ChE 182
Major 2

Styrene Production

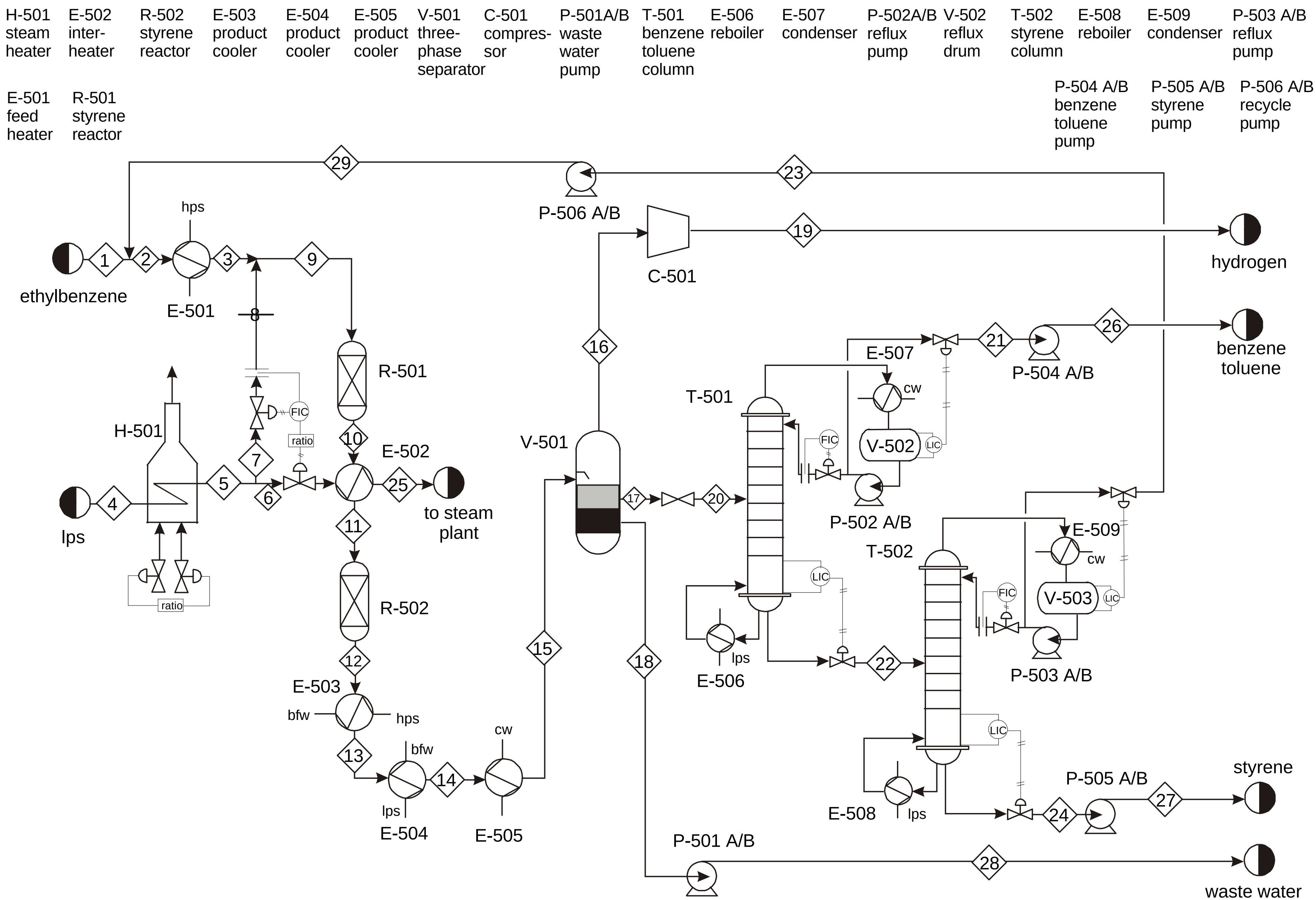
Thank you for your analysis of the intermittent problems in our styrene production facility, Unit 500. The ratio controller on H-501 has been fixed and the process is once again running at design conditions.

