Cumene Production – Change in Reactor Conditions

Further to recent work regarding the problems in Unit 800, it was determined that the propylene feed was off-spec. The new supplier has agreed to provide financial compensation for problems caused by the off-spec feed, but is reporting problems maintaining the desired specifications. Until we can come to agreement with another supplier, we will have to adapt to the feed provided by the current supplier. We have increased the frequency and rigor of analysis of arriving propylene, and it appears that the range of propane impurity is 5 -10 wt %. Therefore, we need to identify the required operating temperatures for the reactor which will maintain the production rate of cumene corresponding to this range of propane impurity. Please provide a performance curve for this situation along with operating instructions necessary to maintain these conditions.

We are still concerned about market conditions for cumene, which are very tight. We are in direct competition with some local companies who have recently built cumene plants. Management is very concerned about our competitiveness since these other companies are beginning to under-cut our prices. They may switch to one of these "outside" suppliers for our phenol unit because the cost of buying cumene may soon be lower than the cost of producing cumene in Unit 800. Management wants to find out if any significant savings in operating costs can be found for Unit 800 in order to maintain the profitability of the Unit. A shut-down is scheduled in three months, so new equipment can be installed if you so recommend. However, any equipment that is recommended must be received by then, this precludes the purchase of "big ticket" items that require long lead times. The company criterion for profitability is an internal rate of return of 15%, before taxes, amortized over 10 years.

Assignment

Specifically, you are to prepare the following by …….(2 weeks from now)

1. a written report showing the performance curve, containing a clear and concise explanation of how these operating conditions are to be maintained, and detailing your recommendations for process modifications for cost savings

2. a list of new equipment to be purchased, if any, including size, cost, and materials of construction

3. an analysis of the marginal increase in profitability created by your recommended modifications

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

5. a signed copy of the attached confidentiality statement

Report Format

This report should be brief. Most of the report should be an executive summary, not to exceed 10 double-spaced, typed pages, which summarizes your recommendations, rationale, and profitability analysis. Figures and tables may be included (do not count against page limit) in the executive summary. An appendix should be attached which 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 will require re-writing. Be sure to follow the format outlined in the guide for written reports. Failure to follow the prescribed format will be grounds for a re-write.

Oral Presentation

You will be expected to present and defend your results to management representatives some time between the week of ……. Your presentation should be 10-15 minutes, followed by about a 30 minute question and answer period. Make certain that you prepare for this meeting since it is an important part of your assignment. You should provide at least one hard copy of your slides at the beginning of your presentation.

Appendix 1 - Process Information

A PFD for Unit 800 is given in Figure 1. The stream table, Table 1, and the utility summary table, Table 2, for current design operation (5% propane in propylene) are also included.

The kinetics for the reactions are as follows:

$$\underset{propylene}{C_3H_6} + \underset{benzene}{C_6H_6} \xrightarrow{k_1} \underset{cumene}{C_9H_{12}}$$

$$r_1 = k_1 c_p c_b \qquad \text{mole/gcat sec}$$

$$k_1 = 3.5\times 10^4 \exp\left(\frac{-24.90}{RT}\right)$$

$$\underset{propylene}{C_3H_6} + \underset{cumene}{C_9H_{12}} \xrightarrow{k_2} \underset{p-diisopropyl\ benzene}{C_{12}H_{18}}$$

$$r_2 = k_2 c_p c_c \qquad \text{mole/gcat sec}$$

$$k_2 = 2.9\times 10^6 \exp\left(\frac{-35.08}{RT}\right)$$

where the units of the activation energy are kcal/mol, the units of concentration are mol/l, temperature is in Kelvin, and the bulk catalyst density is approximately 1000 kg/m^3

Table 1: Current Operating Conditions for Unit 800

Stream No.	1	2	3	4
Stream Name	benzene feed	propylene feed		
Temp °C	25	25	41	28
Pres kPa	101.3	1166	101.3	3150
Vapor mole fraction	0	0	0	0
Flowrate (tonne/h)	8.19	4.64	16.37	4.64
Total kmol/h	105.00	110.27	209.53	110.27
Flowrates in kmol/h				
Benzene	105.00	-	202.92	
Propylene	-	105.00	2.84	105.00
Propane	-	5.27	2.83	5.27
Cumene	-	-	0.94	-
P-Diisopropyl Benzene	-	-	-	-

Stream No.	5	6	6a	7
Stream Name				reactor feed
Temp °C	44	41	214.0	350
Pres kPa	3150	3125	3095	3075
Vapor mole fraction	0	0	1	1
Flowrate (tonne/h)	16.37	21.01	21.01	21.01
Total kmol/h	211.89	322.16	322.16	322.16
Flowrates in kmol/h				
Benzene	205.27	205.27	205.27	205.27
Propylene	2.89	107.89	107.89	107.89
Propane	2.79	8.06	8.06	8.06
Cumene	0.94	0.94	0.94	0.94
P-Diisopropyl Benzene	-	-	-	-

