ORDRE DES INGÉNIEURS DU QUÉBEC

NOVEMBER 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 LIQUEFIED NATURAL GAS (LNG) PLANT

You read in the newspaper the announcement of the construction of a new liquefied natural gas (LNG) plant. According to the newspaper article, the cost of the project's total capital investment would be $ 0.8 billion. The capacity of the plant would be 500 000 metric tons per year and LNG conversion revenues of $ 200 / ton. For the economic analysis of the project, we only consider the liquefaction operation, so we do not consider the cost of natural gas in operating costs, nor in revenues. You may assume that the working capital represents 15% of the total capital investment of the project.

a) What would be the annual financing costs (average annual interest charges) for this project,

given that the project is financed at 50% over 15 years at an interest rate of 6% and that the loan will be repaid with equal annuities over 15 years.

b) According to the usual thumb rules for chemical plant construction projects, what could be the total annual production costs? It will be assumed that the electricity consumption is 50 MW, at 8 760 hours / year at $ 0.034 / kWh, the cost of labor and other raw materials of $ 8 and $ 5 / ton, respectively. It will also be assumed that administrative expenses, sales expenses and R & D costs represent $ 5,000,000 / year. For the other components of direct costs, use the typical cost factors (rules of thumb) for industrial projects.

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

PROBLEM 2 - (15 points)

SIZING, COSTS OF OPERATION AND PURCHASE OF A REACTOR

Figure 1 shows a cooled reactor, in which the raw material is added continuously. The reactor consists of a shell and tube heat exchanger, in which the reactants are introduced on the tube side, which is filled with a catalyst. Product C is formed in the reactor before being continuously discharged to the subsequent stages, and the reaction is exothermic. Cold water is circulated on the shell side, at countercurrent of the process side (tubes), as shown in the following diagram.

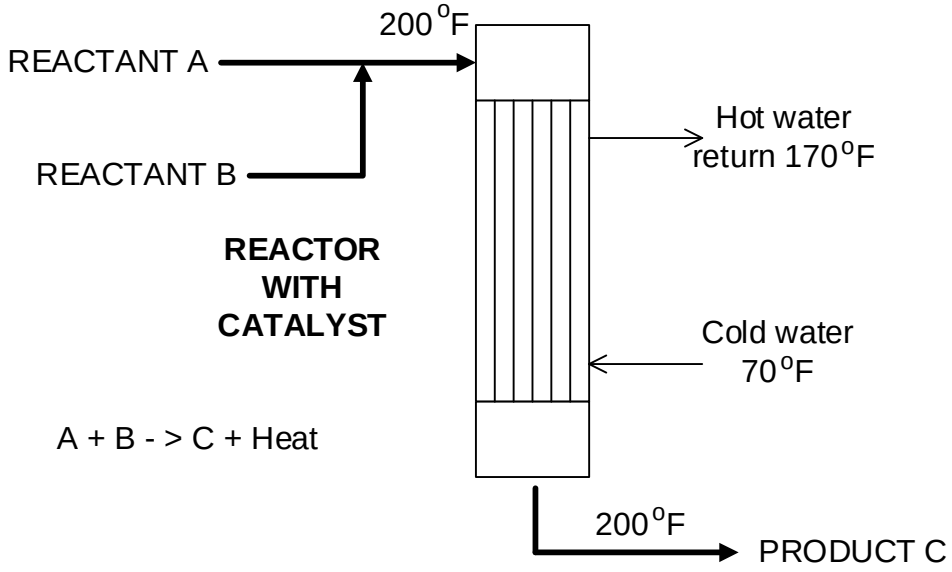

Figure 1 – Flow diagram: Water cooled catalyst reactor

a) Knowing that the reactor production rate is 10 000 lbs / h of product C, and the heat of reaction is 15 000 BTU / lb of C, what would be the annual cost of cooling the reactor, at a price of $ 0.05 / cubic meter of cooling water and 8 760 hours of operation per year?

NB: Given 1000 kg/m3 for the water density, 1 BTU/lb/oF for the water heat capacity, 200 ^{o}F at the inlet and outlet of the tube-side reactor, and that the reactor is adiabatic. The cooling water temperature on the shell side is 70 ^{o}F and the hot water return is 170 ^{o}F.

b) Given that the overall heat transfer coefficient of the exchanger would be 300 BTU/h/^{o}F/ft^{2} for this application, what would be the exchange surface area of the reactor?

c) Assuming that the purchasing cost of a heat exchanger with the same specifications is $ 100 000, but a reference exchange surface area of only 1000 ft^2, and using the usual rules of thumb for process equipment, which could be the cost of the reactor?

