mixture | 0.100637 | MMkcal/hr         | kmol/hr       |

Fig. 2. Flowsheet of PHI-PSD for separating the toluene/ethanol mixture.

Fig. 6 shows dynamic performances of PHI-PSD for separating the toluene/ethanol mixture under large feed disturbances.

Fig. 7 shows T-xy diagram of acetone/methanol.

Fig. 8 shows flowsheet of PHI-PSD for separating the acetone/methanol mixture.

Fig. 9 shows temperature profiles PHI-PSD for separating the acetone/methanol mixture: (a) the LPC and (b) the HPC.

Fig. 10 shows differential temperature of PHI-PSD with DTC for separating the acetone/methanol mixture.

Fig. 11 shows the proposed control structure with DTC of PHI-PSD for separating the acetone/methanol mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.

Fig. 12 shows the proposed control structure with PCTC of PHI-PSD for separating the acetone/methanol mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.

Fig. 13 shows dynamic performances of PHI-PSD for separating the acetone/methanol mixture under ±10% feed disturbances.

Fig. 14 shows dynamic performances of PHI-PSD for separating the acetone/methanol mixture under large feed disturbances.

Fig. 15 shows flowsheet of FHI-PSD for separating the toluene/ethanol mixture.

Fig. 16 shows temperature profiles of FHI-PSD for separating the toluene/ethanol mixture: (a) the LPC and (b) the HPC.
Fig. 3. Temperature profiles of PHI-PSD for separating the toluene/ethanol mixture: (a) the LPC and (b) the HPC.

Fig. 4. The proposed control structure with DTC of PHI-PSD for separating the toluene/ethanol mixture: (a) control faceplate and (b) flowsheet equations.

Fig. 17 shows the proposed control structure with DTC of FHI-PSD for separating the toluene/ethanol mixture: (a) control faceplate and (b) flowsheet equations.

Fig. 18 shows the proposed control structure with PCTC of FHI-PSD for separating the toluene/ethanol mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.

Fig. 19 shows dynamic performances of FHI-PSD for separating the toluene/ethanol mixture under large feed disturbances.

Fig. 20 shows T-xy diagram of methanol/chloroform.

Fig. 21 shows flowsheet of FHI-PSD for separating the methanol/chloroform mixture.
Fig. 22 shows temperature profiles of FHI-PSD for separating the methanol/chloroform mixture: (a) the LPC and (b) the HPC.

Fig. 23 shows differential temperature of FHI-PSD with DTC for separating the methanol/chloroform mixture.

Fig. 24 shows the proposed control structure with DTC of FHI-PSD for separating the methanol/chloroform mixture: (a) control faceplate and (b) flowsheet equations.
Fig. 6. Dynamic performances of PHI-PSD for separating the toluene/ethanol mixture under large feed disturbances.
Fig. 7. T-xy diagram of acetone/methanol.

Fig. 8. Flowsheet of PHI-PSD for separating the acetone/methanol mixture.

Fig. 9. Temperature profiles PHI-PSD for separating the acetone/methanol mixture: (a) the LPC and (b) the HPC.
Fig. 10. Differential temperature of PHI-PSD with DTC for separating the acetone/methanol mixture.

Fig. 25 shows the proposed control structure with PCTC of FHI-PSD for separating the methanol/chloroform mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.

Fig. 26 shows dynamic performances of FHI-PSD for separating methanol/chloroform mixture under ±10% feed disturbances.

Fig. 27 shows dynamic performances of FHI-PSD for separating methanol/chloroform mixture under large feed disturbances.

Fig. 28 shows T-xy diagram of ethanol/ethyl acetate at 101.3 kPa.

Fig. 29 shows flowsheet of FHI-PSD for separating the ethyl acetate/ethanol mixture.

Fig. 30 shows temperature profiles of FHI-PSD for separating the ethyl acetate/ethanol mixture: (a) the HPC and (b) the LPC.

Fig. 31 shows the proposed control structure with DTC of FHI-PSD for separating the ethyl acetate/ethanol mixture: (a) control faceplate and (b) flowsheet equations.