Stream No.	8	9	10	11
Stream Name	reactor effluent	fuel gas purge	crude product	benzene recycle
Temp °C	350	90	90	57
Pres kPa	3025	175	175	175
Vapor mole fraction	1	1	0	0
Flowrate (tonne/h)	21.01	1.19	19.82	8.18
Total kmol/h	223.06	19.89	203.17	106.89
Flowrates in kmol/h				
Benzene	108.96	7.88	101.08	100.27
Propylene	8.86	5.97	2.89	2.89
Propane	8.06	5.27	2.79	2.79
Cumene	94.39	0.77	93.62	0.94
P-Diisopropyl Benzene	2.79	-	2.79	-

Stream No.	12	13	14
Stream Name		cumene product	p-DIPB for fuel
Temp °C	179	178	222
Pres kPa	190	190	210
Vapor mole fraction	0	0	0
Flowrate (tonne/h)	11.64	11.08	0.56
Total kmol/h	96.28	92.60	3.68
Flowrates in kmol/h			
Benzene	0.81	0.81	-
Propylene	-	-	-
Propane	-	-	-
Cumene	92.68	91.76	0.92
P-Diisopropyl Benzene	2.79	0.03	2.76

Table 2: Utility Summary for Unit 800

Stream Name	hps to E-801	condensate from E-801
Temp °C	254	254
Pres kPa	4237	4237
Flowrate in (tonne/h)	7.6	7.6

Stream Name	mps to E-804	condensate from E-804
Temp °C	185.5	185.5
Pres kPa	1135	1135
Flowrate in (tonne/h)	3.56	3.56

Stream Name	hps to E-806	condensate from E-806
Temp °C	254	254
Pres kPa	4237	4237
Flowrate in (tonne/h)	3.25	3.25

Stream Name	cw to E-802	cw from E-802
Temp °C	30	45
Pres kPa	516	496
Flowrate in (tonne/h)	261.3	261.3

Stream Name	cw to E-803	cw from E-803
Temp °C	30	45
Pres kPa	516	496
Flowrate in (tonne/h)	85.88	85.88

Stream Name	cw to E-805	cw from E-805
Temp °C	30	45
Pres kPa	516	496
Flowrate in (tonne/h)	87.50	87.50

Stream Name	bfw to R-801	hps from R-801
Temp °C	90	254
Pres kPa	4237	4237
Flowrate in (tonne/h)	4.06	4.06

Appendix 2 – Equipment Summary

Tanks (not shown on flowsheet)

TK-801 storage tank for benzene, there are two tanks, one feeding Stream 1 and one in a filling mode each tank is 450 m^3

TK-802 storage tank for propylene**,** there are two tanks, one feeding Stream 2 and one in a filling mode each tank is 450 m^3

Pumps (assume efficiency independent of flowrate)

P-801 centrifugal, 75% efficient, driver rated at 21.9 kW

P-802 centrifugal, 75% efficient, driver rated at 6.8 kW

P-803 centrifugal, 75% efficient, driver rated at 2.4 kW

P-804 centrifugal, 75% efficient, driver rated at 1.0 kW

P-805 centrifugal, 75% efficient, driver rated at 3.3 kW

Heat Exchangers (all one pass on each side, unless otherwise noted; h_i refers to tube side; tube wall resistance negligible, unless otherwise noted)

E-801 uses high pressure steam, steam in shell, Q = 12,800 MJ/h
A = 20.8 m^2 in two zones
desubcooling zone: A = 13.5 m^2, U = 600 W/m^2°C, h_i = 667 W/m^2°C
vaporizing zone: A = 7.3 m^2, U = 1500 W/m^2°C, equal resistances on both sides

E-802 condenser for flash unit, process stream in shell, 1-2 configuration
Q = 16257 MJ/h, A = 533 m^2

E-803 total condenser for T-801, condensing fluid in shell
A = 151 m^2, U = 450 W/m^2°C, all resistance on water side

E-804 reboiler for T-801
A = 405 m^2, U = 750 W/m^2°C, approximately equal resistances

E-805 total condenser for T-802, condensing fluid in shell
A = 24.6 m^2, U = 450 W/m^2°C, all resistance on water side

E-806 reboiler for T-802
A = 64.0 m^2, U = 750 W/m^2°C, approximately equal resistances

Fired Heater

H-801	Q = 6334 MJ/h (heat actually added to fluid) capacity 10,000 MJ/h of heat added to fluid 70% efficiency

Reactor

R-801	shell and tube packed bed with phosphoric acid catalyst supported on kieselguhr boiler feed water in shell to produce high pressure steam (bfw pump not shown) reactor volume = 6.50 m^3, heat exchange area = 342 m^2 234 tubes, 3.0 in (7.62 cm) ID, 6 m long U = 65 $W/m^2 °C$, all resistance on reactor side heat removal required = 9,840 MJ/h

