Chapter 14  
Pasteurization and Sterilization

Review Questions

Which of the following statements are true and which are false?

1. The decimal reduction time $D$ is the heating time in min at a certain temperature required for the number of viable microbes to be reduced to 10% of the original number.
2. The z value is the temperature increase required for a ten-fold decrease in $D$.
3. Thermal death time is the heating time required to give commercial sterility.
4. Thermal death time does not depend on the initial microbial load.
5. The D value does not depend on the initial microbial load.
6. The D value of a microorganism is independent of the food item.
7. The D value of a microbe is a measure of the thermal resistance of the microbe.
8. If the number of microbes in a process has to be reduced from an initial load of $10^6$ to a final $10^{-4}$, the required thermal death time will be $10D$.
9. If the number of microbes in a canned product is reduced from $10^3$ to $10^{-4}$, it means that 1 can in 100000 may be spoiled.
10. As the process temperature increases, the thermal death time increases.
11. A 10D process is usually applied as a minimum heat treatment for Clostridium botulinum.
12. Typical z values are 5.5 °C for vegetative cells, 10 °C for spores, and 22 °C for nutrients.
13. A $D_{121.1} = 0.21$ min is usually assumed for Clostridium botulinum.
14. The accepted risk for Clostridium botulinum is $10^{-12}$.
15. The accepted spoilage probability for mesophilic spoilage microorganisms is usually $10^{-5}$.
16. The accepted spoilage probability for thermophilic spoilage microorganisms upon incubation after processing is usually $10^{-2}$.
17. The slowest heating point of a can filled with a liquid food is the geometric center of the can.
18. The worst case scenario for calculating the lethal effect in a holding tube for a Newtonian liquid is to assume that the residence time is half the mean residence time.

19. In calculating the lethal effect in a solid particulate flowing in a two-phase flow in a holding tube, the convective heat transfer resistance at the surface of the particulate can be neglected.

20. The Ball Formula method is an alternative method to the general method for calculating the lethal effect of a sterilization process.

21. For the purpose of thermal processing, foods are divided into low acid foods (pH > 4.5) and high acid foods (pH < 4.5).

22. High acid foods need more heat treatment than low acid foods.

23. Clostridium botulinum is of concern in high acid foods.

24. Spoilage microorganisms is the major concern in low acid foods.

25. Thermal treatment of high acid foods is usually carried out at temperatures ≤100 °C.

Examples

Example 14.1

The decimal reduction time $D$ at 121 °C ($D_{121}$) and the value $z$ for a thermophilic spore in whole milk were determined experimentally to be equal to 30 s and 10.5 °C respectively. Calculate the $D$ value at 150 °C ($D_{150}$).

Solution

Step 1
The effect of temperature on $D$ is given by:

$$D_{T_1} = D_{T_2} 10^{\frac{T_2 - T_1}{z}}$$

(14.1)

Step 2
Substitute values in eqn (14.1) and calculate $D_{150}$:

$$D_{150} = 0.5 \times 10^{\frac{121-150}{10.5}} = 0.000865 \text{ min}$$

Example 14.2

Determine the required heating time at 121 °C, $F_{121}$ value, in the case of Example 14.1 for a 9 log cycles population reduction.
Solution

Step 1
The required F value at temperature T for a certain population reduction is given by:

\[ F_T = D_T \log \frac{N_0}{N} \]  

(14.2)
e.g., for 12 log cycles population reduction, \( F = 12D \).
Equation (14.2) can be used to convert log cycles of reduction into \( F_T \) (min at T) if \( D_T \) is known.

Step 2
Substitute values in eqn (14.2) and find \( F_{121} \):

\[ F_{121} = D_{121} \log \frac{N_0}{N} = 0.5 \times 9 = 4.5 \text{ min} \]

Thus the sterilizing value or the lethality for this process is \( F = 4.5 \) min.

Example 14.3

Find two equivalent processes, at 100 °C and 150 °C, which will deliver the same lethality as the required \( F_{121} \) value of 4.5 min calculated in the previous example.

