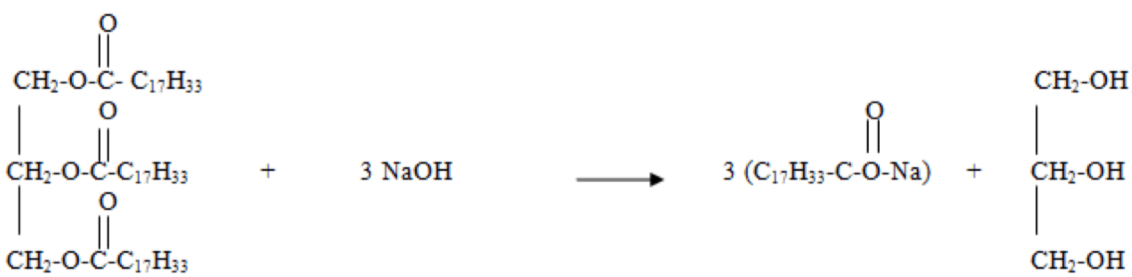
Chemical Engineering Thermodynamics
Quiz 4
February 7, 2019

Pork lard is composed of about 45% of the triglyceride of oleic acid (18 carbon fatty acid with one unsaturated bond) called glyceryl trioleate. For this problem, consider that lard is composed solely of oleic acid triglyceride. Through saponification (see reaction scheme below) it can be converted to soap and glycerol (also called glycerin) both of which are widely used in the cosmetic and personal care industry. After filtration of the crystallized soap (use $\Delta H_{melting}$ similar to ΔH_{vap}), crude glycerol is obtained by neutralization of the glycerol solution using concentrated HCl. The crude glycerol is then distilled to remove water and oleic acid salt and the liquid product. A second distillation yields 99.9% glycerol and a waste stream. The table on the next page lists the stream compositions. Use the heat of formation method to **fill out the table below and:**

a) **Find the heat needed to cool or heat the saponification reaction (only calculate streams 1,2). State if cooling or heating is needed.**
b) **Find the heat duty for the second boiler in the distillation step (only calculate streams 5,7,8).**
c) Extra credit: The last distillation is at a high temperature requiring a large heat input and possible degradation of the product. How could this step be improved?



Triglyceride Sodium hydroxide Soap Glycerol

NOTE: Soap (Oleic Acid Salt) is a crystalline solid which releases the heat of melting to crystallize.

Table of Thermodynamic Parameters

Material	State	ΔHf298K (kJ/mol)	MW (g/mol)	Tc (°K)	w	ΔHvap (kJ/mole)	Tboil (°K)	ΔHmelt (kJ/mole)	Tmelt (°K)	Cp A (J/(Kmole))	Cp B	Cp C	Cp D
Triglyceride	L	-2190	885							23	-1.76E-02	4.72E-04	0
NaOH (L)	L	-417	40							419	-1720	2.95	-1.6
H2O	L	-286	18	647	0.34		373			72.4	1.04E-02	-1.50E-06	0
Oleic Acid Salt	L	-765	282	819	1.19	83.8	456	39.6	287	811	0	0	0
Oleic Acid Salt	S		282					39.6	287	923	0	0	
Oleic Acid Salt	V	-562	282			203	468						
Glycerin	L	-670	92.1			91.7	560			220	0	0	0
Glycerin	V	-578	92.1							200	0	0	0

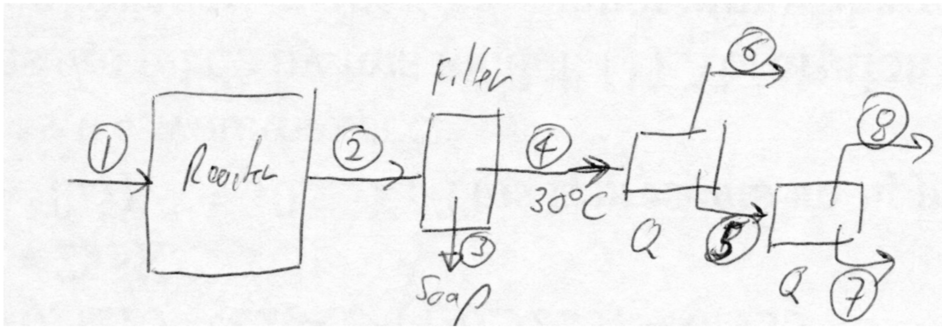


Fig. 1. Reactor Scheme showing reactor, filter, first and second distillation columns.