Distillation Columns

T-801	removes benzene impurity overhead for recycle medium pressure steam used in reboiler cooling water used in condenser, returned at maximum allowable temperature reflux ratio = 0.44 27 trays, 50% efficient 24 in tray spacing, 3 in weirs diameter = 1.13 m, active area = 75% of total area Q_c = -5,490 MJ/h Q_r = 7,100 MJ/h
T-802	removes cumene product overhead high pressure steam used in reboiler cooling water used in condenser, returned at maximum allowable temperature reflux ratio = 0.63 37 trays, 50% efficient 24 in tray spacing, 3 in weirs diameter = 1.26 m, active area = 75% of total area Q_c = -5,490 MJ/h Q_r = 5,520MJ/h

Vessels

V-801	Benzne feed drum	4.2 m height, 1.4 diameter
V-802	flash drum	5.2 m height, 1 m diameter
V-803	T-801 reflux drum	4 m long, 1.6 m diameter
V-804	T-802 reflux drum	6.5 m long, 1.6 m diameter

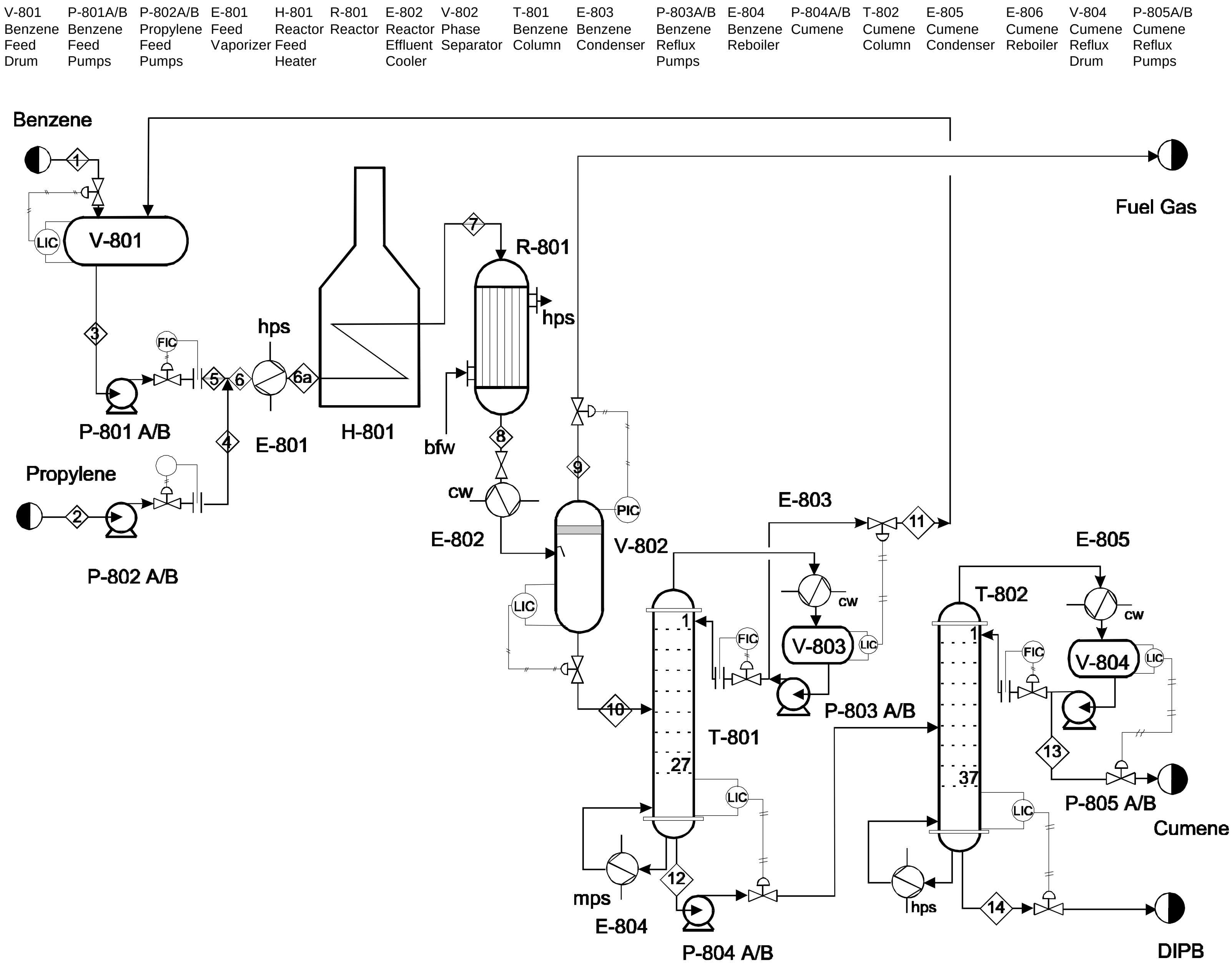

Figure 1: Process Flow Diagram for the Production of Cumene Process (Unit 800)