

Dimensioning a Distillation Column for Separation of Water and Ethanol

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Introduction

This example shows how to make a simple model for a binary distillation process by combining functionality in the Thermodynamics node, available when licensed to the Chemical Reaction Engineering Module, and the Transport of Concentrated Species interface. In this model the separation of a non-ideal mixture of ethanol and water is studied. The required equilibrium relationship is generated using the Equilibrium Calculation functionality available when using the Thermodynamics node. The model is used to find the optimal design of the column in terms of the length of the stripping and rectifying sections to meet a set of specified distillate and bottoms compositions.

Distillation Background

Distillation is the most prominent separation method in chemical process industries. In a typical application, as shown in Figure 1, a liquid mixture of two or more species is fed into a tall cylindrical column somewhere near the middle. For purpose of illustration, this example is limited to two species. There is a heat source in a collecting vessel or column section at the bottom of the column called the reboiler. Liquid from the feed runs down the column and is heated and partially vaporized in the reboiler. Normally, some of the liquid in the reboiler is continuously removed as the bottoms product. The vapor generated in the reboiler rises up toward the top of the column, where it is condensed in an externally cooled vessel or column section called the condenser. Some of the condensed liquid in the condenser is normally removed as the overhead product or distillate. The remainder of the condensed liquid is sent back down the column as reflux. With heat

added at the bottom and removed at the top, the temperature decreases from bottom to top of the column that operates at nearly constant pressure.



Figure 1: Packed distillation column schematic.

The separation process inside the column is governed by the difference in tendency to vaporize, or volatility, of the two species. Generally, the species with the lower boiling point will vaporize easier and concentrate in the vapor phase. As the liquid flowing down the column contacts the vapor rising up, mass transfer occurs between the phases as each species seeks to reach chemical equilibrium. The equilibrium condition dictates the relative amounts, or composition, of each species that would be in each phase at equilibrium at a certain temperature and pressure. The vapor phase will have a higher composition of the more volatile species at every point in the column. As the vapor phase rises up the column, the equilibrium composition shifts (with decreasing temperature) to drive the vapor phase toward purity in the more volatile component. Similarly, the liquid phase flowing down the column is driven toward purity in the less volatile component.

Inside, the column will have one of two types of internals designed to provide intimate contact between the vapor and liquid phases and facilitate their approach to equilibrium. The column will either contain a series of stages or be filled with a specialized packing. A

staged column contains a number of horizontal plates or trays with liquid flowing across while vapor bubbles through. In an idealized column, the liquid flowing down after crossing a stage will be in equilibrium with the vapor rising up from that stage. A packed column will contain one or more sections of random or structured packing material made of metal, ceramic, or plastic in specialized shapes. Void spaces inside and between the packing particles allow for high fluid flow rates with limited pressure drop. Ideally the packing is wetted with a thin film of liquid with vapor flowing past the liquid film with a high surface area to promote mass transfer between the phases.

In practice, chemical equilibrium will not be reached due to mass transfer limitations and with finite column height the distillate and bottoms products will not be completely pure. More stages or a larger height of packing in a column will provide higher purity products, but will require a taller, more expensive, column. For a given column height, a higher reflux will provide higher product purity, but will yield a lower distillate product flow rate and will require a larger diameter column to accommodate the increased internal flow.

Model Definition

As in virtually all chemical processes, analysis and design of a distillation column requires a combination of mass balances, energy balances, equilibrium relationships, and rate equations. This example considers binary distillation with a saturated liquid feed in a packed column and makes use of two common simplifying assumptions:

- The molar heats of vaporization of the feed species are equal.
- The heat loss from the column and other heat effects, like heat of solution, are negligible.

These assumptions let us model the process without considering heat effects or energy balances. They also dictate that the liquid and vapor molar flow rates are constant in each column section, the so called stripping section below the feed and the so called rectifying section above the feed location. That is, for every mole of liquid evaporated within the column, a mole of vapor is condensed. This assumption is known as constant molar overflow and is not as unrealistic in practice as it may seem (Ref. 1).

Considering a saturated liquid feed means that all of the feed joins the liquid in the stripping section such that

$$L_{\rm s} = L_{\rm r} + F \tag{1}$$

Here L_s is the liquid flow rate from the stripping section into the reboiler, L_r is the liquid flow rate from the condenser into the rectifying section, and *F* the feed flow rate. Other

feed conditions would alter the analysis slightly since some or all of the feed would join the vapor phase in the rectifying section under other conditions.

