EEN-E3003, Industrial drying and evaporation processes

Home exam, March 28, 2022

You can answer the questions either in English or Finnish

(Jos vastaat suomeksi, merkitään suorituskieleksi suomi)

PROBLEM 1

Dry solid contents of a solution increases from 4% to 12% in a mechanical recompression evaporator (MVR). The feed of solution into the evaporator is 21000kg/h and its inlet temperature is 80°C. The outlet temperature of the concentrate is 90°C and the outlet temperature of the condensate is 100°C.

A) How much water is evaporated in the evaporator?
B) What is the electricity consumption of the compressor? You can ignore boiling point elevation of the solution.
C) Figure 1 shows location of a condensate pump that pumps condensate out of the evaporator. The pressure loss in the pipes is 130 Pa/m and the NPSH number reported by the manufacturer is 2.1 m. Is the condensate pump situated correctly in the system?

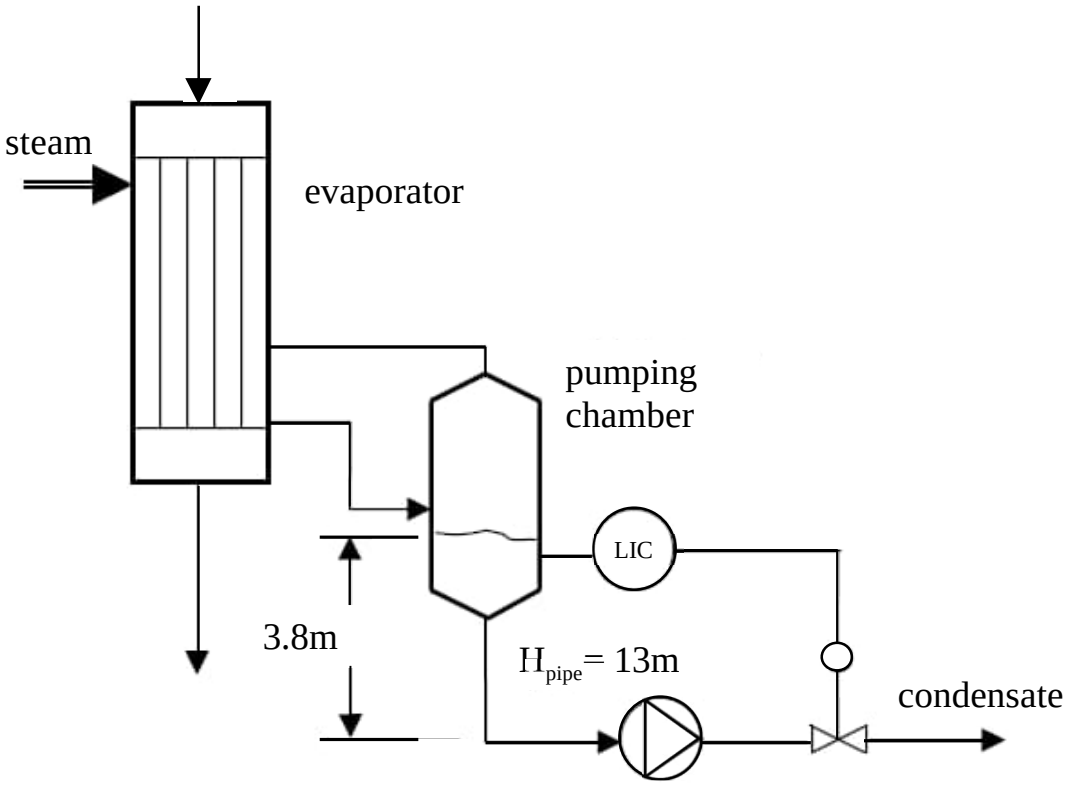

Figure 1: Location of a condensate pump after the evaporator

PROBLEM 2

Boards are dried in a drying kiln. When the drying begins, the moisture content of the boards is 1.6 kg/kg_{ds} and temperature 18°C. Temperature of the drying air is 100°C, relative humidity 1.6% and total pressure100kPa. The average heat transfer coefficient for the boards is 6.7 $W/(m^2K)$. The evaporation surface of a board is 0.23 m^2 and volume 0.00125m^3. Density of dry board is 300kg_{ds}/m^3.

