ChE 455
Fall 2020
Major

Styrene Production

Styrene is the monomer used to make polystyrene, which has a multitude of uses, the most common of which are in packaging and insulated, styrofoam beverage cups. Styrene is produced by the dehydrogenation of ethylbenzene. Ethylbenzene is formed by reacting ethylene and benzene, and one of the ways benzene is made is by the hydrodealkylation or transalkylation of toluene, which is obtained as a byproduct of gasoline manufacture. There is very little ethylbenzene sold commercially. Most ethylbenzene manufacturers convert it directly into styrene in the same plant.

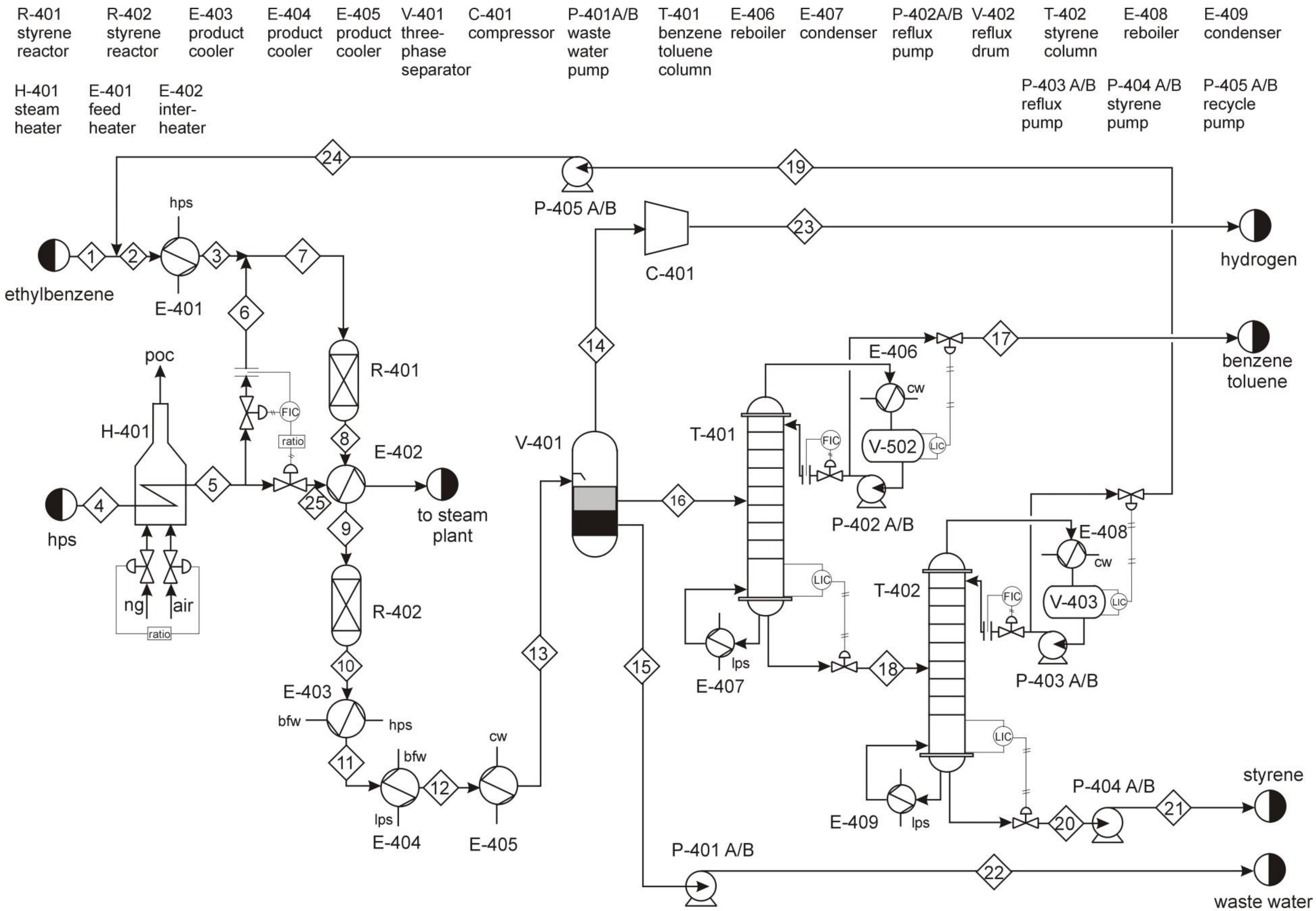
The plant at which you are employed currently manufactures ethylbenzene and styrene. This plant was recently acquired by your company in a takeover, and a team of engineers has been assigned to solve the problems observed in the process over the last few years. The unit to which you are assigned, Unit 400, converts the ethylbenzene into styrene, producing around 100,000 metric tons per year of 99.8 wt % styrene.