The column design task considered here is to determine the height of packing and feed location required to separate a feed of known flow rate and composition into distillate and bottom streams of specified purity. Additional process parameters to be specified include the boil-up rate, or vapor molar flow rate within the column, and the overall gas phase mass transfer coefficient, K_{ya} . In practice, the boil-up rate will depend on the heat input to the reboiler. We specify the boil-up rate as

$$V_{\rm s} = V_{\rm r} \tag{2}$$

That is, the vapor flow rate from the reboiler into the stripping section equals the vapor flow rate into the condenser.

Overall and species mass balances allow us to calculate the molar flow rates of our bottoms, B, and distillate, D, by solving two equations in the two unknowns:

$$F = B + D \tag{3}$$

$$x_{\rm f}F = x_{\rm b}B + x_{\rm d}D \tag{4}$$

where x_f, x_b , and x_d are mole fractions of the more volatile species in the feed, bottoms, and distillate streams, respectively.

The internal liquid flows are then found from:

$$L_{\rm r} = V_{\rm r} - D \tag{5}$$

along with Equation 1. All of these flow rates are found in the model by algebraic manipulation in the **Parameters** node under **Global Definitions** in the **Model Builder** Window.

Neglecting any variation in the radial direction, we model the distillation column in one dimension using two line segments (see Figure 2). One segment of length, H_s , represents the stripping section, while the other segment of length H_r , represents the rectifying section. The goal of the model is to determine the values of H_s and H_r that provide the specified bottoms and distillate compositions. We assume values of H_s and $H = H_s + H_r$,

solve for the compositions in the vapor and liquid phases at every point in the column, and iterate until the outlet compositions match the design specifications.



Figure 2: One dimensional model geometry including the boundary conditions for the mole fraction of ethanol in each phase.

To solve for the mass transfer we use two instances of the Transport of Concentrated Species Interface, one for the vapor phase and one for the liquid phase. The mass transfer between the phases is accounted for as using a Reacting Source node where the source rate is defined as

$$R_1 = K_{\rm va}(y_{\rm el} - y_1)M_1 \tag{6}$$

where K_{ya} is an overall gas phase mass transfer coefficient in mol/(m³·s), y_{e1} is the mole fraction of the more volatile species that would be reached at equilibrium, and M_1 is the molar mass of the more volatile species. This provides a mass transfer rate of the more volatile species from the liquid phase to the vapor phase. A similar expression with opposite sign describes the simultaneous mass transfer of the less volatile component in accordance with our constant molar overflow assumption. The value of y_{e1} at each point is found using an Equilibrium Calculation node added in the Thermodynamic system under Thermodynamics. The mass transfer coefficient will depend on the fluid and packing properties and the local fluid velocities and may vary along the height of the column. Correlations for K_{ya} are available in the literature. In this example we assume a constant value of $K_{va} = 75 \text{ mol}/(\text{m}^3 \cdot \text{s})$ for illustrative purposes.

The molar flows of liquid and vapor within the column are accounted for by specifying the velocity in each phase. In this lumped parameter model based on an overall gas phase mass transfer coefficient, we use an equivalent gas phase velocity for the liquid phase to put them on the same basis. This is essentially a form of scaling the liquid phase velocity to be on the same order of magnitude as the gas phase velocity. To convert a molar flow rate, L_r for example, to a velocity, u_{Lr} , we assume a column diameter, determine a cross-sectional area, A, and assume ideal gas molar volume at standard conditions for both phases:

$$u_{\rm Lr} = \frac{L_{\rm r} 0.022414 \text{ m}3/\text{mol}}{A} \tag{7}$$

The boundary conditions for our mass transfer problem are shown in Figure 2. We specify the mass fraction of the bottoms in the vapor phase and the mass fraction of the feed and distillate in the liquid phase. H_s and H are varied by guess and check or using a parameter sweep until a solution is found where the liquid phase bottoms composition equals that specified in the vapor phase, and the vapor phase distillate composition equals that specified in the liquid phase.

Results and Discussion

Figure 3 shows the results of an equilibrium calculation, available in Thermodynamics, generating an x-y diagram for the ethanol-water system at 1 atm pressure. The NRTL thermodynamic model was used for the liquid phase, while an ideal gas assumption is used for the gas phase.