Fig. 32 shows the proposed control structure with PCTC of FHI-PSD for separating the ethyl acetate/ethanol mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.

Fig. 33 shows dynamic performances of FHI-PSD for separating the ethanol/ethyl acetate mixture under large feed disturbances.

Fig. 34 shows T-xy diagram of toluene/pyridine at 101.3 kPa.

Fig. 35 shows flowsheet of EA-PSD for separating the toluene/pyridine mixture.

Fig. 36 shows temperature profiles of EA-PSD for separating the toluene/pyridine mixture: (a) the LPC and (b) the HPC.

Fig. 37 shows the proposed control structure with DTC of EA-PSD for separating the toluene/pyridine mixture: (a) control faceplate and (b) flowsheet equations.

Fig. 38 shows the proposed control structure with PCTC of EA-PSD for separating the toluene/pyridine mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.

Fig. 39 shows dynamic performances of EA-PSD for separating the toluene/pyridine mixture under large feed disturbances.

Fig. 40 shows T-xy diagram of methanol/trimethoxysilane.

Fig. 41 shows flowsheet of the HPC->LPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture.

Fig. 42 shows temperature profiles of the HPC->LPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture: (a) the HPC and (b) the LPC.

Fig. 43 shows the proposed control structure with DTC of the HPC->LPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture: (a) control faceplate and (b) flowsheet equations.
Fig. 11. The proposed control structure with DTC of PHI-PSD for separating the acetone/methanol mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.

Fig. 44 shows the proposed control structure with PCTC of the HPC->LPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.

Fig. 45 shows dynamic performances of the HPC->LPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture under large feed disturbances.

Fig. 46 shows flowsheet of the LPC->HPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture.
Fig. 12. The proposed control structure with PCTC of PHI-PSD for separating the acetone/methanol mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.

Fig. 47 shows temperature profiles of the LPC->HPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture: (a) the LPC and (b) the HPC.

Fig. 48 shows the proposed control structure with DTC of the LPC->HPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture: (a) control faceplate and (b) flowsheet equations.

Fig. 49 shows the proposed control structure with PCTC of the LPC->HPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.
Fig. 13. Dynamic performances of PHI-PSD for separating the acetone/methanol mixture under ±10% feed disturbances.
Fig. 14. Dynamic performances of PHI-PSD for separating the acetone/methanol mixture under large feed disturbances.
Fig. 15. Flowsheet of FHI-PSD for separating the toluene/ethanol mixture.

Fig. 16. Temperature profiles of FHI-PSD for separating the toluene/ethanol mixture: (a) the LPC and (b) the HPC.

Fig. 50 shows dynamic performances of the LPC->HPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture under large feed disturbances.

Section 1 Common information
The column bases and reflux drums are sized to provide 10 min of liquid holdup when half full. All the controllers are PI controllers: the tuning constants of pressure controllers are the same with default values with a gain of 20 and an integral time of 12 min; the tuning constants of flow controllers are the conventional values with a gain of 0.5 and an integral time of 0.3 min; the tuning constants of level controllers are the conventional values with a gain of 2 and an integral time of 9999 min. The temperature and composition controllers are tuned by the Tyreus-Luyben method after relay-feedback tests. The dead times of the temperature controller and composition controller are 1 min and 3 min, respectively.

Section 2 PHI-PSD for separating the toluene/ethanol mixture (LPC->HPC sequence)
The control loops of the proposed control structure with DTC of PHI-PSD for separating the toluene/ethanol mixture are listed as below:

1. The fresh feed is flow controlled.
2. The operating pressure of the LPC is controlled by manipulating the heat removal rate of the condenser.
Section 3 PHI-PSD for separating the acetone/methanol mixture (LPC->HPC sequence)

In the LPC, the 47th-stage temperature (T47) is selected to be controlled. In the HPC, the 55th-stage temperature (T55) is selected to be controlled for PCTC, while the difference between the bottom temperature and T55 is controlled for DTC. The diagram of operating pressure vs. differential temperature is shown in Fig. 10.

