PROBLEMS

1) One pound (0.454 kg) of head lettuce is packaged in an air tight container with a volume of 4 lt. The product occupies 80 % of the volume, the rest being air. If the product is at a constant temperature of 4°C, calculate how long it will take for oxygen content in the package to drop to 2.5 % of air. Respiration quotient is defined as the ratio of CO_2 produced to O_2 consumed is 1.0 for the reaction. (a = 26.7 mW/kg, b = 0.088/°C, M.Wt.CO_2 = 44, and of O_2 = 32 g/gmol, 1 mgCO_2 produces 10.7 J)

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{ENERGY}$$

Heat

Solution:

4 Lt { 20% air | 80% product }

$$q = a \cdot e^{b.T} = 26.7 \times e^{0.088 \times (4)} \Rightarrow$$

$$q = 38 \text{ mW/kg product} = 38 \times 10^{-3} \text{ J/kg.s}$$

$$\frac{\text{mg } CO_2 \text{ produced}}{h} = 38 \times 10^{-3} \frac{J}{kg \cdot s} \times \frac{1 \text{ mg} CO_2}{10.7 \text{ J}} \times \frac{3600 \text{ s}}{1 \text{ hr}} \times 0.454 \text{ kg}$$

$$= 5.8 \text{ mg } CO_2/h = 5.8 \times 10^{-3} \text{ g } CO_2 \text{ produced}/h$$

$$\frac{\text{gmol } CO_2}{h} = \text{g mol } O_2 \text{ depleted}/h = \frac{5.8 \times 10^{-3} \text{ g } CO_2/h}{44 \text{ g } CO_2/\text{gmol } CO_2}$$

$$= 1.318 \times 10^{-4} \text{ g mol } CO_2/h \equiv \text{g mol } O_2 \text{ depleted}/h.$$

Air → 21% O_2, 79% N_2

Stoichiometric coeff.: 1 mol O_2 → 1 mol CO_2

The total # of moles of air originally in the container is

$$n = \frac{PV}{RT} = \frac{1 \text{ atm} \times (4 \text{ Lt} \times 20/100)}{[0.08206 \text{ Lt} \cdot \text{atm}/(\text{mol.K})] \times (273+4) \text{K}}$$

$n = 0{,}0352$ mol air.

Since the RQ is 1.0, there will be no net change in the total # of moles of gases inside the container. The # of moles of oxygen when the concentration is 2.5 % is;

$n_{O_2} = 0{,}025 \times 0{,}0352 = 0{,}00088$ mol O_2 (Final O_2 content)

The original # of moles of $O_2 = 0{,}21 \times 0{,}0352$
$= 0{,}007392$ mol O_2

The # of moles of O_2 that must be depleted (consumed) by respiration is:

n_{O_2} depletion $= 0{,}007392 - 0{,}00088 = 0{,}006512$ mol O_2

The time required to deplete O_2 to the desired level:

$$\text{Time} = \frac{0{,}006512 \text{ mol } O_2}{0{,}0001318 \text{ mol } O_2/h} = 49.4 \text{ hr.}$$

2) For experimental work 50 ton of apples are stored in an air-tight cold storage with volume V. The product occupies 83.33 % of the volume, the rest being air in which is containing 3 % O_2. If the product is kept at a constant temperature of 2.22°C, calculate the volume of the cold storage for the oxygen to drop to 0.8 % of initial air in 60 hr. Assume respiration quotient is 1.0 and the constants *a* and *b* for the heat of respiration of apple is 19.4 mW/kg and 0.108/ºC, respectively. R = 0.08206 m^3.atm/(kgmol.K). Combustion of glucose releases 10.7 J/mg CO_2.

Solution: $q = a \cdot e^{b \cdot T} = 19.4 \times e^{0.108(2.22)} = 24.656 \, mW/kg$

$$\frac{mg\,CO_2 \text{ produced}}{h} = 24.656 \times 10^{-3} \frac{J}{kg \cdot s} \times \frac{1\,mg\,CO_2}{10.7\,J} \times \frac{3600\,s}{1\,h} \times 50 \times 10^3\,kg$$

$$= 414773.8 \frac{mg\,CO_2}{h} \times \frac{1\,g}{1000\,mg} \times \frac{1\,kg}{1000\,g} \cong 0.415\,kg\,CO_2/h$$