Process Description

The process flow diagram is shown in Figure 1. The reactions, the kinetics, and the equilibrium equations are detailed in Appendix 1. Ethylbenzene feed is mixed with recycled ethylbenzene, heated, and then mixed with high-temperature, superheated steam. Steam is an inert in the reaction, which drives the equilibrium (shown in Equation 1 in the Appendix 1) to the right by reducing the concentrations of all components. Since styrene formation is highly endothermic, the superheated steam also provides energy to drive the reaction to the right. The reactants then enter two adiabatic packed beds with interheating. The products are cooled, producing steam from the high-temperature reactor effluent. The cooled product stream is sent to a three-phase separator, in which light gases (hydrogen, methane, ethylene), organic liquid, and water each exit in separate streams. The hydrogen stream is further purified as a source of hydrogen elsewhere in the plant. The small amount of benzene and toluene is distilled and either incinerated for its fuel value or returned to the ethylbenzene process (since the benzene raw material always has some toluene impurity). The ethylbenzene and styrene stream is distilled to separate unreacted ethylbenzene for recycle from the styrene product.

The styrene product can spontaneously polymerize at higher temperatures. Since our product styrene is sent directly to the polymerization unit, experience suggests that as long its temperature is maintained below 125°C, there is no spontaneous polymerization problem. Since this is below styrene's normal boiling point, and since low pressure pushes the equilibrium to the right, much of this process is run at low pressures, with much of the separation section at vacuum.

Tables 1 and 2 show the design conditions for Unit 400. Table 3 contains an equipment list. Other pertinent information and calculations are contained in Appendix 2.



Unit 400: Production of Styrene from Ethylbenzene

Table 1
Stream Tables for Unit 400

Stream No.	**1**	**2**	**3**	**4**	**5**
Temperature (°C)	136.00	116.04	240.00	253.79	800.00
Pressure (kPa)	200.00	190.00	170.00	4237.00	4202.00
Vapor Mole Fraction	0.00	0.00	1.00	1.00	1.00
Total Flow (kg/h)	13,052.22	23,965.10	23,965.10	72,353.71	72,353.71
Total Flow (kmol/h)	123.42	226.21	226.21	4016.30	4016.30
Component Flows					
Water	0.00	0.00	0.00	4016.30	4016.30
Ethylbenzene	121.00	223.73	223.73	0.00	0.00
Styrene	0.00	0.06	0.06	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00
Benzene	1.21	1.21	1.21	0.00	0.00
Toluene	1.21	1.21	1.21	0.00	0.00
Ethylene	0.00	0.00	0.00	0.00	0.00
Methane	0.00	0.00	0.00	0.00	0.00

Stream No.	**6**	**7**	**8**	**9**	**10**
Temperature (°C)	722.03	566.57	504.27	550.00	530.07
Pressure (kPa)	170.00	160.00	150.00	135.00	125.00
Vapor Mole Fraction	1.00	1.00	1.00	1.00	1.00
Total Flow (kg/h)	54,045.00	78,010.10	78,010.18	78,010.18	78,010.19
Total Flow (kmol/h)	3000.00	3226.21	3317.28	3317.28	3346.41
Component Flows					
Water	3000.00	3000.00	3000.00	3000.00	3000.00
Ethylbenzene	0.00	223.73	132.35	132.35	102.88
Styrene	0.00	0.06	91.06	91.06	120.09
Hydrogen	0.00	0.00	90.69	90.69	119.38
Benzene	0.00	1.21	1.28	1.28	1.37
Toluene	0.00	1.21	1.52	1.52	1.86
Ethylene	0.00	0.00	0.07	0.07	0.16
Methane	0.00	0.00	0.31	0.31	0.65

Table 1
Stream Tables for Unit 400 (cont'd)

