PROBLEMS

Problem 1

Regarding various aspects of food science and engineering, are the following statements true or false?

1.( ) The following table lists values of the constant *k* for various solutes in Norrish's equation for water activity of solutions.

Solute	*k*
Glucose	0.7
Sucrose	2.7
Fructose	0.7
Glycerol	0.38
Citric acid	6.17
Malic acid	1.82

With reference to the data above, the water activity of a 60% fructose solution can be calculated to be greater than 0.9. In your analysis of this statement, take 180 g mol^{-1} as the molar mass of glucose.

2.( ) The *F*-value at 121.1°C equivalent to 99.99% inactivation of a strain of *C. tetani* is 1.05 min. The corresponding *D*-value at 121.1°C can be calculated to be greater than 0.25 min.

3.( ) Sealed tubes containing equal numbers of spores of an isolate from a spoiled canned food were heated for 15 and 30 min, both at 114.8°C. The survivors were, respectively, 8100 and 110. The *D*-value for this survivor data can be calculated to be greater than 9 min.

4.( ) The F_0-value (i.e., the *F*-value at 121.1°C) for 99.999% inactivation of *C. perfringens* is 1.3 min. Knowing that the *z*-value for this bacterium under the pertaining conditions equals 8°C, the corresponding *F*-value at a temperature of 123°C can be calculated to be greater than 0.85 min.

5.( ) The most prominent application of industrial microwave heating in food applications has been the tempering of meat for further processing. Presently, two narrow bands of microwave frequency are used in the United States, one centered at 915 MHz and the other at 2450 MHz. The greater frequency (2450 MHz band) offers advantages for the tempering of thick products because of its deeper penetration capability.

Recommended edited book chapter: Ahmed and Ramaswamy (*in* Rahman, 2020).

6.( ) It is known that beef at 25°C exposed to microwaves at a frequency of 2450 MHz has relative dielectric constant equal to 64 and dielectric loss factor equal to 17. Accordingly, the loss tangent for this beef material is greater than 0.25.

7.( ) The penetration depth of microwaves in a food system may be defined variously; one recurring approach is to take penetration depth as the inverse of the attenuation factor α'. Per this definition, the penetration depth of 2450-MHz microwaves irradiated on the beef slab described in the previous statement can be calculated to be greater than 2 cm.

8.( ) The approximate heat evolution rate from avocados stored at 5°C is about 70 watts per megagram (W/Mg). Likewise, the heat evolution rate for blackberries at the same temperature is 110 W/Mg. Accordingly, the total cooling load caused by two metric tonnes of avocados and 800 kg of blackberries stored in a walk-in chamber at 5°C is greater than 220 watts.

9.( ) In a fruit-packaging house, oranges are washed on a perforated belt conveyor by water sprays and dried in a stream of high-speed air at room temperature before waxing. The oranges may be considered to be 6-cm diameter spheres initially at 25°C. Thus, the convective mass transfer coefficient on the surface of an orange, when exposed to air at 12 m/s, is greater than 6 cm/s. In your analysis of this statement, take 1.21 kg/m^3 and 1.8×10^{-5} Pa·s as the density and viscosity of air, respectively, and assume that the diffusivity of water vapor in air at 25°C is 3.0×10^{-5} m^2/s.

10.( ) A pump delivers 80 L/min of a Newtonian liquid food with specific gravity 1.04 and viscosity of 120 cP. The food flows through a 30-mm diameter pipe of length 40 m. The pressure drop required to maintain this flow is greater than 300 kPa.

11.( ) In a certain drying operation, air is to be moved through a grain bed at a rate of 2.5 m^3/s against a pressure of 320 Pa. Assuming an efficiency of 58%, the input power required is greater than 1.3 kW.

12.( ) A noodle is being dried during the falling-rate region between a critical moisture content of 0.6 kg water/kg solids and a final moisture content of 0.24 kg water/kg solids. The mass diffusivity of water vapor within the noodle is 2×10^{-7} cm^2/s and the noodle is long enough to be taken as an infinite cylinder with radius 0.5 mm. The equilibrium moisture content is 0.2 kg water/kg solids. The falling-rate drying time for this system can be calculated to be greater than 1.5 hours.

Extensional flows find wide application in situations of interest for food engineers, from industrial processes to simple eating rituals such as sucking a beverage through a straw or spreading butter on bread with a knife.
13.( ) For a Newtonian liquid food, the Troutonian ratio with respect to biaxial tension is equal to 3. ■ **(A black square indicates the end of a multi-paragraph statement.)**

Recommended edited book chapter: Rozanska (*in* Ahmed and Basu, 2023).

Peleg and Corradini (2011) reviewed the state of the practice in microbial growth models for food applications. They note that researchers traditionally approach microbial population dynamics with a 'primary' model and a complementary or 'secondary' model. A primary model describes the relationship between population count (or some proxy thereof) and time. In turn, the secondary model addresses the effects of extrinsic parameters such as temperature and pH.
14.( ) Among secondary models, a lasting trend among research groups has been to rely on Arrhenius-like equations, whereby the effect of variables such as pH and water activity increases monotonically with temperature, with a so-called 'activation energy' as a key parameter. The well-defined theoretical underpinnings for the activation energy parameter and the ease with which Arrhenius-like models can incorporate the optimum growth temperature in microbial dynamics are reasons why this approach has been a common choice of 'secondary model.' ■

Recommended research: Peleg and Corradini (2011) .

Degradation of food pigments, usually known as *browning*, is aesthetically unpleasant and may be accompanied by the formation of compounds that compromise flavor, aroma, and nutritional value. Three important pathways may be involved in browning development: sugar caramelization, Maillard reaction, and oxidation of ascorbic acid.

15.( ) Several reviews and original research papers, including Labuza (1970), Waletzko and Labuza (1976), and Labuza and Saltmarch (1982), have noted that the progress of browning in foodstuffs, especially when it comes to the Maillard reaction, can be shown to follow second-order kinetics. ■

Recommended research: Labuza (1970); Waletzko and Labuza (1976); Labuza and Saltmarch (1982).

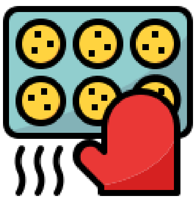
Use of high-voltage pulsed electric fields (PEFs) has been attempted as a preservation technique for fruit juices. Although the inhibitory effect of PEFs in microorganisms is not well understood, it appears to be related to a dielectric breakdown of cell membranes in response to the applied electric field.

16.( ) According to Aronsson (2002) and Aronsson *et al.* (2001), Gram-positive bacteria such as *Lysteria monocytogenes* and *Lysteria innocua* are more sensitive to PEF treatment than Gram-negative bacteria. ■

Recommended research: Aronsson *et al.* (2001) and Aronsson (2002).

17.( ) Use of ionizing irradiation in food processing is growing steadily around the world, especially as awareness of the innocuous safety profile of irradiated foods becomes more widespread. Indeed, irradiated food is safe even when the radiation treatment greatly exceeds regulatory guidelines, and the loss of macronutrients is usually minimal – only a decrease in certain vitamins has been demonstrated, but even then the loss has been of the same magnitude as in other manufacturing processes, such as drying or canning.

Recommended edited book chapter: Nishihira (*in* Andersen, 2020).



In baking, it is of considerable interest to be able to relate the rheological properties of a dough to loaf volume and fine structure. Fan *et al.* (1999) contributed to this research topic by developing an insightful numerical model. The model describes the growth of a bubble in response to the internal pressure exceeding the atmospheric pressure as a result of diffusion of CO_2 and moisture from a surrounding dough phase into the bubble interior. The temperature of the system rose steadily and was assumed to be independent of position.

18.( ) Fan's group found that the dough volume increased linearly with time irrespective of the temperature range. ■

Recommended research: Fan *et al.* (1999).

Farkas *et al.* (1996) developed a simple model for heat and moisture transfer in a semi-infinite slab undergoing immersion frying. In their approach, immersion frying was viewed as a Stefan moving boundary problem with coupled heat and mass transfer, in which a *crust* region, initially nonexistent, increased in thickness during frying while a *core* region decreased in thickness. The moving boundary was 'immobilized' via a coordinate transformation, the geometry was discretized with a Crank-Nicolson finite difference technique, and the problem was solved with the Gauss-Seidel method.