The process flow diagram is shown in Figure 1. Tables 1 and 2 show the design conditions for Unit 500. In order to decrease the cost of manufacture for the styrene process, it is desirable to lower the steam input to the reactor, possibly lower the steam temperature, and optimize the economics for selectivity for styrene. It has also been suggested to purchase a new heat exchanger to use Stream 25 to preheat and vaporize the ethylbenzene in Stream 2, Stream 3, or Stream 23. Your assignment is to determine optimal placement and operating conditions for this improvement. As always, you may include additional process modifications that are profitable. The existing production rate and purity of styrene must be maintained. Limitations on the reactors are a maximum temperature of 1000 K, a maximum pressure of 2.5 bar, and a minimum pressure of 0.75 bar.

It is required that the temperature and pressure entering the three-phase separator be maintained at existing values. The pressure can be maintained by adding either a valve or a small pump before the flash. It is possible that the temperature can be maintained by adjusting the utility flows in E-503 through E-505. If this is not possible, there is a spare, unused heat exchanger that can be put into service. Since we already have this heat exchanger, there is no capital cost; however, you should include the required utility cost in the incremental EAOC.

The objective function is the incremental EAOC, as defined in Chapter 5 of your textbook[1]. The only incremental capital cost is that for the new heat exchanger. You decide exactly where to place it. Assume that the minimum approach temperature allowable in this new heat exchanger is 50°C. The incremental savings in cost of manufacture will be from reduced low-pressure steam use (use cost per kg in Table 3.4), reduced ethylbenzene feed ($0.56/kg), reduced natural gas use in H-501 (Table 3.4), and possibly high-pressure steam in E-501 (use cost per GJ in Table 3.4). Assume the cost of manufacture changes by the sum of the incremental changes in the costs of low-pressure steam, ethylbenzene, natural gas, and high-pressure steam. Use an internal hurdle rate of 15% before taxes, with an equipment life of 10 years.

Since optimization of the feed section will change the flowrates, temperatures, and concentrations of each stream, you also must analyze all units from the feed through E-505 to determine the conditions (*T* and *P*) of all streams through Stream 15. This analysis must be quantitative, detailed, and not done on Chemcad except for the reactor. You may assume that the all stream physical properties are unchanged from the design case. Clearly, the separation section will also be affected. For this preliminary evaluation, you should analyze qualitatively the effect the changes in the feeds to the separation section will have on the units in the separation section.



Unit 500: Production of Styrene from Ethylbenzene

Table 1
Stream Tables for Unit 500

Stream No.	1	2	3	4	5	6
Temperature (°C)	136	116	225	159	800	800
Pressure (kPa)	210	200	180	600	565	565
Vapor Mole Fraction	0	0	1	1	1	1
Total Flow (kg/h)	19417	54890	54890	227784	227784	83664
Total Flow (kmol/h)	183.6	517.8	517.8	12644	12644	4644
Component Flows						
Water				12644	12644	4644
Ethylbenzene	180	512.7	512.7			
Styrene		1.2	1.2			
Hydrogen						
Benzene	1.8	1.8	1.8			
Toluene	1.8	2.13	2.13			
Ethylene						
Methane						

Stream No.	7	8	9	10	11	12
Temperature (°C)	800	799	632	609	650	640
Pressure (kPa)	565	180	170	160	145	135
Vapor Mole Fraction	1	1	1	1	1	1
Total Flow (kg/h)	144120	144120	199010	199010	199010	199010
Total Flow (kmol/h)	8000	8000	8517.6	8614.7	8614.7	8662.7
Component Flows						
Water	8000	8000	8000	8000	8000	8000
Ethylbenzene			512.7	399.1	399.1	336.36
Styrene			1.2	86.8	86.8	120.67
Hydrogen				69.0	69.0	88.1
Benzene			1.8	13.1	13.1	27.5
Toluene			2.13	18.7	18.7	33.3
Ethylene				11.3	11.3	25.7
Methane				16.6	16.6	31.1

