A 21st Century Textbook for Material and Energy Balances

Matthew Liberatore

COLORADO SCHOOL OF MINES
engineering the way

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Start With A Literature Review

"The students receiving the multimedia learning modules performed significantly better on both tests than the students experiencing the text-based presentations" T. Stelzer, et al., Am. J. Phys. 2009, *77*, 184–190.

"Students also reported limitations of the textbook, contrasting it to the diversity of resources available via the Internet" C. S. Lee, et al., J. Eng. Ed. 2013, 102, 269–288.

"Participants with pre-lesson quiz scores in the lower-quartile improved 64% more (p-value < 0.001) with the interactive web-native content than with the static web content." Edgcomb &Vahid, ASEE Conf. Proc. 2014. (zyante.com)

Textbook = 20th Century Technology

OLD Technology

20th Century Technologies

2014 Nobel Prize

https://www.inkling.com/blog/2014/10/prototype-fidelity-digital-content/ accessed 10/2014.

21st Century Textbook = Software

Pen

The Evolution of Publishing

Printing Press

Textbooks

Adobe

PDF & ePublishing

Why Software Trumps ‘Print’

Type of Textbook	Cost	Interactivity	Updates
Fundamentals of Material and Energy Balances	$29.99 for web, iOS, Android	Yes	Frequent
Traditional Textbook	$71.50 for Kindle	No	Once per decade

Learn more at www.readswipesolve.com

MEB = The comprehension course

The 1st chemical engineering course

A gateway to the rest of the curriculum

Concepts covered:

- Mass/mole/atom balances
- Reacting systems
- Vapor-liquid equilibrium
- Energy balances
- Transient systems

Building from the bottom up

Goal: Develop problem solving skills and conceptual understanding

How:

Quick hitting concepts

Scaffolded, tiered examples

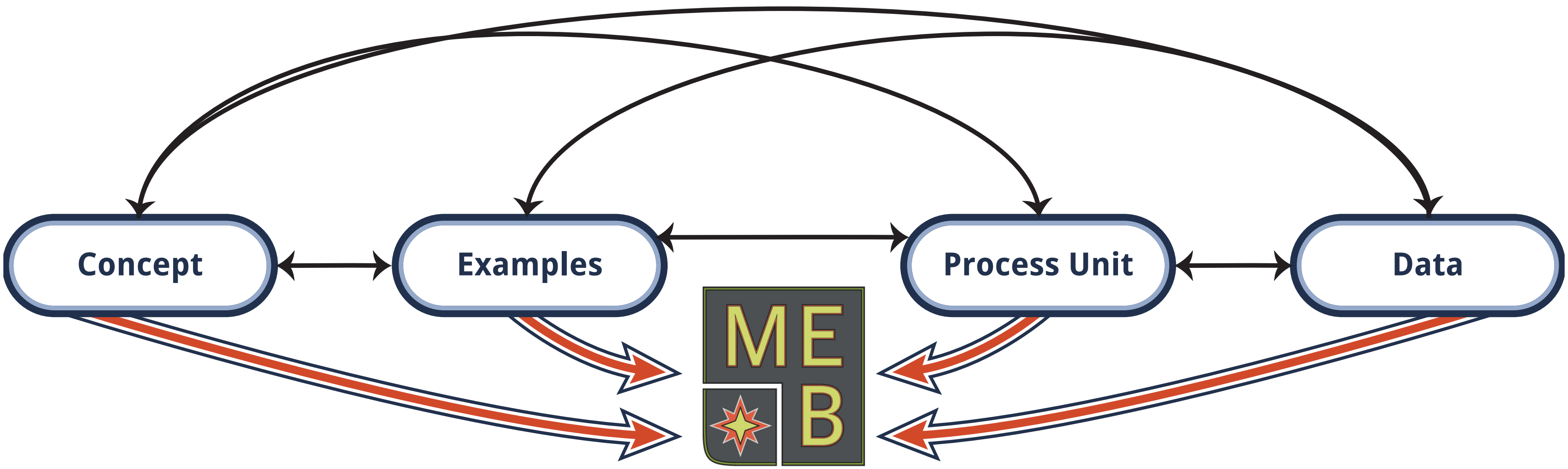
Interactivity and decision making

Scaffolded Tool for Active Reading©

Minimum Text

Non linear

Interactive Feedback



Quick Hitting Concepts

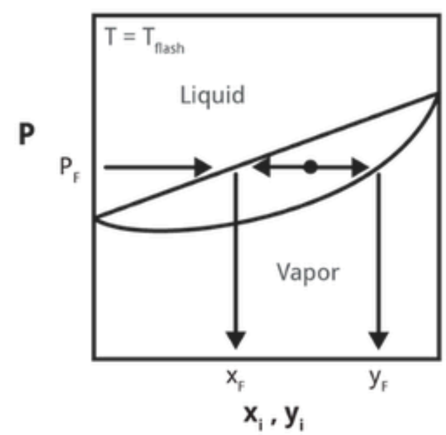
Fundamentals of Material and Energy Balances

MEB

Search

Flash separation

Flash is another type of vapor-liquid equilibrium. In this case, a fluid of known composition is placed at a set temperature and pressure. The temperature and pressure are selected so at equilibrium both vapor and liquid phases are present. Generally, one of the product phases (liquid or vapor) contains a large fraction of one of the species from the initial mixture.



6-5

Figure 6.5 Pxy diagram showing flash separation

Flashcards = interactive definitions

Concept: Properties of water

Notes 0 ADD NOTE +

Properties of water

Water is a very well studied substance, and a wealth of tabulated water properties are available. Reading the "steam tables" is an important skill to determining properties from density to enthalpy for liquid and vapor water. Some general vocabulary and simple phase diagrams are introduced and then some rules of thumb on determining the phase and properties from given information concludes this concept. While steam tables are provided in the Appendix, the concepts for the properties of water translate to most single species.

Six basic terms are defined here. The terms bubble point and dew point are covered in Chapter 6.

PHASE	PHASE BOUNDARY	SATURATED
SATURATION T	SATURATION P	PHASE DIAGRAM

Next, the basic phases of water and pure substances are defined.

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Flashcards = interactive definitions

Properties of water

Water is a very well studied substance, and a wealth of tabulated water properties are available. Reading the "steam tables" is an important skill to determining properties from density to enthalpy for liquid and vapor water. Some general vocabulary and simple phase diagrams are introduced and then some rules of thumb on determining the phase and properties from given information concludes this concept. While steam tables are provided in the Appendix, the concepts for the properties of water translate to most single species.

Six basic terms are defined here. The terms bubble point and dew point are covered in Chapter 6.

Different forms that a pure substance can exist. Solid, liquid, and gas are the most common	PHASE BOUNDARY	Two phases existing in equilibrium
SATURATION T	P where vaporization starts at a given T	PHASE DIAGRAM

Next, the basic phases of water and pure substances are defined.

Concept: Properties of water

Notes 0 ADD NOTE +

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Choose Your Example/Adventure

C6 flash

A liquid mixture containing 79 mol% cyclohexane and the balance n-pentane enters a flash tank. The tank is maintained at 98°C and 29 psia. The flow rate of the entering stream is 96 mol/min.
Part a. Draw and label a process flow diagram.
Part b. Find the molar flow rates (mol/min) and mole fractions of the exiting stream(s).
Concept question. The entering flow rate increases by 17%, the composition of the pentane in the exiting liquid stream will increase, decrease or stay the same.

Jump to different levels using links:

Problem statement
Numerical answers
Diagram only
Equations only
Full Solution
Concept question