A) What is the evaporation rate just in the beginning of drying? You can assume that the Lewis number is 1.
B) What is the critical moisture content of the board (kg/kg_{ds}), when the mass of board decreases 4 g during the initial heating period and the constant drying rate period lasts 1780 seconds?

PROBLEM 3

A CHP plant produces 6 MW of electricity and 30 MW of process heat. Total efficiency of the plant is 0.87.The plant combusts both bark and coal. The moisture content of bark is 60 % w.b. and the lower heating value of the dry bark is 18.9 MJ/kg_{ds}. The lower heating value of coal is 24 MJ/kg and its mass flow rate into the boiler is 0.2kg/s. The plant quits the use of coal by drying bark before the boiler in a dryer which uses waste heat as a heat source.

A) What must the final moisture content of the bark be that the plant can quit the use of coal?
B) Temperature of the drying air before the heating is 15°C and relative humidity 60%. Temperature of the drying air after the dryer is 35°C and absolute humidity 0.025kg/kg_{da}. What is the specific heat consumption of the dryer, if there are no heat losses in the dryer? Total pressure is 100kPa.

PROBLEM 4

A) Figure 2 (next page) shows the drying curve of a material. Material dries in a room, where the temperature is 70°C, relative humidity 20% and total pressure 100kPa. Temperature of the material in the beginning of drying is 12°C. What is the vapor pressure in the material when the time is 0s and 3500s?

