EEN-E3003, Industrial drying and evaporation processes
Home exam, April 14, 2021
You can answer the questions either in English or in Finnish
(Jos vastaat suomeksi, merkitään suorituskieleksi suomi)

PROBLEM 1

Figure 1 shows the drying curve of forest residue that has been measured using a fixed bed dryer. Figure 1 also shows initial values of the measurement. The same forest residue is going to be dried in a continuous belt dryer with the mass flow rate of 1.3 kg_{ds}/s. The mass flow rate of drying air through the dryer is 50 kg/s and the inlet temperature is 70°C. The air velocity, inlet air humidity and bed height are the same as in Fig. 1.

A) What is the final moisture content of forest residue if its initial moisture content is the same as in Fig. 1?

B) How much saturated steam at 1 bar is needed to heat the air from 15°C to the drying temperature of the dryer?

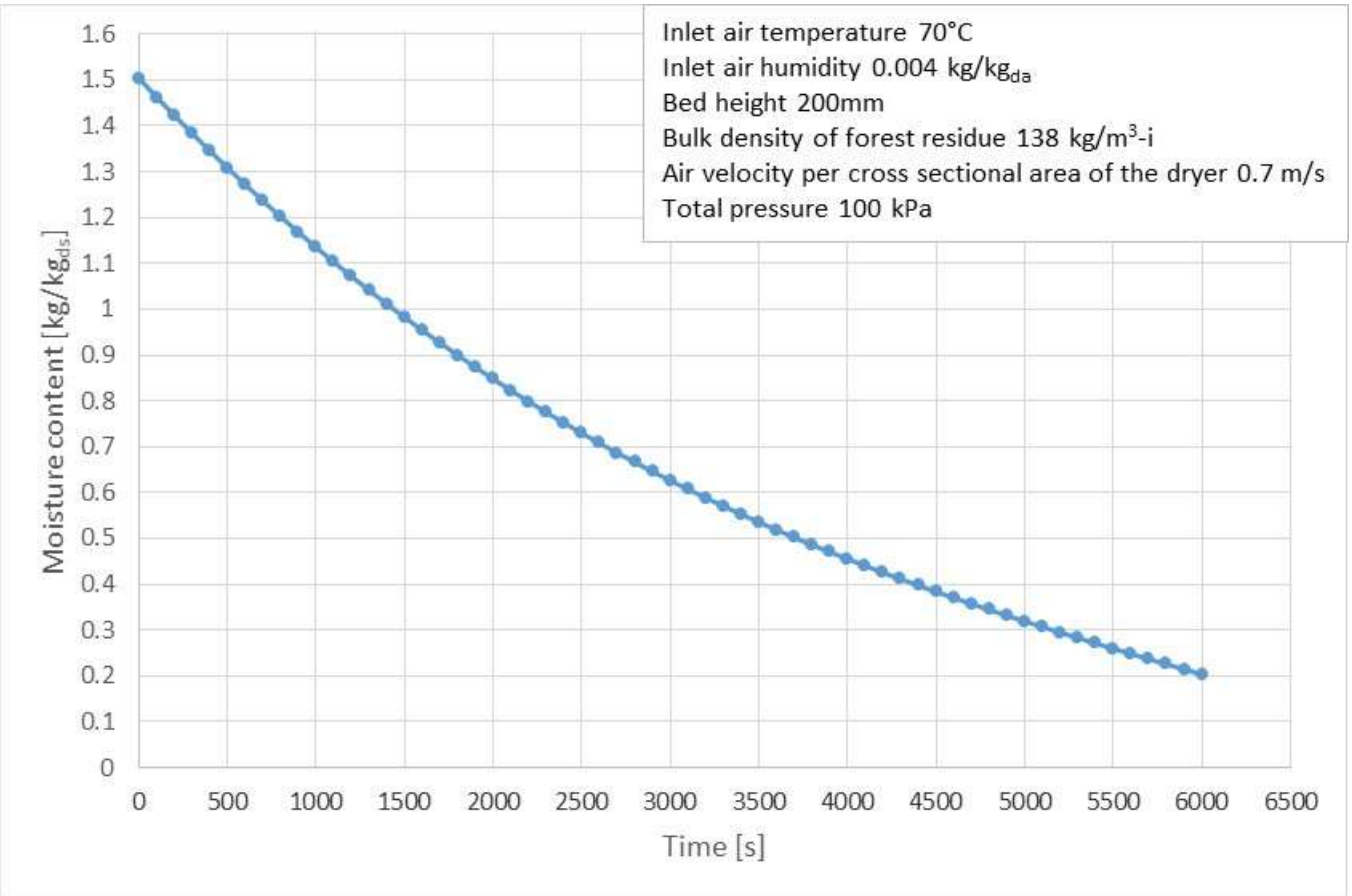

Figure 1. Drying curve of forest residue measured in a fixed bed dryer

PROBLEM 2

A moist sample is set in the room, where the temperature is 26°C, relative humidity 40% and total pressure 101 kPa. Mass of the sample is 1500 g (total mass) and evaporation surface 0.45m^2. Heat capacity of the moist sample is 3.0 kJ/(kg°C). When the sample is set in the room, its temperature is 60°C. During the first three seconds, the mass of the sample reduces 1.2 g. What is the temperature of the sample after the first three seconds if you can assume that the moisture and temperature distributions inside the sample are uniform? Lewis Number is approximately 1.