Since RQ is 1 $\Rightarrow \frac{kg\,mol\,CO_2 \text{ evolved}}{h} = \frac{kg\,mol\,O_2 \text{ depleted}}{h}$

$$\frac{mol\,CO_2}{h} = \frac{0.415\,kg\,CO_2/h}{44\,kg\,CO_2/kgmol\,CO_2} = 9.426 \times 10^{-3}\,kgmol\,CO_2/h = 9.426 \times 10^{-3}\,kgmol\,O_2 \frac{\text{depleted}}{h}$$

$$n_{air} = \frac{PV}{RT} = \frac{1\,atm \times (1 - 0.8333) \times V}{0.08206 \times (273 + 2.22)} \Rightarrow$$

$$n_{air} = 7.38 \times 10^{-3} V\,(kgmol/m^3)$$

$$n_{O_2} = 7.38 \times 10^{-3} V\,(kgmol/m^3) \times 0.03 = 2.214 \times 10^{-4} V\,(kgmol/m^3)$$
(initial)

$$n_{O_2}\text{ final} = 7.38 \times 10^{-3} V \times \frac{0.8}{100} = 5.904 \times 10^{-5} V\,(kgmol/m^3)$$

$$n_{O_2}\text{ depleted} = 2.214 \times 10^{-4} V - 5.904 \times 10^{-5} V = 1.6238 \times 10^{-4} V \left(\frac{kgmol}{m^3}\right)$$

O_2 : 3% ⟶ 0.8% in 60 hr.

$$60\,h = \frac{1.6238 \times 10^{-4} V\,(kgmol/m^3)}{9.426 \times 10^{-3}\,(kgmol/h)} \Rightarrow$$

9.426×10^{-3} → O_2 depletion rate.

$$V = 3483\,m^3$$

3) It is desired to cool cabbage from 30 to 5°C in 4 hr. Calculate the heat generation (kJ/kg) during this cooling period. (a = 337 mW/kg, b = 0.041/°C).

Solution:

$$30^\circ C \longrightarrow 5^\circ C \quad (T_1 \to T_2), \quad t = 4\,hr \equiv 14400\,s.$$

$$q = \frac{a \cdot e^{b \cdot T_1}}{\left[\frac{T_1 - T_2}{t}\right] \times b} \times \left[1 - e^{-b(T_1 - T_2)}\right]$$

$$q = \frac{337\,\frac{mW}{kg} \times e^{0.041/^\circ C \times 30^\circ C}}{\left[\frac{(30-5)^\circ C}{14400\,s}\right] \times 0.041/^\circ C} \times \left[1 - e^{-0.041/^\circ C \times (30-5)^\circ C}\right]$$

$$q = \frac{337 \times 10^{-3}\,W/kg \times 3.42}{7.12 \times 10^{-5}/s} \times 0.64 = \frac{0.737\,\frac{J}{s \cdot kg}}{7.12 \times 10^{-5}/s} = 10351\,\frac{J}{kg} = 10.35\,\frac{kJ}{kg}$$

4) A head lettuce of 454 g is packaged in an air tight container. If the product is at a constant temperature of 4°C and RQ is 0.87, then, calculate the amount of oxygen consumed in mol/hr. (a = 26.7 mW/kg, b = 0.088/°C, 1 mg CO_2 produces 10.73 J).

Solution:

$$q = a \cdot e^{bT} = 26.7 \times e^{0.088 \times 4} \simeq 38\,mW/kg = 38 \times 10^{-3}\,\frac{W}{kg} = 38 \times 10^{-3}\,\frac{J}{kg\,lettuce \cdot s}$$

$$\frac{mg\ CO_2\ produced}{h} = 38 \times 10^{-3}\,\frac{J}{kg \cdot s} \times \frac{1\,mg\,CO_2}{10.7\,J} \times \frac{3600\,s}{1\,h} \times 0.454\,kg$$

$$\simeq 5.804\ mg\ CO_2\ produced/h.$$

$$gmol\ CO_2/h = \frac{5.8 \times 10^{-3}\,g}{44\,g/gmol} = 1.318 \times 10^{-4}\ \frac{gmol\ CO_2}{h}\ produced.$$

$$RQ = \frac{\text{mol } CO_2 \text{ produced}}{\text{mol } O_2 \text{ depleted}} = 0{,}87 \ \frac{\text{mol } CO_2}{\text{mol } O_2}$$

$$\text{gmol } O_2 \text{ depleted}/h = 1{,}318\times10^{-4}\ \frac{\text{gmol } CO_2}{h} \times \frac{1 \text{ gmol } O_2 \text{ depleted}}{0{,}87 \text{ gmol } CO_2}$$

$$= 1{,}514\times10^{-4} \text{ gmol } O_2 \text{ depleted}/h$$

5) 2 kg of a respiring food product is stored at a constant temperature. If RQ is 0.9 and 102 mW heat/kg product is generated during storage, calculate the number of moles of CO_2 produced and O_2 consumed/hr. (1 mg CO_2 produces 10.7 J energy, CO_2 = 44 g/gmol, O_2 = 32 g/gmol).

