

***Transport Processes and Separation Process
Principles 5th edition Geankoplis Solutions Manual***

SKU: 9780134181028-SOLUTIONS

Instructor Manual for

Transport Processes and Separation Process Principles

Fifth Edition

Christie John Geankoplis
A. Allen Hersel
Daniel Lepek



Boston • Columbus • New York • San Francisco • Amsterdam • Cape Town
Dubai • London • Madrid • Munich • Paris • Montreal • Toronto • Delhi • Mexico City
São Paulo • Hong Kong • Seoul • Singapore • Taipei • Tokyo

The author and publisher have taken care in the preparation of this work, but make no expressed or implied warranty of any kind and assume no responsibility for errors or omissions. No liability is assumed for incidental or consequential damages in connection with or arising out of the use of the information or programs contained herein.

Visit us on the Web: informit.com

Copyright © 2019 Pearson Education, Inc.

This work is protected by United States copyright laws and is provided solely for the use of instructors in teaching their courses and assessing student learning. Dissemination or sale of any part of this work (including on the World Wide Web) will destroy the integrity of the work and is not permitted. The work and materials from it should never be made available to students except by instructors using the accompanying text in their classes. All recipients of this work are expected to abide by these restrictions and to honor the intended pedagogical purposes and the needs of other instructors who rely on these materials.

ISBN-13: 978-0-13-418163-9
ISBN-10: 0-13-418163-8

September 2020, version 2

Publisher's Note: This Instructor Manual is a work in process. Any pages without a supplied solution will be replaced at future releases.

(1.2-1)

$$\text{Eq. (1.3-4) } k = 353.2 = {}^{\circ}\text{C} + 273.15 \quad {}^{\circ}\text{C} = 80.05 = \boxed{80^{\circ}\text{C}}$$

$$\text{Eq. (1.3-2) } {}^{\circ}\text{C} = 80.0 = (1/1.8)({}^{\circ}\text{F} - 32) \quad {}^{\circ}\text{F} = \boxed{176^{\circ}\text{F}}$$

$$\text{Eq. (1.3-3) } {}^{\circ}\text{R} = {}^{\circ}\text{F} + 460 = 176 + 460 \quad {}^{\circ}\text{R} = \boxed{636^{\circ}\text{R}}$$

(1.2-2)

$$\text{Eq. (1.3-2) } ^\circ\text{C} = (1/1.8)(^\circ\text{F} - 32) = (1/1.8)(155 - 32) = \boxed{68.33^\circ\text{C}}$$

$$\text{Eq. (1.3-4) } \text{K} = ^\circ\text{C} + 273.15 = 68.33 + 273.15 = \boxed{341.5\text{K}}$$

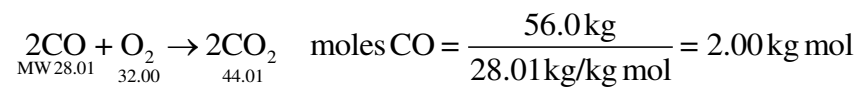
$$\text{Eq. (1.3-3) } ^\circ\text{R} = ^\circ\text{F} + 460 = 155 + 460 = \boxed{615^\circ\text{R}}$$

(1.3-1)

$$\text{MW}(\text{O}_2) = 32.00, \quad \text{MW}(\text{N}_2) = 28.02$$

$$\text{MW}(\text{air}) = 0.21(32.00) + 0.79(28.02) = \boxed{28.9 \text{ kg / kg mol}}$$

(1.3-2)



$$\text{moles O}_2 = 1.00, \quad 1.00(32.00) = \boxed{32.0 \text{ kg O}_2} \quad 2.00(44.0) = \boxed{88.0 \text{ Kg CO}_2}$$

(1.3-3)

Gas	g	MW	g mol	mol/sec
N ₂	20	28.02	0.7138	0.1648 mol/sec
O ₂	83	32.00	2.5938	0.5990
CO ₂	45	44.01	1.0225	0.2362
Total	148 g		4.330/g mol	1.0000

$$\text{Average mol wt} = \frac{148 \text{ g}}{4.3301 \text{ g mol}} = \begin{array}{l} 34.2 \text{ g/g mol} \\ 34.2 \text{ kg/kg mol} \end{array}$$

(1.3-4)

(1.3-5)

