ORDRE DES INGÉNIEURS DU QUÉBEC

MAY 2019 SESSION

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

16-CH-A5 Chemical Plant Design and Economics

PROBLEM 1 - (35 points)

NEW MAGNESIUM PROCESS

You read in the newspaper the announcement of the construction of a magnesium plant. According to the newspaper article, the cost of the project's total capital investment would be $ 750 million. The capacity of the plant would be 60 000 metric tons per year and revenues of $ 300 million / year of metal. The article also mentions that the raw material would be an abandoned mining residue of asbestos mines, with zero costs for the project, and containing an average of 24% magnesium. It will be assumed that the working capital represents 15% of the total capital investment of the project.

a) The article mentions that the project is financed by a $ 300 million loan over 15 years at a 4% interest rate. What would then be the *average annual interest cost*, assuming that this loan is repaid with equal 15-year annuities?

b) According to the usual rules of thumb for chemical plant construction projects, what could be the total annual production costs?

It will be assumed that the electricity consumption is 18 MWh / ton of Mg, at 8760 hours / year at $ 0.024 / kWh, the cost of ingredients and other services are $ 600 / ton of Mg and the costs of the labor $ 500 / ton of Mg, respectively. For other components of annual costs, use typical factors (rules of thumb) that are common for industrial projects.

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

PROBLEM 2 - (15 points)

SIZING, OPERATING AND PURCHASE COSTS OF AN EVAPORATOR

Given a forced circulation evaporator, in which 6 000 lbs / h of a mother solution containing 1% (by weight) of dissolved solids is continuously concentrated. The evaporator consists of a shell and tube heat exchanger, into which the solution is introduced on the tube side and the live steam is injected on the shell side. The concentrated solution is transferred to a flash tank, from where the steam is directed to a condenser. The concentrated solution at 6% (by weight) of dissolved solids is extracted from the return loop of the separator, and the mother solution is introduced upstream of the circulation pump. The process is illustrated in the following diagram.

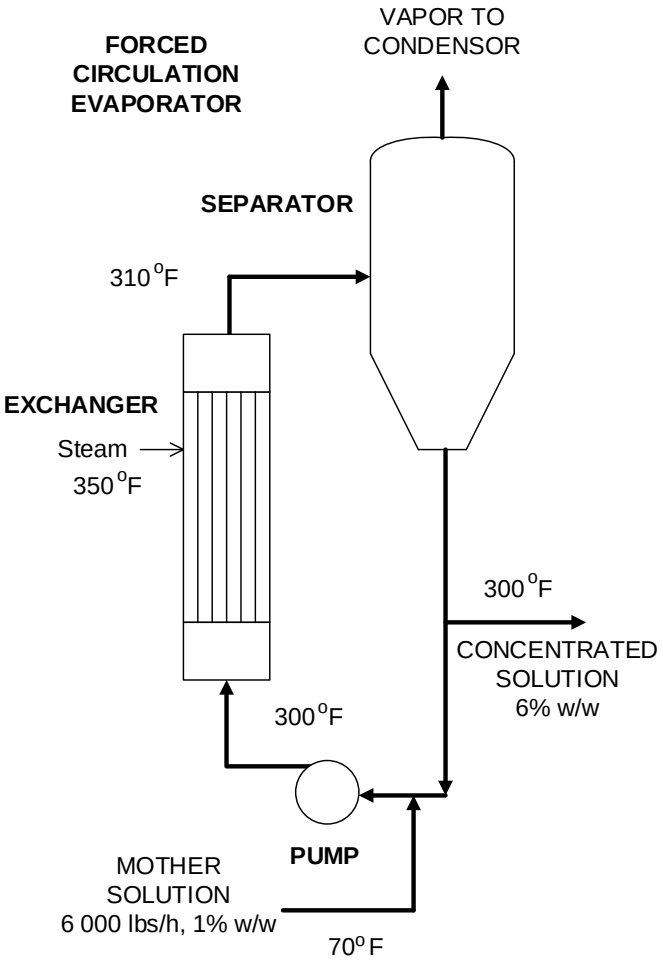

Figure 1 – Flowsheet of a forced circulation evaporator operated using steam

a) Given that the temperature of the mother solution is 70 ^{o}F, and that the circulation loop rises from 300 ^{o}F to 310 ^{o}F in the exchanger, what would be the annual cost of vapor required from the evaporator, at a steam cost of 5$ / million BTU and for 8 760 hours of operation per year?

Note: One will take 1 BTU / lb / ^{o}F and 1000 BTU / lbs for the heat capacity and latent heat of the mother solution, respectively, and 1050 BTU / lb for the heat of live steam at 350 ^{o}F.

b) Given that the overall heat transfer coefficient of the exchanger would be 175 BTU / h / ^{o}F / ft^{2} for this evaporator, what would be the required surface area of the exchanger?

c) Assuming that the purchase cost of an evaporator with the same specifications is $ 200 000, but with a reference area of only 150 ft^{2} of exchange area, and using the usual rules of thumb for process equipment, what could be the cost of this evaporator?