The calculated results for vapor and liquid phase compositions inside a column designed to separate a 50 mole percent mixture of ethanol in water to yield a distillate of 85 mole percent ethanol and a bottoms product of 5 mole percent ethanol are shown in Figure 4. The required heights found by trial are $H_s = 1.3$ m and H = 12 m. In the model a Parametric Sweep study step was used to compute the column composition when varying the stripping section length. The design criteria to be met in this case is that the ethanol mole fraction in the vapor and liquid phase should coincide at the bottom. Using a section length less than about 1.3 m, the liquid phase mole fraction exiting the column is higher than that of the vapor phase. Correspondingly, for a section longer than 1.3 m, the liquid phase mole fraction is lower than that of the vapor phase. The same analysis can be made for the top of the column. The optimal column height is found when the phase compositions match also at the top.

Figure 5 presents the results from Figure 4 on an x-y plot along with the equilibrium curve of Figure 3. Readers familiar with the traditional McCabe-Thiele distillation analysis will note that it is no coincidence that our calculated results trace out straight operating lines



for the stripping and rectifying sections that intersect at the feed composition for this case with a saturated liquid feed.

Figure 3: x-y diagram for ethanol-water at 1 atm pressure using the NRTL model.



Figure 4: Mole fraction of ethanol in the vapor and liquid phases as a function of column height for a distillation column designed to separate a 50 mole percent ethanol-water mixture to yield products with $x_b = 0.05$ and $x_d = 0.85$ mole fraction ethanol. Heights required were $H_s = 1.3$ m and H = 12 m.



Figure 5: x-y diagram showing the calculated operating lines within the distillation column described in Figure 4.

Reference

1. E.L. Cussler, *Diffusion: Mass Transfer in Fluid Systems*, 3rd ed., Cambridge University Press, 2009.

Application Library path: Chemical_Reaction_Engineering_Module/ Thermodynamics/distillation_column

Note: This model is included in the booklet *Introduction to Thermodynamic Properties.*

Modeling Instructions

From the File menu, choose New.

NEW

In the New window, click 🙆 Model Wizard.

MODEL WIZARD

- I In the Model Wizard window, click 0D.
- 2 In the Select Physics tree, select Chemical Species Transport>Reaction Engineering (re).
- 3 Click Add.
- 4 Click 🗹 Done.

REACTION ENGINEERING (RE)

Species 1

- I In the Model Builder window, under Component I (compl) right-click Reaction Engineering (re) and choose Species.
- 2 In the Settings window for Species, locate the Species Name section.
- **3** In the text field, type E.
- **4** In the **Reaction Engineering** toolbar, click \downarrow **Species**.

Species 1

- I In the Settings window for Species, locate the Species Name section.
- **2** In the text field, type W.
- 3 In the Reaction Engineering toolbar, click A Thermodynamics and choose Thermodynamic System.

SELECT SYSTEM

- I Go to the Select System window.
- 2 From the Phase list, choose Vapor-liquid.
- 3 Click Next in the window toolbar.

SELECT SPECIES

- I Go to the Select Species window.
- 2 In the Species list, select ethanol (64-17-5, C2H60).
- 3 Click + Add Selected.

- 4 In the Species list, select water (7732-18-5, H2O).
- **5** Click + Add Selected.
- 6 Click Next in the window toolbar.

SELECT THERMODYNAMIC MODEL

- I Go to the Select Thermodynamic Model window.
- 2 From the list, choose NRTL.
- 3 Click Finish in the window toolbar.

REACTION ENGINEERING (RE)

- I In the Model Builder window, under Component I (compl) click Reaction Engineering (re).
- 2 In the Settings window for Reaction Engineering, locate the Mixture Properties section.
- **3** Select the **Thermodynamics** check box.
- 4 Locate the Species Matching section. In the table, enter the following settings:

Species	From Thermodynamics
E	C2H6O
W	H2O

GLOBAL DEFINITIONS

Vapor-Liquid System 1 (pp1)

In the Model Builder window, under Global Definitions>Thermodynamics right-click Vapor-Liquid System I (ppI) and choose Equilibrium Calculation.

SELECT SPECIES

- I Go to the Select Species window.
- 2 Click 🔣 Add All.
- **3** Click **Next** in the window toolbar.