(1.4-1)

$$P = 2.4 \text{ mm Hg}$$

From Appendix A.1

$$1 \text{ atm} = 760 \text{ mm Hg}$$

$$P = \frac{2.4 \text{ mm Hg}}{760 \text{ mm Hg/atm}} = \boxed{3.16 \times 10^{-3} \text{ atm}}$$

$$1 \text{ atm} = 33.90 \times 12 \text{ in. H}_2\text{O (at 4}^\circ\text{C)}$$

$$P = \frac{2.4}{760} \text{ atm} \left(33.90 \times 12 \frac{\text{in. H}_2\text{O}}{\text{atm}} \right) = \boxed{1.285 \text{ in. H}_2\text{O}}$$

$$1 \text{ } \mu\text{m} = 10^{-3} \text{ mm}$$

$$P = \frac{2.4 \text{ mm}}{10^{-3} \text{ mm}/\mu\text{m}} = \boxed{2,400 \mu\text{m Hg}}$$

$$1 \text{ atm} = 1.01325 \times 10^5 \text{ Pa}$$

$$P = \frac{2.4}{760} \text{ atm} \left(1.01325 \times 10^5 \frac{\text{Pa}}{\text{atm}} \right) = \boxed{320 \text{ Pa}}$$

(1.4-2)

$$V_1 = 65.0 \text{ ft}^3, T_1 = 460 + 90 = 550 \text{ }^\circ\text{R}, T_2 = 460 + 65 = 525 \text{ }^\circ\text{R}$$

From Appendix A.1, 1 atm = 14.696 psia

$$p_1 = 29.0 + 14.696 = 43.696 \text{ psia}, p_2 = 75.0 + 14.696 = 89.696 \text{ psia}$$

$$p_1 = 43.696/14.696 = 2.975 \text{ atm}, p_2 = 89.696/14.696 = 6.104 \text{ atm}$$

Eq. (1.4-2)

$$V_2 = V_1 \frac{p_1}{p_2} = 65.0 \frac{(2.975)}{(6.104)} = \boxed{30.24 \text{ ft}^3}$$

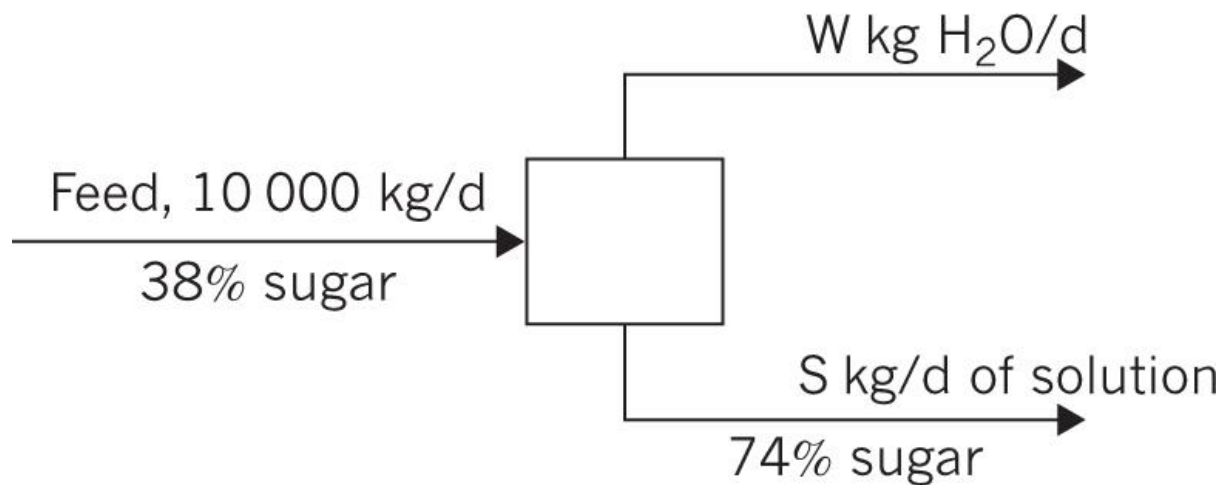
$$R = 0.7302 \text{ ft}^3 \cdot \text{atm/lb mol} \cdot ^\circ\text{R}, \text{ MW of N}_2 = 28.01$$

Eq. (1.4-1)

$$n = pV/RT = (2.975)(65.0)/(0.7302)(550) = \boxed{0.4815 \text{ lb mol}}$$

$$\text{Density, } = (0.4815)(28.01)/30.24 = \boxed{0.446 \text{ lb}_m/\text{ft}^3}$$