Stream No.	**11**	**12**	**13**	**14**	**15**
Temperature (°C)	267.00	180.00	65.00	65.00	65.00
Pressure (kPa)	110.00	95.00	80.00	65.00	65.00
Vapor Mole Fraction	1.00	1.00	0.15	1.00	0.00
Total Flow (kg/h)	78,010.19	78,010.19	78,010.19	255.64	54,045.00
Total Flow (kmol/h)	3346.41	3346.41	3346.41	120.20	3000.00
Component Flows					
Water	3000.00	3000.00	3000.00	0.00	3000.00
Ethylbenzene	102.88	102.88	102.88	0.00	0.00
Styrene	120.09	120.09	120.09	0.00	0.00
Hydrogen	119.38	119.38	119.38	119.38	0.00
Benzene	1.37	1.37	1.37	0.00	0.00
Toluene	1.86	1.86	1.86	0.00	0.00
Ethylene	0.16	0.16	0.16	0.16	0.00
Methane	0.65	0.65	0.65	0.65	0.00

Stream No.	**16**	**17**	**18**	**19**	**20**
Temperature (°C)	65.00	69.89	125.02	90.83	123.67
Pressure (kPa)	65.00	45.00	65.00	25.00	55.00
Vapor Mole Fraction	0.00	0.00	0.00	0.00	0.00
Total Flow (kg/h)	23,709.57	289.52	23,420.04	10,912.92	12,507.12
Total Flow (kmol/h)	226.21	3.34	222.88	102.79	120.08
Component Flows					
Water	0.00	0.00	0.00	0.00	0.00
Ethylbenzene	102.88	0.10	102.78	102.73	0.05
Styrene	120.09	0.00	120.09	0.06	120.03
Hydrogen	0.00	0.00	0.00	0.00	0.00
Benzene	1.37	1.37	0.00	0.00	0.00
Toluene	1.86	1.86	0.00	0.00	0.00
Ethylene	0.00	0.00	0.00	0.00	0.00
Methane	0.00	0.00	0.00	0.00	0.00

Table 1
Stream Tables for Unit 400 (cont'd)

Stream No.	**21**	**22**	**23**	**24**	**25**
Temperature (°C)	123.78	65.04	202.21	90.96	800.00
Pressure (kPa)	200.00	200.00	140.00	200.00	4202.00
Vapor Mole Fraction	0.00	0.00	1.00	0.00	1.00
Total Flow (kg/h)	12,507.12	54,045.00	255.64	10,912.92	18,308.71
Total Flow (kmol/h)	120.08	3000.00	120.20	102.79	1016.30
Component Flows					
Water	0.00	3000.00	0.00	0.00	1016.30
Ethylbenzene	0.05	0.00	0.00	102.73	0.00
Styrene	120.03	0.00	0.00	0.06	0.00
Hydrogen	0.00	0.00	119.38	0.00	0.00
Benzene	0.00	0.00	0.00	0.00	0.00
Toluene	0.00	0.00	0.00	0.00	0.00
Ethylene	0.00	0.00	0.16	0.00	0.00
Methane	0.00	0.00	0.65	0.00	0.00

Table 2
Utility Summary for Unit 400
(all units of kg/h)

E-401	**E-403**	**E-404**	**E-405**
hps	bfw → hps	bfw → lps	cw
7982	18,451	5562	3,269,746

E-406	**E-407**	**E-408**	**E-409**
cw	lps	cw	lps
309,547	7,550	1,105,980	21,811

Table 3
Partial Equipment Summary

Heat Exchangers

H-401 fired heater – refractory-lined, stainless-steel tubes design Q = 23.63 MW max Q = 25.00 MW	**E-401** carbon steel A = 260 m^2 boiling in shell, condensing in tubes 1 shell – 2 tube passes Q = 13,530 MJ/h
E-402 316 stainless steel A = 226 m^2 steam in shell, process fluid in tubes 1 shell – 2 tube passes Q = 8322 MJ/h	**E-403** 316 stainless steel A = 1457 m^2 boiling in shell, process fluid in tubes 1 shell – 2 tube passes Q = 44,595 MJ/h
E-404 carbon steel A = 702 m^2 boiling in shell, process fluid in tubes 1 shell – 2 tube passes Q = 13,269 MJ/h	**E-405** 316 stainless steel A = 1446 m^2 cw in shell, process fluid in tubes 1 shell – 2 tube passes Q = 136,609 MJ/h
E-406 carbon steel A = 172 m^2 process fluid in shell, cooling water in tubes 1 shell – 2 tube passes Q = 12,909 MJ/h	**E-407** carbon steel A = 64 m^2 boiling in shell, steam condensing in tubes desuperheater – steam saturated at 150°C 1 shell – 2 tube passes Q = 15,699 MJ/h
E-408 carbon steel A = 385 m^2 process fluid in shell, cooling water in tubes 1 shell – 2 tube passes Q = 46,363 MJ/h	**E-409** carbon steel A = 176 m^2 boiling in shell, steam condensing in tubes desuperheater – steam saturated at 150°C 1 shell – 2 tube passes Q = 45,565 MJ/h