19.( ) One particularly important limitation of the Farkas *et al.* (1996) model is that, while it accounts for moisture transport, it did not account for either oil flux or oil accumulation into the fried foodstuff. ■

Recommended research: Farkas *et al.* (1996).

Caseins are milk phosphoproteins that, owing to their excellent physicochemical properties – exceptional water binding capacity, favorable emulsifying and foaming behavior – have been extensively used in the food industry. As noted by Beliciu (2011), casein micelles are constituted of four main variants, namely α_{s1}-casein, α_{s2}-casein, β-casein, and κ-casein.

20.( ) The α_{s1}-, α_{s2}-, and κ-caseins are precipitated by calcium, which acts as a kind of 'cement' holding a casein micelle together. In turn, β-casein is not only soluble in calcium, but also interacts with and inhibits the precipitation of the calcium-sensitive caseins, initiating the formation of the stable colloidal state. Simply put, β-casein stabilizes the calcium-sensitive caseins. ■

Recommended research: Beliciu (2011); Shekar *et al.* (2006).

Most commercial meat products have been and continue to be shipped in high oxygen (approximately 80% O_2) packages complemented with slight additions of CO_2 and/or N_2. The main purpose of gaseous oxygen is to promote oxymyoglobin, which is responsible for the cherry red color that is a mainstay of perceived meat quality. Carbon dioxide is added to prevent selective microbial growth. Finally, nitrogen gas is added to maintain pack shape.

21.( ) Importantly, addition of oxygen to modified atmosphere packaging of muscle foods increases shelf life and is free of negative chemical interactions with the meat being preserved, be it beef, lamb, or any other kind. ■

Recommended edited book chapter: O'Sullivan and Kerry (*in* Toldrá, 2010).

22.( ) The Lineweaver-Burk plot for an enzymatic reaction in a souring food was shown to yield a maximum reaction velocity of 160 μmol/L·min and a slope of 0.375 min. For a substrate concentration of 40 μmol/L, the velocity of the reaction can be calculated to be greater than 55 μmol/L·min.

▶ Problem 2

In an experiment on thin-layer drying, wheat at a moisture content of 30% (dry basis) was dried at an air temperature of 38°C and relative humidity of 50%. Determine the moisture content and drying rate after 5 minutes of continuous drying. The equations for drying constant and dynamic equilibrium moisture content are

$$k = 290e^{-2170/(T_a+273.15)} \left[\text{min}^{-1}\right]$$

$$(1-RH) = \exp\left(-c\left(T_a+273.15\right)M_e^n\right)$$

where $c = 3.2\times10^{-6}$ and $n = 2.8$. T_a is given in °C.

(A) $M(t=5) = 7.72\%$ and $dM/dt = -1.37\%\ \text{min}^{-1}$

(B) $M(t=5) = 7.72\%$ and $dM/dt = -2.74\%\ \text{min}^{-1}$

(C) $M(t=5) = 15.43\%$ and $dM/dt = -1.37\%\ \text{min}^{-1}$

(D) $M(t=5) = 15.43\%$ and $dM/dt = -2.74\%\ \text{min}^{-1}$

▶ Problem 3

A sample of rough rice was dried in a thin layer at 45°C. Process engineers measured the moisture contents at 3 and 6 hours to be 15% (dry basis) and 8% (d.b.), respectively. Assuming a rate constant $k = 0.502$ hour^{-1}, determine the equilibrium moisture content for this time interval.

(A) $M_e = 1.5\%$

(B) $M_e = 4\%$

(C) $M_e = 6\%$

(D) $M_e = 7.5\%$

▶ Problem 4

A three-bladed industrial propeller is used to mix a liquid food in the laminar region. The stirrer is 0.25 m in diameter and is rotated at 1.8 Hz. Due to corrosion, the propeller has to be replaced by a flat two-bladed paddle, 0.65 m in diameter. The power requirements in W for the propeller and the flat paddle are given by the following expressions, where N is the rotational speed in Hz and D is the diameter in meters. If the same motor is used for the propeller and the paddle, the speed (Hz) at which the paddle should rotate is ______ Hz.

Device	Power requirement (W)
Propeller	$P = 1964N^2D^3$
Paddle	$P = 1748N^2D^3$

(A) 0.20 Hz

(B) 0.46 Hz

(C) 0.92 Hz

(D) 1.31 Hz

▶ Problem 5

Wheat was stored in a cylindrical concrete silo of diameter 5 m and height 24 m. The wall thickness is 16 cm. Determine the heat gain per m when the inside temperature is 20°C and the outside temperature is 10°C. The thermal conductivity of concrete may be taken as 1.1 W/m·K.

(A) $|q|$ = 0.86 kW/m

(B) $|q|$ = 1.22 kW/m

(C) $|q|$ = 2.19 kW/m

(D) $|q|$ = 2.63 kW/m

▶ Problem 6

Rough wheat was stored in a concrete (k = 1.1 W/m·K) cylindrical bin of 6 m diameter and 16 cm wall thickness. The inside and outside temperatures are 18 and 36°C, respectively. What thickness of loosely packed rock wool insulation of thermal conductivity 0.1 W/m·K should be added to reduce the heat gain through the wall by 85%?

▶ Problem 7.1

A piece of raw fish shaped as a 2.4-cm thick slab is placed over a hot metallic plate. The surface of the fish in contact with the hot surface attains a temperature of 110°C at time t = 0 and retains this temperature throughout the observation. Assuming unsteady heat conduction, calculate the temperature 1 cm from the hot surface of the fish after 18 minutes. The initial temperature of the fish at this distance from the hot surface is 8°C and the thermal diffusivity of the fish is 1.2×10^{-7} m^2/s.

Hint: The solution to the unsteady heat conduction equation for this situation is

$$\frac{T_e - T}{T_e - T_o} = \frac{4}{\pi}\sum_{n=0}^{\infty}\frac{(-1)^n}{2n+1}\cos\left(\frac{(2n+1)\pi x}{2L}\right)\exp\left(-\frac{(2n+1)^2\pi^2}{4}\mathrm{Fo}\right)$$

(A) $T(x$ = 1 cm$)$ = 45.5°C

(B) $T(x$ = 1 cm$)$ = 57.7°C

(C) $T(x$ = 1 cm$)$ = 76.8°C

(D) $T(x$ = 1 cm$)$ = 91.0°C

▶ Problem 7.2

Reconsider the previous problem. Calculate how long it will take for the temperature on the non-heated surface of the fish slab to increase by 1% of the initial temperature difference.

▶ Problem 8

A prismatic 8 cm × 8 cm × 12 cm piece of beef is being heated by microwave irradiation. The microwave system releases waves of narrowband frequency centered at 2450-MHz using an electric field at 10 V/cm. The beef is initially at 25°C; its density and specific heat are 1080 kg/m^3 and 3.9 kJ/kg·K, respectively. Also, the same dielectric data given in statement 6 of Problem 1 apply here as well. Estimate the temperature of the beef after 75 seconds.

(A) T = 66.3°C

(B) T = 80.2°C

(C) T = 95.3°C

(D) T = 101°C

▶ Problem 9

The viscosity of apple and grape juice can be estimated with equations of general form

$$\frac{\eta}{\eta_w} = \exp\left[\frac{A\times c[^\circ\mathrm{Brix}]}{100 - B\times c[^\circ\mathrm{Brix}]}\right]$$

where η is the viscosity of the fluid in mPa·s, η_w is the corresponding viscosity of water at the same temperature, c denotes sugar content in °Brix, and constants A and B are given below. Find the ratio of the viscosity of 30°Brix apple juice at 20°C to that of 30°Brix grape juice at the same temperature. Take the viscosity of water at 20°C to be 1 mPa·s.

