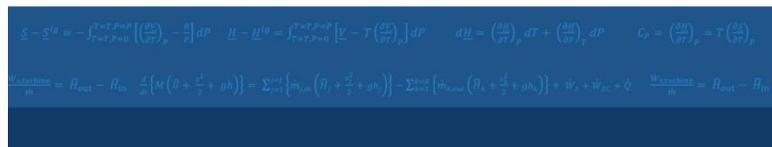
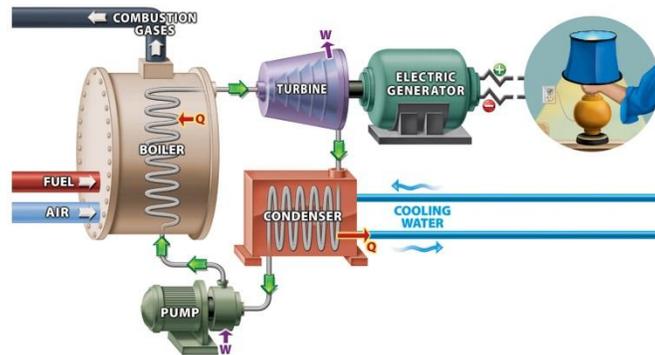
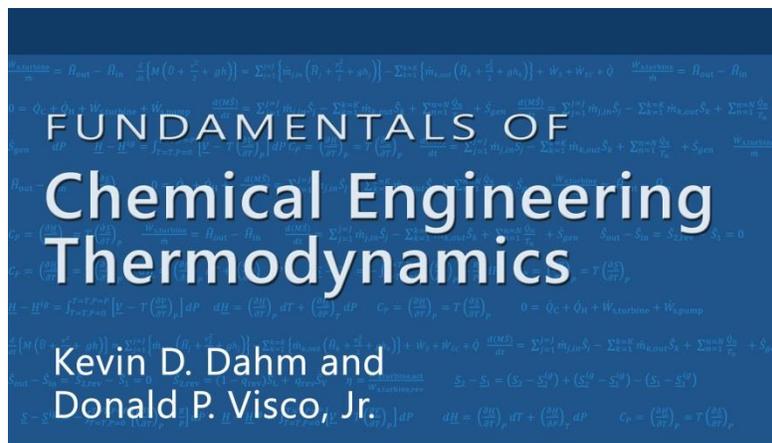


An Instructor's Solutions Manual to Accompany

FUNDAMENTALS OF CHEMICAL ENGINEERING THERMODYNAMICS

KEVIN D. DAHM AND DONALD P. VISCO, JR.





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ISBN-13: 978-1-133-59845-9
ISBN-10: 1-133-59845-5

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**INSTRUCTOR'S SOLUTIONS
MANUAL
TO ACCOMPANY**

**FUNDAMENTALS OF
CHEMICAL
ENGINEERING
THERMODYNAMICS**

FIRST EDITION

KEVIN D. DAHM AND DONALD P. VISCO, JR.

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3-25) A two-step, steady state process is used to compress 100 kg/min of nitrogen from $P=1$ bar and $T=250$ K to $P=10$ bar and $T=250$ K. First, an adiabatic compressor is used to convert the nitrogen from $P=1$ bar and $T=250$ K to $P=10$ bar and $T=300$ K. Then a heat exchanger is used to cool the nitrogen to $T=250$ K. Find the work added in the compressor, and the heat removed in the heat exchanger.

A) Use an ideal gas model

B) Use Figure 2-3 as much as possible. If you need an equation of state, use the van der Waals equation, with $a=1.37 \times 10^6$ bar·cm⁶/mol² and $b=38.6$ cm³/mol.

