

16-CHEM-A5, CHEMICAL PLANT DESIGN and ECONOMICS

MAY 2018

3 hours duration

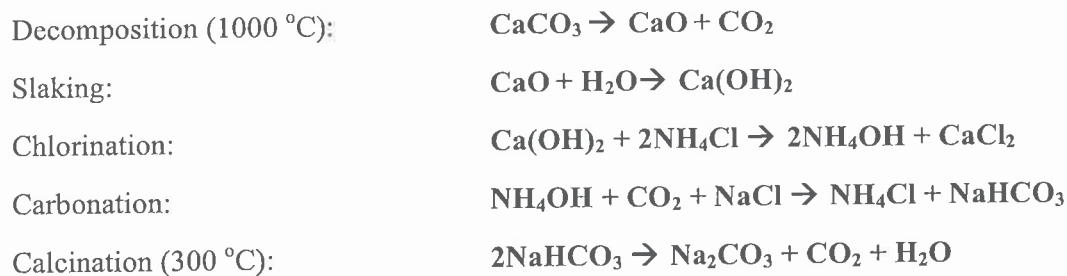
NOTES

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. The examination is a **CLOSED BOOK EXAM**. One aid sheet allowed written on both sides.
3. Candidates may use approved **Sharp/Casio** calculator.
4. **Five (5) questions** constitute a complete exam paper.
5. The questions are of equal value (**20 points each**).
6. Only the **first five questions** as they appear in the answer book(s) will be marked.
7. Clarity and organization of the answer are important. For questions that require calculations, please show all your steps.
8. State all assumptions clearly.

- Q1. Sodium bicarbonate (Na_2CO_3) is a key reactant in the production of glass and paper. Sodium bicarbonate is produced from limestone (CaCO_3) and salt via the following reaction



However, the reaction does not proceed as written above. Instead, Na_2CO_3 is produced indirectly by involving five salient reactions listed below, beginning with the decomposition of limestone into lime and carbon dioxide at $1000\text{ }^\circ\text{C}$:



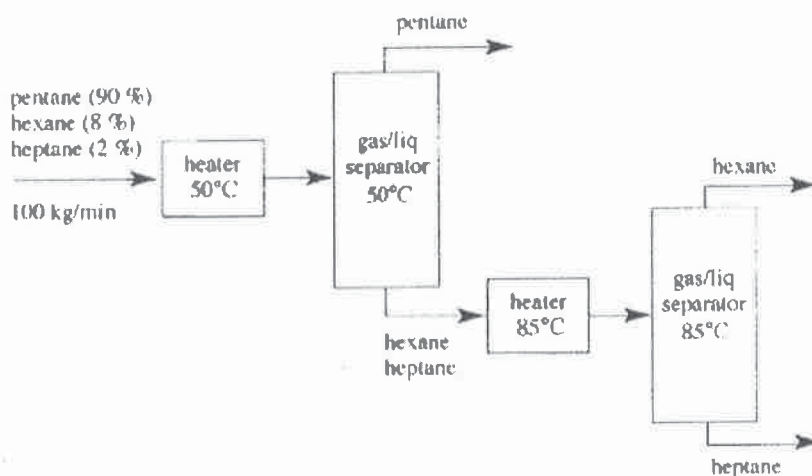
Design a chemical process flow sheet to produce Na_2CO_3 based on the reactions listed above including labeling of units and listing of components in all streams. Your process should minimize waste and reactants.

ADDITIONAL INFORMATION:

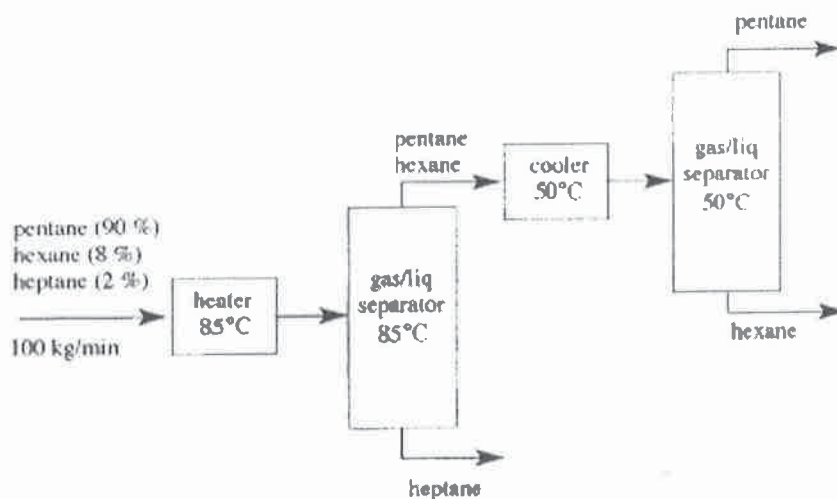
- Assume each reaction goes to completion, i.e., reactants are entirely converted to products.
- Slaking, chlorination, and carbonation occur in aqueous solutions.
- CaCl_2 , NH_4OH , and NH_4Cl are highly soluble in water.
- NaHCO_3 is only slightly soluble in water.
- CaCO_3 , Ca(OH)_2 , NaHCO_3 , Na_2CO_3 , and NH_4Cl are solids at $20\text{ }^\circ\text{C}$.
- NH_4OH exists only in aqueous solution.
- Ionic solids decompose when heated.
- Assume CaCl_2 does not react with CO_2 .

Q2. There are two schemes for separating a mixture of pentane (boiling point = 36 °C), hexane (boiling point = 69 °C), and heptane (boiling point = 98 °C) as shown below:

SCHEME #1



SCHEME #2



Explain which scheme is superior. State your choice based on the lowest depreciation. Assume the annual cost of a unit is proportional to its input capacity in kg/min. A unit twice as large costs twice as much, and energy costs are directly proportional to the amount of energy consumed.

Q3. There are 6 steps or sequences generally followed from conception of idea to the construction and operation of a chemical plant; process research, preliminary process design, preliminary process evaluation, process development, final plant design, and final process evaluation. A chemically feasible process is fundamentally characterized by process research and pilot plant studies, followed by process design and development that can be scaled up with sufficient confidence level to a commercial plant.

(a) [10 points] List ten major items that covers the process design and development of a chemical plant.

(b) [10 points] When designing processes or facilities for some applications, process engineers must decide whether to opt for batch or continuous reactor operation. Briefly write start-up, normal operating procedure and shutdown procedures for a batch reactor operation, including safety requirements.

Q4. Distillation is the most widely used method in the chemical industry for separating components of a solution, which are relatively volatile and components of the solution are required to be separated in pure form.

(a) [12 points] List and describe the steps in the overall design of a distillation column.

(b) [8 points] Distillation is carried out either in a tray tower or a in a packed tower. List and describe the criterion of selection between tray distillation tower and packed distillation tower.

Q5. Storage tanks, reaction vessels, pipes, ducting, etc., are covered with linings in order to give underlined structure protection against chemical attack, prevent contamination of the materials being processed, and minimize the effect of abrasion. List and describe with examples five commonly used linings for chemical plants and equipment.

- Q6.** In developing a flow sheet for the production of a chemical, it is desirable to consider the environmental ramifications of using each unit operation in the process rather than postponing this consideration until the flow sheet is finished. This is more likely to result in a chemical process that has less potential to cause environmental harm. In many instances, this environmentally benign design will also be more profitable, the improved design will require lower waste treatment and environmental compliance costs and will convert a higher percentage of raw materials to sellable product. List and describe six considerations for pollution prevention in the design of chemical process unit operations.