(1.5-1)



Basis: 10 000 kg/a feed

Total balance

$$10\,000 = S + W$$

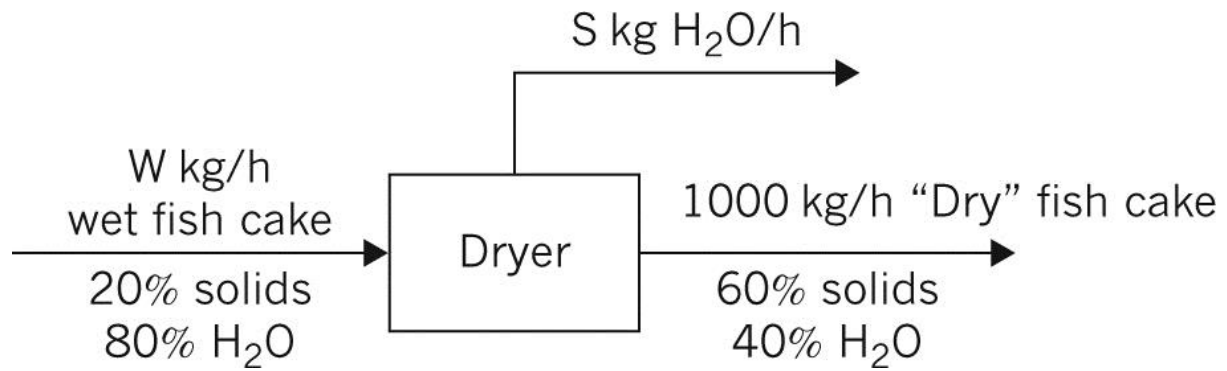
Solids balance

$$0.38 (10\,000) = 0.745 + (0)W$$

$$W = 10000 - 5135 = \boxed{4865 \text{ kg H}_2\text{O/d}}$$

$$\boxed{S = 5135 \text{ kg/d of 74\% solution}}$$

(1.5-2)



Basis: 1000 kg/h “dry” fish cake

Solids balance

$$0.20W = S(0) + 0.60(1000)$$

$$W = 3000 \text{ kg/h wet cake feed}$$

Total balance

$$W = S + 1000$$

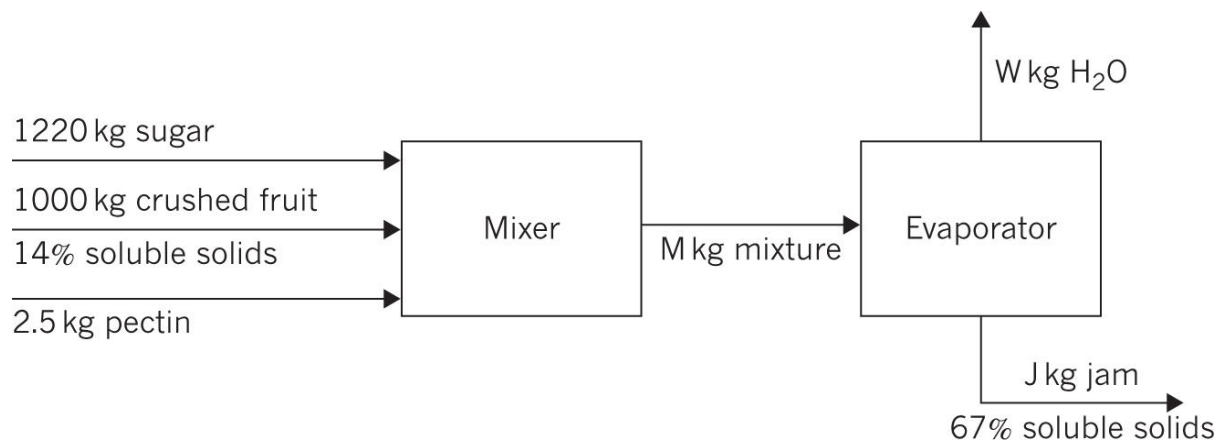
$$3000 = S + 1000$$

$$S = 2000 \text{ kg H}_2\text{O/h}$$

(1.5-3)

(1.5-4)

(1.5-5)



