

# ORDRE DES INGÉNIEURS DU QUÉBEC

## MAY 2018 SESSION

Open-book examination  
Calculators : only authorized models  
Duration : 3 hours

### 16-CH-A5 Chemical Plant Design and Economics

#### PROBLEM 1 - (35 points)

##### NEW ALUMINIUM PLANT

You read the newspaper announcing the construction of a new aluminium plant. According to the newspaper article, the cost of the project's total capital investment would be \$ 2.0 billion. The expected plant capacity will be 400 000 metric tons per year and the metal selling price is 2 500\$/ton.

a) What would be the direct production costs of this project ?

We assume that electricity consumption will be 15 kWh/kg of metal, the electricity purchasing cost of 3.4 cent/kWh, operation labor and raw material costs of 100 and 700 \$/ton of metal, respectively. To estimate other direct costs components, you can use typical cost factors ("rules of thumb") for chemical industrial project.

It will be assume that the working capital is 15% of the total capital investment of the project.

b) From typical factor for chemical process construction costs, estimate what may be the total annual production costs for this project ? (we will assume that general expenses like sales costs, administrative costs, R&D and financial costs are around 200 000 000\$/year)

c) What would be the gross rate of return on investment (ROI) of the project?

## PROBLEM 2 - (15 points)

### ESTIMATION OF REACTOR INSTRUMENTATION AND OPERATING COSTS

Given a heated reactor, which is fed with raw material A with addition of a catalyst B. The mix is then transferred in a reactor for a given residence time, before being continuously transferred to the next process step.

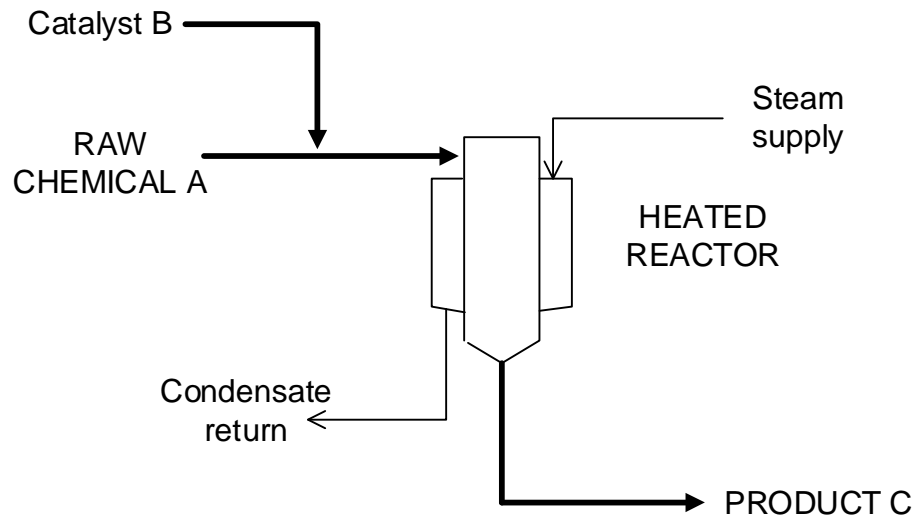


Figure 1 – Heated reactor with catalyst addition process flow diagram

- Given the reactor production rate of  $100 \text{ m}^3/\text{h}$ , and the residence time of 10 h to reach a complete conversion of raw material to product, what will be the reactor size, in terms of volume ?
- Given a specific heat of reactor solution of  $1 \text{ BTU}/\text{lb}/^\circ\text{F}$ , and a steam price of  $3\$/\text{million BTU}$ , what will be the hourly steam cost required to operate the reactor?

NB : We will assume that solution specific volume is  $1000 \text{ kg}/\text{m}^3$ , inlet and outlet reactor temperature are  $20$  and  $80^\circ\text{C}$  respectively, and assumption of adiabatic reactor operation.