Table 1
Stream Tables for Unit 500 (cont'd)

Stream No.	13	14	15	16	17	18
Temperature (°C)	270	180	65	65	65	65
Pressure (kPa)	120	105	90	75	75	75
Vapor Mole Fraction	1	1	.025	1	0	0
Total Flow (kg/h)	199010	199010	199010	2682	53493	142715
Total Flow (kmol/h)	8662.7	8662.7	8662.7	216.3	517.8	7928.6
Component Flows						
Water	8000	8000	8000	71.4		7928.6
Ethylbenzene	336.36	336.36	336.36		336.36	
Styrene	120.67	120.67	120.67		120.67	
Hydrogen	88.1	88.1	88.1	88.1		
Benzene	27.5	27.5	27.5		27.5	
Toluene	33.3	33.3	33.3		33.3	
Ethylene	25.7	25.7	25.7	25.7		
Methane	31.1	31.1	31.1	31.1		

Stream No.	19	20	21	22	23	24
Temperature (°C)	197	65	66	119.5	105	124.5
Pressure (kPa)	240	60	40	60	210	60
Vapor Mole Fraction	1	0	0	0	0	0
Total Flow (kg/h)	2682	53493	5548	47905	35473	12432
Total Flow (kmol/h)	216.3	517.8	63.9	453.9	334.2	119.7
Component Flows						
Water	71.4					
Ethylbenzene		336.36	3.36	333.0	332.66	0.34
Styrene		120.67	0.1	120.53	1.20	119.3
Hydrogen	88.1					
Benzene		27.5	27.5			
Toluene		33.3	32.9	0.33	0.33	
Ethylene	25.7					
Methane	31.1					

Table 1
Stream Tables for Unit 500 (cont'd)

Stream No.	25	26	27	28	29
Temperature (°C)	700	66	124.5	65	105
Pressure (kPa)	565	200	200	200	210
Vapor Mole Fraction	1	0	0	0	0
Total Flow (kg/h)	83664	5548	12432	142715	35473
Total Flow (kmol/h)	4644	63.9	119.7	7928.6	334.2
Component Flows					
Water	4644			7928.6	
Ethylbenzene		3.36	0.34		332.66
Styrene		0.1	119.3		1.20
Hydrogen					
Benzene		27.5			
Toluene		32.9			0.33
Ethylene					
Methane					

Table 2
Utility Summary for Unit 500

E-501	**E-503**	**E-504**	**E-505**
hps	bfw → hps	bfw → lps	cw
17,566 kg/h	67,256 kg/h	14,790 kg/h	9,455,376 kg/h

E-506	**E-507**	**E-508**	**E-509**
lps	cw	lps	cw
15,878 kg/h	671,941 kg/h	163,505 kg/h	8,173,446 kg/h

Styrene Production Reactions

The reactions for styrene production are as follows:

$$\underset{\text{ethylbenzene}}{C_6H_5C_2H_5} \underset{2}{\overset{1}{\rightleftarrows}} \underset{\text{styrene}}{C_6H_5C_2H_3} + \underset{\text{hydrogen}}{H_2} \qquad (1)$$

$$\underset{\text{ethylbenzene}}{C_6H_5C_2H_5} \overset{3}{\longrightarrow} \underset{\text{benzene}}{C_6H_6} + \underset{\text{ethylene}}{C_2H_4} \qquad (2)$$

$$\underset{\text{ethylbenzene}}{C_6H_5C_2H_5} + \underset{\text{hydrogen}}{H_2} \overset{4}{\longrightarrow} \underset{\text{toluene}}{C_6H_5CH_3} + \underset{\text{methane}}{CH_4} \qquad (3)$$

Other Information

Table 3 contains an equipment list for Unit 500 as it currently operates. Other pertinent information and calculations are contained in the appendix.