Basis: 1000 kg crushed fruit

Soluble solids balance over whole process

$$1220 + 0.14(1000) + 2.5 = 0.67J + W(0)$$

$$\boxed{J = 2033.5 \text{ kg jam}}$$

Total balance over mixer

$$1220 + 1000 + 2.5 = M$$

$$\boxed{M = 2222.5 \text{ kg mixture}}$$

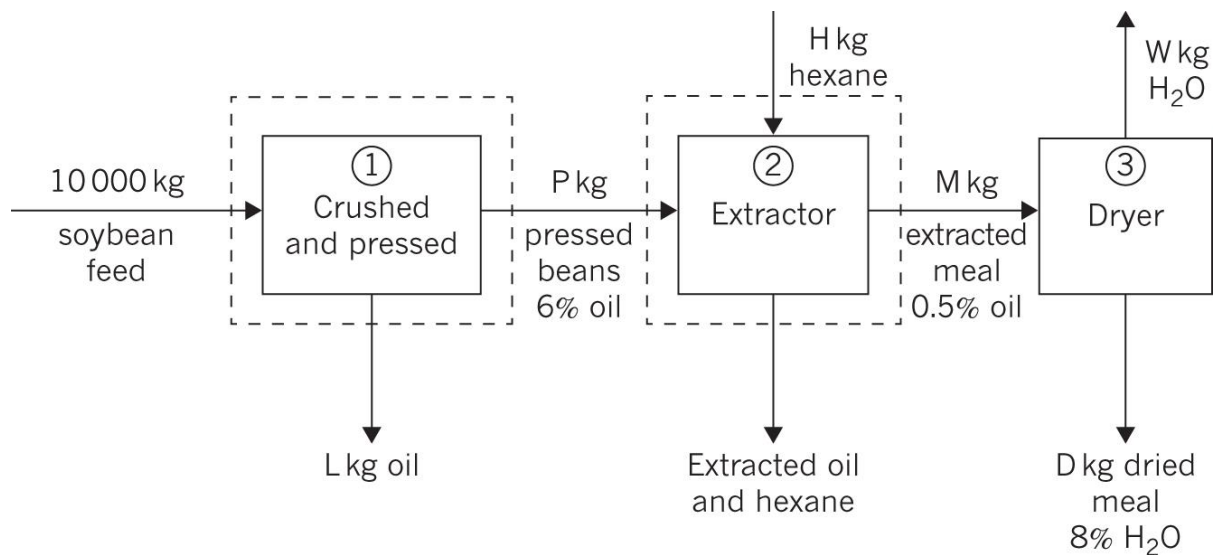
Total balance over evaporator

$$2222.5 = W + 2033.5$$

$$\boxed{W = 189 \text{ kg H}_2\text{O}}$$

(1.5-6)

(1.5-7)



Soybean feed

	%	kg	
Oil	18.0	1800	
Protein	35.0	3500	} meal
Carbohydrate	27.1	2710	
Fiber, ash	9.4	940	
Moisture	10.5	1050	
	<u>100.0</u>	<u>10,000</u>	

(a) Balance on meal (1)



$$0.82(10000) = 0.94P \quad \boxed{P = 8723 \text{ kg dressed beans}} \quad L = 1277 \text{ kg oil}$$

Total balance

$$10,000 = L + P$$

(b) Balance on meal (2)



$$0.94(8723) = 0.995M \quad \boxed{M = 8241 \text{ kg extracted meal}}$$

$$\text{kg oil} = 0.005(8241) = 41 \text{ kg oil in meal}$$

(c) Composition of M

Oil 41 kg

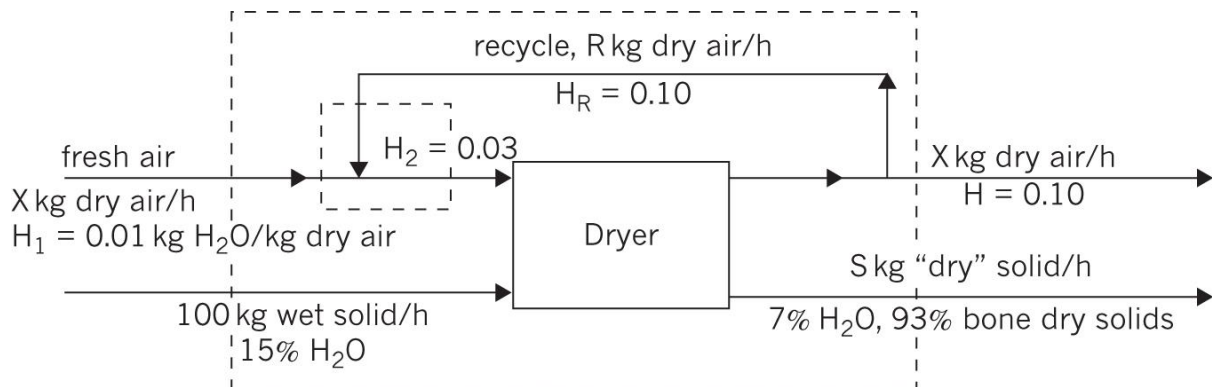
Protein	3500
Carbohydrate	2710
Fiber, ash	940
H ₂ O	1050
M =	8241 kg

