16-CHEM-A5, CHEMICAL PLANT DESIGN and ECONOMICS

DECEMBER 2017

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. Air contaminated with SO_2 and NO_2 can be cleaned by bubbling air through a suspension of $Mg(OH)_2$ in water. The following two reactions occur in the suspension:

$$SO_2 + Mg(OH)_2 \rightarrow MgSO_3 + H_2O$$

$$2NO_2 + Mg(OH)_2 \rightarrow Mg(NO_2)_2 + H_2O + \tfrac{1}{2}O_2$$

Excess $Mg(OH)_2$ removes all the SO_2 and NO_2 from the air. The magnesium solids decompose upon heating as follows:

$$MgSO_3 \rightarrow MgO + SO_2 \quad (\text{at } 200\ ^\circ C)$$

$$\tfrac{1}{2}O_2 + Mg(NO_2)_2 \rightarrow MgO + 2NO_2 \quad (\text{at } 250\ ^\circ C)$$

$$Mg(OH)_2 \rightarrow MgO + H_2O \quad (\text{at } 350\ ^\circ C)$$

The second reaction above uses excess oxygen. $Mg(OH)_2$ can be regenerated by the following reaction:

$$MgO + H_2O \rightarrow Mg(OH)_2 \quad (\text{at } 20\ ^\circ C)$$

SO_2 and NO_2 are collected separately and later converted to H_2SO_4 and HNO_3, respectively.

Using the information table given below, design a process to produce clean air, SO_2 and NO_2 from air polluted with SO_2 and NO_2. You may use MgO, H_2O and air as reactants. You need not isolate pure SO_2 and NO_2; you may produce water solutions of each SO_2 and NO_2.

	Melting Point (°C)	**Boiling Point (°C)**	**Solubility in Water**
N_2	-210	-196	-
O_2	-218	-183	-
SO_2	-73	-10	-
NO_2	-11	21	-
H_2O	0	100	-
$MgSO_3$	200	-	Insoluble
$Mg(NO_2)_2$	250	-	Highly Soluble
$Mg(OH)_2$	350	-	Insoluble
MgO	2852	3600	Insoluble

Q2. You form a small company to produce a specialty chemical. You purchase equipment that will produce 100 kg of the specialty chemical per year if operated for 40 hours/week. The equipment has a capital cost of $150,000, which includes installation. The equipment has a lifetime of 5 years, and the operating costs are listed in the table below:

Fixed Costs	$40,000/year	Rent, taxes, etc.
Payroll: Yourself	$120,000/year	$100,000 salary + $20,000 in benefits (health insurance, pension, etc.)
Payroll: Employees	$55,000/year/employee	$40,000 wages + $15,000 in benefits (health insurance, pension, etc.)
Variable Costs	$400/kg of specialty chemical produced	

(a) **[9 points]** Three employees are needed to operate the process. Calculate the minimum selling price (in $/kg) for the specialty chemical produced that will yield a return on investment (ROI) of 20%.

(b) **[11 points]** You increase production to 200 kg of the specialty chemical per year by adding a night shift of three additional employees. The salary of the night-shift employees is 25% higher than the day-shift employees. Calculate the minimum selling price (in $/kg) for the specialty chemical produced that will yield a return on investment (ROI) of 20% if you company produces 200 kg of the specialty chemical per year using two work shifts.

Q3. The most popular and successful modern movement toward greater safety in the chemical processing industries is known as Inherently Safer Design (ISD). The goal of this concept is to design production modules that are so safe that catastrophic failure cannot occur.

(a) **[9 points]** List and describe five specific ISD principles that apply to preliminary process design.

(b) **[11 points]** List and describe the four steps for Inherently Safer Predesign (ISPD).

Q4. The reactor is the heart of a chemical process, where chemical reactions are carried out to transform feeds into products. Reactor design is a vital step in the overall design of the process, and it is important to ensure that the equipment specified will be capable of achieving the desired yields and selectivity when operated at full scale. Therefore, the design of a chemical reactor should not be carried out in isolation from overall process design. List and describe the steps in the overall procedure for a chemical reactor design.

Q5. A Materials Safety Data Sheet (MSDS) is a document summarizing the hazards, health, and safety information for a chemical. It contains the information needed to begin analyzing materials and process hazards; to understand the hazards to which the workforce is exposed; and to respond to a release of the material or other incident where emergency response personnel may be exposed to the material. List the sections contained in a typical MSDS for a chemical.

Q6. Waste arises mainly as by-products or unused reactants from a process, or as off-specification product produced through misoperation. When waste is produced, processes must be incorporated in the design for its treatment and safe disposal.

(a) **[6 points]** List 8 techniques used to treat and dispose waste.

(b) **[4 points]** Describe techniques to treat and dispose gaseous wastes.

(c) **[4 points]** Describe techniques to treat and dispose liquid wastes.

(d) **[2 points]** Describe techniques to treat and dispose solid wastes.

(e) **[4 points]** Describe techniques to treat and dispose aqueous wastes.