**9.6-3. Prediction in Constant-Rate Drying Region**

A granular insoluble solid material wet with water is being dried in the constant-rate period in a pan 0.61 m x 0.61 m and the depth of material is 25.4 mm. The sides and bottom are insulated. Air flows parallel to the top drying surface at a velocity of 3.05 m/s and has a dry bulb temperature of 60°C and wet bulb temperature of 29.4°C. The pan contains 11.34 kg of dry solid having a free moisture content of 0.35 kg H2O/kg dry solid and the material is to be dried in the constant-rate period to 0.22 kg H2O/kg dry solid.

**(a) Predict the drying rate and the time in hours needed.**

1. Using Figure 9.3-2, the wet bulb and dry bulb temperatures, a relative humidity, H, can be found as 0.01325 kg water vapor/kg dry air

2. Calculate the humid volume by using equation 9.3-7.

VH = (2.83x10-3 + 4.56\*10-3 \* H) \* T

VH = (2.83x10-3 + 4.56\*10-3 \* 0.01325) \* (273.13 + 60) = 0.9633 m3/kg dry air

3. Calculate the density,

m3

4. At Tw of 29.4, the lambaW can be found from the steam tables as *2432.2 kJ/kg* #Mozier

5. G = v \* p \* 3600 = 11549.346 kg/(m2h)

6. h = 0.0204 \* G0.8 = 36.281 W/(m2K)

7. Substituting into Equation 9.6-8:

**RC =** \* (T – Tw) \* (3600) = \* (60-29.4) \* (3600) = **1.6432 kg/h\*m2**

8. Find the time of drying

**Time to dry =** \* ΔX = **= 2.411 hours**

**(b) Predict the time needed if the depth of material is increased to 44.5 mm.**

Since the drying is accomplished in a liner fashion, the time for a new depth can be claulayed using a ratio.

**Time to dry new depth of 44.5 mm = t2** = = **4.224 hrs**

**9.7-2. Drying Tests with a Foodstuff**

In order to test the feasibility of drying a certain foodstuff, drying data were obtained in a tray dryer with air flow over the top exposed surface having an area of 0.186 m2. **The bone-dry sample weight was 3.765 kg dry solid**. At equilibrium after a long period, the wet sample weight was 3.955 kg H20 + solid. Hence, 3.955 - 3.765, **or 0.190, kg of equilibrium moisture** was present. The following sample weights versus time were obtained in the drying test.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Time (hr) | Weight (kg) | Time (hr) | Weight (kg) | Time (hr) | Weight (kg) |
| 0 | 4.944 | 2.2 | 4.554 | 7.0 | 4.019 |
| 0.4 | 4.885 | 3.0 | 4.404 | 9.0 | 3.978 |
| 0.8 | 4.808 | 4.2 | 4.241 | 12.0 | 3.955 |
| 1.4 | 4.699 | 5.0 | 4.150 |  |  |

(a) Calculate the free moisture content X kg H2O/kg dry solid for each data point and plot X versus time. (Hint: For 0 h, 4.944 - 0.190 - 3.765 = 0.989 kg free moisture in 3.765 kg dry solid. Hence, X = 0.989/3.765)

1. Equilibrium Moisture = 3.955 - 3.765, or 0.190 kg

2. At t = 0, w0 – w = 4.944 – 3.955 = 0.989

X = 0.989 kg / 3.765 kg = 0.263

At t = 0.4, w0 – w = 4.885 – 3.955 = 0.930 X = 0.989 kg / 3.765 kg = 0.247

At t = 0.8, w0 – w = 4.808 – 3.955 = 0.853 X = 0.853 kg / 3.765 kg = 0.227

At t = 1.4, w0 – w = 4.699 – 3.955 = 0.744 X = 0.744 kg / 3.765 kg = 0.198

At t = 2.2, w0 – w = 4.554 – 3.955 = 0.599 X = 0.599 kg / 3.765 kg = 0.159

At t = 3.0, w0 – w = 4.404 – 3.955 = 0.449 X = 0.449 kg / 3.765 kg = 0.119

At t = 4.2, w0 – w = 4.241 – 3.955 = 0.286 X = 0.286 kg / 3.765 kg = 0.076

At t = 5.0, w0 – w = 4.150 – 3.955 = 0.195 X = 0.195 kg / 3.765 kg = 0.052

At t = 7.0, w0 – w = 4.019 – 3.955 = 0.064 X = 0.064 kg / 3.765 kg = 0.017

At t = 9.0, w0 – w = 3.978 – 3.955 = 0.023 X = 0.023 kg / 3.765 kg = 0.006

At t = 12.0 w0 – w = 3.955 – 3.955 = 0.0 X = 0.000 kg / 3.765 kg = 0.000

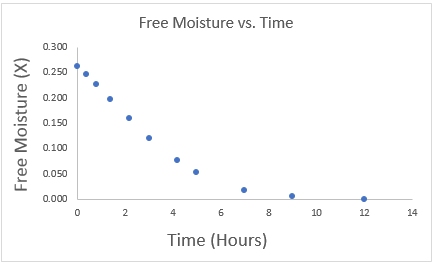


Figure 1. Plot X vs. time

(b) Measure the slopes, calculate the drying rates R in kg H2O/h\*m2, and plot R versus X.

