ME 6203
MASS TRANSPORT

Application of liquid diffusion model to drying of thin slabs

Please study the following cases for which the one dimensional diffusion equation was solved. Problems 1 through 7 are designed to let you evaluate your understanding of the diffusional phenomena. Write brief answers to the questions. (Groups of 2)

Model material: Potato slice; Initial moisture content: 4.6 kg/kg db.

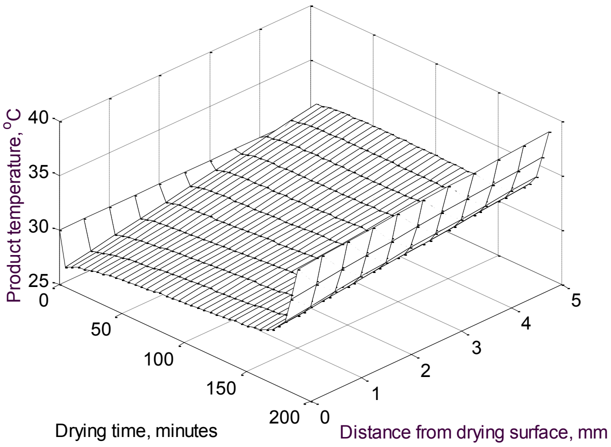
Effect of shrinkage	
Case-1	Mode of heat input: Convection; Drying air condition: V_{air} = 2 m/s, T_{air} = 45 ^oC, RH_{air} = 15%; Initial thickness of material = 5 mm; Shrinkage: Ideal shrinkage.
Case-2	Mode of heat input: Convection; Drying air condition: V_{air} = 2 m/s, T_{air} = 45 ^oC, RH_{air} = 15%; Initial thickness of material = 5 mm; Shrinkage: No shrinkage.
Effect of different modes of heat input	
Case-3	Modes of heat input: Convection and conduction; Drying air condition: V_{air} = 2 m/s, T_{air} = 45 ^oC, RH_{air} = 15%; Conduction heat flux: 500 W/m^2; Initial thickness of material = 5 mm; Shrinkage: No shrinkage.
Case-4	Modes of heat input: Convection and radiation; Drying air condition: V_{air} = 2 m/s, T_{air} = 45 ^oC, RH_{air} = 15%; Temperature of radiation heater: 110 ^oC; Initial thickness of material = 5 mm; Shrinkage: No shrinkage.
Case-5	Modes of heat input: Convection and Microwave; Drying air condition: V_{air} = 2 m/s, T_{air} = 45 ^oC, RH_{air} = 15%; Microwave power: 0.6 W/g of initial wet material; Initial thickness of material = 5 mm; Shrinkage: No shrinkage.
Effect of stepwise change of drying air temperature	
Case-6	Temperature profile of drying air: Square wave-form Maximum air temperature: T_{air} = 45 ^oC with RH_{air} = 15%; Minimum air temperature: T_{air} = 30 ^oC with RH_{air} = 33.8%; Cycle time: 4 hours; Mode of heat input: Convection; Drying air condition: V_{air} = 2 m/s; Initial thickness of material = 5 mm; Shrinkage: No shrinkage.
Case-7	Temperature profile of drying air: Step down-form Maximum air temperature: T_{air} = 45 ^oC with RH_{air} = 15%; Minimum air temperature: T_{air} = 30 ^oC with RH_{air} = 33.8%; Time step size: 2 hours; Temperature step size: -5 ^oC; Mode of heat input: Convection; Drying air velocity: V_{air} = 2 m/s; Initial thickness of material = 5 mm; Shrinkage: No shrinkage.
Case-8	Temperature profile of drying air: Step up-form Minimum air temperature: T_{air} = 30 ^oC with RH_{air} = 33.8%; Maximum air temperature: T_{air} = 45 ^oC with RH_{air} = 15%; Time step size: 2 hours; Temperature step size: 5 ^oC; Mode of heat input: Convection; Drying air velocity: V_{air} = 2 m/s; Initial thickness of material = 5 mm; Shrinkage: No shrinkage.
Case-9	Temperature profile of drying air: Step down-form Maximum air temperature: T_{air} = 65 ^oC with RH_{air} = 5.8%; Minimum air temperature: T_{air} = 45 ^oC with RH_{air} = 15%; Temperature step size: -5 ^oC;