Reactors

R-401 316 stainless steel, packed bed cylindrical catalyst pellet (1.6 mm×3.2 mm) void fraction = 0.4 V = 25 m^3 9.26 m tall, 1.85 m diameter	**R-402** 316 stainless steel, packed bed cylindrical catalyst pellet (1.6 mm×3.2 mm) void fraction = 0.4 V = 25 m^3 9.26 m tall, 1.85 m diameter

Towers

T-401 carbon steel *D* = 3.0 m 61 sieve trays 54% efficient feed on tray 31 12 in tray spacing 1 in weirs column height = 61 ft = 18.6 m	**T-402** carbon steel *D* = 6.9 m 158 bubble cap trays 55% efficient feed on tray 78 6 in tray spacing 1 in weirs column height = 79 ft = 24.1 m

Other Equipment

C-401 carbon steel *W* = 134 kW 60% adiabatic efficiency	**V-401** carbon steel $V = 26.8\ m^3$
P-401 A/B stainless steel *W* = 2.59 kW (actual) 80% efficient	**P-404 A/B** carbon steel *W* = 0.775 kW (actual) 80% efficient
P-405 A/B carbon steel W = 0.825 kW (actual) 80% efficient	

Problem

Your company acquired this plant from another company through a take-over. Previously, this other company was having many problems meeting specifications and had lost customers because of these problems. Your company is in the process of diagnosing and fixing these problems to bring the plant back on-line at full capacity with a product that meets specifications. It is desired to bring the plant back on-line as soon as possible.

Task 1: It has been identified that there is a problem in the steam plant that will require quite some time to fix. Therefore, Stream 4, the source of high-pressure steam will not be available. Note that high pressure steam used elsewhere will still be available. Because of excess capacity, it will be possible to use *medium pressure steam* (available at 10 barg, 184°C) as a process feed, i.e., as Stream 4. Your task is to identify what changes in plant operating conditions must be made to run the plant at **maximum** production rate of styrene without violating any operating constraints as specified in this document including product quality(ies). No new equipment can be purchased for this scenario.

Task 2: It has been identified that there is a problem in the steam plant that will require quite some time to fix. Therefore, Stream 4, the source of high-pressure steam will not be available. Note that high pressure steam used elsewhere will still be available. Because of excess capacity, it will be possible to use *low pressure steam* (available at 5 barg, 160°C) as a process feed, i.e., as Stream 4. Your task is to identify what changes in plant operating conditions must be made to run the plant at **maximum** production rate of styrene without violating any operating constraints as specified in this document including product quality(ies). No new equipment can be purchased for this scenario.

Task 3: It has been identified that there is a problem in one of the burners in H-401 and H-401 needs to be run at 70% of the design duty till a replacement burner with muffle is available. Your task is to identify what changes in plant operating conditions must be made to run the plant at **maximum** production rate of styrene without violating any operating constraints as specified in this document including product quality(ies). No new equipment can be purchased for this scenario.

Task 4: Additionally, current market conditions for styrene are very tight. Whatever we can do to improve the economic performance of Unit 400 will help the bottom line. Therefore, identify any long term improvements in the process. You may assume for this part of the assignment that there is no issue with the steam plant, i.e., high-pressure steam is available as Stream 4 and all the burners in H-401 are available. New equipment can be purchased for this scenario. Any such changes should be justified based on capital and operating costs. Capital costs for new equipment items may be estimated using Capcost and the costs for utilities may be taken from Chapter 8 of your textbook.

Deliverables

Each member of a team will individually be responsible for either Task 1 or Task 2 or Task 3. All team members will work together on Task 4.

Specifically, the following is to be completed by 8:00 a.m., Monday, November 2, 2020:

1. Prepare a report not exceeding 35 pages including everything (excluding the CHEMCAD report, but signed confidentiality statement is counted towards the page numbers), conforming to the department guidelines, detailing the operating conditions in the plant that will allow the maximum production rate of styrene. The report should provide a logical flow of the analysis made that justifies the changes made. There will be four separate sections in the report conforming to Task 1, Task 2, Task 3, and Task 4. Each student will need to clearly identify which task (out of Task 1, 2, and 3) he/she worked on and write about half a page summary of their contribution to Task 4. Each section must include updated versions of Table 1 and Table 2. **DO NOT** include equipment from the original design. For Table 1, component flowrates should be given in terms of molar flowrates as in this document.