- Assuming that the installed reactor capital cost would be of  $1\,000\,000 \$$ , and using typical installation factor for chemical industry, what could be the instrumentation and control cost of this project ?

### PROBLEM 3 - (20 points)

#### REUSE OF A PACKED TOWER SCRUBBER

A plant is evaluating the possibility of reuse an existing packed tower scrubber to comply with a regulation on atmospheric contaminant. The scrubber could clean diluted acid vapor contained in foul air exhausted from a chemical process. The air flow to handle will be  $10\,000\text{ m}^3/\text{h}$  of air contaminated with  $100\text{ mg/m}^3$  of sulfuric acid, and the standard to respect will be  $1\text{ mg/m}^3$  at the scrubber outlet.

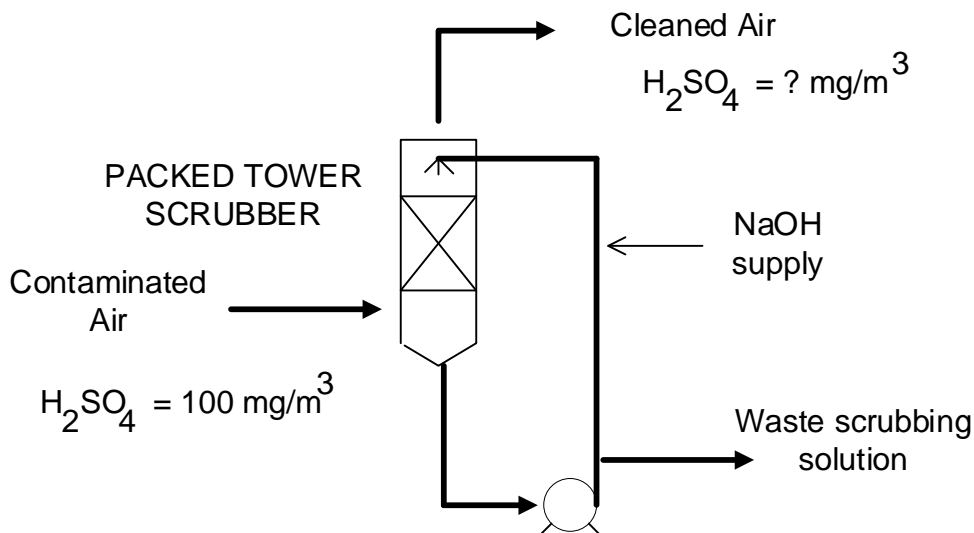


Figure 2 – Acid scrubber control process diagram.

a) Given that the scrubber bed consists in 10 feet of random packing, for which the height of transfer unit (HTU) is 1 foot for the normal scrubber operating conditions, using a diluted water-NaOH solution, what will be the scrubber acid outlet concentration?

We will assume that for system air- $\text{H}_2\text{SO}_4$  – NaOH-water, the number of transfer unit (NTU) may be :  $\text{NTU} = \ln(Y_i/Y_o)$ , where  $Y_i$  and  $Y_o$  represent acid concentrations in the air at the scrubber inlet and outlet, respectively.

b) You need to estimate the cost for a new scrubber, but the only data you have is a quote of 150 000\$ for a scrubber with the same specification, but for a capacity ten times higher (100 000 m<sup>3</sup>/h). Based on rules of thumb relating purchased equipment costs to the critical size of process equipment, estimate the cost of a new scrubber for the required capacity of 10 000 m<sup>3</sup>/h.

c) Estimate the annual cost of NaOH to neutralize the sulfuric acid, given the unit NaOH cost of 1\$/kg and annual operation of 8 400 hours/year. Molecular weights of acid and base are 98 and 40 g/mole, respectively.