EQUILIBRIUM SPECIFICATIONS

- I Go to the Equilibrium Specifications window.
- 2 From the Amount base unit list, choose mol.
- **3** Find the **Equilibrium conditions** subsection. From the **First condition** list, choose **Pressure**.
- 4 From the Second condition list, choose Phase fraction.
- 5 Click Next in the window toolbar.

EQUILIBRIUM FUNCTION OVERVIEW

- I Go to the Equilibrium Function Overview window.
- 2 Click Finish in the window toolbar.

GLOBAL DEFINITIONS

Analytic I (an I)

- I In the Home toolbar, click f(X) Functions and choose Global>Analytic.
- 2 In the Settings window for Analytic, type x_y in the Function name text field.
- 3 Locate the Definition section. In the Expression text field, type Flash1_1_PhaseComposition_Vapor_ethanol(p,n,x1,x2).
- 4 In the **Arguments** text field, type p, n, x1, x2.
- 5 Locate the Units section. In the Arguments text field, type Pa, 1, mol/mol, mol/mol.
- 6 In the Function text field, type mol/mol.

Parameters 1

- I In the Model Builder window, click Parameters I.
- 2 In the Settings window for Parameters, locate the Parameters section.
- 3 Click 📂 Load from File.
- 4 Browse to the model's Application Libraries folder and double-click the file distillation_column_parameters.txt.

ADD STUDY

- I In the Home toolbar, click $\stackrel{\text{res}}{\longrightarrow}$ Add Study to open the Add Study window.
- 2 Go to the Add Study window.
- **3** Find the **Physics interfaces in study** subsection. In the table, clear the **Solve** check box for **Reaction Engineering (re)**.
- 4 Find the Studies subsection. In the Select Study tree, select Preset Studies for Selected Physics Interfaces>Stationary.
- 5 Click Add Study in the window toolbar.
- 6 In the Home toolbar, click $\sim\sim$ Add Study to close the Add Study window.

STUDY I

Step 1: Stationary

- I In the Settings window for Stationary, click to expand the Study Extensions section.
- 2 Select the Auxiliary sweep check box.

- 3 Click + Add.
- **4** In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
n (Vapor phase fraction)		

5 Click + Add.

6 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
n (Vapor phase fraction)	0 1	
x1 (Mole fraction species 1)	range(0,0.01,1)	

7 From the Sweep type list, choose All combinations.

8 In the Home toolbar, click **= Compute**.

RESULTS

ID Plot Group I

In the Home toolbar, click 🔎 Add Plot Group and choose ID Plot Group.

Global I

- I In the ID Plot Group I toolbar, click 🔄 Global.
- 2 In the Settings window for Global, locate the y-Axis Data section.
- 3 Click **Clear Table**.
- **4** In the table, enter the following settings:

Expression	Unit	Description
x_y(P,n,x1,x2)	1	

- 5 Click to expand the Legends section. Clear the Show legends check box.
- 6 In the ID Plot Group I toolbar, click 🗿 Plot.
- 7 Click to expand the Coloring and Style section. In the Width text field, type 2.

Equilibrium Curve

- I In the Model Builder window, under Results click ID Plot Group I.
- 2 In the Settings window for ID Plot Group, type Equilibrium Curve in the Label text field.
- 3 Locate the Plot Settings section. Select the x-axis label check box.

- 4 Select the y-axis label check box.
- **5** In the associated text field, type y1.
- 6 Click to expand the Title section. From the Title type list, choose None.
- 7 Locate the Legend section. From the Position list, choose Middle right.

EQUILIBRIUM CURVE PARAMETERIZATION

- I In the Model Builder window, click Study I.
- 2 In the Settings window for Study, type Equilibrium Curve Parameterization in the Label text field.

REACTION ENGINEERING (RE)

Generate Space-Dependent Model I

- I In the Reaction Engineering toolbar, click 📫 Generate Space-Dependent Model.
- 2 In the Settings window for Generate Space-Dependent Model, locate the Component Settings section.
- 3 From the Component to use list, choose ID: New.
- **4** Locate the **Physics Interfaces** section. Find the **Chemical species transport** subsection. From the list, choose **Transport of Concentrated Species: New**.
- 5 Locate the Space-Dependent Model Generation section. Click Create/Refresh.

COMPONENT 2 (COMP2)

In the Model Builder window, expand the Component 2 (comp2) node.