Assignment

Specifically, you are to prepare the following by 9:00 am, Monday, November 15, 1999:

1. an optimization of the process improvements to the feed section of the styrene process

2. results of a detailed, quantitative performance analysis on all units through E-505

3. results of a qualitative performance analysis of the separation section. This should include items such as, but not limited to, how the tower heat exhangers are affected and how the reflux ratio is affected.

4. a written report, conforming to the guidelines, detailing the information in items 1 through 3, above

5. a legible, organized set of calculations justifying your recommendations, including any assumptions made

6. a signed copy of the attached confidentiality statement

Table 3
Partial Equipment Summary

E-501 carbon steel A = 541 m^2 boiling in shell, condensing in tubes 1 shell – 2 tube passes Q = 29695 MJ/h	**E-503** 316 stainless steel A = 2006 m^2 boiling in shell, process fluid in tubes 1 shell – 2 tube passes Q = 162.8 GJ/h
H-501 fired heater – refractory design Q = 88.26 MW max Q = 100 MW	**E-504** carbon steel A = 2133 m^2 boiling in shell, process fluid in tubes 1 shell – 2 tube passes Q = 35.16 GJ/h
R-501 316 stainless steel, packed bed cylindrical catalyst pellet (1.6 mm×3.2 mm) void fraction = 0.4 V = 1000 m^3 5 reactors in parallel at 200 m^3 20 m tall, 3.6 m diameter	**R-502** 316 stainless steel, packed bed cylindrical catalyst pellet (1.6 mm×3.2 mm) void fraction = 0.4 V = 700 m^3 5 reactors in parallel at 140 m^3 20 m tall, 3.0 m diameter
E-505 carbon steel A = 2904 m^2 cw in shell, process fluid in tubes 1 shell – 2 tube passes Q = 395.9 GJ/h	**V-501** carbon steel V = 34.7 m^3
E-502 316 stainless steel A = 456 m^2 steam in shell, process fluid in tubes 1 shell – 2 tube passes Q = 19237 MJ/h	**C-501** carbon steel W = 364.2 kW 80% adiabatic efficiency
P-501 carbon steel W = 6.4 kW (actual) 80% efficient	**P-505** carbon steel W = 0.75 kW (actual) 80% efficient
P-504 carbon steel W = 0.38 kW (actual) 80% efficient	**P-506** carbon steel W = 2.65 kW (actual) 80% efficient

Table 3 (cont'd)
Partial Equipment Summary

T-501 carbon steel 46 sieve trays 55% efficient total condenser (E-507) feed on tray 26 reflux ratio = 11.4 24 in tray spacing, 2 in weirs column height = 92 ft = 28 m top diameter = 3.6 m bottom diameter = 2.7 m tapered column	**T-502** carbon steel total condenser (E-509) feed at location equivalent to tray 36 reflux ratio = 25.8 structured packing $C_f = 1$ diameter = 4.1 m *HETP* = 0.3 m height = 34.5 m
E-506 carbon steel $A = 76.7$ m^2 boiling in shell, condensing in tubes 1 shell – 2 tube passes $Q = 331.2$ GJ/h	**E-509** carbon steel $A = 680$ m^2 condensing in shell, cw in tubes 1 shell – 2 tube passes $Q = 342.0$ GJ/h
E-507 carbon steel $A = 127$ m^2 condensing in shell, cw in tubes 1 shell – 2 tube passes $Q = 281.1$ GJ/h	**E-508** carbon steel $A = 902$ m^2 boiling in shell, condensing in tubes 1 shell – 2 tube passes $Q = 341.1$ GJ/h

Report Format

This report should conform to the guidelines. It should be bound in a folder that is not oversized relative to the number of pages in the report. It should be organized like a standard design report. Figures and tables should be included as appropriate. An appendix should be attached that includes items such as the requested calculations. These calculations 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 some time between November 15 and November 19, 1999. Your presentation should be 15-20 minutes, followed by about a 30 minute question and answer period. Make certain that you prepare for this presentation since it is an important part of your assignment. You should bring at least one hard copy of your slides to the presentation, and should be handed out at the beginning of the presentation.

Late Reports

Late reports 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

Appendix

Same as in styrene1.