

CHG 3112 PROCESS SYNTHESIS, DESIGN AND ECONOMICS

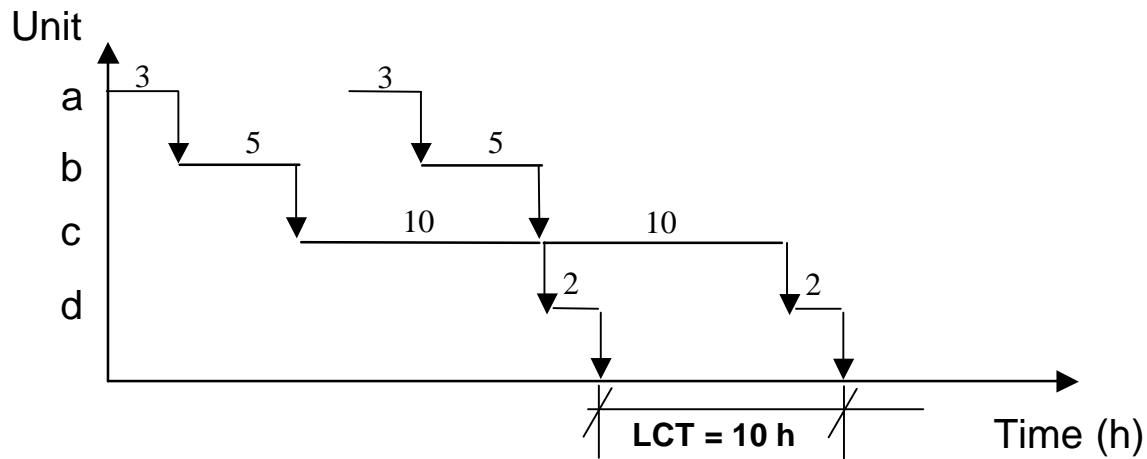
Midterm Solutions

Q1 (5 marks)

Feasibility study, basic engineering design, detailed engineering design, construction, start up, and operation.

Q2 (40 marks)

a) (10)



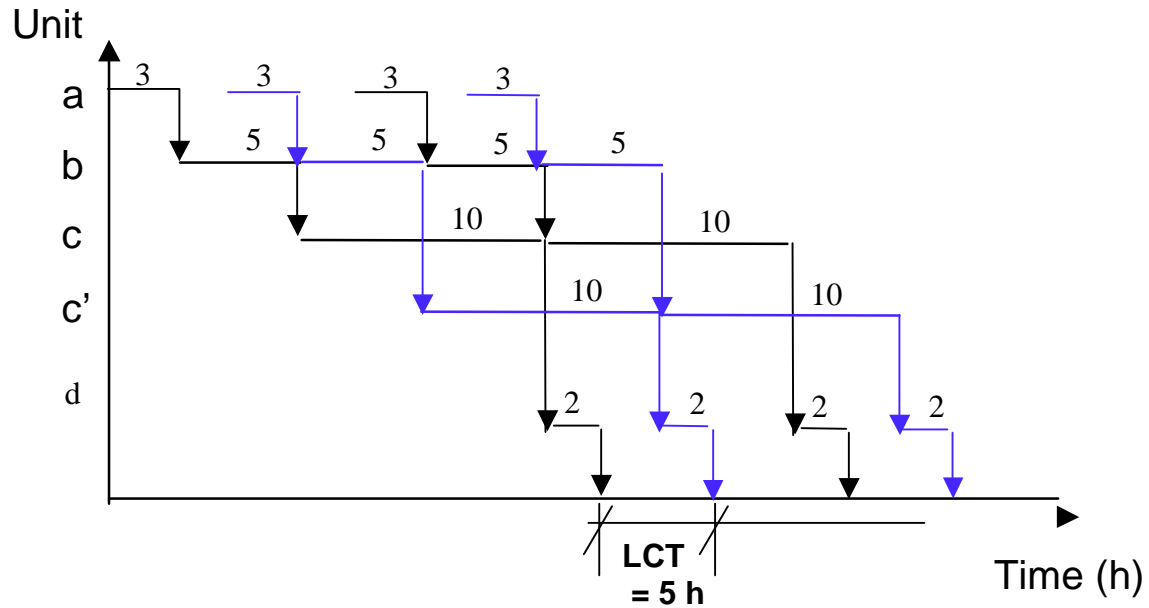
50 batch cycles are needed to process 3000 kg, so
makespan = $(50-1) \times 10 + (3+5+10+2) = 510$ hours