Example: Numerical Answers

Numerical answers

$$x_{2,C} = \boxed{0.914}$$

$$y_{3,C} = \boxed{0.757}$$

$$x_{2,P} = \boxed{0.086}$$

$$y_{3,P} = \boxed{0.243}$$

$$\dot{n}_2 = \boxed{20.4\ \frac{\text{mol}}{\text{min}}}$$

$$\dot{n}_3 = \boxed{75.6\ \frac{\text{mol}}{\text{min}}}$$

Example: Diagram

Diagram

Figure 6.6a C6 flash PFD

Example: Equations

Equations

$$\dot{n}_1 = \dot{n}_2 + \dot{n}_3$$
$$y_{1,C} \cdot \dot{n}_1 = x_{2,C} \cdot \dot{n}_2 + y_{3,C} \cdot \dot{n}_3$$
$$y_{3,C} \cdot P = x_{2,C} \cdot P_C^{sat}$$
$$y_{3,P} \cdot P = x_{2,P} \cdot P_P^{sat}$$
$$1 = x_{2,P} + x_{2,C}$$
$$1 = y_{3,P} + y_{3,C}$$

Example: Full Solution

$\boxed{\text{Step 2}}$ Stream 1

$\boxed{\text{Step 3}}$ Only 1 system to write balances.

$\boxed{\text{Steps 4, 5, 6}}$ Mole balances

Overall: $\dot{n}_1 = \dot{n}_2 + \dot{n}_3$

Compenent C: $y_{1,C} \cdot \dot{n}_1 = x_{2,C} \cdot \dot{n}_2 + y_{3,C} \cdot \dot{n}_3$

$\boxed{\text{Step 7}}$ Two Raoult's laws, Antoine equation, and two sum of mole fractions.

Raoult's Law C: $y_{3,C} \cdot P = x_{2,C} \cdot P_C^{sat}$

Raoult's Law P: $y_{3,P} \cdot P = x_{2,P} \cdot P_P^{sat}$

Sum mole fractions: $1 = x_{2,P} + x_{2,C}$

Sum mole fractions: $1 = y_{3,P} + y_{3,C}$

Antoine equation: $\log_{10} P^{sat} = A - \dfrac{B}{T + C}$

$\boxed{\text{Steps 8, 9, 10, 11}}$ 6 unknowns: 2 balances, 2 Raoult's laws, 2 sum mole fractions. Solve.

Use given T and Antoine equation to find P^{sat} values.

$P_C^{sat}(T = 98^\circ C) = 1242 \text{ mmHg} = 165600 \text{ Pa}$

$P_P^{sat}(T = 98^\circ C) = 4224 \text{ mmHg} = 563100 \text{ Pa}$

Many ways to solve this system of equations. One way is:

Plug sum mole fractions in Raoult's Law for P. Solve Raoult's law C for $y_{3,C}$ and plug $y_{3,C}$ into Raoult's Law P. Solve for $x_{2,C}$.

$$y_{3,C} = \frac{x_{2,C} \cdot P_C^{sat}}{P} \text{ and } (1 - y_{3,C}) \cdot P = (1 - x_{2,C}) \cdot P_P^{sat} \rightarrow$$

$$x_{2,C} = \frac{P - P_P^{sat}}{P_C^{sat} - P_P^{sat}} \rightarrow x_{2,C} = \boxed{0.914}$$

$$y_{3,C} = \frac{x_{2,C} \cdot P_C^{sat}}{P} \rightarrow y_{3,C} = \boxed{0.757} \text{ and } x_{2,P} = \boxed{0.086} \quad y_{3,P} = \boxed{0.243}$$

Plug overall balance into component balance to find flow rates.

$$y_{1,C} \cdot \dot{n}_1 = x_{2,C} \cdot \dot{n}_2 + y_{3,C} \cdot (\dot{n}_1 - \dot{n}_2) \rightarrow \dot{n}_2 = \boxed{20.4 \tfrac{mol}{min}} \text{ and } \dot{n}_3 = \boxed{75.6 \tfrac{mol}{min}}$$

$\boxed{\text{Step 12}}$ Check using component P balance or any atom balance.

12 steps problem solving method

Example: Full Solution

Step 2 Stream 1

Step 3 Only 1 system to write balances.

Steps 4, 5, 6 Mole balances

Overall: $\dot{n}_1 = \dot{n}_2 + \dot{n}_3$

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Step 12 Check using component P balance or any atom balance.

12 steps problem solving method

Example: Concept Question

Question 1

A liquid mixture containing 79 mol% cyclohexane and the balance n-pentane enters a flash tank. The tank is maintained at 98^{o}C and 29 psia. The flow rate of the entering stream is 96 mol/min.