2. The report should include a set of suggestions for process improvements, recommended modifications, the operating and capital costs of such modifications based on your work on Task 4. As noted above, this will be a single section. This section must include updated versions of Table 1 and Table 2 and Figure 1, in case of topological changes.

3. The report would also include a legible, organized set of calculations, if any, justifying your recommendations, including any assumptions made. These should be included in a well-organized appendix.

4. Include a signed copy of the attached confidentiality statement in the report as well.

5. The report addressing items listed above should be uploaded to eCampus under assignment titled "Major Main Report" in the CHE 455 course home page. Remember to name the file as: 'Major_Report_Group#x,Member1lastname_Member2lastname_Member3lastname' so that the group can be identified when these files are downloaded. It should be submitted by 8 am on November 2nd , 2020. To avoid confusion, only one designated member from each group should upload the report.

6. For Tasks 1, 2, 3, and 4, a copy of the converged Chemcad report **MUST** be provided electronically. Stream properties (k, μ, c_p, etc.) should **NOT** be included in this report. The report should be uploaded to eCampus under assignment titled "Major Chemcad Report" in the CHE 455 course home page. Remember to name the file as: 'Chemcad_Report_Group#x,Member1lastname_Member2lastname_Member3lastname' so that the group can be identified when these files are downloaded. It should be submitted by 8 am on November 2nd , 2020. Again, to avoid confusion, only one designated member from each group should upload the report.

Report Format

This report should conform to the department guidelines, which are available at the end of the following web page: http://cbe.statler.wvu.edu/undergraduate/projects. Figures and tables should be included as appropriate. An appendix should be attached that includes items such as the requested calculations. The calculations in the appendix should be easy to follow. The confidentiality statement should be the very last page of the report.

The written report is a very important part of the assignment. Poorly written and/or organized written reports may require re-writing. Be sure to follow the format outlined in the guidelines for written reports. Failure to follow the prescribed format may be grounds for a re-write.

Oral Presentation

You will be expected to present and defend your results sometime between November 2, 2020 and November 13, 2020. This will happen over Zoom, and a link for which will be sent in advance by the instructors. Your presentation will be followed by about a 30-40 minute question and answer period. Make certain that you prepare for this presentation since it is an important part of your assignment. You should upload your presentation to eCampus under assignment titled "Major Presentation" in the CHE 455 course home page at least 1 hour before your Q&A. Only one designated member from each group should upload the file. Remember to name the file as: 'Major_Presentation_Group#x,Member1lastname_Member2lastname_Member3lastname'.

Since you will be doing this assignment in groups of 3, the following rules will apply. Each team member will first present their own task for 5 min (either Task 1 or 2 or 3). The presentation for Task 4 should be completed in a total of 5-6 min. Task 4 can be presented by one designated member of the team or by 2 team members or the entire team by taking turns – each team is free to decide this time distribution for Task 4, but note that Task 4 presentation must be completed within 6 min. Overall it is desired that the entire presentation is completed within 20-21 min. To avoid switching machines, we suggest that the machine of one of the team members is used while others are given access for remote control or that team member can simply toggle the slides for others as needed. Each team member will answer questions related to their individual task. Questions on Task 4 can be directed to any team member. Each team member will be assessed separately for their oral presentation and their response to questions.

Other Rules

You may discuss this major only with your partners. Discussion, collaboration, or any other interaction with anyone not in your group (including those in this class, not in this class, not at the University, etc.) is prohibited.

Consulting is available from the instructor (Dr. Bhattacharyya). Chemcad consulting, i.e., questions on how to use Chemcad, not how to interpret results, is unlimited and free, but only from the instructor. Each group may receive 15 free minutes of consulting from the instructor. After 15 minutes of consulting, the rate is 2.5 points deducted for 15 minutes or any fraction of 15 minutes, on a cumulative basis. To receive consulting of any kind (including Chemcad questions), all team members must be present.

Late Reports

Late reports (written or oral) are unacceptable. The following severe penalties will apply:

- late report on due date before noon: one letter grade (10 points)
- late report after noon on due date: two letter grades (20 points)
- late report one day late: three letter grades (30 points)
- each additional day late: 10 additional points per day

Additional Information

An Excel spreadsheet is provided with design calculations for most of the major equipment. Data on the relative heat transfer resistances are included in the spreadsheet. Information about the reactor and towers is taken directly from the Chemcad report.