<u>Solution:</u>

$$\frac{\text{gmol } CO_2}{h} = 102\times10^{-3}\ \frac{J}{kg\cdot s} \times 2\,kg \times \frac{1\times10^{-3}\text{ g } CO_2}{10{,}7\ J} \times \frac{1 \text{ gmol } CO_2}{44\text{ g } CO_2} \times \frac{3600\,s}{1h}$$

$$= 1{,}559\times10^{-3} \text{ gmol } CO_2 \text{ produced}/h$$

$$\text{gmol } O_2 \text{ depleted}/h = 1{,}559\times10^{-3}\ \frac{\text{gmol } CO_2}{h} \times \frac{1 \text{ gmol } O_2}{0{,}9 \text{ gmol } CO_2}$$

$$= 1{,}7332\times10^{-3} \text{ gmol } O_2 \text{ depleted}/h.$$

6) a) The data for minimum storage life of well packaged chicken is tabulated as follows:

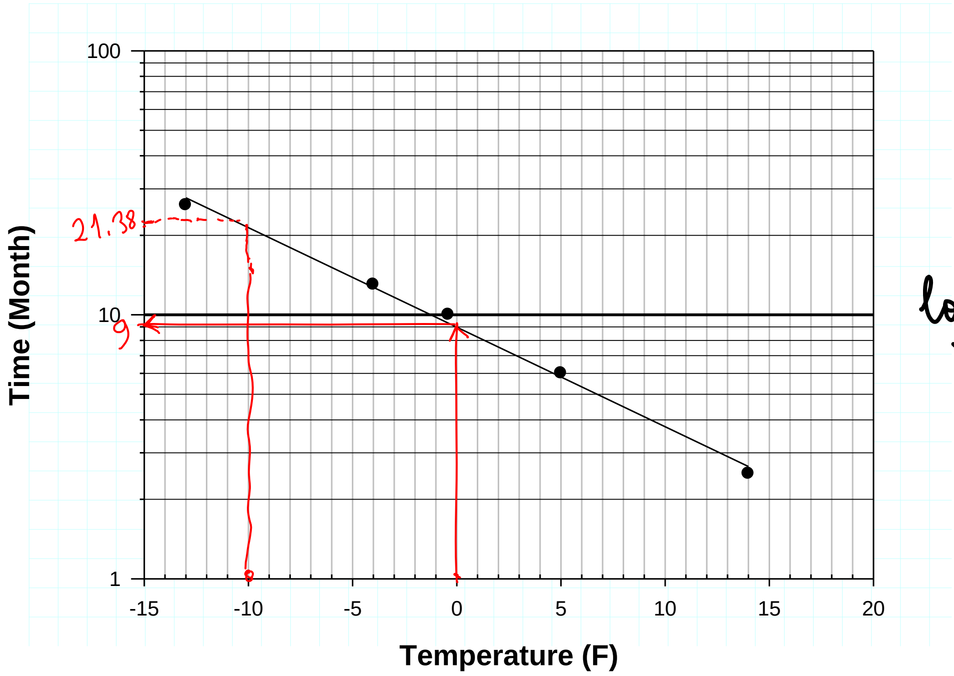
Temperature	°C	-10	-15	-18	-20	-25
	°F	+14	+5	-0.4	-4	-13
Time (month)		2.5	6	10	13	26

What would be the equivalent duration of storage at a steady temperature of 0°F ?

b) The time-temperature history of this well packaged chicken during storage is: Let us suppose that the temperature of packaged product rises linearly with time from an initial -10 to +2°F in 0.5 month, is held at +2°F for 2 months, rises linearly to +14°F in 0.1 month, held at +14°F for 0.1 month, falls linearly to -6°F in 0.3 month, and is held at -6°F for an additional 3 months.

How much longer could the product be held at the final temperature of -6°F before it reached the end of its expected "minimum life" ? Assume the fraction of quality lost is 0.563 during storage.

Solution: a) Draw time vs T on a semi-log paper ⇒



$\log H = 0{,}9531 - 0{,}0377 \times T$

Duration of chicken in the storage at 0°F is about 9 months.

b) Find the storage life of chicken at the temperatures given in time-temperature history by using semi-log paper

T(°F)	H (From Semi-log paper)
−10	21.38
−6	15.11
+2	7.545
+14	2.66

The fraction of quality lost is 0,563.