The rate of drying can be calculated using the following equation:

R = (wt - w) / (A \* ti)

At t = 0.0, R = undefined

At t = 0.4, R = (4.885 – 3.955) / (0.186 \* 0.4) = 12.50

At t = 0.8, R = 5.732

At t = 1.4, R = 2.857

At t = 2.2, R = 1.464

At t = 3.0, R = 0.804

At t = 4.2, R = 0.366

At t = 5.0, R = 0.210

At t = 7.0, R = 0.0492

At t = 9.0, R = 0.0137

At t = 12, R = 0

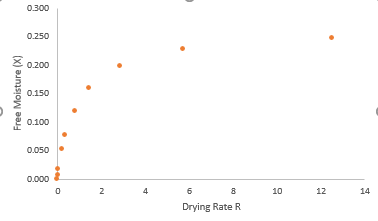
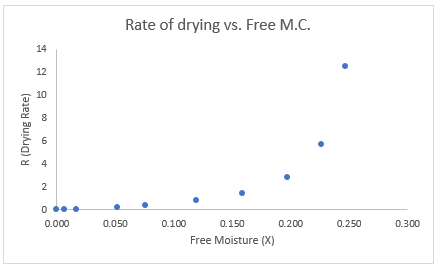


Figure 2. Rate of drying vs Free Moisture

(c) Using this drying-rate curve, predict the total time to dry the sample from X = 0.20 to X 0.04. Use graphical integration for the falling-rate period. What is the drying rate Rc in the constant-rate period and X . F**ind times for the constant rate period and falling rate period.**

**Example 9.7a in Geankoplis**

**Constant Rate Period:**

X1 = 0.20 X2 = XC = 0.119 (found from graph inference)

***t = 1.546 hours***

**Falling Rate Period**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Time | Weight | X | R | 1/R | DelX | 1/R(av) | DelX/R(av) |
| 0 | 4.944 | 0.263 |  |  |  |  |  |
| 0.4 | 4.885 | 0.247 | 12.5 | 0.08 | 0.016 | 0.127222 | 0.00199364 |
| 0.8 | 4.808 | 0.227 | 5.732527 | 0.174443 | 0.020 | 0.262222 | 0.00536283 |
| 1.4 | 4.699 | 0.198 | 2.857143 | 0.35 | 0.029 | 0.516569 | 0.01495513 |
| 2.2 | 4.554 | 0.159 | 1.463832 | 0.683139 | 0.039 | 0.96295 | 0.03708573 |
| 3 | 4.404 | 0.119 | 0.804659 | 1.242762 | 0.040 | 1.987115 | 0.07916793 |
|  |  |  |  |  |  | Total = | 0.13856526 |

**Total time is falling time plus constant time = 2.704 + 1.646 = 4.2 hours**

**9.8-1. Drying of Biological Material in Tray Dryer**

A granular biological material wet with water is being dried in a pan 0.305 x 0.305 m and 38.1 mm deep. The material is 38.1 mm deep in the pan, which is insulated on the sides and the bottom. Heat transfer is by convection from an air stream flowing parallel to the top surface at a velocity of 3.05 m/s, having a temperature of 65.6°C and humidity H = 0.010 kg H2O/kg dry air. The top surface receives radiation from steam-heated pipes whose surface temperature TR = 93.3°C. The emissivity of the solid is E = 0.95. It is desired to keep the surface temperature of the solid below 32.2°C so that decomposition will be kept low.

Guess and check to find correct Ts value

**Calculate the surface temperature and the rate of drying for the constant-rate period.**

VH = (2.83x10-3 + 4.56\*10-3 \* H) \* T

VH = (2.83x10-3 + 4.56\*10-3 \* 0.010) \* (273.13 + 65.6) = 0.9741 m3/kg dry air

3. Calculate the density, m3

4. G = v \* p \* 3600 = 3.05 \* 1.0368 \* 3600 = 11384.6 kg/(m2h)

5. hC = 0.0204 \* G0.8 = 35.866 W/(m2K)

TR = 93.3°C = 366.45 K TS = 32.3°C = 305.35 K

h = W/(m2K)

Since the bottom is insulated, there is no conduction and Uk = 0.