	A (T = Temp. in K)	B (T = Temp. in K)	Concentration Range	Temperature Range
Apple juice	$-0.24 + 917.92/T$	$2.03 - 0.00267T$	14 – 39 °Brix	20 – 80°C
Grape juice	$-3.79 + 1821.45/T$	$0.86 + 0.000441T$	19 – 35 °Brix	20 – 80°C

(A) $\eta_{\text{apple}}/\eta_{\text{grape}}$ = 1.07
(B) $\eta_{\text{apple}}/\eta_{\text{grape}}$ = 1.42
(C) $\eta_{\text{apple}}/\eta_{\text{grape}}$ = 1.77
(D) $\eta_{\text{apple}}/\eta_{\text{grape}}$ = 2.04

▶ Problem 10

An orange juice sample has the following composition.

Water	88.2 g / 100 g
Carbohydrates	10.4 g / 100 g
Protein	0.73 g / 100 g
Total lipids	0.32 g / 100 g
Ash	0.35 g / 100 g

The juice is being placed in a 5 cm × 5 cm × 15 cm prismatic container and undergoes heating by exposure to hot water at 100°C for 4 minutes. The initial temperature of the orange juice is 30°C. Assuming the convective heat transfer coefficient in the steam environment to be 200 W/m^2·K, calculate the temperature of the orange juice at the end of the thermal treatment. **Use the tables in the Additional Information section.**
(A) T = 41.5°C
(B) T = 56.1°C
(C) T = 73.6°C
(D) T = 92.0°C

▶ Problem 11

Thermal processing for commercial sterilization of peas has significant influence on quality attributes. Food preservation engineers want to assess the performance of a hypothetical thermal process in which the peas are heated to 126°C for 42 minutes. Specifically, they want to quantify the impact of this procedure on the peas' content of ascorbic acid (vitamin C) and thiamine. The kinetic parameters for ascorbic acid are rate constant k = 0.009 min^{-1} at 132.2°C and activation energy E_A = 117.6 kJ/mole; similarly, the kinetic parameters for thiamine are k = 0.0435 min^{-1} at 138°C and E_A = 97.1 kJ/min. Composition data for raw peas indicate that the vitamin C and thiamine contents are 40 mg/100 g and 0.27 mg/100 g, respectively. Assuming first-order kinetics, determine the concentrations of vitamin C and thiamine remaining after the thermal treatment in question.
(A) $C_{vitamin\ C}$ = 16.05 mg/100 g; $C_{thiamine}$ = 0.124 mg/100 g
(B) $C_{vitamin\ C}$ = 16.05 mg/100 g; $C_{thiamine}$ = 0.248 mg/100 g
(C) $C_{vitamin\ C}$ = 32.1 mg/100 g; $C_{thiamine}$ = 0.124 mg/100 g
(D) $C_{vitamin\ C}$ = 32.1 mg/100 g; $C_{thiamine}$ = 0.248 mg/100 g

▶ Problem 12

A fluid food product with a constant viscosity of 9 cP and a density of 1100 kg/m^3 is to be pasteurized in a continuous system that heats the food to 85°C followed by holding in a 50.8-mm diameter sanitary pipe from which it leaves at 80°C. The process is designed to achieve a 11 decimal reduction of *Staphylococcus aureus*, which has a D-value at 85°C close to 0.008 min. Calculate the length of the holding tube if the flow rate is 20 L/min.
(A) L = 0.85 m
(B) L = 1.73 m
(C) L = 2.75 m
(D) L = 3.46 m

▶ Problem 13

A fluid food product with constant viscosity of 75 cP and density of 1050 kg/m^3 is being processed in a holding tube of 8 m length and 0.5 cm diameter. The flow rate through the tube is 28.3 L/min. The fluid temperature at the exit of the holding tube is 130°C. Find the number of decimal reductions achieved by this system if the *D*-value of a hypothetical microbe at 121.1°C is 1.8 min; the *z*-value has been estimated to be 25°C.

(A) *Decimal reduction* = 7.2
(B) *Decimal reduction* = 9.5
(C) *Decimal reduction* = 10.3
(D) *Decimal reduction* = 11.9

▶ Problem 14

A pulsed electric field (PEF) process is being designed for reduction of the *S. enterica* population in a new food product from 1000 to 10^{-3} per kg. The kinetic parameters are: threshold electric field intensity E_c = 9 kV/cm, threshold treatment time t_t = 20 μs, and temperature coefficient function K = 8.05[1 – 0.04(T – 15)] kV/cm (with T given in °C). In the instrumentation at hand, the dimensions of the cell include a 0.6-cm gap and a 2.4-cm width, and an electric field intensity of 20 kV/cm will be used. The product has density 980 kg/m^3 and viscosity equal to 70 cP. Determine the length of the PEF cell needed when the product entering the system is at a temperature of 25°C and flows at a rate of 50 kg/min.

(A) L = 5.1 cm
(B) L = 10.2 cm
(C) L = 15.4 cm
(D) L = 20.4 cm

▶ Problem 15

Match the enzymes in Group I with the corresponding functions in Group II.

Group I	Group II
P. Amylase	**1.** Softening of dough
Q. Invertase	**2.** Conversion of sucrose to glucose and fructose
R. Phosphatase	**3.** Conversion of starch to maltose
S. Protease	**4.** Effectiveness of pasteurization

(A) P-1; Q-2; R-3; S-4
(B) P-3; Q-2; R-1; S-4
(C) P-2; Q-3; R-4; S-1
(D) P-3; Q-2; R-4; S-1

▶ Problem 16

Spoilage of milk involves a well-defined succession of:

P → *Lactobacillus*
Q → Yeasts and molds
R → *Lactococcus lactis*
S → Protein-digesting bacteria

The correct order of succession is:
(A) S → Q → R → P
(B) S → R → Q → P
(C) Q → S → P → R
(D) R → P → Q → S

▶ Problem 17

Match the fermented food products in Group I with the corresponding microorganisms in Group II.

Group I	Group II
P. Yoghurt	**1.** *Lactobacillus acidophilus* and *Lactobacillus delbrueckii*
Q. Cheese	**2.** *Leucostonoc mesenteroides* and *Lactobacillus plantarum*
R. Sauerkraut	**3.** *Lactobacillus delbrueckii* and *Streptococcus thermophillus*
S. Kefir	**4.** *Lactobacillus casei* and *Lactococcus lactis*

(A) P-1; Q-4; R-2; S-3
(B) P-4; Q-3; R-1; S-2
(C) P-3; Q-4; R-2; S-1
(D) P-3; Q-2; R-4; S-1

▶ Problem 18

Associate the spoilage effects in Group I with the corresponding microorganisms in Group II.

Group I	Group II
P. Causes green rot of eggs	**1.** *Salmonella enterica*
Q. Spoils home canned foods	**2.** *Pseudomonas fluorescens*
R. Spoils seafood, especially oysters	**3.** *Vibrio parahaemolyticus*
S. Spoils poultry products	**4.** *Clostridium botulinum*

(A) P-4; Q-1; R-3; S-2
(B) P-3; Q-4; R-2; S-1
(C) P-2; Q-4; R-1; S-3
(D) P-2; Q-4; R-3; S-1

▶ Problem 19

An industrial yeast culture for use in production of a fermented beverage has specific growth rate $\mu = 0.14$ h^{-1}. Cell growth follows Monod kinetics under oxygen limitation with constant $K_O = 0.1$ and the yield coefficient is $Y_O = 0.88$ kg cell/kg oxygen consumed. The product of mass transfer coefficient k_L and specific interfacial area a may be taken as k_La = 6×10^{-4} s^{-1}. The maximum specific growth rate for the yeast species is $\mu_{\max}$ = 0.21 h^{-1} and the equilibrium concentration of oxygen may be taken as $c^* = 7.5$ mg L^{-1}. Assuming that all nutrients besides oxygen are in large excess, what is the maximum cell concentration achieved in this operation?
(A) x = 99.1 kg/m^3
(B) x = 134 kg/m^3
(C) x = 151 kg/m^3
(D) x = 160 kg/m^3

ADDITIONAL INFORMATION

Table 1. Density of nutrients as a function of temperature. Densities are in kg/m^3 and temperatures in °C.

