CHEM-E7175 Process safety and sustainability
Exam 10.12.2020; 14 -17:30

1. (5p) Explain how the management of change (MOC) could have helped to prevent the Bhopal accident?

2. (5p) In a process heat exchanger: Tube to tube-sheet joint failure results in mixing of process fluids and incompatible heat transfer fluids, resulting in a system over pressure and/or the formation and release of a toxic material. Propose design solutions for:
   a. Inherent safety
   b. Passive safety
   c. Active safety

3. (10p) A company manufactures phenol C_6H_5OH from benzene C_6H_6 by first chlorinating it with chlorine gas to chlorobenzene C_6H_5Cl and hydrogen chloride gas (which is washed in an absorber):

   $$C_6H_6 + Cl_2 \rightarrow C_6H_5Cl + HCl \quad \text{(very exothermic)}$$

   Thereafter chlorobenzene is reacted with aqueous sodium hydroxide solution to form phenol:

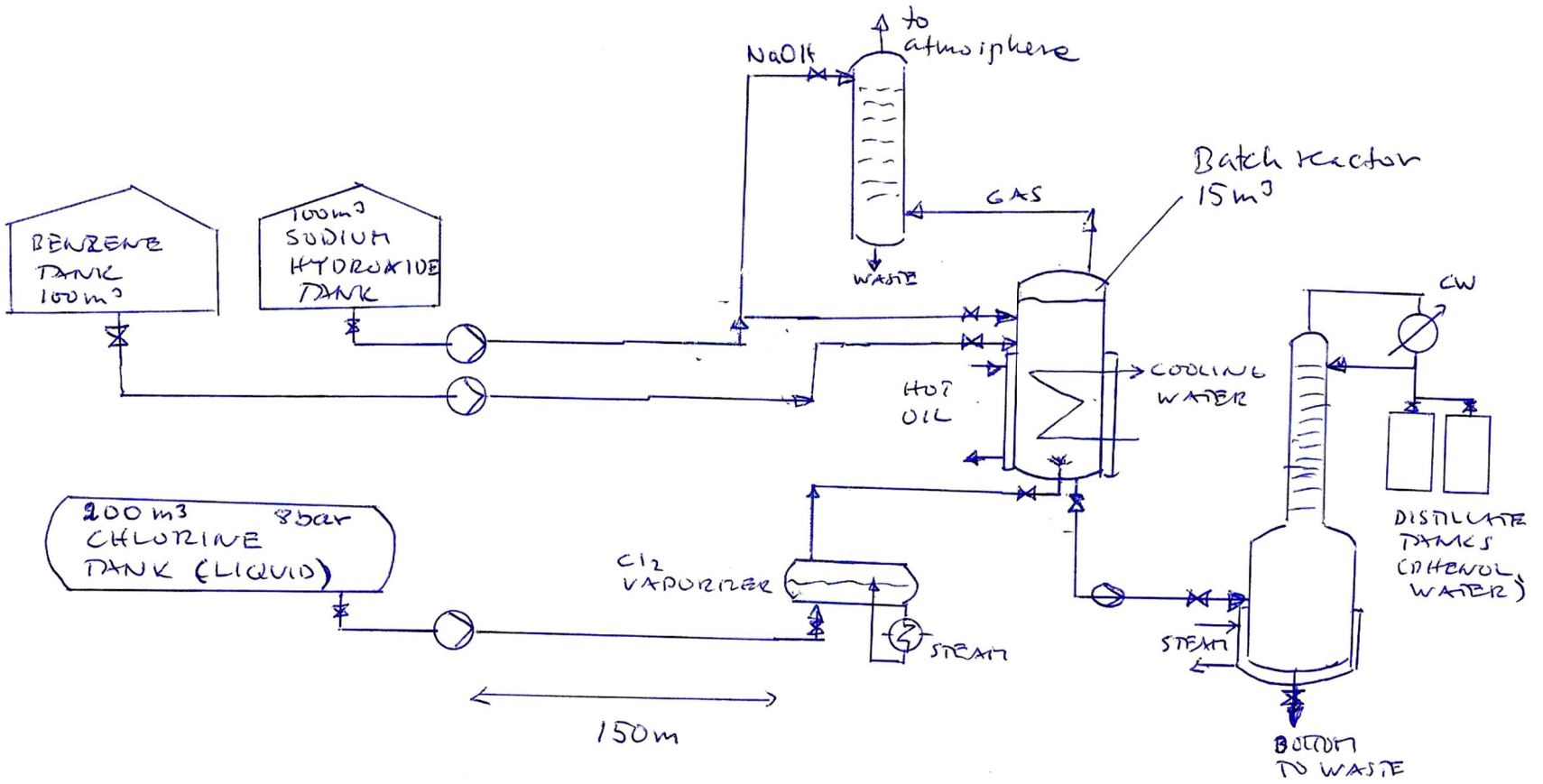
   $$C_6H_5Cl + NaOH \rightarrow C_6H_5OH + NaCl \quad \text{(slightly exothermic)}$$

   All reactions are done in the same batch reactor of 15 m^3 working volume.
   First reaction step is done by bubbling chlorine gas through liquid in the reactor, since the mass transfer from chlorine gas to benzene is slow. The conditions are 50 ^oC and atmospheric pressure with 2h residence time.
   After this chlorobenzene is heated to 230 ^oC with a hot oil system. Then aqueous solution of NaOH is added. The reaction takes 20 min. Pressure is about 20 bar during this reaction step.
   Finally, the water and phenol are distilled away in a batch distillation column and salts are left in the bottom of the column with some phenol and unknown by-products. The mixture is discarded as waste and burned. The batch distillation takes about 2 hours. A process diagram is enclosed.

The compounds have the following NEPA ratings (scale 0…4, 4 is worst), boiling points (BP), material factors (MF) and ERPG-2 values:

Components	**Health**	**Flammability**	**Reactivity**	**BP ^oC**	**MF**	**ERPG-2 mg/m^3**
Chlorobenzene	2	3	0	132	16	705
Benzene	2	3	0	80	16	480
Phenol	4	2	0	181	10	190
Chlorine	4	0	0	-35	1	8.7

Propose inherently safer improvements to the process at each process steps described.



BATCH DISTILLATION COLUMN (ATMOSPHERIC) 15m³