W05

You have been hired as a junior food processing engineer at a leading fruit processing company. Your first task is to analyze and optimize the drying process of mango slices to produce high-quality dried mangoes, a favorite snack enjoyed by millions around the world.

The food processing company wants to produce dried mango slices using the semicylindrical dryer. The dryer's long semicylindrical shape allows for a continuous and efficient drying process.

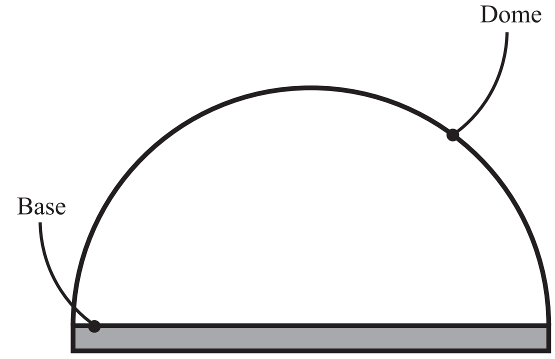

Figure 8: Cross section of the mango dryier

Given parameters:

- The dryer is a long, curved duct with a diameter of 1.5 meters.
- The base temperature is 370 Kelvin.
- The base emissivity is 0.5.
- The base acts as an opaque body.
- The dome temperature is 1000 Kelvin.
- The dome emissivity is 0.8.
- The dome does not reflect any radiation.
- The latent heat of vaporization for water is 2.3 MJ/kg

In this case study, we explore the process of drying organic materials, focusing on the production of dried mango slices. We will examine the application of a semicylindrical dryer designed to efficiently remove moisture from water-soaked mango slices while preserving their natural flavors and nutrients.

a Determine all four view factors.

b Give the values of the emissivity, transmissivity, and reflectivity for the base and dome.

From now on, it can be assumed that all bodies act as black bodies. The temperatures and other parameters remain the same.

c Determine the wavelength that holds the maximum power coming off of the dome.

d Determine the net rate of heat transfer per unit length from the dome to the base.

e Determine the drying rate per unit length experienced by the wet mango slices as they pass through the semicylindrical dryer.

f How long will it take the mango slices to heat up 1 ^{o}C?

g Reflect on your given answer. Is it realistic? If not, what is the implication for the time needed to heat up the mango's one degree if the assumption is not valid?

h Your boss would like you to improve the drying rate by improving the design. Mention one **design improvement** and explain why this improves the drying rate.

Solution W05

a Determine all four view factors.

As the base is a flat plate, it is straightforward that it cannot see itself. So:

$$\rightarrow F_{\mathrm{B}\rightarrow\mathrm{B}} = 0$$

(0.5) Correct reasoning view factor

From the summation rule around the base it then yields:

$$F_{\mathrm{B}\rightarrow\mathrm{B}} + F_{\mathrm{B}\rightarrow\mathrm{D}} = 1$$

(0.5) Correct calculation of view factor

$$\rightarrow F_{\mathrm{B}\rightarrow\mathrm{D}} = 1$$

Using the reciprocity rule, $F_{\mathrm{D}\rightarrow\mathrm{B}}$ can be determined:

$$F_{\mathrm{D}\rightarrow\mathrm{B}} A_{\mathrm{D}} = F_{\mathrm{B}\rightarrow\mathrm{D}} A_{\mathrm{B}}$$

$$\rightarrow F_{\mathrm{D}\rightarrow\mathrm{B}} = F_{\mathrm{B}\rightarrow\mathrm{D}} \frac{D \cdot L}{\frac{1}{2}\pi D \cdot L} = \frac{2}{\pi}$$

(0.5) Correct calculation of view factor

And using the summation rule around the dome it yields:

$$F_{\mathrm{D}\rightarrow\mathrm{D}} + F_{\mathrm{D}\rightarrow\mathrm{B}} = 1$$

$$\rightarrow F_{\mathrm{D}\rightarrow\mathrm{D}} = 1 - \frac{2}{\pi}$$

(0.5) Correct calculation of view factor

b Give the values of the emissivity, transmissivity, and reflectivity for the base and dome.