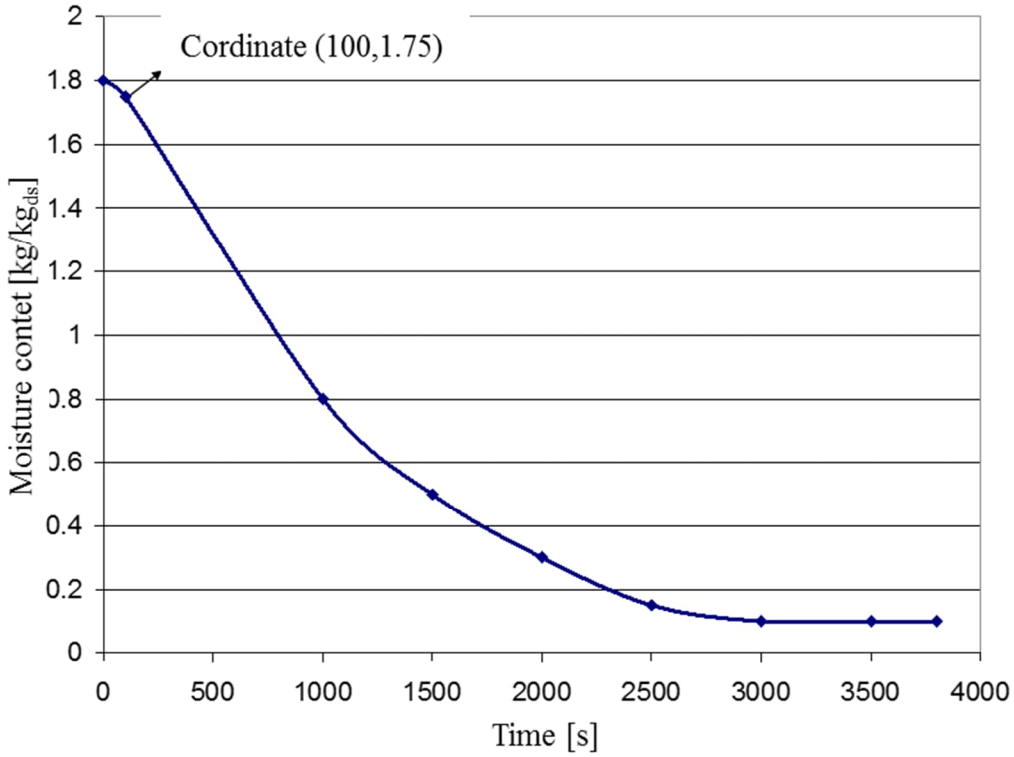

Figure 2. Drying curve of a material.

B) Author A has published a paper in journal of drying technology and s/he models dying rate in a direct superheated steam dryer using the following equation

$$m'' = \frac{1}{\frac{1}{G_s} + \frac{1}{G_u}} \ln \frac{p_o - p_y}{p_o - p_V} \qquad (1)$$

where G_s and G_u describes mass transfer resistances inside the material and in the boundary layer, respectively. p_o is the total pressure, p_y is the ambient vapor pressure and p_v is the vapor pressure inside the material.

Author B has also published a paper in the same journal and s/he has modelled drying rate in a direct superheated steam dryer using the following equation

$$m'' = -\frac{K}{\nu} \frac{\partial p}{\partial z} \qquad (2)$$

where K is permeability, ν is kinematic viscosity, p is the pressure and z is the characteristic length. Is it correct to model drying rate in a direct superheated steam dryer using both equations (1) and (2), or has one of the authors used a wrong model for the drying rate? If one of the authors has used a wrong model which one of the authors has done it? Justify your answer. You do not get any points if you just guess.

C) Wood chips are dried in a direct superheated steam dryer from the initial moisture content of 59 % (wet basis) to the final moisture content of 3 % (wet basis). The pressure inside the dryer is 3 bar and the inlet temperature of the steam is ca. 176°C. The surface temperature of the particles is immediately measured after the dryer using four different temperature measurement techniques A-D. Techniques show the following surface temperatures: A 134°C, B 182°C, C 143°C and D 174°C. Which one of the techniques probably shows the correct surface temperature? Justify you answer.

D) Figure 3 shows three steam heated evaporators A, B and C. One of these evaporators cannot evaporate the feed in real life. Which one and why?

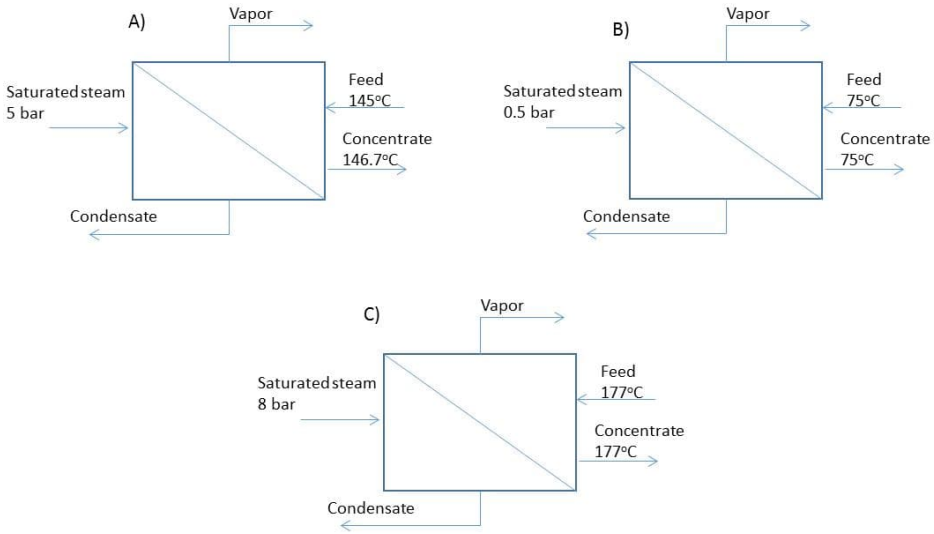

Figure 3. Steam heated evaporators

E) Figure 4 (next page) shows various biomasses. You should dry forest residues at mill A and bark at mill B. A drying specialist suggests that you should use a fluidized bed dryer for drying of forest residues at mill A and a rotary dryer for bark drying at mill B. Is this a correct suggestion in your opinion? Justify your answer.