Solving for

The approximated value of is too far of the margin, therefore a new assumption of was assumed. This leads to values of 31.3°C, 0.0305 2429. Since the value does not change appreciably, the **Ts of 31.3oC is a good choice.**

**9.9-3. Diffusion Coefficient.**

Experimental drying data of a typical nonporous biological material obtained under constant drying conditions in the falling-rate region are tabulated below.

|  |  |  |  |
| --- | --- | --- | --- |
| X/XC | t(h) | DLTheorritical | DL |
| 1.00 | 0 | 0 | --- |
| 0.65 | 2.5 | 0.12 | 1.3601E-09 |
| 0.32 | 7.00 | 0.46 | 1.8621E-09 |
| 0.17 | 11.4 | 0.67 | 1.6654E-09 |
| 0.10 | 14.0 | 0.86 | 1.7406E-09 |
| 0.06 | 16.0 | 1.7 | 3.0107E-09 |

Drying from one side occurs with the material having a thickness of 10.1 mm. The data appear to follow the diffusion equation. Determine the average diffusivity over the range X/Xc = 1 .0-0.10.

Using the following equation (9.9-12), the theoretical DL can be calculated. This value can then be used to find the DL using chart 9.9-1

The average value of the DLs were taken. The **average diffusivity** over the range is:

**1.93x10-9 m2/s**

**9.10-5. Drying in a Continuous Tunnel Dryer.**  P. 605-608

A rate of feed of 700 lbm dry solid/hr containing a free moisture content of X1 = 0.4133 lb H2O/lb dry solid is to be dried to X2 = 0.0374 lb H2O/lb dry solid in a continuous counter flow tunnel dryer. A flow of 13,280 lbm dry air/hr enters at 203°F with an H2 = 0.0562 lb H2O/lb dry air. The stock enters at the wet bulb temperature of 119°F and remains essentially constant in temperature in the dryer. The saturation humidity at 119°F from the humidity chart is Hw = 0.0786 lb H2O/lb dry air. The surface area available for drying is (A/Ls) = 0.30 ft2/lb m dry solid. A small batch experiment was performed using constant drying conditions, air velocity, and temperature of the solid approximately the same as in the continuous dryer. The equilibrium critical moisture content was found to be Xc = 0.0959 lb H2O/lb dry solid, and the experimental value of kyMB was found as 30.15 lbm air/h·ft2. In the falling-rate period, the drying rate was directly proportional to X.

For the continuous dryer, calculate the **time in the dryer** in the **constant-rate zone** and in the **falling-rate zone.**

Material Balance Equation:

**A. Constant-Rate Period:**

3. Substitute 1. into 2. to get a new equation 3.

4. Since = constant for adiabatic drying, equation 3 can be integrated.

or

Calculate and . = 0.00826 and

**4.24 hours**

**B. Falling-Rate Period:**

Situations where unsaturated surface drying occurs. Hw is constant for adiabatic drying and the drying rate is directly dependent upon X

2. Substitute Equation 1 into time integral to get Time of drying

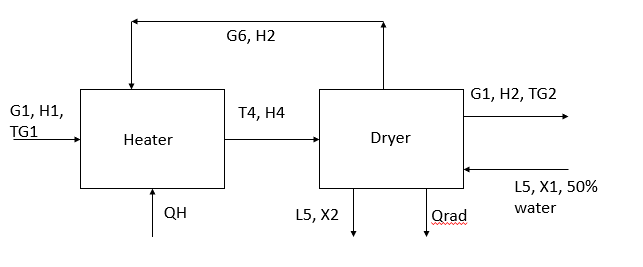
3. Substituting G dH/Ls in for dX and (H – H2)G/Ls + X2 for X results in an equation, that can be integrated to get equation 3.

**Falling Rate Zone Drying Time, t = 0.47 hours**

**9.10-6. Air Recirculation in a Continuous Dryer.**

The wet feed material to a continuous dryer contains 50 wt % water on a wet basis and is dried to 27 wt % by countercurrent air flow. The dried product leaves at the rate of 907.2 kg/hr. Fresh air to the system is at 25.6°C and has a humidity of H = 0.007 kg H20/kg dry air. The moist air leaves the dryer at 37.8°C and H = 0.020 and part of it is recirculated and mixed with the fresh air before entering a heater. The heated mixed air enters the dryer at 65.6°C and H = 0.010. The solid enters at 26.7°C and leaves at 26.7°C

**Calculate** the **fresh-air flow**, the **percent air leaving the dryer that is recycled**, the **heat added in the heater**, and the **heat loss from the dryer**.



**Figure 3.** Diagram of problem 9.10-6

G – water, L – dried product, H – humidity, TG – recirculated air

1. Heater Water Balance

2. Material Balance on Dryer Water

L5 = 907.2(0.73) = 662.25 kg dry solid/h

Solve for G1 and G6

**Fresh Air Flow (G1) = 32,094 kg/h**

3. The **percent air leaving the dryer that is recycled** can be calculated as:

**Recycled percent = 23.08%**

Solve for Heat added to the heater **QH = 440.6 kW**

5. Heat Balance on Dryer

Solve for heat lost from the dryer, **Qdry = 44.7 kW**

**Derivation of Fig 9.11-1**

**Derivation of Critical Moisture Content**