The quality remaining $= 1 - \int \frac{1}{H} dt$

$= 1 - 0{,}563 = 0{,}437.$

At −6°F storage; $0.437 \times 15.11 \cong 6.6$ months can be held before it reached the end of its expected minimum life.

7) A well packaged food product is stored at fluctuating temperature for 6 months. At the end of the storage period the fraction of high quality lost is 0.60. How much longer could the product be held at the temperature of -15°C before it reached the

end of its expected minimum life ? The data for minimum storage life for the product is;

Temperature (°C)	**-10**	**-15**	**-18**	**-20**	**-25**
Time (month)	**2.5**	**6**	**10**	**13**	**26**

<u>Solution:</u>

$\int \frac{1}{H} \cdot dt = 0.6 =$ quality lost.

Remaining fraction of quality = 1 − 0.6 = 0.40

Normally, at −15°C the life is 6 months (given).

For the remaining fraction; 0.40×6 = 2.4 months can be stored at −15°C.

8) The mathematical expression for storage life of chicken is

Log(H) = 0.9531 – 0.0377xT (From question 6)

where, H is duration of the product in the storage in month, T is the storage temperature in °F.

a) How much longer could the product be held at steady temperatures of -10°F ?

b) The product is exposed to fluctuating temperatures during storage and $\int \left(\frac{1}{H}\right) dt$ is estimated to be 0.4. How much longer could the product be held further at -10°F ?

c) Calculate % change in shelf life (decrease or increase) at this temperature.

Solution:

a) $\log(H) = 0{,}9531 - 0{,}0377 \times T \Rightarrow$

The life at $-10°F$; $\log(H) = 0{,}9531 - 0{,}0377 \times (-10) \Rightarrow$

$H = 21{,}38$ months

b) $\int \frac{1}{H} \cdot dt = 0{,}4 \rightsquigarrow$ quality lost.

Remaining quality fraction $= 1 - 0{,}40 = 0{,}60$

At $-10°F \Rightarrow H = 0{,}6 \times 21{,}38 = 12.83$ months

c) change in shelf life $= 21{,}38 - 12{,}83$

$= 8{,}55$ months decrease at $-10°F$.

% change (decrease) $= \frac{8{,}55}{21.38} \times 100 \cong 40\%$

9) Homework: In a cold storage room which is 18 m long, 9 m in width and 4 m in height. 100 tons of apples are stored at 7°C for 4 months. Due to the respiration of apple, 0.113 m^3/(ton.day) CO_2 is produced. 21-10 % volume of CO_2 is thought to be maintained in this cold storage. When the amount of CO_2 is increased to 21 % volme, the air starts to recirculation from cold storage through active carbon until the amount of CO_2 is reduced to 10 % volume. The absorptivity of CO_2 is 11.36 gmoleCO_2/kg active carbon. According to the data given above, if the product occupies 148 m^3 of the storage,

a) how many times should you recirculate the air through absorption unit ?

b) how many kg of active carbon and oxygen are required fort his purpose for each time ? (R = 0.08206 L.mol/(gmol.K)

<u>Solution:</u>

10) a) Cauliflower produces 36 mgCO_2/(kg.h) at 10°C. If the Q_{10} value is 2.4, what would be the respiration rate [mgCO_2/(kg.h)] at 20°C ?

b) In order to reduce the respiration rate to 60 mg CO_2/(kg.h), to which temperature should we cool the cauliflower ? Use the same Q_{10} value.

<u>Solution:</u> a) $Q_{10} = 2.4$ (Given)

$$Q_{10} = \frac{\text{Resp. Rate at } 20°C}{\text{Resp. Rate at } 10°C} \Rightarrow 2.4 = \frac{\text{mg } CO_2 \text{ produced/kg.h}}{36}$$

$$\Rightarrow \text{mg } CO_2 \text{ produced}/(\text{kg.h}) = 86.4$$

b) $Q_{10} = 2.4$ (given)

$$Q_{10} = \left(R_2/R_1\right)^{[10/(T_2-T_1)]} \Rightarrow 2.4 = \left(\frac{86.4}{60}\right)^{\left(\frac{10}{20-T}\right)} \Rightarrow$$

Take log of both sides $\Rightarrow 0{,}38 = \left(\frac{10}{20-T}\right) \times \log\left(\frac{86.4}{60}\right)$

$\Rightarrow T = 15{,}84\,^{\circ}C$

<u>Homework:</u> Use the same data given in Q1. If RQ is 0.80 now, calculate how long it will take for oxygen content in the package to drop to 2.5 % of air.