#### **PROBLEM 4 - (20 points)**

##### **CENTRIFUGAL PUMP MOTOR SIZING AND ANNUAL POWER COST**

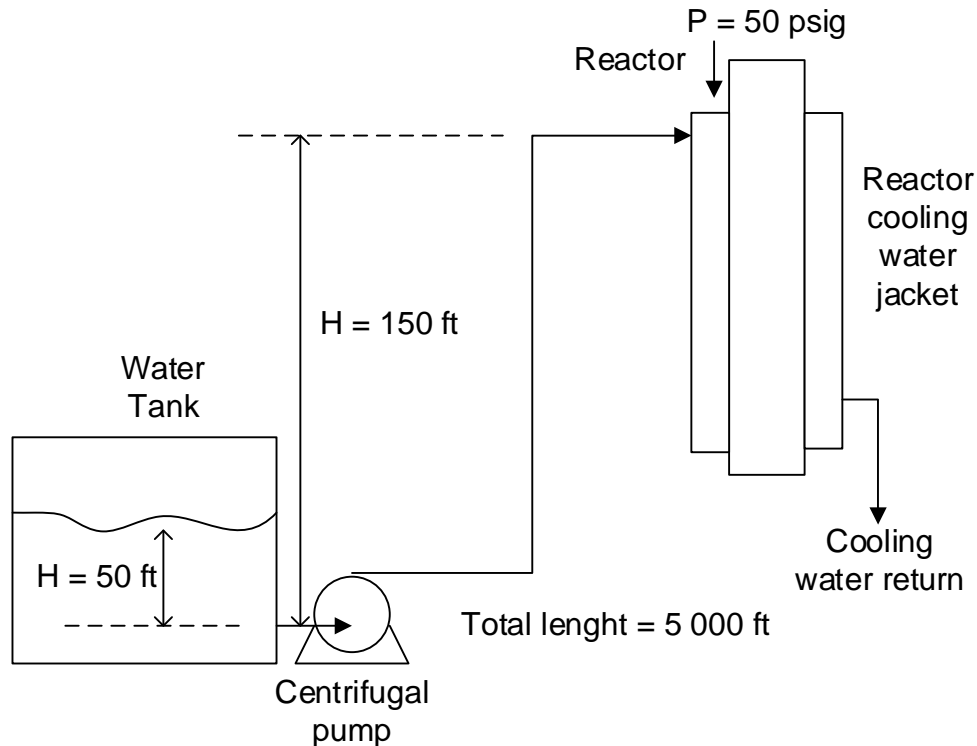
We ask you to size a pipe, in order to transfer 1000 USGPM of cooling water to feed a reactor jacket located 5 000 ft from the pump location, 150 ft above the pump inlet, at the reactor cooling water pressure of 50 psig (see figure 3). The pump will take water from a tank with an average level of 50 ft.

a) What is the optimum pipe diameter that you propose at the pump outlet, using rules of thumb (typical water velocity) ?

b) Considering the gravity, the pressure and the friction losses, what will be the required motor power for the pump, in kW ?

We may assume 85% and 90% for mechanical and motor electrical efficiencies, respectively. We will assume that the friction losses are 1.9 ft of water column per 100 ft of pipe.

c) Based on your previous calculations, what will be the annual power cost, for an operation of 8 400 hours per year at 0.05\$/kWh ?



**Figure 3 – Cooling water circuit flow diagram.**

Note :  $7.48 \text{ USG} = 1 \text{ cubic foot}$ ,  $101.3 \text{ kPa} = 14.696 \text{ psig}$ ,  $g=9.81 \text{ m/s}^2$   
 $\text{water density}=1000 \text{ kg/m}^3$

### **PROBLEM 5 - (10 points)**

#### **INTEREST COSTS OF AN INDUSTRIAL PROJECT**

You read in the newspaper the announcement of the construction of a new lithium carbonate plant. According to the newspaper article, the cost of the project's total capital investment would be \$ 0.8 billion. It is mentioned that the project is financed by a loan of \$ 400 million over 15 years at an interest rate of 6%. What would be the average annual interest cost on this loan, assuming it is repaid with equal 15-year annuities?