Gantt chart: 5 marks, LCT: 2 mark, makespan: 3 marks

b) (10)

Gantt chart: 5 marks

Based on the heuristics - locate the parallel unit at the unit with the LCT and operate the parallel unit at out-of-phase mode, adding a single unit parallel to unit c and operating at out-of-phase. (2 marks)

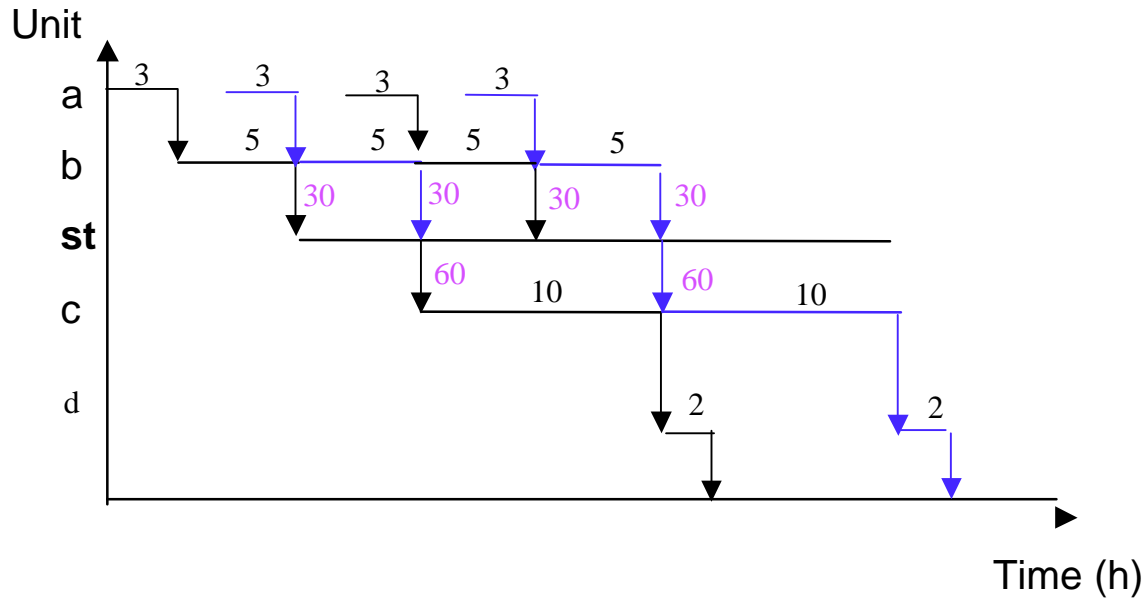


- Advantages: 1. Reduce LCT from 10 to 5 hours, this will double the production rate or half the batch size (i.e., equipment sizes); (1 mark)
2. Increase the utilization of units a, b and d from (1 mark)

Unit	Original	Modified
a	30%	60%
b	50%	100%
c	100%	100% (5/5)
d	20%	40%

Disadvantages: 1. One extra equipment. (1 mark)

c) (15)



Gantt chart: 5 marks

Heuristics: locate the storage in the train without the original time limiting stage, to reduce the batch size of the train. Since unit b is the most expensive one, its size should be reduced. Thus, locate the minimal capacity storage between units b and c. This will reduce the batch size of upstream train from 60 kg to 30 kg:

$$B^u/T^u = B^d/T^d \Rightarrow B^u/5 = 60/10 \Rightarrow B^u = 30 \text{ kg} \quad (4 \text{ marks})$$