PROBLEM 3 - (20 points)

TURPENTINE RECOVERY OF PULP KRAFT PROCESS

A plant is evaluating the possibility of recovering turpentine formed during wood cooking by the Kraft process. The vapors are separated from the cooking process, directed to a separator and a primary condenser, followed by a secondary condenser. The condensers are of the shell and tube type, with the vapors on the tube side. The flow rate of steam to be treated would be 10 000 lbs / h of water (98%) / turpentine (2%), and the split between contaminated water and turpentine according to the following scheme.

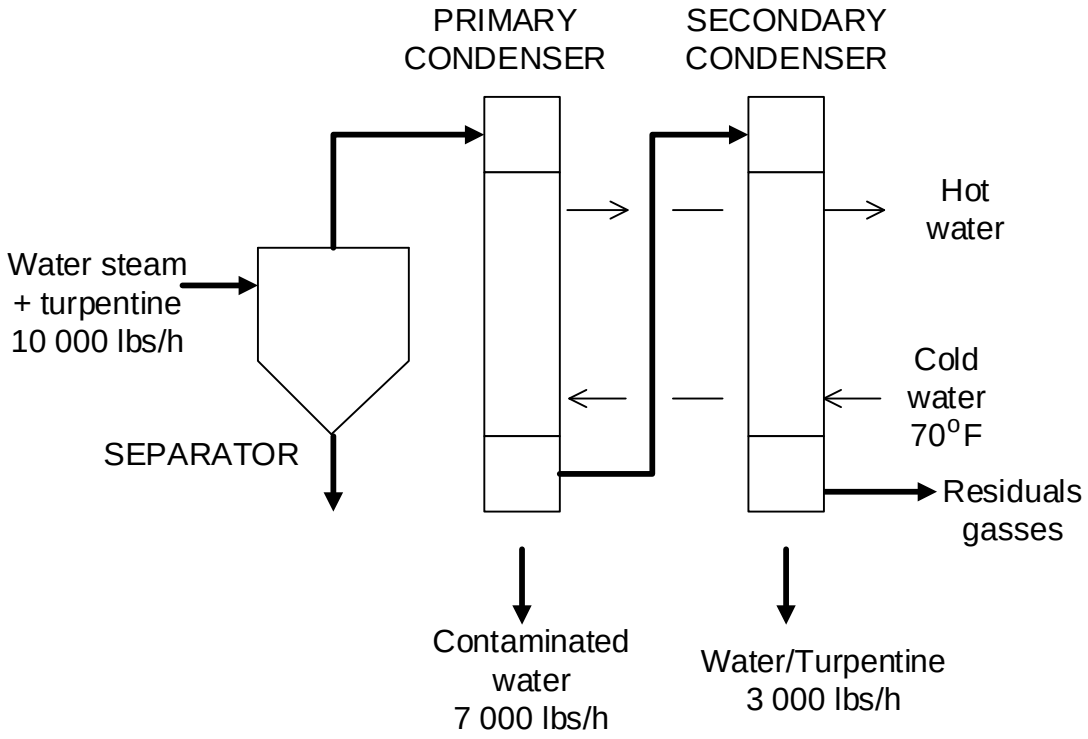

Figure 2 – Flow diagram: Turpentine recovery system

a) Knowing that the cost of purchasing process equipment would be 250k$, what could be the cost of fixed capital investment, using the typical cost factors (rules of thumb) common to industrial projects?

It will be assumed that all the necessary services are available and existing, that no building is necessary and that it is a fluid process.

b) Assuming that the latent heat of condensation of the water / turpentine mixture is 1000 BTU / lb, that water at 70 °F is used to operate both condensers, and that the residual gas energy is negligible, calculate annual energy savings recovered at $ 5 / million BTU based on 8 400 hours per year.

c) Assuming that turpentine (2%, by weight of feed) recovered is worth $1400 / tonne, and that the operating costs of the system are negligible, what would be the gross rate of return on investment (ROI) of the project?