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) 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.

B) What does boiling point elevation mean, and why is it important to know it when evaporators are designed?

C) Figure 2 shows three steam heated evaporators A, B and C. One of these evaporators cannot evaporate the feed in real life. Which one and why?

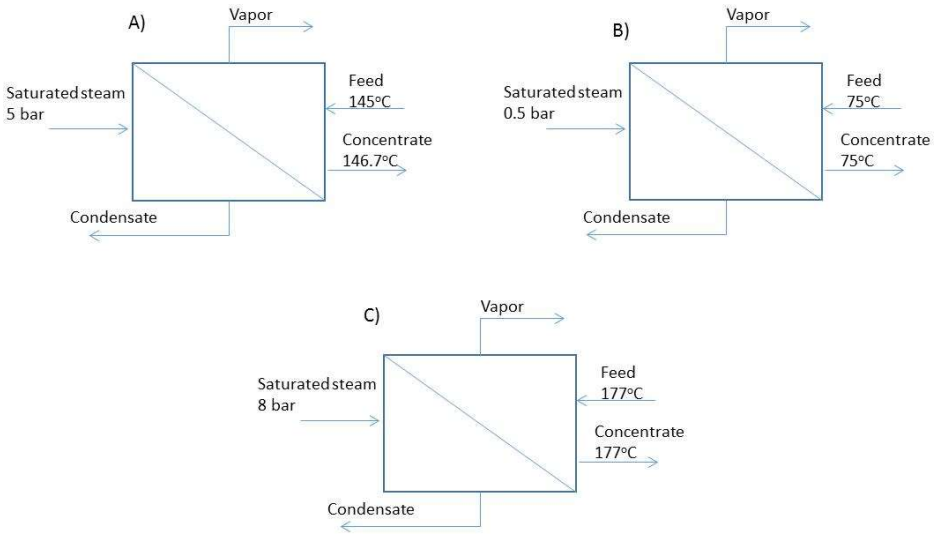

Figure 2. Steam heated evaporators

D) Figure 3 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 critical moisture content of material? What is the vapor pressure in the material when the time 500s?

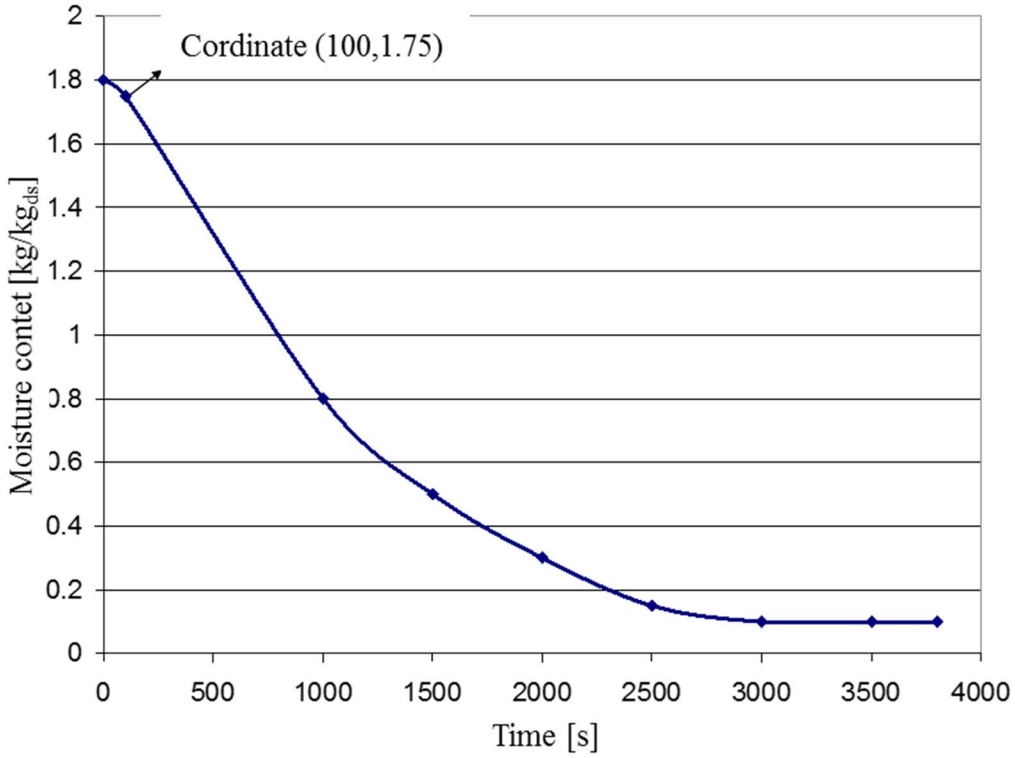

Figure 3. Drying curve of a material.

E) 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.