Component	Temperature function
Protein	$\rho = 1.3299\times10^3 - 5.1840\times10^{-1}T$
Fat	$\rho = 9.2559\times10^2 - 4.1757\times10^{-1}T$
Carbohydrate	$\rho = 1.5991\times10^3 - 3.1046\times10^{-1}T$
Ash	$\rho = 2.4238\times10^3 - 2.8063\times10^{-1}T$
Water	$\rho = 9.9718\times10^2 + 3.1439\times10^{-3}T - 3.7574\times10^{-3}T^2$

Table 2. Specific heat capacity of nutrients as a function of temperature. Specific heats are in kJ/kg·K and temperatures in °C.

Component	Temperature function
Protein	$c_p = 2.0082 + 1.2089\times10^{-3}T - 1.3129\times10^{-6}T^2$
Fat	$c_p = 1.9842 + 1.4733\times10^{-3}T - 4.8008\times10^{-6}T^2$
Carbohydrate	$c_p = 1.5488 + 1.9625\times10^{-3}T - 5.9399\times10^{-6}T^2$
Ash	$c_p = 1.0926 + 1.8896\times10^{-3}T - 3.6817\times10^{-6}T^2$
Water (0 – 150°C)	$c_p = 4.1289 + 9.0864\times10^{-3}T + 5.4731\times10^{-6}T^2$

SOLUTIONS

P.1 ➡ Solution

1. False. Per Norrish's equation, the water activity of a food is given by

$$\log_{10}\left(\frac{a_w}{x_w}\right) = -k\left(1-x_w\right)^2$$

where a_w is water activity, x_w is the mole fraction of water, and k is a constant that depends on the solute. For the glucose solution under consideration, constant $k = 0.7$ and the value of x_w is

$$x_w = \frac{40/18}{40/18 + 60/180} = 0.870$$

so that

$$\log_{10}\left(\frac{a_w}{0.870}\right) = -0.7 \times (1 - 0.870)^2 = -0.0118$$

$$\therefore \frac{a_w}{0.870} = 10^{-0.0118} = 0.973$$

$$\therefore a_w = 0.973 \times 0.870 = \boxed{0.847}$$

2. True. A 99.99% inactivation is equivalent to 4 decimal reductions (one survivor in 10,000), hence $S = 4$. The value of D_0 (i.e., the D-value at 121.1°C) then becomes

$$D_0 = \frac{F_0}{S} = \frac{1.05}{4} = \boxed{0.263 \text{ min}}$$

3. False. This is a straightforward application of the formula

$$D = \frac{t_2 - t_1}{\log_{10}(N_1) - \log_{10}(N_2)} = \frac{30 - 15}{\log_{10}(8100) - \log_{10}(110)} = \boxed{8.03 \text{ min}}$$

4. False. The formula to use is

$$\log_{10}\left(\frac{F}{F_0}\right) = \frac{T_0 - T}{z} \;\rightarrow\; \log_{10}\left(\frac{F}{1.3}\right) = \frac{121.1 - 123}{8} = -0.2375$$

$$\therefore F = 1.3 \times 10^{-0.2375} = \boxed{0.752 \text{ min}}$$

5. False. As microwaves are absorbed by a food material, their intensity is attenuated by the penetration depth. The loss factor increases with the temperature, the product surface heats up faster and faster, and the penetration depth simultaneously decreases. The lower frequency (915-MHz-centered band) offers advantages for the tempering of thick products because of its deeper penetration and longer wavelength when compared to the higher frequency (2450-MHz-centered band). For these reasons, Ahmed and Ramaswamy (2020) note that most food tempering facilities presently employ 915-MHz frequency instrumentation whenever possible, except when regulations do not permit use of this frequency.

Recommended edited book chapter: Ahmed and Ramaswamy (*in* Rahman, 2020).

6. True. The loss tangent is given by the ratio of dielectric loss factor (ε'') to relative dielectric constant (ε'). For the given data,

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} = \frac{17}{64} = \boxed{0.266}$$

7. False. The attenuation factor α' is expressed as

$$\alpha' = \frac{2\pi}{\lambda}\left[\frac{\varepsilon'}{2}\left(\sqrt{1 + \tan^2\delta} - 1\right)\right]^{1/2}$$

We already have the relative dielectric constant $\varepsilon' = 64$ and the loss tangent $\tan\delta = 0.266$. The wavelength λ for 2450-MHz microwave radiation can be calculated as

$$\lambda = \frac{c}{f} = \frac{3.0 \times 10^8}{2450 \times 10^6} = 0.122 \text{ m} = 12.2 \text{ cm}$$

so that

$$\alpha' = \frac{2\pi}{12.2} \times \left[\frac{64}{2}\left(\sqrt{1 + 0.266^2} - 1\right)\right]^{1/2} = 0.543 \text{ cm}^{-1}$$

The penetration depth d then becomes

$$d = \frac{1}{\alpha'} = \frac{1}{0.543} = \boxed{1.84 \text{ cm}}$$

8. True. Two metric tonnes amount to 2 megagrams; therefore, the cooling load associated with this mass of avocado fruit is 2 × 70 = 140 W. Similarly, the cooling load required for 0.8 megagrams of blackberries is 0.8 × 110 = 88 W. The total cooling load then becomes 140 + 88 = 228 W.

9. True. We first compute the Reynolds number:

$$\mathrm{Re}_D = \frac{\rho u d}{\mu} = \frac{1.21\times 12\times 0.06}{1.8\times 10^{-5}} = 48,400$$

and the Schmidt number:

$$\mathrm{Sc} = \frac{\mu}{\rho D} = \frac{1.8\times 10^{-5}}{1.21\times\left(3.0\times 10^{-5}\right)} = 0.496$$

For flow around a single sphere, the following correlation is often used for the Sherwood number:

$$\mathrm{Sh} = 2 + 0.552\,\mathrm{Re}^{0.53}\,\mathrm{Sc}^{1/3} = 2 + 0.552\times 48,400^{0.53}\times 0.496^{1/3} = 135$$

Lastly, the mass transfer coefficient follows from the definition of Sherwood number:

$$\mathrm{Sh} = \frac{h_m\times d}{D} \;\rightarrow\; h_m = \frac{\mathrm{Sh}\times D}{d}$$

$$\therefore h_m = \frac{135\times\left(3.0\times 10^{-5}\right)}{0.06} = 0.0675\ \text{m/s}$$

$$\therefore \boxed{h_m = 6.75\ \text{cm/s}}$$

10. True. The flow rate is converted as $Q = 80 \times 1/60 \times 10^{-3} = 0.00133$ m^3/s. The corresponding flow velocity is

$$u = \frac{0.00133}{\frac{\pi}{4}\times 0.03^2} = 1.88\ \text{m/s}$$

The corresponding Reynolds number is

$$\mathrm{Re}_D = \frac{\rho u D}{\mu} = \frac{(1.04\times 1000)\times 1.88\times 0.03}{120\times 10^{-3}} = 489$$

Since Re_D is well below 2000, flow is laminar and the pressure drop can be calculated with the Poiseuille equation:

$$\Delta p = \frac{8\mu L Q}{\pi R^4} = \frac{8\times\left(120\times 10^{-3}\right)\times 40\times 0.00133}{\pi\times 0.015^4} = 321,000\ \text{Pa}$$

$$\therefore \boxed{\Delta p = 321\ \text{kPa}}$$

11. True. Noting that power equals the product of flow rate and pressure drop, we have

$$W = Q\Delta p = 3.0\times 320 = 800\ \text{Pa}$$

Assuming an efficiency of 66%, the required power input becomes

$$W_i = \frac{W}{\eta} = \frac{800}{0.58} = 1380\ \text{W} = \boxed{1.38\ \text{kW}}$$

12. False. The falling-rate drying time for an infinite cylinder is given by

$$t_f = \frac{r_c^2}{\beta^2 D}\ln\left[\frac{4}{\beta^2}\left(\frac{w_c - w_e}{w - w_e}\right)\right]$$

where $r_c = 0.5\times10^{-3}$ m is the radius of the cylinder, $D = 2\times10^{-11}$ m^2/s is the mass diffusivity of water vapor within the noodle, $\beta \approx 2.4048$ is the first root of the first kind, zero-order Bessel equation, $w_c = 0.6$ kg/kg is the critical moisture content, $w_e = 0.2$ kg/kg is the equilibrium moisture content, and $w =$

0.24 kg/kg is the final moisture content. Substituting the pertaining variables brings to

$$t_f = \frac{\left(0.5\times10^{-3}\right)^2}{2.4048^2\times\left(2\times10^{-11}\right)}\times\ln\left[\frac{4}{2.4048^2}\times\left(\frac{0.6-0.2}{0.24-0.2}\right)\right] = 4180\text{ s}$$

$$\therefore \boxed{t_f = 1.16\text{ h}}$$

13. False. Generally speaking, the Troutonian ratio is the ratio of extensional viscosity to shear viscosity:

$$\text{To} = \frac{\text{Extensional viscosity}\left(\eta_E\right)}{\text{Shear viscosity}\left(\eta_S\right)}$$

Ideally, $\eta_E = 3\eta_S$ for uniaxial extension, $\eta_E = 4\eta_S$ for planar extension, and $\eta_E = 6\eta_S$ for biaxial extension. It follows that, for biaxial extension:

$$\text{To} = \frac{6\eta_S}{\eta_S} = \boxed{6}$$

Reference: Rozanska (*in* Ahmed and Basu, 2023).