PROBLEM 3 - (20 points)

INCINERATION OPTIONS FOR VOLATILE ORGANIC COMPOUNDS (VOC)

A new organic acid plant must control VOC emissions from the plant reactor to meet environmental standards by incinerating these emissions. Given that the energy value of contaminants can be considered negligible, you have to evaluate the optimal alternative between a direct incinerator compared to a catalytic incinerator with a combustion chamber of 800 ft^{3}. The direct incinerator will consume approximately 30 million BTU / h of natural gas and the catalytic incinerator approximately 3 million BTU / h. Since the plant is new, the project's economic horizon will be 15 years at 8 000 h of operation per year.

a) Using the figure 2 and based on the factorial cost analysis of the of fixed capital investment, estimate the installed cost of each incinerator. The process is fluid.

b) Assuming that operating costs are limited to annual incinerator service costs (given 1 000 BTU / ft^{3} for natural gas heat of combustion and at $ 0.30 / m^{3}), what would be the optimal choice for the plant ?

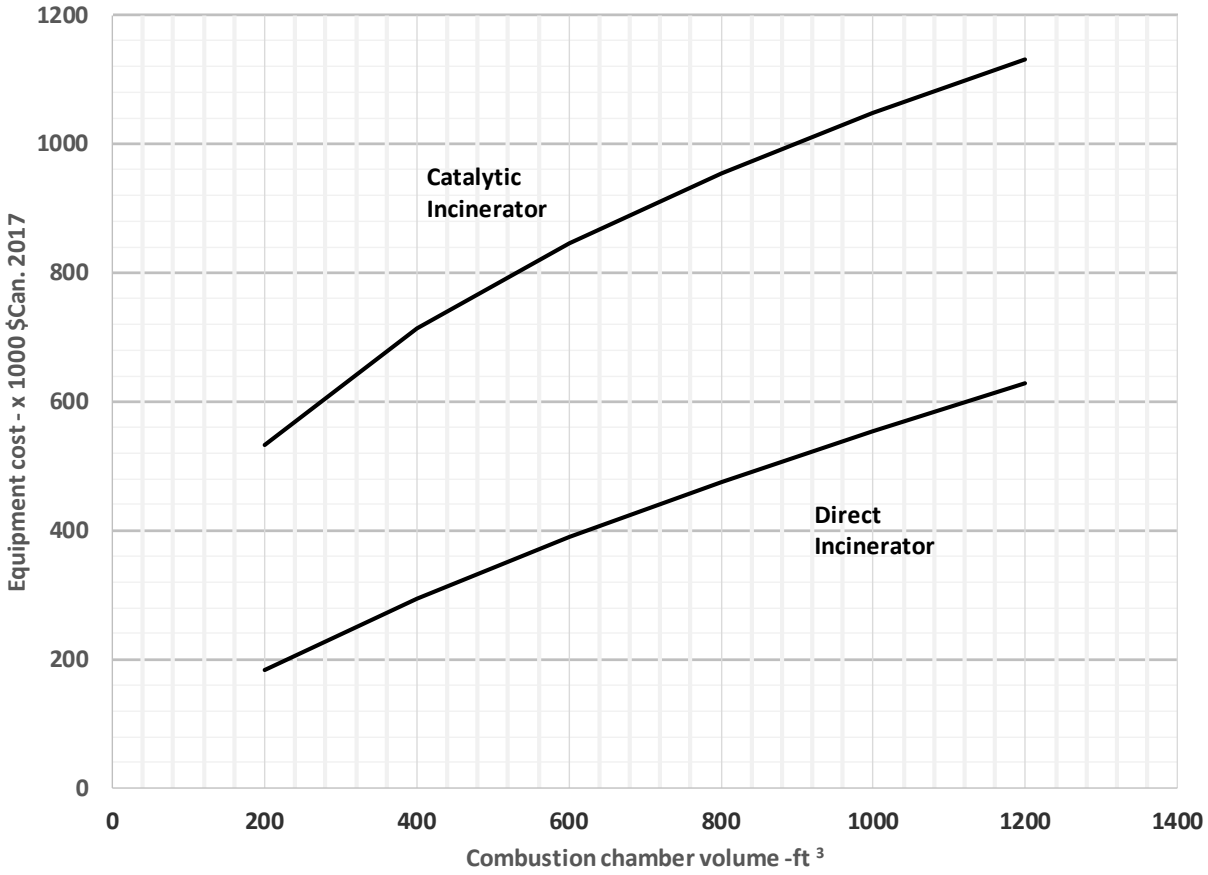

Figure 2- Purchase cost of a catalytic incinerator and a direct incinerator as function of the volume of the combustion chamber

PROBLEM 4 - (20 points)

HEAT RECOVERY FROM A COGENERATION PLANT

A company plans to recover heat from the cooling tower of a cogeneration plant. The concept is to add a pump on the recirculation tank of the cooling tower to direct warm water (at 40 ^{o}C) to the heat exchanger of a greenhouse to allow producers to heat their facilities. An engineering study showed that if the water return temperature of the greenhouses was 25 ^{o}C, 100 Million BTU / h could be recovered, with a 10 000 USGPM circulation pump.