	Temperature controller: On/off type temperature controller is simulated to maintain maximum allowable product temperature of 45^{o}C; Mode of heat input: Convection; Drying air velocity: V_{air} = 2 m/s; Initial thickness of material = 5 mm; Shrinkage: No shrinkage.
Optimization of heat pump (HP)	
Case-10 *(Base case)*	Mode of heat input: Convection; Heat Pump: Turned off during drying process; Drying air condition: V_{air} = 2 m/s, T_{air} = 45 ^{o}C, RH_{air} = 30%; Initial thickness of material = 5 mm; Shrinkage: No shrinkage.
Case-11	Mode of heat input: Convection; Heat Pump: Turned on during drying process; Drying air condition: V_{air} = 2 m/s, T_{air} = 45 ^{o}C, RH_{air} = 7%; Initial thickness of material = 5 mm; Shrinkage: No shrinkage.
Case-12	Mode of heat input: Convection; Heat Pump: Turned on with full capacity for 0 to 2 hours and with half capacity for 2 to 4 hours of drying process; Drying air condition: V_{air} = 2 m/s, T_{air} = 45 ^{o}C; RH_{air}: 7% from 0 to 2 hours, 15% from 2 to 4 hours and 30% from 4 to 8 hours Initial thickness of material = 5 mm; Shrinkage: No shrinkage.
Case-13	Mode of heat input: Convection; Heat Pump: Turned on with full capacity for 0 to 2 hours of drying process; Drying air condition: V_{air} = 2 m/s, T_{air} = 45 ^{o}C; RH_{air}: 7% from 0 to 2 hours and 30% from 4 to 8 hours; Initial thickness of material = 5 mm; Shrinkage: No shrinkage.
Effect of flipping of product	
Case-14 *(Base case)*	Without flipping of product Mode of heat input: Convection; Drying air condition: V_{air} = 2 m/s, T_{air} = 45 ^{o}C, RH_{air} = 10%; Initial thickness of material = 10 mm; Shrinkage: No shrinkage.
Case-15	Product is flipped after every 1 hrs of drying; Mode of heat input: Convection; Drying air condition: V_{air} = 2 m/s, T_{air} = 45 ^{o}C, RH_{air} = 10%; Initial thickness of material = 10 mm; Shrinkage: No shrinkage.
Sun drying	
Case-16 *(Base case)*	Mode of heat input: Convection; Drying air condition: V_{air} = 2 m/s, T_{air} = 45 ^{o}C, RH_{air} = 30%; Initial thickness of material = 5 mm; Shrinkage: No shrinkage.
Case-17	Mode of heat input: Solar radiation Location: Singapore, Month: October, Time: 7.00 am to 7.00 pm Initial thickness of material = 5 mm; Shrinkage: No shrinkage.

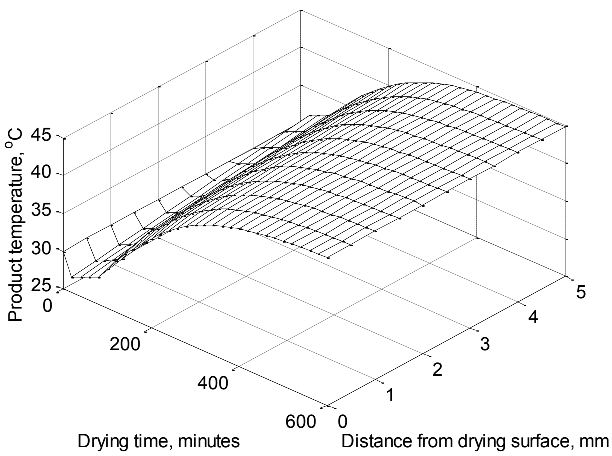
ME 6203
MASS TRANSPORT

Home assignment: Application of liquid diffusion model to drying of thin slabs

Problem – 1.



Case-1



Case-2

Temperature distribution across the product during drying using pure convection. Case-1: with ideal shrinkage. Case-2: without shrinkage. Temperature of the product drops sharply at the beginning of drying process for both of the cases. Finally the temperature distributions become different for Case-1 and 2. Why?