14. False. As Peleg and Corradini (2011) put it, the Arrhenius equation has been somewhat recklessly transplanted from chemical kinetics, for which it was originally derived, to microbial kinetics, with puzzling consequences. For one, the notion of 'energy of activation' may have been precisely defined in chemistry, but the fact that microbial growth is likewise defined by such a parameter remains to be justified. Further, the inclusion of the gas constant *R,* which appears in most Arrhenius-like equations, may have a well-established meaning in the study of gaseous systems, but makes no sense at all in the description of microbial growth kinetics.

Reference: Peleg and Corradini (2011).

15. False. In actuality, several investigators have found that simple *zero-order kinetics* can describe the kinetics of browning with reasonable accuracy. Recall that for a zero-order reaction the concentration of the compound of interest evolves linearly with time. For a browning pigment formation, we may write (Labuza and Saltmarch, 1982)

$$B = B_0 + k_z t$$

where B is the brown pigment concentration at time t, B_0 is the browning pigment formation at $t = 0$, k_z is the zero-order rate constant, and t is time.

References: Labuza (1970); Waletzko and Labuza (1976); Labuza and Saltmarch (1982). See also Villota and Hawkes (*in* Heldman *et al.*, 2019).

16. False. The Gram-positive bacteria *Listeria monocytogenes* and *Listeria innocua* are less sensitive to PEF treatment than Gram-negative bacteria. Possibly, the more rigid and thicker cell wall of Gram-positive bacteria constitutes a protection against PEF (Aronsson, 2002). Aronsson *et al.* (2001) studied the effect of PEF treatment on four organisms (*Escherichia coli, Listeria innocua*, *Leucostonoc mesenteroides,* and *Saccharomyces cerevisiae*) and found that the most resistant organisms were *Listeria innocua* and *Leucostonoc mesentroides*, with only a 3 log cycles reduction when compared to a 6 and 5.4 log cycles reduction in the case of *Saccharomyces cerevisiae* and *Escherichia coli*, respectively.

References: Aronsson *et al.* (2001) and Aronsson (2002); see also Cserhalmi (*in* Hui, 2006).

17. True. Recently, the joint FAO/IAEA/WHO Study Group on High-Dose Irradiation (JSGHDI) stated that any food irradiation treatment at any high dose is acceptable as long as it is palatable. In other words, any food subjected to inappropriate irradiation treatment may have lost its essential properties but is not hazardous for consumption. Moreover, irradiation generally does not cause any significant loss of macronutrients.

Recommended edited book chapter: Nishihira (*in* Andersen, 2020).

18. False. Things are a little more complicated. Fan *et al.* (1999) found a marked dependence of rate of increase in dough volume and rate of heating. Crucially, those authors found that the volume of dough increased almost linearly with time until the temperature reached almost 65°C; for this temperature range, a constant extensional rate at 2.0 – 4.0×10^{-4} s^{-1} was observed. A further increase in temperature caused the extensional rate to drop sharply, suggesting a decrease in dough expansion. The dough volume essentially stopped increasing at approximately 85 – 90°C.

Reference: Fan *et al.* (1999).

19. True. Farkas *et al.* (1996) acknowledge that omission of oil flux and oil accumulation is a drawback of their model, especially if it were applied to fried food systems such as a potato chip, for which oil or fat may account for as much as 40% of the final weight.

Reference: Farkas *et al.* (1996).

20. False. It is κ-casein, not β-casein, that is responsible for the micelle-stabilizing effect mentioned in the statement. The crucial role of κ-casein in micelle stabilization has been corroborated by Shekar *et al.* (2006), who reported that κ-casein-deficient mice did not lactate because of destabilization of the micelles in the lumina of the mammary glands.

Reference: Beliciu (2011); Shekar *et al.* (2006).

21. False. Modified atmosphere packaging (MAP) at high oxygen levels has been shown to promote oxidation of muscle lipids over time, which may lead to the development of undesirable flavors. The oxidation of polyunsaturated fatty acids accelerates meat rancidity and has been correlated with negative effects on color, nutritional quality, and texture of beef.

Reference: O'Sullivan and Kerry (*in* Toldrá, 2010).

22. True. A Lineweaver-Burk plot is a line given by

$$\frac{1}{V}=\frac{k_m}{V_{\max}}\frac{1}{[S]}+\frac{1}{V_{\max}}$$

Substituting V_{max} = 160 μmol/L·min, [S] = 40 μmol/L, and the given slope k_m/V_{max} = 0.375 min, we obtain

$$\frac{1}{V}=0.375\times\frac{1}{40}+\frac{1}{160}=0.0156\ \frac{\text{L}\cdot\text{min}}{\mu\text{mol}}$$

The reciprocal of this result is the velocity of the reaction:

$$V=(0.0156)^{-1}=\boxed{64.1\ \frac{\mu\text{mol}}{\text{L}\cdot\text{min}}}$$

P.2 ➡ Solution

Substituting T_a = 38°C into the rate constant equation yields

$$k=290e^{-2170/(38+273.15)}=0.271\ \text{min}^{-1}$$

Then, the dynamic equilibrium moisture content at the temperature in question and relative humidity RH = 0.50 is

$$M_e=\left[\frac{-\ln(1-RH)}{c(T_a+273.15)}\right]^{1/n}=\left[\frac{-\ln(1-0.5)}{(3.2\times10^{-6})\times(38+273.15)}\right]^{1/2.8}=10.36\%$$

so that, after 5 minutes of continuous drying,

$$M=M_e+(M_0-M_e)e^{-kt}=10.36+(30-10.36)e^{-0.271\times5}=\boxed{15.43\%}$$

The corresponding drying rate is

$$\frac{dM}{dt}=-k(M-M_e)=-0.271\times(15.43-10.36)=\boxed{-1.37\%\ \text{min}^{-1}}$$

▶ The correct answer is **C**.

P.3 ➡ Solution

We first write the simplified Page equation for times t_1 = 3 h and t_2 = 6 h separately:

$$\frac{M_1-M_e}{M_0-M_e}=\exp(-kt_1)\ \ \text{(I)}$$

$$\frac{M_2-M_e}{M_0-M_e}=\exp\left(-kt_2\right)\ \text{(II)}$$

Dividing (II) by (I) brings to

$$\frac{\dfrac{M_2-M_e}{\cancel{M_0-M_e}}}{\dfrac{M_1-M_e}{\cancel{M_0-M_e}}}=\frac{\exp\left(-kt_2\right)}{\exp\left(-kt_1\right)}$$

$$\therefore \frac{M_2-M_e}{M_1-M_e}=\exp\left(-k\left(t_2-t_1\right)\right)$$

so that

$$\frac{8-M_e}{15-M_e}=\exp\left(-0.502\times\left(6-3\right)\right)$$

$$\therefore \boxed{M_e=6.0\%}$$

The equilibrium moisture content is six percent.

▶ The correct answer is **C**.