Solution:

A) For an ideal gas:

$$d\bar{H} = C_p^* dT$$

$$(\hat{H}_{out} - \hat{H}_{in}) = C_p^* dT$$

Set up an energy balance around the compressor

$$\frac{d}{dt} \left\{ M \left(\bar{U} + \frac{v^2}{2} + gh \right) \right\} = \dot{m}_{in} \left(\hat{H}_{in} + \frac{v_{in}^2}{2} + gh_{in} \right) - \dot{m}_{out} \left(\hat{H}_{out} + \frac{v_{out}^2}{2} + gh_{out} \right) + \dot{W}_S + \dot{W}_{EC} + \dot{Q}$$

Cancelling terms

$$0 = \dot{m}_{in}(\hat{H}_{in}) - \dot{m}_{out}(\hat{H}_{out}) + \dot{W}_S$$

$$100 \frac{\text{kg}}{\text{min}} (\hat{H}_{out} - \hat{H}_{in}) = \dot{W}_S$$

Using Appendix D

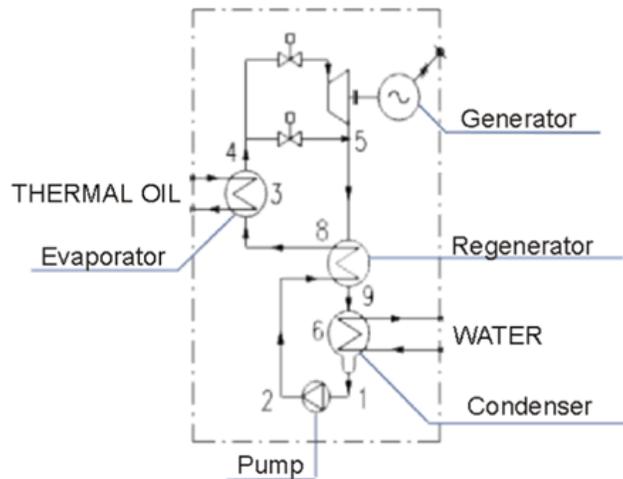
$$d\bar{H} = C_p^* dT$$

$$\frac{C_p^*}{R} = A + BT + CT^2 + DT^3 + ET^4$$

$$d\bar{H} = (RA + RBT + RCT^2 + RDT^3 + RET^4)dT$$

$$\int_{out}^{in} d\bar{H} = \int_{out}^{in} (RA + RBT + RCT^2 + RDT^3 + RET^4)dT$$

5-9) Below is a schematic of a variation on the Rankine Cycle, not for steam but for an organic fluid. This process has been called the “organic Rankine Cycle:”



- Do some research and determine the major advantage of using a Rankine cycle with an organic as a working fluid as opposed to water.
- There are five unit operations in the process above. Describe what is happening in each of those steps (for the organic working fluid).
- There is a valve between line 4→ 5. Why do you think that line exists and why do you think that valve is there?

Solution:

A) The major advantage of the ORC is to obtain useful work from low temperature heat sources. Temperatures too low to boil water will boil many organics, and that is why organic vapor is useful.

B) The turbine/generator is used to convert the internal energy of the organic into useful shaft work. This shaft work is used to create electricity.

The regenerator is used to heat the compressed liquid from the pump. It takes the hot organic from the turbine and reclaims energy so that the boiler does not require as much energy.

The condenser condenses the vapor from the regenerator in order to pressurize it. The purpose of this step is to avoid compressing a vapor because this requires a large amount of work. It is far easier to pressurize a liquid than a vapor.

The pump takes the saturated liquid from the condenser and pressurizes it.

The evaporator uses hot thermal oil to evaporate the compressed liquid past its boiling point. The vapor leaves the boiler as either saturated or superheated.

Chapter 8: Modeling Phase Equilibrium for Pure Compounds

8-10) Estimate the vapor pressure of ethanol at temperatures of $T=0, 50, 100$ and 150°C :

- A) Using the Antoine equation.
- B) Using the Clausius-Clapeyron equation with $\Delta H^{vap}=42.0$ kJ/mol at the normal boiling point of $T=351.5$ K.
- C) Using the shortcut equation.
- D) For each temperature, identify the estimate you consider the most accurate, and explain why.

Solution:

Answers for parts A-C are summarized in the table and sample calculations for $T = 0^\circ\text{C}$ are shown below.

Vapor pressures in bar

| | $T = 0^\circ\text{C}$ | $T = 50^\circ\text{C}$ | $T = 100^\circ\text{C}$ | $T = 150^\circ\text{C}$ |
|-----------------------|-----------------------|------------------------|-------------------------|-------------------------|
| A) Antoine | 0.0163 | 0.2953 | 2.267 | 10.29 |
| B) Clausius-Clapeyron | 0.0164 | 0.2871 | 2.332 | 11.55 |
| C) Shortcut | 0.0250 | 0.3291 | 2.174 | 9.19 |

A) Antoine equation, T expressed in Celsius, P^{sat} expressed in mm Hg.