For the **base**:

It is given that:

$$\epsilon_{\mathrm{B}} = 0.5$$

Also, it is stated that the base is opaque, so:

$$\tau_{\mathrm{B}} = 0$$

(0.5) Correct reasoning of property

Using Kirchoff's law it yields that:

$$\epsilon_{\mathrm{B}} + \tau_{\mathrm{B}} + \rho_{\mathrm{B}} = 1$$

(0.5) Correct calculation of property

$$\rightarrow \rho_{\mathrm{B}} = 0.5$$

For the **dome**:

It is given that:

$$\epsilon_{\mathrm{D}} = 0.8$$

Also, it is stated that the dome does not reflect, so:

$$\rho_{\mathrm{D}} = 0$$

(0.5) Correct reasoning of property

Using Kirchoff's law it yields that:

$$\epsilon_{\mathrm{D}} + \tau_{\mathrm{D}} + \rho_{\mathrm{D}} = 1$$

$$\rightarrow \tau_{\mathrm{D}} = 0.2$$

(0.5) Correct calculation of property

c Determine the wavelength that holds the maximum power coming off of the dome. Wien's displacement law calculates the wavelength with the maximum power as:

$$\lambda_{\mathrm{max,power}} = \frac{2897.8}{T_{\mathrm{dome}}} = \frac{2897.8}{1000} = 2.898\ \mu\mathrm{m}$$

(1) Correct calculation of wavelength

d Determine the net rate of heat transfer per unit length from the dome to the base.

The net rate of heat transfer between two black bodies can be calculated according to the expression:

$$\dot{Q}_{D\to B} = A_{\mathrm{D}} F_{\mathrm{D}\to\mathrm{B}} \sigma \left(T_{\mathrm{D}}^4 - T_{\mathrm{B}}^4\right) = \frac{\pi D}{2} \cdot \frac{2}{\pi} \cdot \left(5.67 \cdot 10^{-8}\right)\left(1000^4 - 370^4\right) = 83.6\ \mathrm{kW/m}$$

(1) Correct calculation of rate of heat transfer

e Determine the drying rate per unit length experienced by the wet mango slices as they pass through the semicylindrical dryer.

From an energy balance, it yields that:

$$\dot{Q}_{\mathrm{evaporation}} = \dot{Q}_{D\to B}$$

(1) Correct energy balance

Where:

$$\dot{Q}_{\mathrm{evaporation}} = \dot{m} h_{\mathrm{fg}}$$

(0.5) The correct definition of rate of heat transfer

Rewriting yields:

$$\dot{m} = \frac{\dot{Q}_{D\to B}}{h_{\mathrm{fg}}} = \frac{83.6 \cdot 10^3}{2.3 \cdot 10^6} = 0.0363\ \mathrm{kg/s \cdot m}$$

(0.5) Correct calculation of drying rate

f Reflect on your given answer. Is it realistic? If not, what is the implication caused by the assumptions on the mango slices and what about the oven itself?

Also, the mango slices will heat up a bit as well, so not all heat is directly used for the evaporation of water. So it will turn out to have a slightly smaller evaporation rate.

(0.5) Correct reflection on assumed energy balance

The assumption of having only black bodies can be made when we are dealing with a perfect absorber, having no reflectivity, having a uniform temperature distribution, having a radiation-dominant scenario, having steady-state conditions, and having high temperatures. Reflection on one of these conditions and why they might not be a perfect approximation can be counted to be correct.

(0.5) Correct reflection on assuming black bodies

g Your boss would like you to improve the drying rate by improving the design. Mention one **design improvement** and explain why this improves the drying rate.

Any design improvement that will increase the rate of heat transfer from the dome to the base can be counted to be correct.

(1) Correct design improvement