P.4 ➡ Solution

For a propeller of 0.25-m diameter rotating at 1.8 Hz, the power required is

$$P_{\text{prop}}=1964N^2D^3=1964\times 1.8^2\times 0.25^3=99.4\ \text{ W}$$

Since the motor is unchanged, the power required by the paddle should be the same as that of the propeller. Accordingly, the paddle speed is found as

$$P_{\text{pad}}=P_{\text{prop}}=1748N^2D^3=99.4$$

$$\therefore 1748\times N^2\times 0.65^3=99.4$$

$$\therefore \boxed{N=0.455\ \text{Hz}}$$

or, equivalently, 27.3 rpm.

▶ The correct answer is **B**.

P.5 ➡ Solution

The heat conduction equation for this cylindrical geometry is

$$\frac{d^2T}{dt^2}+\frac{1}{r}\frac{dT}{dr}=0$$

which can be restated as

$$\frac{d^2T}{dt^2}+\frac{1}{r}\frac{dT}{dr}=\frac{d}{dr}\left(r\frac{dT}{dr}\right)$$

The boundary conditions are $T = T_1$ at $r = r_1$ and $T = T_2$ at $r = r_2$. The solution to the differential equation above is

$$T=\frac{\left(T_2-T_1\right)}{\ln\left(r_2/r_1\right)}\ln\left(\frac{r}{r_1}\right)+T_1$$

so that, introducing Fourier's law,

$$q=-kA\frac{dT}{dr}=\frac{2\pi kL\left(T_1-T_2\right)}{\ln\left(r_2/r_1\right)}$$

In the case at hand, k = 1.12 W/m·K, L = 1 m, r_1 = 5 m, r_2 = 5.16 m, T_1 = 10°C, and T_2 = 20°C, giving

$$q=\frac{2\pi\times 1.1\times 1\times\left(10-20\right)}{\ln\left(2.58/2.5\right)}=-2190\ \text{W/m}$$

$$\therefore \boxed{q=-2.19\ \text{kW/m}}$$

▶ The correct answer is **C**.

P.6 ➡ Solution

The heat gain can be determined with the same radial heat conduction equation used in Problem 5:

$$q = \frac{2\pi kL(T_1 - T_2)}{\ln(r_2/r_1)} = \frac{2\pi \times 1.1 \times 1 \times (18-36)}{\ln(3.08/3)} = -4730 \text{ W/m}$$

Now, for a two-layer system the solution becomes

$$q = \frac{2\pi(T_1 - T_3)}{\ln(r_2/r_1)/k_A + \ln(r_3/r_2)/k_B}$$

so that, solving for *ln*(r_3/r_2):

$$\ln\left(\frac{r_3}{r_2}\right) = \left[\frac{2\pi(T_3 - T_1)}{|q|} + \frac{\ln(r_2/r_1)}{k_A}\right]k_B$$

If the heat gain is to be reduced by 85%, we must have q = 0.15 × 4730 = 710 W/m; thus,

$$\ln\left(\frac{r_3}{3.08}\right) = \left[\frac{2\pi \times (36-18)}{710} + \frac{\ln(3.08/3.0)}{1.1}\right] \times 0.1$$

$$\therefore \ln\left(\frac{r_3}{3.08}\right) = 0.01832$$

$$\therefore r_3 = 3.08 \times \exp(0.01832) = 3.137 \text{ m}$$

Accordingly, the required thickness of rock wool is $r_3 - r_2$ = 3.137 – 3.08 = 0.057 m = 5.7 cm.

P.7 ➡ Solution

Problem 7.1: The temperature distribution can be established from the expression we were given as a hint. Since the fish is heated only from one side, the characteristic dimension is the thickness of the fish, not the half thickness. The Fourier number then becomes

$$\text{Fo} = \frac{\alpha t}{L^2} = \frac{(1.2 \times 10^{-7}) \times (22 \times 60)}{0.024^2} = 0.275$$

We may retain only the first term in the infinite series if the Fourier number is somewhat lower than 0.2; this is not the case here. The following MATLAB code can be used to compute the sum on the right-hand side for n ranging from 0 to 10, which is comfortably more than enough for an accurate result. The final portion of the code solves the given heat conduction equation for temperature T:

```
syms n
x = 0.01;
L = 0.024;
Fo = 0.275;
Te = 110;
T0 = 8;
expression = (-1)^n/(2*n+1)*cos(((2*n+1)*pi*x)/(2*L))*...
    exp(-(2*n+1)^2*pi^2*Fo/4);
V = subs(expression, n, 0:10);
RHS = 4/pi*double(sum(V));
f = @(T) (Te - T)/(Te - T0) - RHS;
TGuess = 60;
TFinal = fzero(f, TGuess);
fprintf('The final temperature is %2.1f \n', TFinal)
```

Here's the output:

```
The final temperature is 57.7
```

That is, the temperature 1 cm above the hot surface, 18 minutes after the fish is initially placed over the surface, is about 57.7°C.

▶ The correct answer is **B**.

Problem 7.2: As long as the temperature change on the cold surface of the fish slab is less than 1% of the initial temperature difference, the steak can be treated as a semi-infinite body. For a semi-infinite body with uniform initial temperature and constant surface temperature, the solution to the heat conduction equation is

$$\frac{T_e - T}{T - T_0} = \text{erf}\left(\frac{x}{2\sqrt{\alpha t}}\right) \quad \text{(I)}$$

But

$$\frac{T - T_0}{T_e - T_0} = 0.01$$

so

$$\frac{T_e - T_0}{T_e - T_0} = 1 - \frac{T - T_0}{T_e - T_0} = 1 - 0.01 = 0.99$$

Substituting in (I),

$$0.99 = \text{erf}\left(\frac{x}{2\sqrt{\alpha t}}\right)$$

The argument has to be equal to 1.82 for the error function to be equal to 0.99. Hence,

$$0.99 = \text{erf}\left(\frac{x}{2\sqrt{\alpha t}}\right) \rightarrow \frac{x}{2\sqrt{\alpha t}} = 1.82$$

$$\therefore t = \frac{(x/3.64)^2}{\alpha} = \frac{(0.024/3.64)^2}{1.2\times10^{-7}} = \boxed{362\ \text{s}}$$

P.8 ➡ Solution

The conversion of microwave energy into thermal energy can be estimated with the relationship

$$\Pi = \left(55.61\times10^{-14}\right)E^2 f \varepsilon' \tan\delta \quad \text{(I)}$$

where Π is power dissipation (in W/cm^3), E is the electric field intensity (in V/cm), f is the wave frequency (in Hz), ε' is the relative dielectric constant, and *tan* δ is the loss tangent. In turn, the thermal energy required for a given increase in temperature is given by

$$q = \rho c_p V \frac{dT}{dt} \quad \text{(II)}$$

where q is the thermal power (in W), ρ is the density of the product being heated (in kg/m^3), c_p is the specific heat capacity of the product (in kJ/kg·K), T is temperature (in °C), and t is time. Assuming that all energy dissipation from the microwave is converted into thermal energy and a corresponding increase in product temperature, we can equate (I) and (II) to obtain

$$\frac{dT}{dt} = \left(55.61\times10^{-14}\right)E^2 f \varepsilon' \frac{\tan\delta}{\rho c_p V}$$

The volume of the beef slab under consideration is $V = 0.08 \times 0.08 \times 0.12 = 7.68\times10^{-4}$ m^3; the relative dielectric constant $\varepsilon' = 64$ and the loss tangent *tan* $\delta = 0.266$ come from statement 6 of Problem 1. All other data are already known, so that

$$\frac{dT}{dt} = \left(55.61\times10^{-14}\right)\times10^2\times\left(2450\times10^6\right)\times64\times\frac{0.266}{1080\times3900\times\left(7.68\times10^{-4}\right)}$$

$$\therefore \frac{dT}{dt} = 7.17\times10^{-4}\ ^\circ\text{C/s for a volume of 1 cm}^3$$

Given the volume of the beef slab = 8 × 8 × 12 = 768 cm^3, the rate of temperature increase becomes

$$\frac{dT}{dt} = \left(7.17\times10^{-4}\right)\times768 = 0.551^\circ\text{C/s}$$

After 75 seconds, the beef temperature is

$$T = 25 + 75 \times 0.551 = \boxed{66.3^{\circ}\text{C}}$$

Thus, after 75 seconds of exposure the temperature of the beef slab is raised from 25°C to 66.3°C.

▶ The correct answer is **A**.