PROBLEM 4 - (20 points)

YEAST DRYER ANNUAL OPERATING COSTS

You are asked to size the ancillary equipment of a yeast drier. The dryer consists of an atomization chamber, a natural gas burner and a 20 m^3/h piston pump for atomizing a 5% (by weight) yeast solution.

a) Considering that the pressure drop of the dryer yeast solution supply circuit is mainly due to the atomizing nozzles (3 000 psig), what would be the power required of the pump motor, in kW?

NB: At this stage of estimation, we will assume 65% and 90% for the mechanical efficiency of the pump and electric motor, respectively. It will further be assumed that the loss of load due to gravity and friction is negligible.

b) Assuming that the energy required from the dryer is primarily that required for the evaporation of water from the yeast solution, what would be the hourly amount of natural gas required for the operation of the dryer, knowing that its overall thermal efficiency overall is 67%. 1 000 BTU/lb will be used as the latent heat of evaporation of the solution and 1 000 BTU/ft^3 as the net heat of combustion of the natural gas.

c) Based on your previous calculations, what would be the total annual operating cost of pump power and burner at 8 400 hr /year, at $ 0.05/kWh of electricity and $ 0.005/ft^3 for natural gas price ?

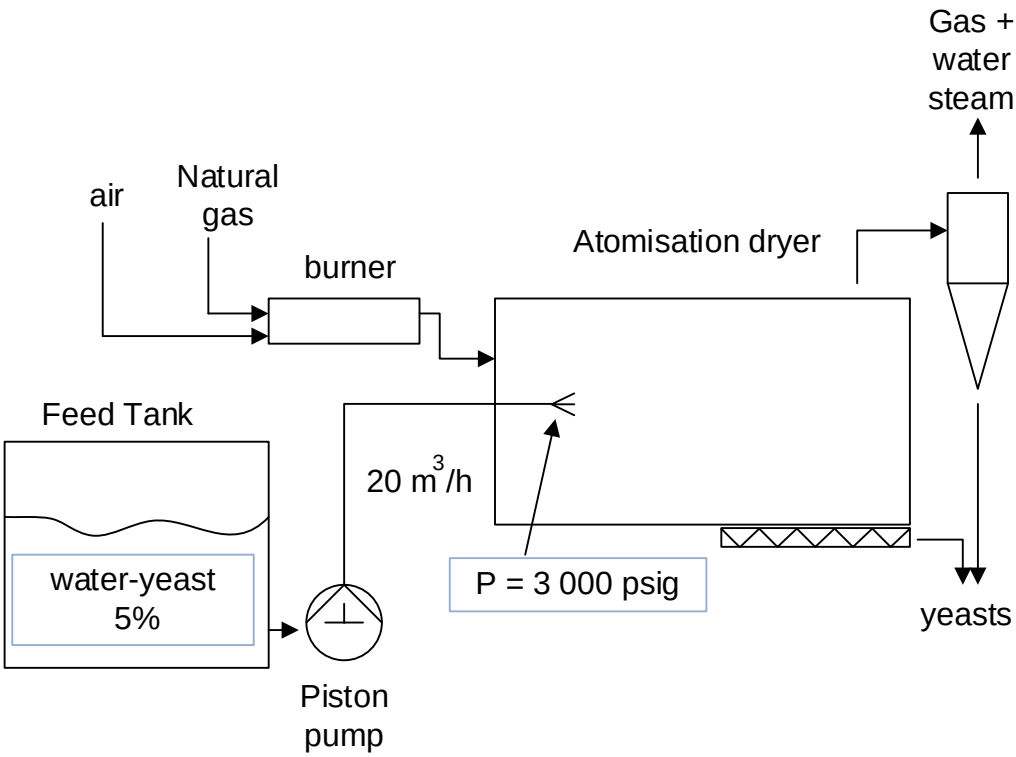

Figure 3 – Flow diagram : Atomisation dryer

Note : 101.3 kPa = 14.696 psia, g=9.81 m/s^2 water density=1000 kg/m^3

PROBLEM 5 - (10 points)

EQUIPMENT AND MAINTENCE COSTS OF AN INDUSTRIAL PROJECT

You read in the newspaper the announcement of the construction of a new terephthalic acid plant. According to the newspaper article, the cost of the project's total capital investment would be $ 750 million. Based on the typical cost factors (rules of thumb) common to industrial projects (the process is solid-fluid):

a) What could be the purchasing costs of equipment?

b) What could be the maintenance costs of the plant?