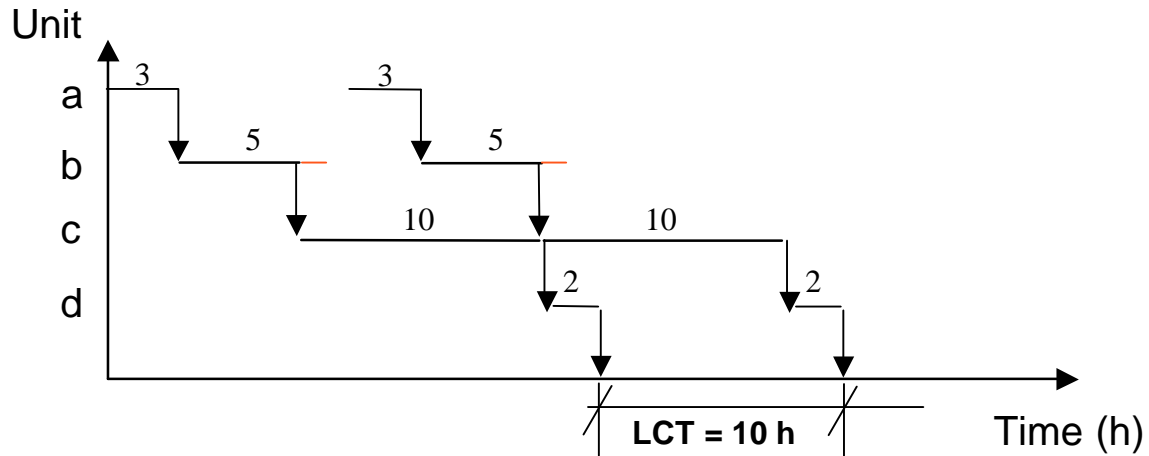
Advantages: 1. Reduce the batch size of upstream train from 60 to 30 kg, which will reduce the sizes of units a and b; (2 marks)

2. Increase the utilization of units a and b: (2 marks)

Unit	Original	Modified
a	30%	60% (3/5)
b	50%	100% (5/5)

Disadvantages: 1. One extra equipment; 2. Possible contamination or degradation of materials due to intermediate storage. (2 marks)

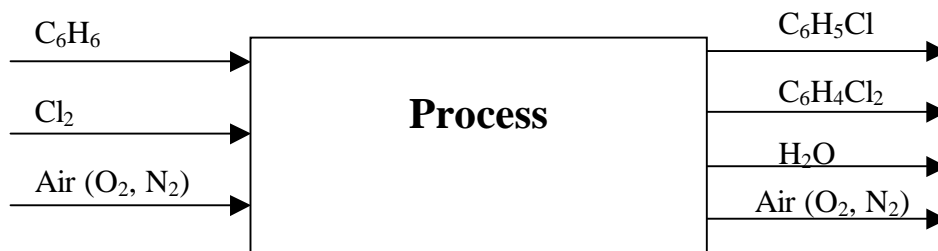
d) (5)



Gantt chart: 4 marks, LCT: 1 mark.

Q3 (55 marks)

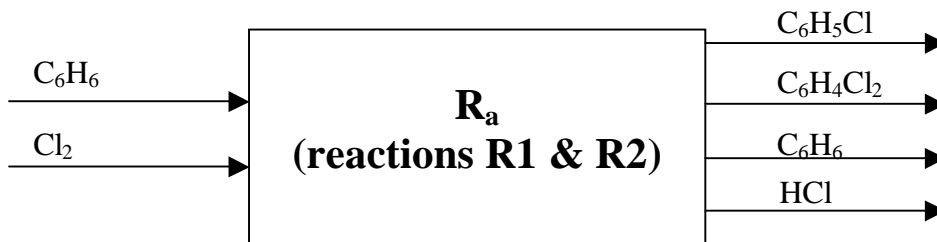
a) (5)