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- Increase
- Decrease
- Stays the same

Need help with this one? Get a hint or show answer.

CHECK ANSWER

C6 flash - concept question

Scoreboard Start Over

0% Complete

Correct	0
Wrong	0
Unanswered	1
Total	**1**

Notes 0 ADD NOTE +

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Example: Concept Question

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How does Raoult's law vary with flow rate?

Need help with this one? Get a hint or show answer.

CHECK ANSWER

C6 flash - concept question

Scoreboard Start Over

0% Complete

Correct	0
Wrong	0
Unanswered	1
Total	**1**

Notes 0 ADD NOTE +

inkling

Example: Concept Question

Question 1

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- Increase
- Decrease
- Stays the same ✓

That's correct!
The flow rate does not change the compositions exiting the tank. Raoult's law is independent of flow rate .

Need help with this one? Get a hint.

DONE

C6 flash - concept question

Scoreboard Start Over

100% Complete

Correct	1
Wrong	0
Unanswered	0
Total	**1**

Notes 0 ADD NOTE +

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Process Unit

Flash tank

Flash separation is a simple process unit where T, P are altered to create separation of one or more components. The exiting vapor and liquid streams are in equilibrium providing one extra equation for each component in equilibrium. The process may be called flash evaporation and the equipment is commonly known as a flash drum. Additional information on flash can be found elsewhere.

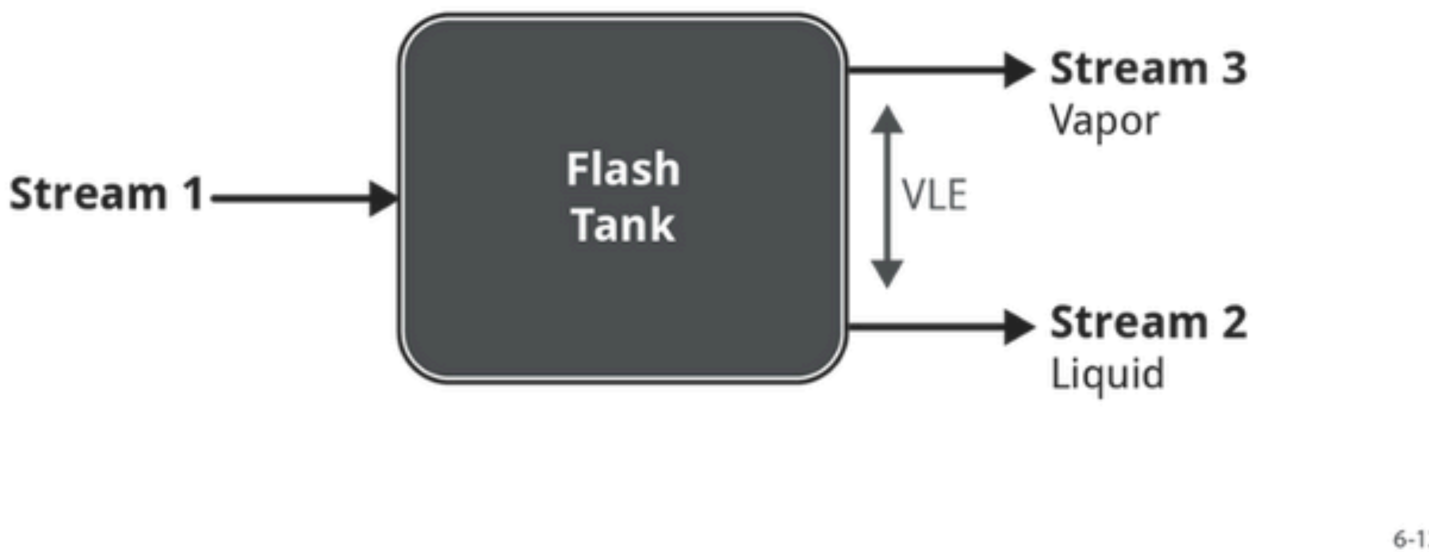


Figure 6-13 **Flash tank.**

Process Unit: External Resources

Create account Log in

Article Talk Read Edit View history Search

WIKIPEDIA
The Free Encyclopedia

- Main page
- Contents
- Featured content
- Current events
- Random article
- Donate to Wikipedia
- Wikimedia Shop