Balance on meal (less H₂O) (3)

$$8241 - 1050 = 0.92 D \quad \boxed{D = 7816 \text{ kg dried meal}}$$

$$\text{Wt}\% = \frac{3500}{7816} \times 100 = \boxed{44.8 \text{ wt \% protein}}$$

(1.5-8)



Basis: 100 kg wet solid/h

Bone dry solids balance on overall process



$$0.85(100) = 0.93S \quad \boxed{S = 91.4 \text{ kg/h "dried" product}}$$

Water balance on overall process



$$0.01x + 0.15(100) = 0.10x + 0.07(91.4)$$

$$\boxed{x = 95.6 \text{ kg/h dry air in fresh air}}$$

Water balance on inlet point



$$0.01X + 0.10R = 0.03(R + X)$$

$$0.01(95.6) + 0.10R = 0.03(R + 95.6)$$

$$\boxed{R = 27.3 \text{ kg/h dry air in recycle air}}$$

Overall check balance on H₂O



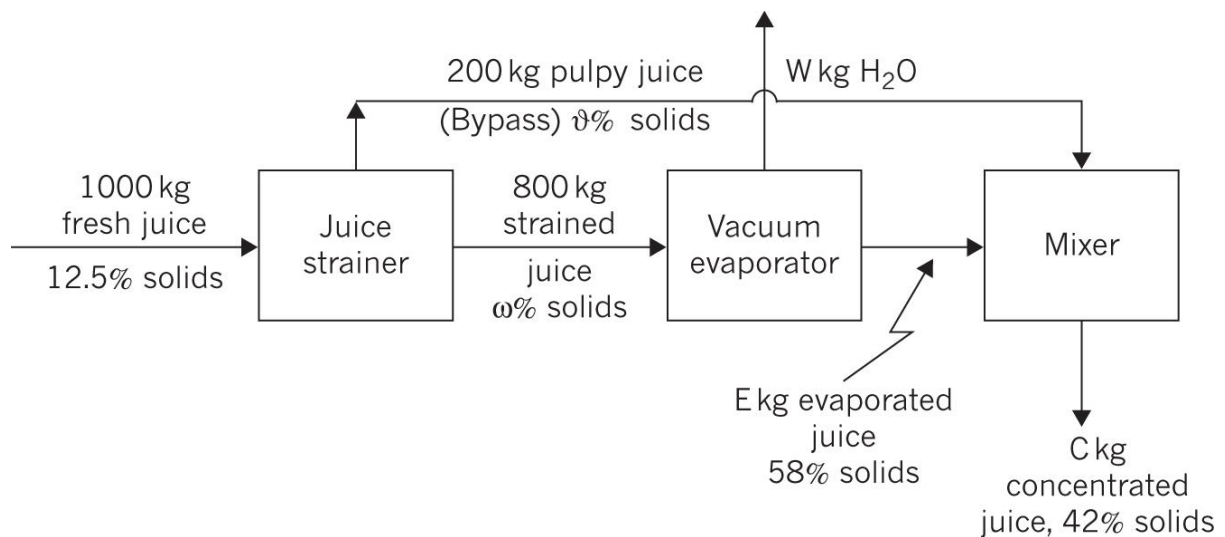
$$0.01(95.6) + 0.15(100) = 0.07(91.4) + 0.10(95.6)$$

$$0.956 + 15.00 = 6.40 + 9.56$$

$$15.956 \cong 15.96 \text{ Hence, a close check.}$$

(1.5-9)

(1.5-10)