-1 mark for missing one stream or having one extra stream

b) (20)

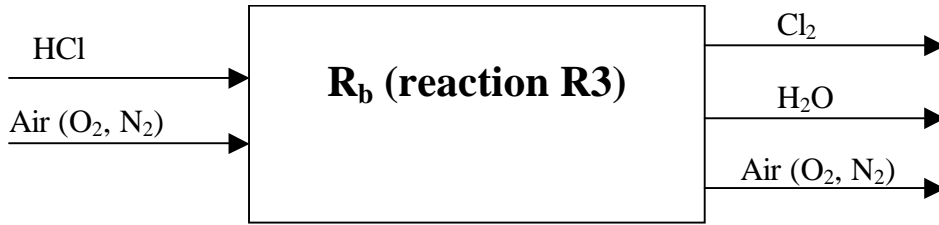
Since reactions R1 and R2 occur under same conditions, they require only one reactor. Reaction R3 requires another reactor. Total number of reactors = 2 (3 marks)



$C_6H_6/Cl_2 = 8/1$

No H_2O nor O_2 in the feeds

(2 marks)

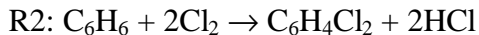
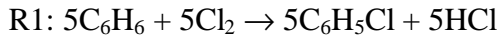


O₂ is in 20% excess of stoichiometric amount (1 mark)

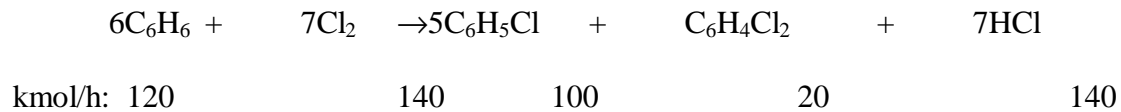
-2 mark for missing one stream or having one extra stream in each block diagram

c) (30)

Since C₆H₅Cl and C₆H₄Cl₂ are produced at 5:1 molar ratio with 100 kmol/h of C₆H₅Cl and 20 kmol/h of C₆H₄Cl₂. The reaction R1 will be adjusted to:

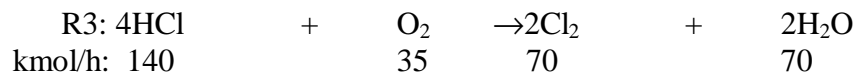


So the overall reactions R1 + R2 will be:



Thus, to produce 100 kmol/h C₆H₅Cl and 20 kmol/h C₆H₄Cl₂, 140 kmol/h Cl₂ is required and 140 kmol/h HCl is produced.