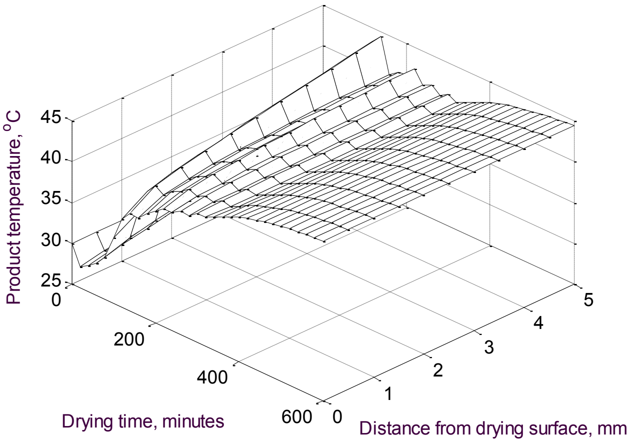
Hint:

Product contains a lot of surface and free moisture at the initial period of drying. Latent heat of vaporization is required for the evaporation of this moisture. Heat transfer by convection from the drying air to the evaporation surface is not enough. Therefore, moisture takes heat from the product itself as well. Consequently temperature of product drops at the initial period of drying. As the drying process progresses, moisture content of the product (especially at the drying surface) drops. As a result water activity and vapor pressure at the drying surface drops. Therefore, for the same drying condition evaporation rate drops (internally controlled drying). As evaporation rate gradually drops, convected heat become gradually enough to supply the latent heat of vaporization. Therefore, the product temperature starts to increase and finally reaches close to the drying air temperature.

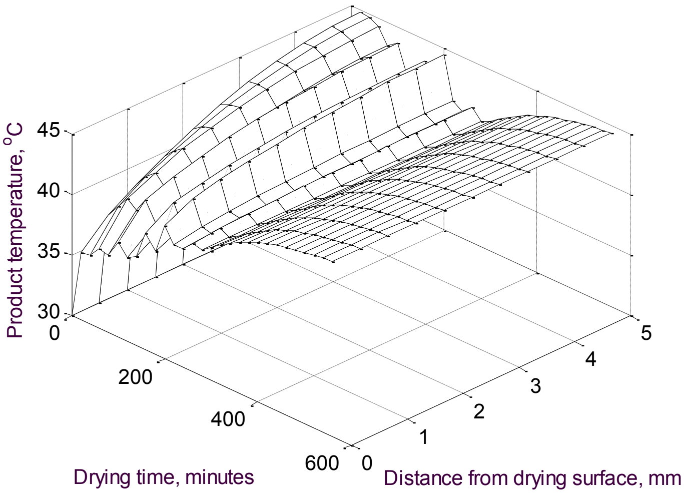
For case-1 (ideal shrinkage), as thickness of product decreases with drying, moisture needs to migrate relatively small path to come to the dying surface. Consequently, evaporation rate becomes fasted and product temperature remains low for longer period of time.

For case-2 (without shrinkage), moisture flux slowly drops with drying time and therefore, product temperature also increase slowly.

Problem – 2.



Case-3



Case-5

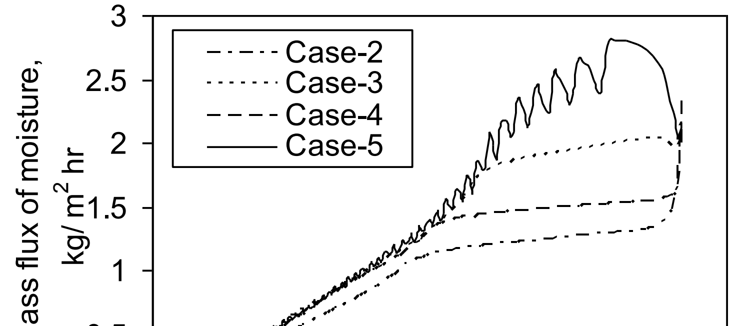
For Case-3, conduction heat is supplied from the bottom surface of the product. Microwave power is supplied to the drying surface of the product for Case-5. However, both Case-3 and 5 show that maximum product temperature is at the bottom surface of the product during drying process. Why?

Hint:

As evaporation of liquid moisture takes place from the drying surface by absorbing heat from the drying air as well as the drying surface of product, temperature of drying surface should be lower. Conduction heater is at the bottom surface of the product. Therefore, temperature of bottom surface will be higher and heat will transfer from bottom surface (higher temperature) to the drying surface (low temperature) by conduction.