Basis: 1000 kg fresh juice

Total balance on overall process

$$1000 = W + C$$

Solids balance on overall process

$$0.125(1000) = W(0) + 0.42 C$$

$$W = 1000 - 298$$

$$W = 702 \text{ kg H}_2\text{O}$$

$C = 298 \text{ kg concentrated juice}$

Balance on evaporator

Total

$$800 = 702 + E$$

$$E = 98 \text{ kg evaporated juice}$$

Solids

$$\frac{w}{100}(800) = 702(0) + 0.58(98)$$

$w = 7.10\% \text{ solids in strained juice}$

Solids balance on mixer

Ancillary material to Geankoplis, et al., Transport Processes and Separation Process Principles, 5/E, ISBN: 9780134181028.
Copyright (c) 2019 Pearson Education, Inc. Do not distribute.

$$\frac{v}{100}(200) + 0.58^{(E)}(98) = 0.42^{(C)}(298)$$

$v = 34.2\%$ solids in pulpy juice by passed
--

(1.5-11)

(1.5-12)

(1.5-13)

(1.5-14)

(1.6-1)

$$g \text{ mol CO}_2 = \frac{250}{44.0} = 5.680$$

$$c_{\text{km}}(298 - 373 \text{ K}) = 38.73 \text{ kJ/kg mol} \cdot \text{K} \quad \text{Table 1.5-1}$$
$$(298 - 373 \text{ K}) = 38.73$$

$$q(373 - 623 \text{ K}) = q_1(298 - 623) - q_2(298 - 373)$$

$$q = \frac{5.680}{1000} [43.06(623 - 298) - 38.73(373 - 298)]$$

$$\boxed{q = 62.98 \text{ kJ}}$$

$$q = \frac{62.98 \text{ kJ} \times 1000}{4.184 \frac{\text{J}}{\text{cal}}} = \boxed{15050 \text{ cal}}$$

$$q = \frac{62.98 \text{ kJ}}{1.05506 \text{ kJ/btu}} = \boxed{59.7 \text{ btu}}$$

(1.6-3)

From appendix A.4, $c_k = 4.02 \text{ kJ/kg} \cdot \text{K}$ at 32.8°C

assume $c_{km} = 4.02$ note: $(t - 10)^\circ\text{C} = (t - 10) \text{ K}$

$$q = 121300 \text{ kJ} = 454 \text{ kg} \left(4.02 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \right) (t - 10) \text{ K}$$

solving, $(t - 10) = 66.5 \text{ K} = 66.5^\circ\text{C}$ $t = 76.5^\circ\text{C}$

(1.6-4)

(a) A.2-9 P = 30 psia Liquid H₂O

$$\begin{aligned}\Delta H &= H_{240^{\circ}\text{F}} - H_{40^{\circ}\text{F}} \\ &= 208.44 - 8.02 = \boxed{200.42 \text{ btu/lb}_m}\end{aligned}$$

(b) P = 24.97 psia

$$\begin{aligned}H_{240^{\circ}\text{F}}(\text{vapor}) &= 1160.7 \\ H_{40^{\circ}\text{F}}(\text{liquid}) &= \underline{8.02} \\ \Delta H &= \boxed{1152.7 \text{ btu/lb}_m}\end{aligned}$$

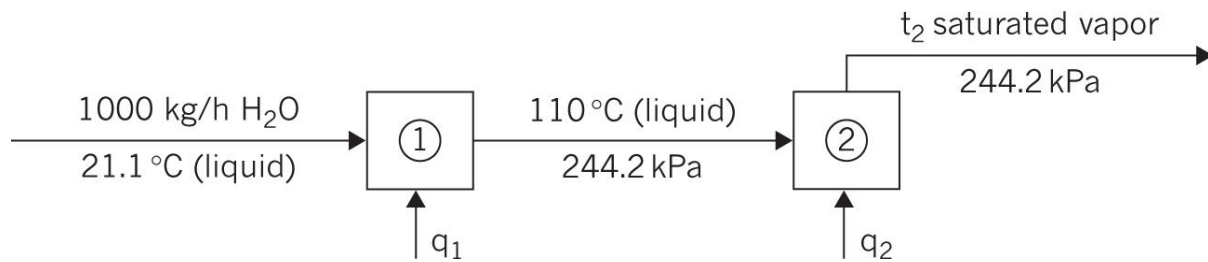
(c) P = 1.0 atm abe

$$\begin{aligned}H_{212^{\circ}\text{F}}(\text{vapor}) &= 1150.5 \\ H_{40^{\circ}\text{F}}(\text{liquid}) &= \underline{28.1} \\ \Delta H &= \boxed{-1122.4 \text{ btu/lb}_m}\end{aligned}$$