GEOMETRY I(ID)

Interval I (i1)

- I In the Model Builder window, expand the Component 2 (comp2)>Geometry 1(1D) node.
- 2 Right-click Geometry I(ID) and choose Interval.
- 3 In the Settings window for Interval, locate the Interval section.
- **4** In the table, enter the following settings:

Coordinates (m)

0 Hs

5 Click 틤 Build Selected.

Interval 2 (i2)

- I Right-click Interval I (iI) and choose Duplicate.
- 2 In the Settings window for Interval, locate the Interval section.
- **3** In the table, enter the following settings:

Coordinates (m)

Hs

- Н
- 4 Click 🟢 Build All Objects.
- **5** Click the \leftrightarrow **Zoom Extents** button in the **Graphics** toolbar.

TRANSPORT OF CONCENTRATED SPECIES (TCS)

- I In the Model Builder window, under Component 2 (comp2) click Transport of Concentrated Species (tcs).
- 2 In the Settings window for Transport of Concentrated Species, locate the Species section.
- **3** From the From mass constraint list, choose wW.

Add a second **Transport of Concentrated Species** interface which will be used to model the liquid phase.

4 From the Home menu, choose Add Physics.

ADD PHYSICS

- I Go to the Add Physics window.
- 2 In the tree, select Chemical Species Transport>Transport of Concentrated Species (tcs).
- **3** Click to expand the **Dependent Variables** section. In the **Mass fractions** table, enter the following settings:

wEl

wWl

- 4 Click Add to Component 2 in the window toolbar.
- 5 From the Home menu, choose Add Physics.

TRANSPORT OF CONCENTRATED SPECIES 2 (TCS2)

- I In the Settings window for Transport of Concentrated Species, locate the Species section.
- 2 From the From mass constraint list, choose wWI.
- 3 In the Model Builder window, expand the Transport of Concentrated Species (tcs) node.

DEFINITIONS (COMP2)

Variables I

- I In the Model Builder window, expand the Component 2 (comp2)>Definitions node.
- 2 Right-click Component 2 (comp2)>Definitions and choose Variables.
- 3 In the Settings window for Variables, locate the Variables section.
- 4 Click 📂 Load from File.
- 5 Browse to the model's Application Libraries folder and double-click the file distillation_column_variables.txt.

TRANSPORT OF CONCENTRATED SPECIES (TCS)

Transport Properties 1

In this model, the column temperature and pressure are assumed constant. Define these conditions using the **Default Model Inputs** node. This will make it easy to ensure that the same conditions are applied throughout the model.

- In the Model Builder window, under Component 2 (comp2)>
 Transport of Concentrated Species (tcs) click Transport Properties I.
- 2 In the Settings window for Transport Properties, locate the Model Input section.
- **3** Click **Go to Source** for p_A .

GLOBAL DEFINITIONS

Default Model Inputs

- I In the Model Builder window, under Global Definitions click Default Model Inputs.
- 2 In the Settings window for Default Model Inputs, locate the Browse Model Inputs section.
- 3 In the tree, select General>Pressure (Pa) minput.pA.
- 4 Find the Expression for remaining selection subsection. In the Pressure text field, type P.
- 5 In the tree, select General>Temperature (K) minput.T.
- 6 In the **Temperature** text field, type T.

TRANSPORT OF CONCENTRATED SPECIES (TCS)

Transport Properties 1

I In the Model Builder window, under Component 2 (comp2)>

Transport of Concentrated Species (tcs) click Transport Properties I.

2 In the Settings window for Transport Properties, locate the Density section.

- **3** From the ρ list, choose **Ideal gas**.
- 4 Locate the Convection section. Specify the u vector as

uV x

Initial Values 1

- I In the Model Builder window, click Initial Values I.
- 2 In the Settings window for Initial Values, locate the Initial Values section.
- **3** In the $\omega_{0,wE}$ text field, type wf.

Reaction Sources 1

- I In the Model Builder window, click Reaction Sources I.
- 2 In the Settings window for Reaction Sources, locate the Reactions section.
- 3 From the R_{wE} list, choose User defined. In the associated text field, type -tcs.M_wE* Kya*(ym1-ye1).
- 4 From the R_{wW} list, choose User defined. In the associated text field, type tcs.M_wW* Kya*(ym1-ye1).