P.9 ➡ Solution

For apple juice at 20°C (= 293 K), coefficients A and B are calculated as

$$A = -0.24 + \frac{917.92}{293} = 2.89$$

and

$$B = 2.03 - 0.00267 \times 293 = 1.25$$

so that

$$\eta_{\text{apple}} = 1.0 \times \exp\left[\frac{2.89 \times 30}{100 - 1.25 \times 30}\right] = 4.0 \text{ mPa} \cdot \text{s}$$

Proceeding similarly with grape juice, we obtain

$$A = -3.79 + \frac{1821.45}{293} = 2.43$$

$$B = 0.86 + 0.000442 \times 293 = 0.990$$

so that

$$\eta_{\text{grape}} = 1.0 \times \exp\left[\frac{2.43 \times 30}{100 - 0.990 \times 30}\right] = 2.82 \text{ mPa} \cdot \text{s}$$

Lasty, we compute the ratio

$$\frac{\eta_{\text{apple}}}{\eta_{\text{grape}}} = \frac{4.0}{2.82} = \boxed{1.42}$$

That is to say, 30°Brix apple juice at 20°C is about 40% more viscous than grape juice at the same sugar content and temperature.

▶ The correct answer is **B**.

P.10 ➡ Solution

The equation to use is

$$\frac{T - T_a}{T_i - T_a} = \exp\left(-\frac{hAt}{\rho c_p V}\right) \quad \text{(I)}$$

where T is the final temperature, T_a is the ambient temperature, T_i is the initial temperature, h is the convective heat transfer coefficient, A is the surface area of the container, t is the heat treatment duration, ρ is the density of the product, c_p is the specific heat capacity of the food product, and V is the volume of the container. We already have most of these variables; however, the density ρ and the specific heat c_p must be determined.

Since the juice is initially at 30°C and the heating medium (steam) is at 100°C, a reasonable choice of temperature is the average (30 + 100)/2 = 65°C. Substituting in the temperature functions from the Additional Information section, we find that

$$\rho(\text{water}) = 9.9718 \times 10^{2} + 3.1439 \times 10^{-3} \times 65$$
$$-3.75754 \times 10^{-3} \times 65 = 997.14 \text{ kg/m}^3$$

$$\rho(\text{carb.}) = 1.5991 \times 10^{3} - 3.1046 \times 10^{-1} \times 65 = 1578.9 \text{ kg/m}^3$$

$$\rho(\text{prot.}) = 1.3299 \times 10^{3} - 5.184 \times 10^{-1} \times 65 = 1296.2 \text{ kg/m}^3$$

$$\rho(\text{lipids}) = 9.2559 \times 10^{2} - 4.1757 \times 10^{-1} \times 65 = 898.4 \text{ kg/m}^3$$

$$\rho(\text{ash}) = 2.4238 \times 10^{3} - 2.8063 \times 10^{-1} \times 65 = 2405.6 \text{ kg/m}^3$$

$$\bar{\rho} = 0.882 \times 997.14 + 0.104 \times 1578.9 + 0.0073 \times 1296.2$$
$$+0.0032 \times 898.4 + 0.0035 \times 2405.6 = 1064.4\,\text{kg/m}^3$$

Proceeding similarly with specific heats,

$$c_p(\text{water}) = 4.1289 + 9.0864 \times 10^{-3} \times 65 + 5.4731 \times 10^{-6} \times 65^2 = 4.743\ \text{kJ/kg·°C}$$

$$c_p(\text{carb.}) = 1.5488 + 1.9625 \times 10^{-3} \times 65 - 5.9399 \times 10^{-6} \times 65^2 = 1.651\ \text{kJ/kg·°C}$$

$$c_p(\text{prot.}) = 2.0082 + 1.2089 \times 10^{-3} \times 65 - 1.3129 \times 10^{-6} \times 65^2 = 2.081\ \text{kJ/kg·°C}$$

$$c_p(\text{lipids}) = 1.9842 + 1.4733 \times 10^{-3} \times 65 - 4.8008 \times 10^{-6} \times 65^2 = 2.060\ \text{kJ/kg·°C}$$

$$c_p(\text{ash}) = 1.0926 + 1.8896 \times 10^{-3} \times 65 - 3.6817 \times 10^{-6} \times 65^2 = 1.200\ \text{kJ/kg·°C}$$

$$\bar{c}_p = 0.882 \times 4.743 + 0.104 \times 1.651 + 0.0073 \times 2.081$$
$$+0.0032 \times 2.060 + 0.0035 \times 1.200 = 4.381\ \text{kJ/kg·°C}$$

Now, the area of the juice container, which is a prism, is

$$A = 2 \times 0.05^2 + 4 \times (0.05 \times 0.15) = 0.035\ \text{m}^2$$

while the volume is

$$V = 0.05 \times 0.05 \times 0.15 = 3.75 \times 10^{-4}\ \text{m}^3$$

We are now ready to substitute the pertaining variables into the right-hand side of equation (I):

$$\exp\left(-\frac{hAt}{\rho c_p V}\right) = \exp\left[-\frac{200 \times 0.035 \times (4 \times 60)}{1064.4 \times 4381 \times \left(3.75 \times 10^{-4}\right)}\right] = 0.377$$

Solving for final temperature,

$$T = 0.377 \times (30 - 100) + 100 = \boxed{73.61^\circ\text{C}}$$

▶ The correct answer is **C**.

P.11 ➡ Solution

The first step is to update the rate constants from the given reference temperatures to the process temperature of 126°C (= 399 K). For ascorbic acid:

$$\ln k = \ln k_{\text{ref}} + \left[\frac{E_A}{R}\left(\frac{1}{T_{\text{ref}}} - \frac{1}{T}\right)\right]$$

$$\therefore \ln k = \ln(0.009) + \left[\frac{117{,}600}{8.314} \times \left(\frac{1}{405.2} - \frac{1}{399}\right)\right]$$

$$\therefore \ln k = -4.711 - 0.542 = -5.253$$

$$\therefore k = e^{-5.253} = 0.00523\ \text{min}^{-1}\ \text{at } 126^\circ\text{C}$$

Using the first-order kinetic model, the retention level C/C_0 for the thermal process in focus is

$$\frac{C}{C_0} = \exp(-kt) = \exp(-0.00523 \times 42) = 0.803$$

Hence, the concentration of ascorbic acid remaining after the thermal process is 0.803 × 40 = 32.1 mg/100 g. Now, we turn to the retention of thiamine; the updated rate constant is

$$\ln k = \ln k_{\text{ref}} + \left[\frac{E_A}{R}\left(\frac{1}{T_{\text{ref}}} - \frac{1}{T}\right)\right]$$

$$\therefore \ln k = \ln(0.0435) + \left[\frac{97{,}100}{8.314} \times \left(\frac{1}{411} - \frac{1}{399}\right)\right]$$

$$\therefore \ln k = -3.135 - 0.855$$

$$\therefore \ln k = -3.99$$

$$\therefore k = e^{-3.99} = 0.0185 \text{ min}^{-1} \text{ at } 126^{\circ}\text{C}$$

The retention level follows as

$$\frac{C}{C_0} = \exp(-kt) = \exp(-0.0185 \times 42) = 0.460$$

Accordingly, the concentration of thiamine remaining after the thermal process is 0.460 × 0.27 = 0.124 mg/100 g.

▶ The correct answer is **C**.

P.12 ➡ Solution

The average velocity of flow in the tube is

$$\bar{V} = \frac{q}{\frac{\pi d^2}{4}} = \frac{\left(\frac{20}{60}\right) \times 10^{-3}}{\frac{\pi \times 0.0508^2}{4}} = 0.164 \text{ m/s}$$

The Reynolds number is determined next:

$$\text{Re}_d = \frac{\rho \bar{V} d}{\mu} = \frac{1100 \times 0.164 \times 0.0508}{9 \times 10^{-3}} = 1020$$

Since $Re_d < 2000$, we may assume that flow is laminar or transitional. Following Toledo (2018), it is prudent to calculate the holding length on the basis of *maximum* velocity. The maximum velocity for Hagen-Poiseuille flow may be taken as twice the average velocity, or

$$V_{\text{max}} = 2\bar{V} = 2 \times 0.164 = 0.328 \text{ m/s}$$

The *F*-value is the required process time, and must be equal to the residence time in the tube for the fastest flowing particle. For a decimal reduction S = 11, we have $F = t_{min} = S \times D = 11 \times 0.008 = 0.088$ min. The corresponding tube length then becomes

$$t_{\text{min}} = \frac{L}{V_{\text{max}}} \rightarrow L = V_{\text{max}} t_{\text{min}}$$

$$\therefore L = 0.328 \times (0.088 \times 60) = \boxed{1.73 \text{ m}}$$

A tube of approximately 1.7 meters is needed to achieve the desired decimal reduction in the food sample.