You should assume that the flow of cooling water through any heat exchanger may be increased by a maximum of 25% from the current value and the exit temperature of the cooling water must never exceed 45ºC. Flow rates of steam and boiler feed water should not be increased by more than 30%.

A converged Chemcad simulation for the design case is provided. This is an accurate representation of the current operation of the plant.

Appendix 1
Reaction Kinetics and Equilibrium

The reactions for styrene production are as follows:

$$C_6H_5C_2H_5 \underset{k_2}{\overset{k_1}{\rightleftarrows}} C_6H_5C_2H_3 + H_2 \tag{1}$$

ethylbenzene styrene hydrogen

$$C_6H_5C_2H_5 \xrightarrow{k_3} C_6H_6 + C_2H_4 \tag{2}$$

ethylbenzene benzene ethylene

$$C_6H_5C_2H_5 + H_2 \xrightarrow{k_4} C_6H_5CH_3 + CH_4 \tag{3}$$

ethylbenzene hydrogen toluene methane

Kinetics (subscripts on r refer to reactions in Equation (1) – (3) (adapted from Snyder, J. D. and B. Subramaniam, *Chem. Engr. Sci.*, **49**, 5585-5601, 1994) – the positive activation energy can arise from non-elementary kinetics and/or from reversible reactions:

$$r_1 = 1.177 \times 10^8 \exp\left(-\frac{21708}{RT}\right) p_{eb} \tag{4}$$

$$r_2 = 20.965 \exp\left(\frac{7804}{RT}\right) p_{sty} p_{hyd} \tag{5}$$

$$r_3 = 7.206 \times 10^{11} \exp\left(-\frac{49675}{RT}\right) p_{eb} \tag{6}$$

$$r_4 = 1.724 \times 10^6 \exp\left(-\frac{21857}{RT}\right) p_{eb} p_{hyd} \tag{7}$$

where p is in bar, T is in K, R = 1.987 cal/mol K, and r_i is in mol/m^3 reactor s. When simulating this, or any, reactor in Chemcad, the units for the reactor may be set separately from the units for the rest of the simulation in the "more specifications" tab.

The styrene reaction may be equilibrium limited, and the equilibrium constant is

$$K = \left(\frac{y_{sty} y_{hyd} P}{y_{eb}} \right) \quad (8)$$

and

$$\ln K = 15.5408 - \frac{14852.6}{T} \quad (9)$$

where T is in K and P is in bar.

other data:

bulk catalyst density = 1282 kg/m^3
void fraction = 0.4

Appendix 2
Calculations and Other Pertinent Information

Vessel (V-401)

assume 10 min residence time based on total liquid flow, calculate volume and double it to provide space for vapor disengagement

organic liquid at 26.6 m^3/h
water at 54.0 m^3/h
total liquid flow = 80.6 m^3/h = 1.34 m^3/min
total volume = 26.8 m^3

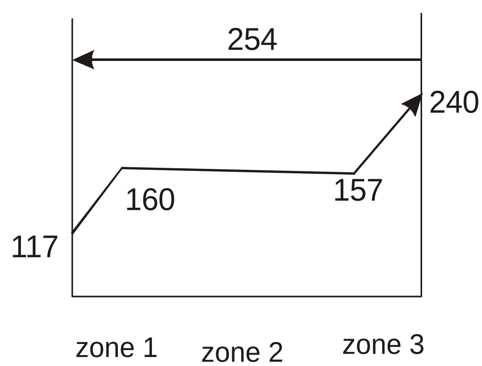
Heat Exchangers

key data:

latent heats
λ_{hps} = 1695 kJ/kg
λ_{mps} = 2002 kJ/kg
λ_{lps} = 2085 kJ/kg

E-401

zone 1
Q_1 = 2301.11 MJ/h
ΔT_{lm} = 114.58°C
liquid organic h = 600 W/m^2K
condensing steam h = 6000 W/m^2K
$U \approx 1/h_i + 1/h_o$ = 545.45 W/m^2K
A = 10.23 m^2