(d) P = 1.0 atm abe

$$\begin{aligned}H_{212^{\circ}\text{F}}(\text{vapor}) &= 1150.5 \\ H_{212^{\circ}\text{F}}(\text{liquid}) &= \underline{180.2} \\ \Delta H &= \boxed{-970.3 \text{ btu/lb}_m \text{ } (-2256.9 \text{ kJ/kg})}\end{aligned}$$

(1.6-5)



From Table A.2-9, $t_2 = 126.6\text{ }^{\circ}\text{C}$ (linear interpolation)

h (liq. at $21.1\text{ }^{\circ}\text{C}$) = 88.56 kJ/kg, h (liq. at $110\text{ }^{\circ}\text{C}$) = 461.30 kJ/kg

H (sat'd vapor at $126.6\text{ }^{\circ}\text{C}$) = 2715.7 kJ/kg

First stage (1)

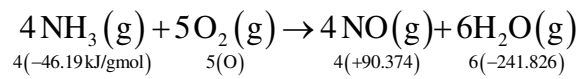
$$q_1 = (461.30 - 88.56 \text{ kJ/kg}) \left(1000 \frac{\text{kg}}{\text{h}} \right) = \boxed{3.7274 \times 10^5 \text{ kJ/h}}$$

Both stages (1) and (2)

$$q_1 + q_2 = (2715.7 - 88.56)(1000) = \boxed{2.6271 \times 10^6 \text{ kJ/h}}$$

(1.6-7)

Table A.3-1 (4.0 g mol NH₃)



Eq. (1.6-7)

$$\begin{aligned} \Delta H^\circ &= \sum \Delta H_{f(\text{products})}^\circ - \sum \Delta H_{f(\text{reactants})}^\circ \\ &= [4(+90.374) + 6(-241.826)] - [4(-46.19) + 5(0)] \\ &\boxed{\Delta H^\circ = -904.7\text{ kJ/gmol} (-216.24\text{ kcal/gmol})} \end{aligned}$$

(1.7-1)