Mass Fraction 1

- I In the Physics toolbar, click Boundaries and choose Mass Fraction.
- 2 Select Boundary 1 only.
- 3 In the Settings window for Mass Fraction, locate the Mass Fraction section.
- 4 Select the Species wE check box.
- **5** In the $\omega_{0,wE}$ text field, type wb.

Outflow I

- I In the Physics toolbar, click Boundaries and choose Outflow.
- 2 Select Boundary 3 only.

TRANSPORT OF CONCENTRATED SPECIES 2 (TCS2)

Transport Properties 1

- In the Model Builder window, under Component 2 (comp2)>
 Transport of Concentrated Species 2 (tcs2) click Transport Properties 1.
- 2 In the Settings window for Transport Properties, locate the Density section.
- **3** From the $M_{\rm wWl}$ list, choose Molar mass (chem/W).
- 4 From the $M_{\rm wEl}$ list, choose Molar mass (chem/E).

5 Locate the Convection section. Specify the u vector as

-uLr x

6 Locate the Diffusion section. In the table, enter the following settings:

Species I	Species 2	Diffusivity	Diffusion coefficient (m ² /s)
wEl	wWI	User defined	1e-20

Initial Values 1

- I In the Model Builder window, click Initial Values I.
- 2 In the Settings window for Initial Values, locate the Initial Values section.
- **3** In the $\omega_{0,wEl}$ text field, type wf.

Transport Properties 2

I In the Model Builder window, under Component 2 (comp2)>

Transport of Concentrated Species 2 (tcs2) right-click **Transport Properties I** and choose **Duplicate**.

- **2** Select Domain 1 only.
- 3 In the Settings window for Transport Properties, locate the Convection section.
- 4 Specify the **u** vector as

-uLs x

Mass Fraction 1

- I In the Physics toolbar, click Boundaries and choose Mass Fraction.
- **2** Select Boundary **3** only.
- 3 In the Settings window for Mass Fraction, locate the Mass Fraction section.
- 4 Select the Species wEI check box.
- **5** In the $\omega_{0,\text{wEl}}$ text field, type wd.

Mass Fraction 2

- I In the Physics toolbar, click Boundaries and choose Mass Fraction.
- 2 Select Boundary 2 only.
- 3 In the Settings window for Mass Fraction, locate the Mass Fraction section.
- 4 Select the Species wEI check box.
- **5** In the $\omega_{0,\text{wEl}}$ text field, type wf.

Outflow I

- I In the Physics toolbar, click Boundaries and choose Outflow.
- 2 Select Boundary 1 only.

Reaction Sources 1

- I In the Physics toolbar, click Domains and choose Reaction Sources.
- 2 In the Settings window for Reaction Sources, locate the Reactions section.
- **3** Select the Mass transfer to other phases check box.
- **4** In the R_{wEl} text field, type tcs.M_wE*Kya*(ym1-ye1).
- **5** In the R_{wWl} text field, type -tcs.M_wW*Kya*(ym1-ye1).
- 6 Click in the Graphics window and then press Ctrl+A to select both domains.

MESH I

Size

In the Model Builder window, under Component 2 (comp2) right-click Mesh I and choose Edit Physics-Induced Sequence.

Size 1

- I In the Model Builder window, right-click Edge I and choose Size.
- 2 In the Settings window for Size, locate the Geometric Entity Selection section.
- **3** From the **Geometric entity level** list, choose **Boundary**.
- 4 Click in the Graphics window and then press Ctrl+A to select all boundaries.
- 5 Locate the Element Size section. From the Calibrate for list, choose Fluid dynamics.
- 6 From the Predefined list, choose Extremely fine.
- 7 Click 🖷 Build Selected.

COLUMN DESIGN

- I In the Model Builder window, click Study 2.
- 2 In the Settings window for Study, type Column Design in the Label text field.

Parametric Sweep

- I In the Study toolbar, click **Parametric Sweep**.
- 2 In the Settings window for Parametric Sweep, locate the Study Settings section.
- 3 Click + Add.

4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
Hs (Height of stripping section)	1.2 1.3 1.4	m

5 In the **Study** toolbar, click **= Compute**.

RESULTS

- ID Plot Group 8
- I In the Home toolbar, click 📠 Add Plot Group and choose ID Plot Group.
- 2 In the Settings window for ID Plot Group, locate the Data section.
- 3 From the Dataset list, choose Column Design/Parametric Solutions I (sol3).
- 4 From the Parameter selection (Hs) list, choose From list.
- 5 In the Parameter values (Hs (m)) list, select 1.3.