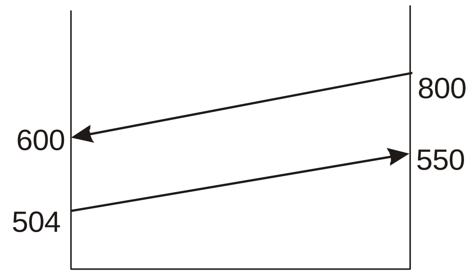
zone 2
Q_2 = 7546.36 MJ/h
ΔT_{lm} = 95.57°C
boiling organic h = 5000 W/m^2K
condensing steam h = 6000 W/m^2K
temperature drop in this zone due to pressure drop
$U \approx$2727.27 W/m^2K
A = 8.04 m^2

zone 3
Q_3 = 3681.13 MJ/h
ΔT_{lm} = 42.93°C
vapor organic h = 100 W/m^2K
condensing steam h = 6000 W/m^2K

$U \approx 98.36$ W/m^{2}K
$A = 242.13$ m^2

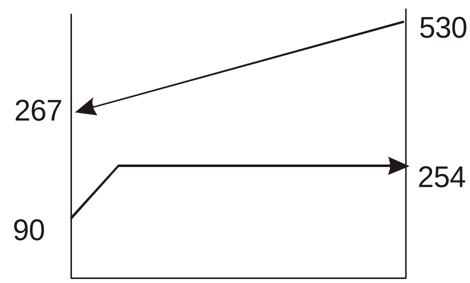
total $A = 260.46$ m^2
steam flowrate from Chemcad in Table 2

E-402



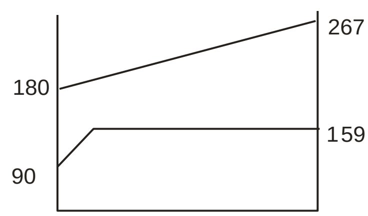
$Q = 8321.66$ MJ/h
$\Delta T_{lm} = 160.71$°C
hot desuperheating steam $h = 200$ W/m^{2}K
hot vapor organic $h = 100$ W/m^{2}K
$U \approx 66.67$ W/m^{2}K
LMTD corr factor – 1-2 exchanger = 0.9529
$A = 226.46$ m^2

E-403



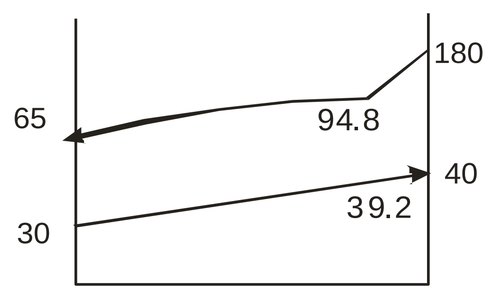
$Q = 44{,}594.43$ MJ/h
$\Delta T_{lm} = 86.09$°C
boiling water $h = 8000$ W/m^{2}K
hot vapor organic $h = 100$ W/m^{2}K
$U \approx 98.77$ W/m^{2}K
$A = 1456.85$ m^2
bfw flowrate from Chemcad in Table 2

E-404



$Q = 13{,}268.50$ MJ/h
$\Delta T_{lm} = 53.13$°C
boiling water $h = 8000$ W/m^{2}K
warm vapor organic $h = 100$ W/m^{2}K
$U \approx 98.77$ W/m^{2}K
$A = 702.43$ m^2
$m = Q/(2085 + 293) = 5579.97$ kg/h (denominator is $\lambda + C_p\Delta T$ in kJ/kg)
bfw flowrate from Chemcad in Table 2

E-405

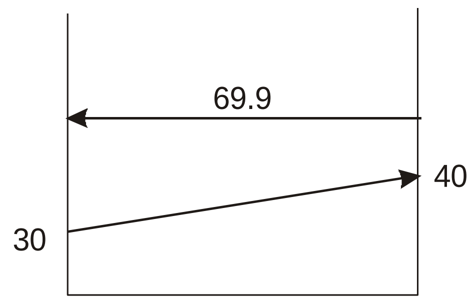


zone 1 - desuperheating
$Q_1 = 12{,}305.74$ MJ/h
$\Delta T_{lm} = 91.37$°C
vapor organic $h = 100$ W/m^{2}K
cooling water $h = 1000$ W/m^{2}K
$U \approx 1/h_i + 1/h_o = 90.91$ W/m^{2}K
$A = 411.53$ m^2

zone 2 – partial condensing – treat like cooling is straight line
Q_2 = 124,303.29 MJ/h
ΔT_{lm} = 44.49°C
partial condensation organic h = 3000 W/m^{2}K
cooling water h = 1000 W/m^{2}K
$U \approx$ 750 W/m^{2}K
A = 1034.78 m^2