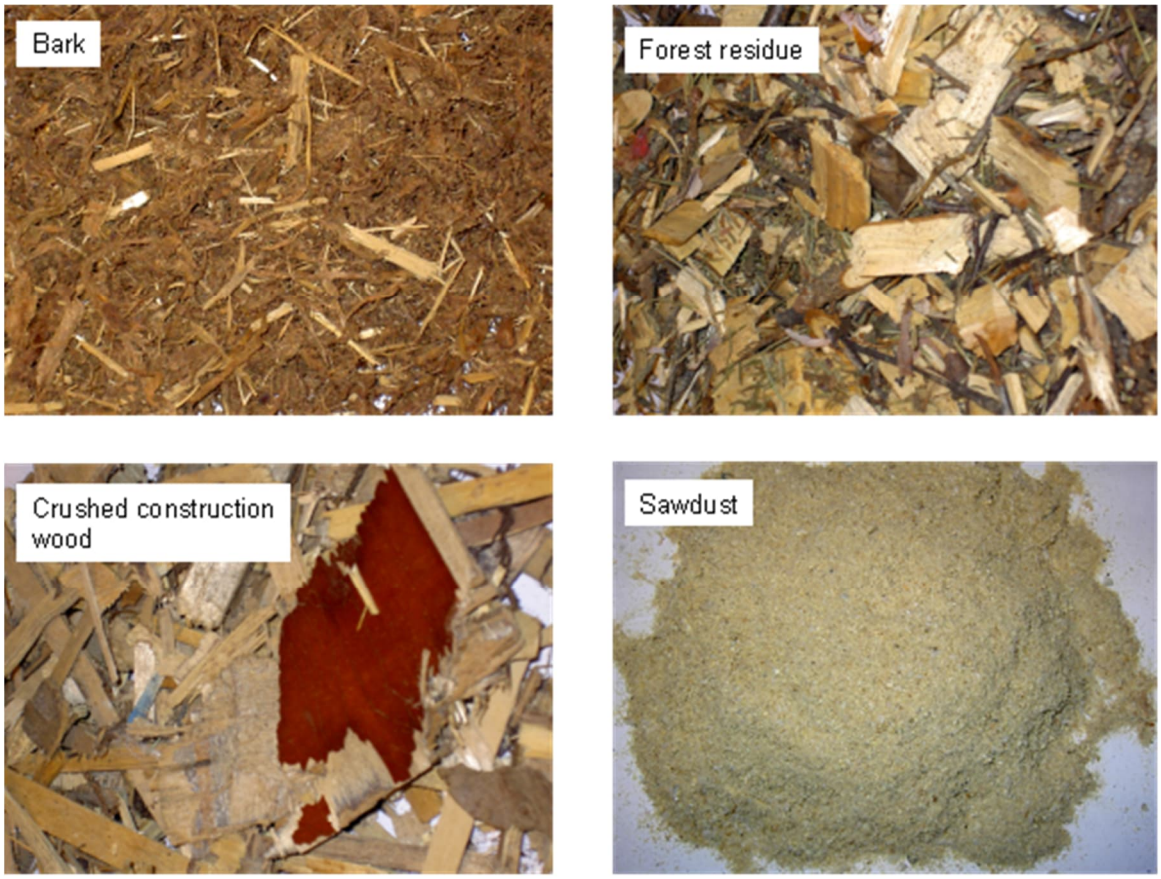

Figure 4. Different biomasses