The control loops of the proposed control structure with DTC of PHI-PSD for separating the acetone/methanol mixture are listed as below:

(1) The fresh feed is flow controlled.
(2) The operating pressure of the LPC is controlled by manipulating the heat removal rate of the condenser.
(3) The reflux ratio of the HPC is fixed.
(4) The reflux ratio of the LPC is fixed.

(3) The reflux ratio of the HPC is fixed.
(4) The reflux ratio of the LPC is fixed.
(5) The reflux drum level of the HPC is controlled by manipulating the distillate flow rate.
(6) The reflux drum level of the LPC is controlled by manipulating the distillate flow rate.
(7) The base level of the HPC is controlled by manipulating the bottom flow rate.
(8) The base level of the LPC is controlled by manipulating the bottom flow rate.
(9) Composition/temperature cascade control is used to control the 21st-stage temperature of the LPC (T21). The ethanol product purity is measured as the input of the composition controller, whose output is the setpoint of the temperature controller. The temperature controller is “on cascade”. T21 is controlled by manipulating the heat removal rate of the auxiliary reboiler.

(10) The differential temperature (DT) of the bottom and the 20th stage of the HPC is controlled by manipulating the ratio of the reboiler duty of the HPC to the feed flow rate.
(5) The reflux drum level of the HPC is controlled by manipulating the distillate flow rate.
(6) The reflux drum level of the LPC is controlled by manipulating the distillate flow rate.
(7) The base level of the HPC is controlled by manipulating the bottom flow rate.
(8) The base level of the LPC is controlled by manipulating the bottom flow rate.
(9) The 47th-stage temperature of the LPC (T47) is controlled by manipulating the heat removal rate of the auxiliary reboiler.
(10) The differential temperature (DT) of the bottom and the 55th stage of the HPC is controlled by manipulating the ratio of the reboiler duty of the HPC to the feed flow rate.

Fig. 18. The proposed control structure with PCTC of FHI-PSD for separating the toluene/ethanol mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.
Fig. 19. Dynamic performances of FHI-PSD for separating the toluene/ethanol mixture under large feed disturbances.
Fig. 20. T-xy diagram of methanol/chloroform.

Fig. 21. Flowsheet of FHI-PSD for separating the methanol/chloroform mixture.

Fig. 22. Temperature profiles of FHI-PSD for separating the methanol/chloroform mixture: (a) the LPC and (b) the HPC.
Section 4 FHI-PSD for separating the toluene/ethanol mixture (LPC->HPC sequence)

The control loops of the proposed control structure with DTC of FHI-PSD for separating the toluene/ethanol mixture are listed as below:

1. The fresh feed is flow controlled.
2. The operating pressure of the LPC is controlled by manipulating the heat removal rate of the condenser.
3. The reflux ratio of the HPC is fixed.
4. The reflux drum level of the HPC is controlled by manipulating the distillate flow rate.
5. The reflux drum level of the LPC is controlled by manipulating the distillate flow rate.
6. The base level of the HPC is controlled by manipulating the bottom flow rate.
7. The base level of the LPC is controlled by manipulating the bottom flow rate.
8. The 11th-stage temperature of the LPC (T11) is controlled by manipulating the reflux ratio.
9. The differential temperature (DT) of the bottom and the 19th stage of the HPC is controlled by manipulating the ratio of the reboiler duty of the HPC to the feed flow rate.

Section 5 FHI-PSD for separating the methanol/chloroform mixture (LPC->HPC sequence)

In the LPC, the 19th-stage temperature (T19) is selected to be controlled. In the HPC, the 23rd-stage temperature (T23) is selected to be controlled for PCTC, while the difference between the bottom temperature and T23 is controlled for DTC. The diagram of operating pressure vs. differential temperature is shown in Fig. 23.