Interaction
- Help
- About Wikipedia
- Community portal
- Recent changes
- Contact page

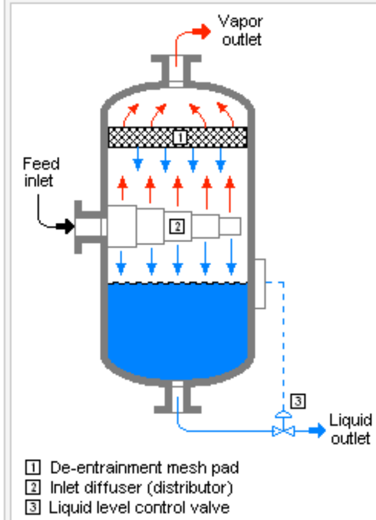
Tools
- What links here
- Related changes
- Upload file
- Special pages
- Permanent link
- Page information
- Wikidata item
- Cite this page

Print/export
- Create a book

Flash evaporation

From Wikipedia, the free encyclopedia

Flash (or partial) evaporation is the partial vapor that occurs when a saturated liquid stream undergoes a reduction in pressure by passing through a throttling valve or other throttling device. This process is one of the simplest unit operations. If the throttling valve or device is located at the entry into a pressure vessel so that the flash evaporation occurs within the vessel, then the vessel is often referred to as a flash drum.[1][2]



A typical flash drum

If the saturated liquid is a single-component liquid (for example, liquid propane or liquid ammonia), a part of the liquid immediately "flashes" into vapor. Both the vapor and the residual liquid are cooled to the saturation temperature of the liquid at the reduced pressure. This is often referred to as "auto-refrigeration" and is the basis of most conventional vapor compression refrigeration systems.

If the saturated liquid is a multi-component liquid (for example, a mixture of propane, isobutane and normal butane), the flashed vapor is richer in the more volatile components than is the remaining liquid.

Uncontrolled flash evaporation can result in a boiling liquid expanding vapor explosion (BLEVE).

Contents [hide]

Data

Antoine equation constants for determining vapor pressure

Vapor Pressure (or Saturation Pressure) is discussed in Chapter 5. The Antoine equation is a very common way to determine vapor pressure as a function of temperature. Three constants are needed to calculate vapor pressures from the Antoine equations. These constants are tabulated here for many common compounds.

$$\log_{10} P^{sat} = A - \frac{B}{T+C}$$

where A, B, C are tabulated here. P^{sat} has units of mmHg and T has units of °C. These tables can easily be copied to a spreadsheet for simplifying vapor pressure calculations.

Compound	Formula	A	B	C	Range (Low T)	Range (High T)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Chloroform	$CHCl_3$	6.90328	1163.03	227.4	-30	150
Cyclohexane	C_6H_{12}	6.84941	1206.001	223.148	19.9	81.6
Cyclohexanol	$C_6H_{13}O$	6.2553	912.866	109.126	93.7	160.7
n-Decane	$n\text{-}C_{10}H_{22}$	6.95707	1503.568	194.738	94.5	175.1
1-Decene	$C_{10}H_{20}$	6.95433	1497.527	197.056	86.8	171.6

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Surveying the Students

Beta Test: Spring 2014 with 153 students

- 80% of class purchased FMEB
- 66% of class found FMEB useful

Most common complaints: Fix the typos, include all of the major course concepts, and data tables

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Completed Summer 2014

What's next? – Research Questions

Usage analytics: How well are students engaged, how long students reading the STAR format versus a traditional paper textbook, which levels of the questions are students using, which difficulty of scaffolded examples are the students using.

Can the 12 step problem solving technique be observed in a time restricted exam setting.

Can this technology be fully integrated with online homework (e.g., Sapling Learning) to provide instructors real time assessment of the students progress in problem solving and conceptual knowledge.

Why Software Trumps 'Print'

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Traditional Textbook	$71.50 for Kindle	No	Once per decade

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