Molar Composition of the streams (Mole except where noted)
(On a one mole tiglyceride basis)

Step	1	2	3	4	5	6	7	8
Triglyceride	1.1	0.1	xxxx	0.1	0.1	0	0.1	0
NaOH (L)	3	0	xxxx	0	0	0	0	0
H2O	17	17	xxxx	15	0	15	0	0
Oleic Acid Salt (S)	0	3	2.8	0	0	0	0	0
Oleic Acid Salt (L)	0	0	xxxx	0.2				
Oleic Acid Salt (V)	0	0	xxxx	0	0	0.2	0	0
Glycerin (L)	0	1	xxxx	0.9	0.9	0	0	0
Glycerin (V)	0	0	xxxx	0	0	0	0	0.9
Temp. °K	298	350	350	298	500	500	600	600
P Mpa	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Fill This Table With Calculated Enthalpies

Step	T °K	P Mpa	State	H kJ	ΔH kJ	Heat or Cool?
1	298	0.1	L			
2	350	0.1	L/S			
3	350	0.1	S	xxxxxx	xxxxxx	xxxxxx
4	298	0.1	L	xxxxxx	xxxxxx	xxxxxx
5	500	0.1	L			
6	500	0.1	V	xxxxxx		
7	600	0.1	L			
8	600	0.1	V			

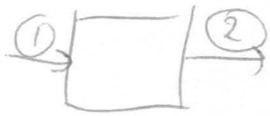
Stage	$\underline{H}$ kJ
1	-7,470
2	-7,630
5	-780
7	-216
8	-466

$\Delta\underline{H}$ kJ

Stages 1–2: → -160 Need to Cool

Stages 5–8: → 98 Need to Heat

a)



$$\underline{H}_1 = \underset{298}{TG}\ 1\,mol\left(\left(\Delta H_f^{298}\right)\right) + \underset{298}{\underset{(L)}{NaOH}}\ 1\,mol\left(\Delta H_f^{298}\right) + \underset{298}{\underset{L}{H_2O}}\left(\left(\Delta H_f^{298}\right)\right)17\,mol$$

$$= -2{,}190\ kJ + (-417\ kJ) - \left(286\ \tfrac{kJ}{mol}\right)17\,mol$$

$$\underline{H}_1 = -7{,}470\ kJ$$

$$\underline{H}_2 = 0.1\,mol\left(\left(-2{,}190\,kJ/mol\right) + \int_{298}^{350\,K}\left(C_{p_{TG}}\,dT\right)\right) \quad (3.48\ kJ/mol)$$

$$+ 17\,mol\left(-286\ kJ/mol + \int_{298}^{350\,K} C_{p_{H_2O}}\,dT\right) \quad (3.93\ kJ/mol)$$

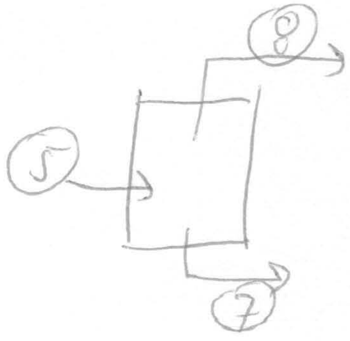
$$+ 2.9\,mol\left(-765\ kJ/mol + \int_{298}^{287\,K} C_{p_{CA}}\,dT + 39.6\ \tfrac{kJ}{mol} + \int_{287}^{350\,K} C_{p_{CA}}\,dT\right) \quad (-0.92\ \tfrac{kJ}{mol}) \quad (58.01\ \tfrac{kJ}{mol})$$

$$+ 1\,mol\left(-670\ \tfrac{kJ}{mol} + \int_{298}^{350} C_{p_F}\,dT\right) \quad (11.4\ kJ/mol)$$

$$\underline{H}_2 = -219\ kJ - 4800\ kJ - 1960\ kJ - 659\ kJ = -7630\ kJ$$

$$\Delta H = -7630\ kJ - (-7{,}470\ kJ) = -160\ kJ$$ Need to Cool

b)



$$\underline{H}_5 = \underset{\substack{TG \\ 500K}}{0.1\,\text{mole}} \left(-2190 \frac{kJ}{mole} + \int_{298}^{500K} \underset{TG(L)}{C_p\,dT} \right)$$

$(18.7\ kJ/mol)$

$$+ \underset{\substack{G(L) \\ 500K}}{0.9\,\text{mole}} \left(-670 \frac{kJ}{mol} + \int_{298}^{500} \underset{G(L)}{C_p\,dT} \right)$$

$(44.4\ kJ/mol)$

$= -780\ kJ$

$$\underline{H}_7 = \underset{\substack{TG \\ 600^\circ K}}{0.1\,\text{mole}} \left(-2190 \frac{kJ}{mole} + \int_{298}^{600} \underset{TG}{C_p\,dT} \right)$$

$(34.9\ \frac{kJ}{mol})$

$= -216\ kJ$

$$\underline{H}_8 = \underset{\substack{G \\ 600K \\ \text{vapor}}}{0.9\,\text{mol}} \left(-578 \frac{kJ}{mol} + \int_{298}^{600} \underset{\substack{G \\ \text{vap}}}{C_p\,dT} \right)$$

$(60.4\ kJ/mol)$

$= -466\ kJ$

$\Delta H = \underline{H}_7 + \underline{H}_8 - \underline{H}_5 = -216\,kJ - 466\,kJ - (-780\,kJ)$

$\Delta H = 98\ kJ$ Need to heat