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

A, B and C for ethanol obtained from Appendix E.

$$\log_{10} P^{sat} = 8.32109 - \frac{1718.10}{0 + 237.52} = 1.0876$$

$$P^{sat} = 10^{1.0876} = (12.23 \text{ mm Hg}) \left(\frac{1 \text{ atm}}{760 \text{ mm Hg}} \right) \left(\frac{1.013 \text{ bar}}{1 \text{ atm}} \right) = 0.0163 \text{ bar}$$

B) Clausius-Clapeyron equation. The given data applies to $P = 1$ atm so let this be state 1.

$$\ln \left(\frac{P_2^{sat}}{P_1^{sat}} \right) = \frac{-\Delta H^{vap}}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

Finding the dew point:

$$P = \frac{1}{\left(\frac{y_1}{P_1^{sat}} + \frac{y_2}{P_2^{sat}}\right)} = \frac{1}{\left(\frac{0.5}{1231.42 \text{ mmHg}} + \frac{0.5}{179.49 \text{ mmHg}}\right)} = 313.32 \text{ mmHg}$$

Because the operating pressure (75 kPa = 562.55 mmHg) is between the bubble (705.46 mmHg) and dew points (313.32 mmHg) pressures of the mixture at this composition, it will partially flash at this temperature.

We can write four equations (2 material balances and 2 Raoult's Law)

The overall material balance is:

$$20 \frac{\text{kmol}}{\text{hr}} = \dot{L} + \dot{V}$$

The material balance on n-pentane is:

$$(0.5)20 \frac{\text{kmol}}{\text{hr}} = x_1 \dot{L} + y_1 \dot{V}$$

Raoult's law for n-pentane is:

$$x_1 P_1^{sat} = y_1 P$$

Raoult's law for 2-propanol is:

$$(1 - x_1) P_2^{sat} = (1 - y_1) P$$

Thus, we have four equations (above) in four unknowns: \dot{L} , \dot{V} , x_1 , y_1

We can solve this set of four equations and four unknowns in a variety of ways. The Solver function on Excel is a reasonable approach. Solving these equations yields:

$$\dot{L} = 13.72 \text{ kmol/hr}$$

$$\dot{V} = 6.28 \text{ kmol/hr}$$

$$x_1 = .364$$

$$y_1 = .797$$

Thus, a liquid stream containing 36.4% by mole n-pentane leaves the flash distillation unit at 13.72 kmol/hr. Likewise, a vapor stream containing 79.7% by mole n-pentane leaves the flash distillation unit at 6.28 kmol/hr.

Entered into O15-O25 for each composition

$$Z_m^V = \frac{PV_m^V}{RT}$$

Entered into N15-N25 for each composition

V_m^L, V_m^V and P, although unknown, still need to be referenced in cells within the spreadsheet. These cells will be varied when we run solver.

Using Appendix C, we can determine our a and b values for each component which will lead to a_m and b_m . We do this the same way we find the parameters for the pure PR EOS:

$$b = 0.07780R \frac{T_c}{P_c}$$

Entered into cell B10 for component 1 and C10 for component 2

$$a_c = 0.45724R^2 \frac{T_c^2}{P_c}$$

Entered into B7 for component 1 and C7 for component 2

$$a = a_c \alpha$$

Entered into B6 for component 1 and C6 for component 2

$$\alpha = [1 + \kappa(1 - T_r^{0.5})]^2$$

Entered into B8 for component 1 and C8 for component 2

$$\kappa = 0.37464 + 1.54226\omega - 0.269932\omega^2$$

Entered into B9 for component 1 and C9 for component 2

Once values for a_1, b_1, a_2 and b_2 are determined, we can now determine the a and b values for the mixture.

$$a_m^L = x_1x_1a_{11} + x_1x_2a_{12} + x_2x_1a_{21} + x_2x_2a_{22}$$

Entered in cells J15-J25

$$a_m^V = y_1y_1a_{11} + y_1y_2a_{12} + y_2y_1a_{21} + y_2y_2a_{22}$$

Entered in cells L15-L25

$$b_m^L = x_1b_{11} + x_2b_{22}$$