We will assume:

i) that the new pump is installed just on the side cooling tower water recirculation tank (atmospheric),
(ii) the distance between the tank and the greenhouse is 1 000 ft,
(iii) the pressure drop across the exchanger is 15 psig

iv) the water inlet is 5 ft above the level of the cooling tower water tank (negligible gravity).

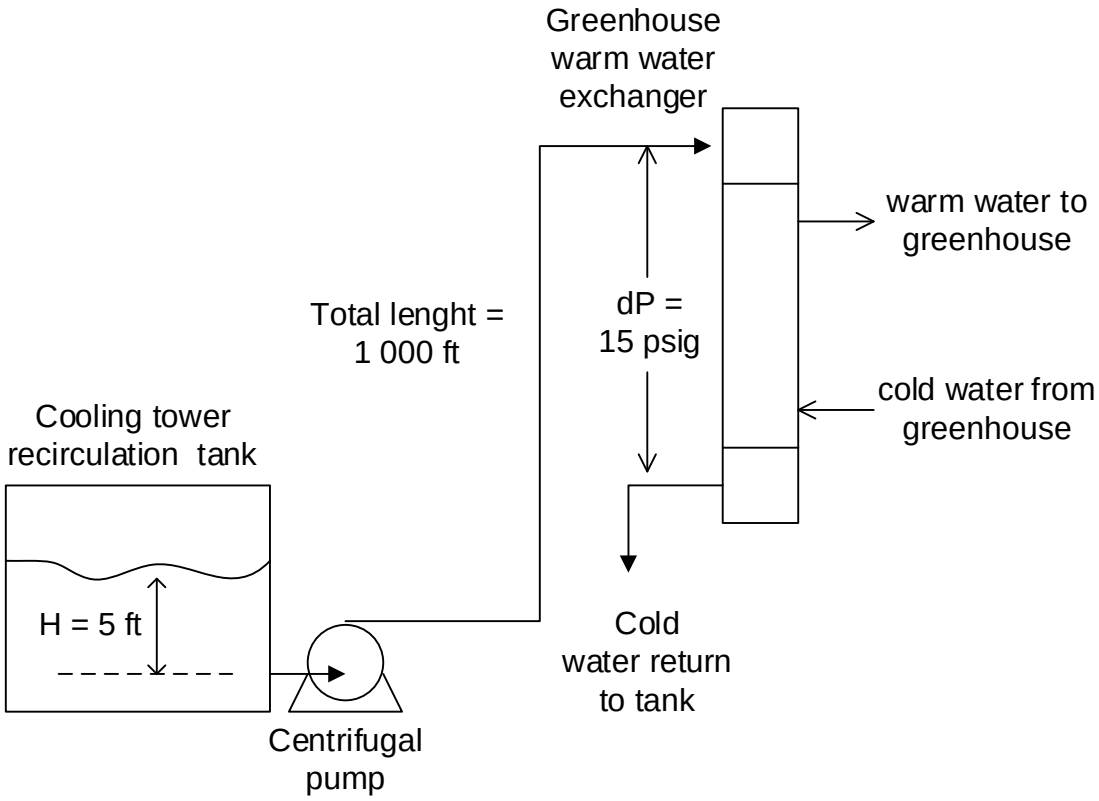

Figure 3 – Flow diagram : Cogeneration plant heat recovey

a) What would be the optimum diameter of a stainless steel pipe, based on the usual rules of thumb at the outlet of a centrifugal pump?

b) What is the annual power cost required by the pump (at $ 0.05 / kWh)?
At this point, it will be assumed that the friction losses of the pipe and accessories are 1 ft of water / 100 ft of pipe. It will be assumed that the mechanical efficiency of the pump is 85% and the efficiency of the motor is 90%.

c) If the company required to be paid $ 5 / Million BTU for the energy recovered by the greenhouse owners, what would be the gross rate of return on investment (ROI) for this project if it is assumed that the total capital cost of the project is 1.5 M$ and that operating costs are limited to the cost of power of the pump?

NB : 101,3 [SS1]kPag = 14,7 psig, g = 9.81 m/s^2, water density =1 000 kg/m^3

PROBLEM 5 - (10 points)

COST OF EQUIPMENT AND ENGINEERING OF AN INDUSTRIAL PROJECT

You read in the newspaper the announcement of the construction of a new liquefied natural gas plant. According to the newspaper article, the cost of the project's total capital investment would be $ 7.5 billion. Based on the typical factors (rules of thumb) for industrial projects (the process is fluid):

a) What could be the purchase costs of equipment for this project?
b) What could be the costs of the detailed engineering of the project?