The control loops of the proposed control structure with DTC of FHI-PSD for separating the methanol/chloroform mixture are listed as below:

1. The fresh feed is flow controlled.
2. The operating pressure of the LPC is controlled by manipulating the heat removal rate of the condenser.
3. The reflux ratio of the HPC is fixed.
4. The reflux drum level of the HPC is controlled by manipulating the distillate flow rate.
5. The reflux drum level of the LPC is controlled by manipulating the distillate flow rate.
6. The base level of the HPC is controlled by manipulating the bottom flow rate.
7. The base level of the LPC is controlled by manipulating the bottom flow rate.
8. The 19th-stage temperature of the LPC (T19) is controlled by manipulating the reflux ratio.
9. The differential temperature (DT) of the bottom and the 23rd stage of the HPC is controlled by manipulating the ratio of the reboiler duty of the HPC to the feed flow rate.
Fig. 24. The proposed control structure with DTC of FHI-PSD for separating the methanol/chloroform mixture: (a) control faceplate and (b) flowsheet equations.

Section 6. FHI-PSD for separating the ethanol/ethyl acetate mixture (HPC->LPC sequence)

The control loops of the proposed control structure with DTC of FHI-PSD for separating the ethyl acetate/ethanol mixture are listed as below:

1. The fresh feed is flow controlled.
2. The operating pressure of the LPC is controlled by manipulating the heat removal rate of the condenser.
3. The reflux ratio of the HPC is fixed.
4. The reflux drum level of the HPC is controlled by manipulating the distillate flow rate.
Fig. 25. The proposed control structure with PCTC of FHI-PSD for separating the methanol/chloroform mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.

(5) The reflux drum level of the LPC is controlled by manipulating the distillate flow rate.
(6) The base level of the HPC is controlled by manipulating the bottom flow rate.
(7) The base level of the LPC is controlled by manipulating the bottom flow rate.
(8) The 25th-stage temperature of the LPC (T25) is controlled by manipulating the reflux ratio.
(9) The differential temperature (DT) of the bottom and the 50th stage of the HPC is controlled by manipulating the ratio of the reboiler duty of the HPC to the feed flow rate.
Fig. 26. Dynamic performances of FHI-PSD for separating methanol/chloroform mixture under ±10% feed disturbances.
The control loops of the proposed control structure with DTC of EA-PSD for separating the toluene/pyridine mixture are listed as below:

1. The fresh feed is flow controlled.
2. The distillate flow rate of the LPC is proportional to the feed flow rate, with the proportion being adjusted by a pyridine product composition controller.
3. The operating pressure of the LPC is controlled by manipulating the heat removal rate of the condenser.
(4) The reflux ratio of the HPC is fixed.
(5) The reflux ratio of the LPC is fixed.
(6) The reflux drum level of the HPC is controlled by manipulating the distillate flow rate.
(7) The reflux drum level of the LPC is controlled by manipulating the makeup flow rate.
(8) The base level of the HPC is controlled by manipulating the bottom flow rate.
(9) The base level of the LPC is controlled by manipulating the bottom flow rate.
(10) The 16th-stage temperature of the LPC (T16) is controlled by manipulating the heat duty of the auxiliary reboiler.
(11) The differential temperature (DT) of the bottom and the 18th stage of the HPC is controlled by manipulating the reboiler duty.

Section 8 PHI-PSD for separating the methanol/trimethoxysilane mixture (HPC->LPC sequence)

The control loops of the proposed control structure with DTC of the HPC->LPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture are listed as below:

(1) The fresh feed is flow controlled.
Fig. 31. The proposed control structure with DTC of FHI-PSD for separating the ethyl acetate/ethanol mixture: (a) control faceplate and (b) flowsheet equations.

(2) The operating pressure of the LPC is controlled by manipulating the heat removal rate of the condenser.
(3) The reflux drum level of the HPC is controlled by manipulating the distillate flow rate.
(4) The reflux drum level of the LPC is controlled by manipulating the reflux flow rate.
(5) The base level of the LPC is controlled by manipulating the bottom flow rate.
(6) The reboiler duty of the HPC is proportional to the feed flow rate. This ratio is manipulated to control the base level of the HPC.
(7) The bottom flow of the HPC is flow controlled at a constant initial value.
(8) The auxiliary reboiler duty is proportional to the feed flow rate.
(9) The differential temperature (DT) of the 3rd stage and the top of the HPC is controlled by manipulating the reflux ratio.
(10) The 5th-stage temperature of the LPC (T5) is controlled by manipulating the reciprocal of the reflux ratio.