Line Graph I

- I Right-click ID Plot Group 8 and choose Line Graph.
- 2 In the Settings window for Line Graph, locate the Selection section.
- **3** From the **Selection** list, choose **All domains**.
- 4 Locate the y-Axis Data section. In the Expression text field, type ym1.
- 5 Click to expand the Coloring and Style section. In the Width text field, type 2.
- 6 Click to expand the Legends section. Select the Show legends check box.
- 7 From the Legends list, choose Manual.
- 8 In the table, enter the following settings:

Legends

Vapor phase

Line Graph 2

- I Right-click Line Graph I and choose Duplicate.
- 2 In the Settings window for Line Graph, locate the y-Axis Data section.
- **3** In the **Expression** text field, type xm1.
- 4 Locate the Legends section. In the table, enter the following settings:

Legends

Liquid phase

5 In the ID Plot Group 8 toolbar, click 🗿 Plot.

Mole Fractions

- I In the Model Builder window, under Results click ID Plot Group 8.
- 2 In the Settings window for ID Plot Group, type Mole Fractions in the Label text field.
- 3 Locate the Title section. From the Title type list, choose Manual.
- 4 In the Title text area, type Ethanol mole fraction.
- 5 Locate the Plot Settings section. Select the x-axis label check box.
- **6** In the associated text field, type Column Height (m).
- 7 Select the y-axis label check box.
- 8 In the associated text field, type x1, y1.
- 9 Locate the Legend section. From the Position list, choose Middle right.
- **IO** In the **Mole Fractions** toolbar, click **O Plot**.

ID Plot Group 9

- I In the Home toolbar, click 📠 Add Plot Group and choose ID Plot Group.
- 2 In the Settings window for ID Plot Group, locate the Data section.
- 3 From the Dataset list, choose Column Design/Parametric Solutions I (sol3).
- 4 From the Parameter selection (Hs) list, choose From list.
- 5 In the Parameter values (Hs (m)) list, select 1.3.

Line Graph 1

- I Right-click ID Plot Group 9 and choose Line Graph.
- 2 In the Settings window for Line Graph, locate the Selection section.
- **3** From the Selection list, choose All domains.
- 4 Locate the y-Axis Data section. In the Expression text field, type ym1.
- 5 Locate the x-Axis Data section. From the Parameter list, choose Expression.
- 6 In the **Expression** text field, type xm1.
- 7 Locate the Coloring and Style section. From the Color list, choose Black.
- 8 In the Width text field, type 2.
- 9 Locate the Legends section. Select the Show legends check box.
- 10 From the Legends list, choose Manual.

II In the table, enter the following settings:

Legends

Column operation

12 In the 1D Plot Group 9 toolbar, click 💿 Plot.

ID Plot Group 9

In the Model Builder window, click ID Plot Group 9.

Global I

I In the ID Plot Group 9 toolbar, click (Global.

- 2 In the Settings window for Global, locate the y-Axis Data section.
- 3 Click 📐 Clear Table.
- **4** In the table, enter the following settings:

Expression	Unit	Description
x_y(P,n,x1,x2)	1	

- 5 Locate the Data section. From the Dataset list, chooseEquilibrium Curve Parameterization/Solution 1 (sol1).
- 6 In the ID Plot Group 9 toolbar, click 💽 Plot.
- 7 Locate the Coloring and Style section. In the Width text field, type 2.
- 8 Locate the Legends section. Clear the Show legends check box.
- 9 Right-click Global I and choose Move Up.
- **IO** In the **ID Plot Group 9** toolbar, click **ID Plot**.

Operating Lines

- I In the Model Builder window, under Results click ID Plot Group 9.
- 2 In the Settings window for ID Plot Group, type Operating Lines in the Label text field.
- 3 Locate the Plot Settings section. Select the x-axis label check box.
- **4** In the associated text field, type x1.
- 5 Select the y-axis label check box.
- 6 In the associated text field, type y1.
- 7 Locate the Title section. From the Title type list, choose None.
- 8 Locate the Legend section. From the Position list, choose Middle right.
- 9 In the Operating Lines toolbar, click 🗿 Plot.

 $24 \ \mid \ \mbox{dimensioning a distillation column for separation of water and }$