▶ The correct answer is **B**.

P.13 ➡ Solution

Noting that q = 28.3 L/min = 4.72×10^{-4} m^3/s, the average flow velocity becomes

$$\bar{V} = \frac{q}{(\pi d^2/4)} = \frac{4.72 \times 10^{-4}}{(\pi \times 0.05^2/4)} = 0.240 \text{ m/s}$$

The Reynolds number is

$$\text{Re}_d = \frac{\rho \bar{V} d}{\mu} = \frac{1050 \times 0.240 \times 0.05}{75 \times 10^{-3}} = 168$$

Thus, flow is clearly laminar. As usual, in Hagen-Poiseuille flow the maximum velocity is twice the average velocity, or

$$V_{\text{max}} = 2\bar{V} = 2 \times 0.240 = 0.48 \text{ m/s}$$

The residence time for the fastest flowing particle is

$$t = \frac{L}{V_{max}} = \frac{8}{0.48} = 16.67 \text{ s}$$

Now, we have the *D*-value for a temperature of 121.1°C, but the fluid food leaves the tube at 130°C. We can easily correct the *D*-value for this latter temperature:

$$\log_{10} D = \frac{\left[\log_{10} D_0 + \left(T_0 - T\right)\right]}{z} = \frac{\log_{10}(1.8) + (130 - 121.1)}{25} = 0.3662$$

$$\therefore D = 10^{0.3662} = 2.32 \text{ min at } 130°\text{C}$$

It remains to compute the number of decimal reductions:

$$\log_{10}\left(\frac{N}{N_0}\right) = \frac{-t}{D}$$

$$\therefore -\log_{10}\left(\frac{N}{N_0}\right) = \frac{16.67}{2.32} = \boxed{7.19}$$

This sterilizing operation yields about 7.2 decimal reductions.

▶ The correct answer is **A**.

P.14 ➡ Solution

Firstly, we compute the temperature-dependent kinetic parameter, namely

$$K = 8.05\left[1 - 0.04(T - 15)\right] = 8.05 \times \left[1 - 0.04 \times (25 - 15)\right] = 4.83 \text{ kV/cm}$$

Then, using the PEF model equation for a reduction $N/N_0 = 10^{-3}/1000 = 10^{-6}$, we have

$$\frac{N}{N_0} = \left(\frac{t}{t_c}\right)^{-(E - E_c)/K} \rightarrow 10^{-6} = \left(\frac{t}{20}\right)^{-(20-9)/4.83}$$

$$\therefore t = 8620 \text{ μs}$$

The maximum product velocity is computed from the flow rate, that is,

$$u = \frac{50}{980 \times (0.006 \times 0.024)} = 354 \text{ m/min} = 5.9 \text{ m/s} \quad \text{(I)}$$

The Reynolds number is

$$\text{Re}_L = \frac{\rho u L}{\mu} = \frac{980 \times 5.9 \times 0.006}{70 \times 10^{-3}} = 496$$

Since Re_L is well below 2000, flow is laminar. The maximum velocity u_{max} may be taken as twice the average velocity *u* calculated in (I), that is,

$$u_{max} = 2u = 2 \times 5.9 = 11.8 \text{ m/s}$$

Given the product velocity and the process time, the length of the PEF cell becomes

$$L = t \times u_{max} = \left(8620 \times 10^{-6}\right) \times 11.8 = 0.102 \text{ m}$$

$$\therefore \boxed{L = 10.2 \text{ cm}}$$

A cell length of approximately 10 centimeters is considered appropriate.

▶ The correct answer is **B**.

P.15 ➡ Solution

Invertase is an enzyme that catalyzes the hydrolysis of sucrose dimer into fructose and glucose. Amylase is an enzyme that catalyzes the hydrolysis of starch polymer into sugar. Alkaline phosphatase is an enzyme that is naturally present in milk, but is destroyed at a temperature close to the pasteurization temperature; in view of this feature, the so-called 'alkaline phosphatase test' can be used to indicate whether milk has been adequately pasteurized or has been contaminated with raw milk after pasteurization.

Proteases are used on a large commercial scale in the production of bread, baked goods, crackers and waffles.

▶ The correct answer is **D**.

P.16 ➡ Solution

Lactococcus lactis is normally the first kind of bacteria observed in souring milk. It is followed by the development of lactobacilli, which, like their predecessors, metabolize lactose and release lactic acid, causing the milk to coagulate. Afterwards, yeasts and molds populate the acid environment left by the bacilli. Lastly, protein-digesting bacteria consume the few remaining nutrients in the milk culture.

▶ The correct answer is **D**.

P.17 ➡ Solution

Lactobacillus delbrueckii and *Streptococcus thermophilus* are lactic acid bacteria used in the production of yoghurt. *Lactobacillus casei* and *Lactococcus lactis* are used in the production of cheese. *Leucostonoc mesenteroides* is a gram-positive bacterium used in the production of fermented foods such as sauerkraut and kimchi. *Lactobacillus acidophilus* is used in the production of kefir and other types of fermented milk.

▶ The correct answer is **C**.

P.18 ➡ Solution

S. enterica is a common pathogen in muscle foods, including poultry and beef. Green rot of eggs is caused by *P. fluorescens*, which release a characteristic green pigment as they multiply in the albumen. *V. parahaemolyticus* is a waterborne pathogen that may be transmitted to humans via contaminated seafood, especially oysters. Finally, *C. botulinum* is an anaerobic pathogen that usually infects humans through consumption of contaminated canned foods.

▶ The correct answer is **D**.

P.19 ➡ Solution

We first equate the mass transfer law for oxygen transfer,

$$Q = k_L a\left(c^* - c\right)$$

to the Monod fermenter kinetics law

$$r_x = \frac{\mu_{\max} c x}{Y_0\left(K_0 + c\right)}$$

so that, solving for the concentration x in the fermenter,

$$x = \frac{k_L a Y_0\left(c^* - c\right)\left(K_0 + c\right)}{\mu_{\max} c} \quad \text{(I)}$$

Also,

$$\mu = \frac{\mu_{\max} c}{K_0 + c}$$

or, equivalently,

$$c = \frac{K_0 \mu}{\mu_{\max} - \mu} = \frac{0.1 \times 0.14}{0.21 - 0.14} = 0.2 \text{ mg L}^{-1}$$

Substituting the pertaining variables in (I),

$$x = \frac{\left(6 \times 10^{-4}\right) \times 0.88 \times \left(7.5 - 0.2\right) \times \left(0.1 + 0.2\right)}{0.21 \times 0.2} \times 3600 = \boxed{99.1 \text{ kg/m}^3}$$

As a final check, it is worthwhile computing the Damköhler number:

$$\text{Da} = \frac{\mu_{\max} x}{k_L a c^* Y_0} = \frac{\left(0.21/3600\right) \times 99.1}{\left(6 \times 10^{-4}\right) \times \left(7.5 \times 10^{-6}\right) \times 0.88} = 1.49 \times 10^6$$

Since $Da \gg 1$, oxygen is indeed a limiting nutrient in the present scenario.

▶ The correct answer is **A**.

ANSWER SUMMARY

Problem 1		T/F
Problem 2		C
Problem 3		C
Problem 4		B
Problem 5		C
Problem 6		Open-Ended
Problem 7	7.1	B
	7.2	Open-Ended
Problem 8		A
Problem 9		B
Problem 10		C
Problem 11		C
Problem 12		B
Problem 13		A
Problem 14		B
Problem 15		D
Problem 16		D
Problem 17		C
Problem 18		D
Problem 19		A

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