Section.9 PHI-PSD for separating the methanol/trimethoxysilane mixture (LPC->HPC sequence)

The control loops of the proposed control structure with DTC of the LPC->HPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture are listed as below:

(1) The fresh feed is flow controlled.
(2) The operating pressure of the LPC is controlled by manipulating the heat removal rate of the condenser.
(3) The reflux drum level of the LPC is controlled by manipulating the distillate flow rate.
(4) The reflux drum level of the HPC is controlled by manipulating the reflux flow rate.
(5) The base level of the LPC is controlled by manipulating the bottom flow rate.
Fig. 32. The proposed control structure with PCTC of FHI-PSD for separating the ethyl acetate/ethanol mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.

(6) The base level of the HPC is controlled by manipulating the ratio of the reboiler duty of the HPC to the feed flow rate.
(7) The bottom flow rate of the HPC is flow controlled at a constant initial value.
(8) The auxiliary reboiler duty is proportional to the feed flow rate.
(9) The differential temperature $(DT_2)$ of the 3rd stage and the top of the HPC is controlled by manipulating the reciprocal of the reflux ratio.
Fig. 3. Dynamic performances of FHI-PSD for separating the ethanol/ethyl acetate mixture under large feed disturbances.
Fig. 34. T-xy diagram of toluene/pyridine at 101.3 kPa.

Fig. 35. Flowsheet of EA-PSD for separating the toluene/pyridine mixture.

Fig. 36. Temperature profiles of EA-PSD for separating the toluene/pyridine mixture: (a) the LPC and (b) the HPC.
Composition/temperature cascade control is used to control the differential temperature (DT) of the 4th stage and the 27th stage of the LPC. Trimethoxysilane product purity is measured as the input of the composition controller, whose output is the setpoint of the temperature controller. The temperature controller is “on cascade”. DT is controlled by manipulating the reflux ratio.

Section.10 Integral absolute error (IAE)
Comparison of IAE of important variables between PCTC and DTC under large feed disturbances is shown in Table 19. If 20% feed disturbance cannot be controlled, 15% feed disturbance is introduced. If 15% feed disturbance cannot be controlled, the values are not presented as the results of 10% feed disturbance have been shown.

Section.11 Other information

2. Experimental design, materials and methods

The simulations are implemented by Aspen Plus and Aspen Dynamics. Aspen Plus is used to establish steady-state designs. After steady-state designs are established, they are converted into dynamic processes. The dynamic research is implemented in Aspen Dynamics.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which have, or could be perceived to have, influenced the work reported in this article.
Fig. 38. The proposed control structure with PCTC of EA-PSD for separating the toluene/pyridine mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.
Fig. 39. Dynamic performances of EA-PSD for separating the toluene/pyridine mixture under large feed disturbances.
Fig. 40. T-xy diagram of methanol/trimethoxysilane.

Fig. 41. Flowsheet of the HPC->LPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture.
Fig. 42. Temperature profiles of the HPC->LPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture: (a) the HPC and (b) the LPC.

Fig. 43. The proposed control structure with DTC of the HPC->LPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture: (a) control faceplate and (b) flowsheet equations.
Fig. 44. The proposed control structure with PCTC of the HPC→LPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.
Fig. 45. Dynamic performances of the HPC->LPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture under large feed disturbances.
Fig. 46. Flowsheet of the LPC->HPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture.

Fig. 47. Temperature profiles of the LPC->HPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture: (a) the LPC and (b) the HPC.
Fig. 48. The proposed control structure with DTC of the LPC->HPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture: (a) control faceplate and (b) flowsheet equations.
Fig. 49. The proposed control structure with PCTC of the LPC→HPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture: (a) control flowsheet, (b) control faceplate and (c) flowsheet equations.
Fig. 50. Dynamic performances of the LPC->HPC sequence of PHI-PSD for separating the methanol/trimethoxysilane mixture under large feed disturbances.
Acknowledgments

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