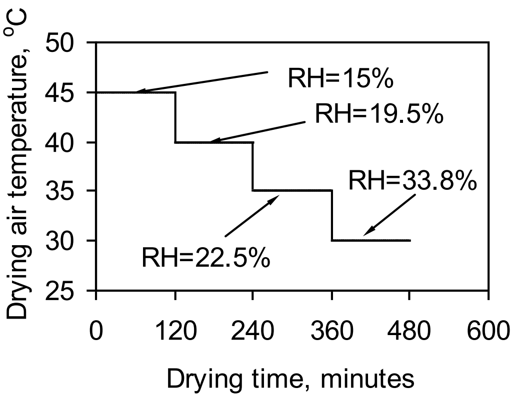
Microwave generates heat volumetrically because of the friction of water molecules among each other. The quantity of heat generate depends on local water content of product and local intensity of microwave power which is a function of depth of product as well as product loss factor. As evaporation of moisture takes place from the drying surface, moisture content at the bottom surface becomes higher than that drying surface. Consequently, temperature at bottom surface becomes higher and generated heat conducted to the drying surface to accelerate evaporation rate.

Problem – 3.

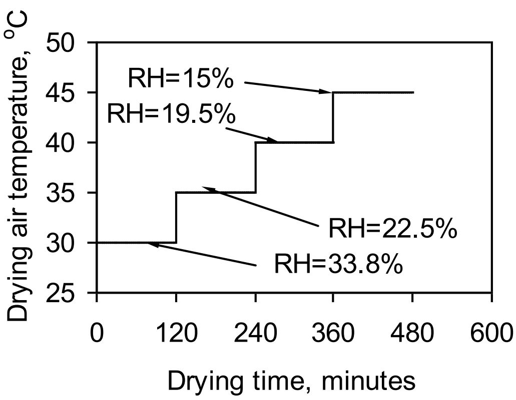


Variation of moisture flux with average moisture content for different modes of heat input. Case-2: pure convection, Case-3: convection and conduction, Case-4: convection and radiation, Case-5: convection and microwave. Explain why mass flux of moisture become almost independent of the modes of heat input for moisture content lower than about 2.5 kg/kg db?

Problem – 4.



Case-7: Step-down profile



Case-8: Step-up profile

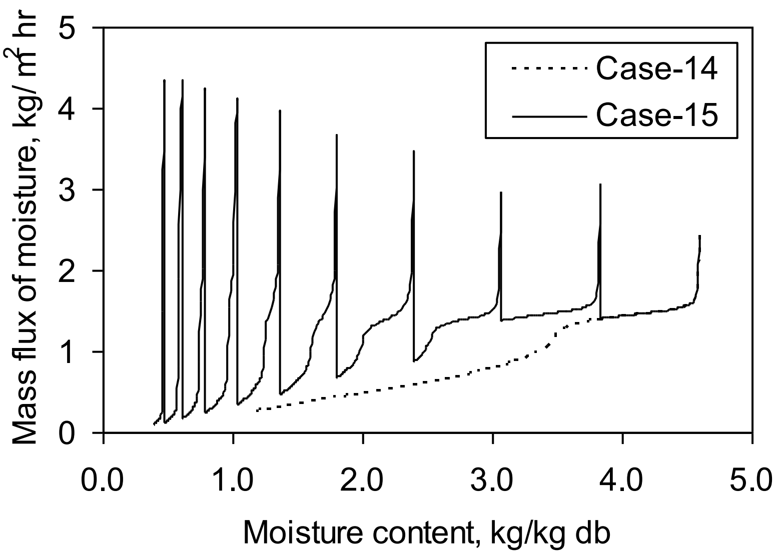
Which profile of stepwise change of drying air temperature could give better drying performance and why?

Problem – 5.

Potato slice was drying using air of relative humidity 7% and temperature of 45°C for the first two hours of drying. After two hours of drying, relative humidity of drying air was increased to 35% keeping air temperature constant to 45°C and drying was continued for another 6 hours. The drying curve is shown in the below figure. Why mass flux of moisture drops sharply at moisture content of about 1.8 kg/kg db. Assume moisture content of product became 1.8 kg/kg db after two hours of drying.

The variation of the flux of moisture with average moisture content of the product due to the change of drying air relative humidity. Why mass flux of moisture drops sharp at moisture content of about 1.8 kg/kg db for Case-12?

Problem – 6.



The variation of the flux of moisture with average moisture content of the product for case-14 (without flipping) and case-15 (with flipping). Explain why does flux of moisture increase due to flipping of product? What could be reason of gradually increasing of mass flux just immediately after flipping as the moisture content of the product decreases?

Problem – 7.

Explain the different behavior of the drying rate curves for shrinking and for non-shrinking slabs. Ideal shrinkage is assumed i.e. volume lost by evaporated liquid is assumed to directly reduce the volume of the drying object (No pores develop). Note that the diffusivity is assumed to vary only with temperature and moisture content. It is determined using only the initial thickness of the drying sample.