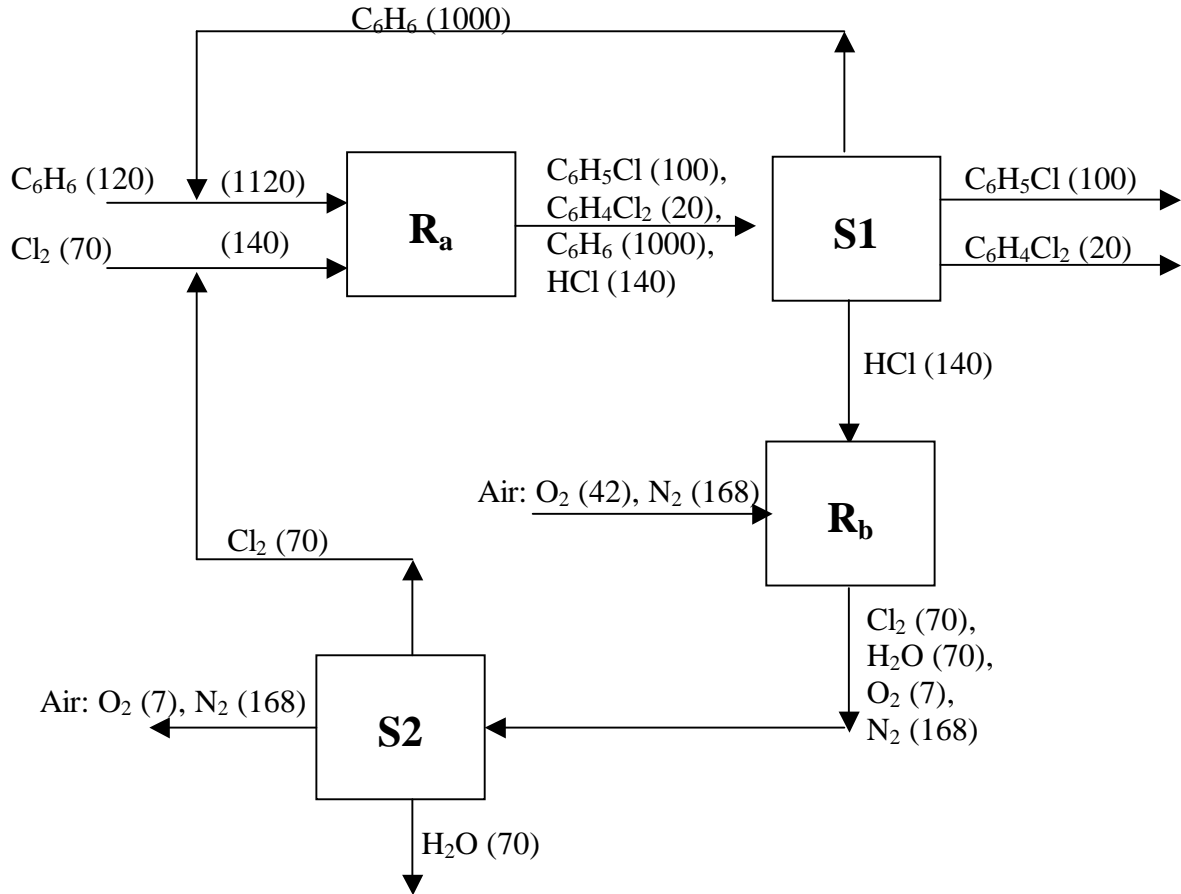
C₆H₆/Cl₂ = 8/1, so C₆H₆ = 1120 kmol/h. But only 120 kmol/h is involved in the reaction. The remaining is 1000 kmol/h.



If 140 kmol/h HCl produced from R1 and R3 is completely recovered in R3, it requires 35 x 1.2 = 42 kmol/h O₂ (only 35 kmol/h is involved in the reaction). It produces 70 kmol/h Cl₂ and H₂O, respectively. Thus, amount of N₂ will be 42 x 4 = 168 kmol/h.

Mass balance: (10 marks)

A proposed species allocation plan is as follows (all the numbers in brackets are in kmol/h):



Species allocation: (17 marks)

Heuristics: (3 marks)

Feed impurities: Feed to R_b – should N_2 be included?

Though N_2 has a NBP $< -48^\circ\text{C}$, it's difficult to separate it from O_2 . Since it's inert, so keep N_2 in the feed. The potential drawback: the extra volume of N_2 will require a larger reactor and increase the load of separation unit S2 as well.

Effluents: From R_a :

- C_6H_5Cl and $C_6H_4Cl_2$ are discharged from the system as products;
- C_6H_6 , as a valuable reactant, is recycled back to the feed stream of R_a ;
- HCl , a reactant to R_b .

From R_b :

- Cl_2 is a valuable reactant and should be separated and recycled to R_a . Since its NBP is $> -48^\circ\text{C}$, so no purging is required;
- N_2 , O_2 and H_2O are discharged as a waste;

Reactor: Reactions R1 and R2 takes place at different conditions compared to reaction R3, so two reactors are required

Note: Detailed identification of separation technology used in separation units S1 and S2 is not required in species allocation.