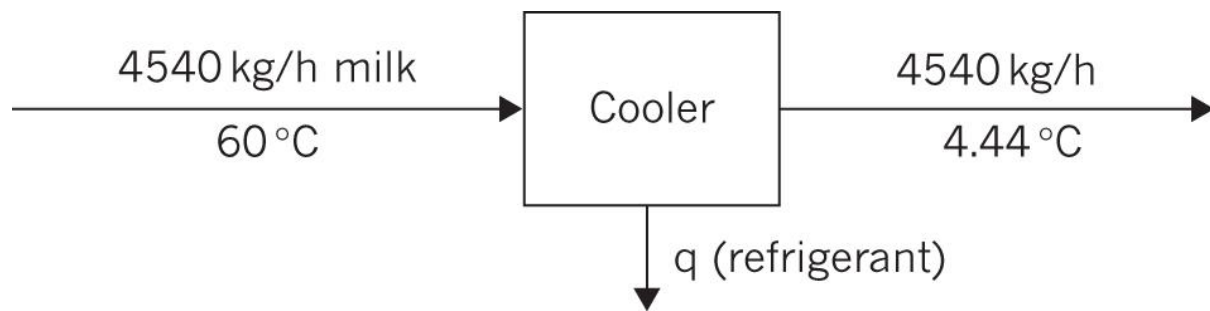


Table A.4-1

$$C_{km} (\text{milk}) = 3.85 \text{ kJ/kg} \cdot \text{K}$$

Heat balance: Datum=25 °C

Input

$$H (\text{milk}) = 4540 (3.85)(60 - 25) = 611765 \text{ kJ/h}$$

Output

$$H (\text{milk}) = 4540 (3.85)(4.44 - 25) = -359368 \text{ kJ/h}$$

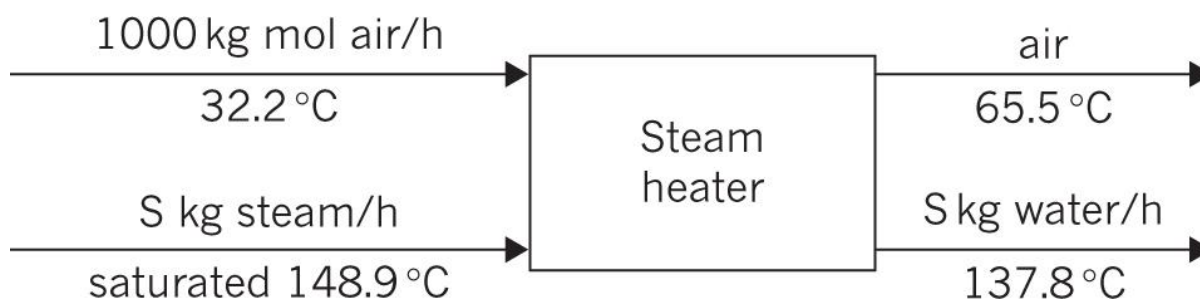
q

$$\text{Input} = \text{Output}$$

$$611765 = -359368 + q$$

$$q = 971133 \text{ kJ/h} = \frac{971,133}{3600} = \boxed{269,6 \text{ kW}} \\ \boxed{(920000 \text{ btu/h})}$$

(1.7-4)



Datum: 25 °C

(air $c_{km} = 29.20 \text{ kJ/kg mol} \cdot \text{K}$ for 25 – 32.2 °C Table 1.6–1)

Heat in

$$H(\text{air}) = (1000)(29.20)(32.2 - 25.0) = 210240 \text{ kJ/h}$$

$$H(\text{steam}) = S(2745.1) = 2745.15 \text{ kJ/h}$$

(Table A.2–9)
148.9 °C

Heat out

$$H(\text{air}) = (1000)(29.25)(65.5 - 25.0) = 1184625 \text{ kJ/h}$$

$$H(\text{water}) = S(579.70) = 579.70S \text{ kJ/h}$$

137.8 °C

In = out

$$210240 + 2745.15 = 1184625 + 579.70S$$

$S = 450 \text{ kg steam/h}$

(1.8-1)

Simpson's Method

$$\text{Eq. (1.8-2) } h = 0.1 \quad m = \frac{b - a}{h} = \frac{0.6 - 0}{0.1} = 6$$

Eq. (1.8-3)

$$A = \int_{x=0}^{x=0.6} f(x) dx = \frac{h}{3} [f_0 + 4(f_1 + f_3 + f_5 + \dots) + 2(f_2 + f_4 + f_6 + \dots)]$$

$$A = \frac{0.1}{3} [100 + 4(75 + 53.5 + 60) + 2(60.5 + 53 + 72.5)]$$

$$A = 38.45$$

(1.8-2)

$$\text{Total flow in m}^3 = \int_{t=0}^{t=t_F} q \, dt \quad \text{Eq. (1.8-1)}$$

where $t = \text{min.}$, and $q = \text{flow rate m}^3/\text{min.}$

The data of flow note q vs. t are plotted as shown.

(a) For the first 60 min., a series of rectangles are drawn as shown. The total area under the curve is the sum of the rectangles A through F.

$$\begin{aligned} \text{Total area} &= 680(10) + 740(10) + 805(10) + 853(10) \\ &\quad + 884(10) + 884(10) \\ &= \boxed{48460 \text{ m}^3 \text{ for 60 min.}} \end{aligned}$$

For 120 min., use rectangles A through L

$$\begin{aligned} \text{Total area} &= 48,460 + 840(10) + 763(10) + 700(10) + 650(10) \\ &\quad + 620(10) + 620(10) \\ &= \boxed{90390 \text{ m}^3 \text{ for 120 min.}} \end{aligned}$$

(b) Simpson's method

Eq. (1.8-3)

$$h = 10 \text{ min.} \quad m = \frac{b-a}{h} = \frac{120-0}{10} = 12$$

Eq. (1.8-4)

$$\begin{aligned} \int_0^{120} f(x) dx &= \frac{h}{3} \left[h_0 + 4 \left(f_1 + f_3 + f_5 + f_7 + f_9 + f_{11} \right) \right. \\ &\quad \left. + 2 \left(f_2 + f_4 + f_6 + f_8 + f_{10} + f_{12} \right) \right] \\ &= \frac{10}{3} \left[655 + 4(705 + 830 + 890 + 800 + 670 + 620) \right. \\ &\quad \left. + 2(780 + 870 + 870 + 725 + 640 + 610) \right] \\ &= \boxed{92350 \text{ m}^3 \text{ for 120 min}} \end{aligned}$$