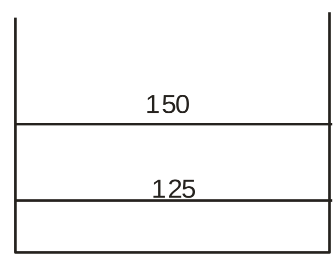
total A = 1446.31 m^2
cw flowrate from Chemcad in Table 2

E-406



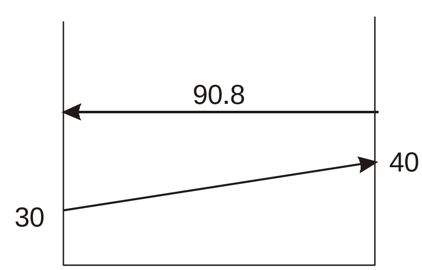
Q = 12,908.82 MJ/h
ΔT_{lm} = 34.65°C
condensing organic h = 1500 W/m^{2}K
cooling water h = 1000 W/m^{2}K
$U \approx$ 600 W/m^{2}K
A = 172.48 m^2
m = 308,528.20 kg/h (denominator is in kJ/kg)

E-407



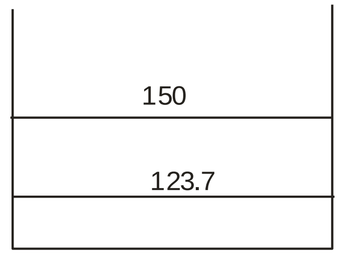
Q = 15,699.48 MJ/h
ΔT_{lm} = 24.98°C
condensing steam h = 6000 W/m^{2}K
boiling organic h = 5000 W/m^{2}K
steam desuperheated to 150°C
$U \approx$ 2727.27 W/m^{2}K
A = 64.01 m^2
m = 7529.73.18 kg/h (denominator is λ of steam kJ/kg)

E-408



Q = 46,362.85 MJ/h
ΔT_{lm} = 55.68°C
condensing organic h = 1500 W/m^{2}K
cooling water h = 1000 W/m^{2}K
$U \approx$ 600 W/m^{2}K
A = 385.49 m^2
m = 1,108,098.71 kg/h (denominator is in kJ/kg)

E-409



Q = 45,565.39 MJ/h
ΔT_{lm} = 26.33°C
steam desuperheated to 150°C
condensing steam h = 6000 W/m^{2}K
boiling organic h = 5000 W/m^{2}K
$U \approx$ 2727.27 W/m^{2}K
A = 176.26 m^2
m = 21,853.90 kg/h (denominator is $C_p\Delta T$ of water in kJ/kg)

T-401

from Chemcad 33 ideal stages, feed at 17 (one subtracted for condenser)
sieve trays
flooding within reasonable range from Chemcad
D = 3.0 m
tray spacing = 0.305 m (= 12 in)
from O'Connell correlation in Chemcad, 0.54 average overall column efficiency
weir height = (0.051 m)(0.54) = 0.0275 m (= 1.08 in)
$\Rightarrow$ 61 stages (so column about 61 ft tall =18.6m)
feed at 17(61/33) = 31

T-402

from Chemcad 87 ideal stages, feed at 43 (one subtracted for condenser)
bubble cap trays
flooding within reasonable range from Chemcad
D = 6.9 m
tray spacing = 0.1525 m (6 in)
from O'Connell correlation in Chemcad, 0.55 average overall column efficiency
weir height = (0.051 m)(0.55) = 0.028 m (1.1 in)
$\Rightarrow$ 158 stages (so column about 79 ft tall = 24.1 m)
feed at 43(158/87) = 78

H-401

from Chemcad Q = 63544 MJ/h = 17.65 MW
but this heater must also heat steam used in E-402 (Stream 25)
total flow is Stream 4 on PFD
so Q = 17.65[(3000+1016)/3000] = 23.62 MW
Max Q = 25.00 MW
split between Streams 6 and 25 is controlled by ratio controller, but the ratio can be changed

Information on other equipment is not available.

Major #1 - Confidentiality Statement

ChE 455
November 2, 2020

This is to certify that the contents of this written report, regarding Major in ChE 455, is the result of my work and my partners' work, and that we have neither collaborated nor discussed this work with **anyone** else, other than the allowable purchasing of consulting time from the instructors. In addition, I agree not to discuss the content of this project with anyone other than my partner until after it has been reviewed in class by Professors Bhattacharyya and Lima.

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Student in ChE 455
November 2, 2020

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Student in ChE 455
November 2, 2020

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Student in ChE 455
November 2, 2020