Solution

Step 1
State your assumptions: All thermal treatment is delivered at a constant temperature of 100 °C or 150 °C.

Step 2
The delivered F value by a process at temperature T equivalent to a reference process \( F_R \) at \( T_R \) is given by:

\[ F_T = F_R \times 10^{\frac{T_R - T}{z}} \]  

(14.3)

Step 3
Substitute values in eqn (14.3) and find \( F_T \):

\[ F_{100} = F_{121} \times 10^{\frac{121 - 100}{10.5}} = 4.5 \times 10^{\frac{121 - 100}{10.5}} = 450 \text{ min} \]

\[ F_{150} = F_{121} \times 10^{\frac{121 - 150}{10.5}} = 4.5 \times 10^{\frac{121 - 150}{10.5}} = 0.0078 \text{ min} \]
Example 14.4

The activation energy for vitamin C thermal destruction for 11.2°C Brix grapefruit juice was calculated to be equal to 4.98 kcal/mol (Ref. 12), based on k values between 61°C and 96°C. Calculate the z value for vitamin C thermal destruction in grapefruit juice.

Solution

The relationship between \( E_a \) and \( z \) is:

\[
z = \frac{2.303 RT^2}{E_a}
\]

or as suggested in (Ref. 13):

\[
z = \frac{2.303 RT_{\text{min}} T_{\text{max}}}{E_a}
\]

Substitute values and calculate \( z \):

\[
z = \frac{2.303 RT_{\text{min}} T_{\text{max}}}{E_a} = \frac{2.303(1.9872 \text{ cal/mol K}) (273 + 61)K (273 + 96)K}{4980 \text{ cal/mol}} = 113.3 \text{ K or °C}
\]

Example 14.5

Calculate the \( F_o \) value for sterilization of cream in a can with the following time-temperature history

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
</tr>
<tr>
<td>5</td>
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<td>19</td>
<td>60</td>
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<td>20</td>
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</table>
Solution

Step 1
Since the $F_0$ value is sought, 121.1 °C and 10 °C will be used as reference temperature and z value respectively. The equivalent time at 121.1 °C of the process will be calculated using the General method with numerical integration:

$$F_0 = \int_0^t 10^{\frac{t-121.1}{10}} \Delta t \approx \sum_0^t 10^{\frac{t-121.1}{10}} \Delta t$$ (14.4)

Step 2
Use the spreadsheet program General method.xls. Insert the data and read the result of the numerical integration of eqn (14.4). Observe the contribution of the heating phase and the cooling phase on $F_0$.

Exercises

Exercise 14.1

The reaction velocity constant $k$ for vitamin C destruction at 121 °C was found equal to 0.00143 min$^{-1}$. Express it in terms of decimal reduction time.

Solution

Step 1
The relationship between $k$ and $D$ is:

$$D_{121} = \frac{2.303}{k}$$

Step 2
Substitute $k$ and calculate $D$:

$$D_{121} = \ldots$$

Exercise 14.2

The reaction velocity constant $k$ for vitamin C thermal destruction for 11.2 °C.Brix grapefruit juice at 95 °C is 0.002503 min$^{-1}$ (Ref. 12). Calculate the time at this temperature for 10% destruction of vitamin C.

Solution

Step 1
Calculate $D$ from $k$:

$$D_{95} = \ldots$$
Step 2
Calculate the required time from an equation analogous to eqn (14.2) of Example 14.2 above.

\[ t = D_{95}\log\frac{C_o}{C} \]

Exercise 14.3

The following time-temperature history was recorded during pasteurization of grapefruit juice. Calculate the thermal destruction of vitamin C due to pasteurization.

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Temperature (°C)</th>
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</thead>
<tbody>
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</table>

Solution

Step 1
Find the equivalent time of the process at 95 °C using the General method with numerical integration as in step 1 of Example 14.5. Use the \(z\) value found in Example 14.4. Use the spreadsheet program General method.xls. Insert the data and read the result.

Step 2
Use the \(D_{95}\) value found in Exercise 14.2 and calculate \(C/C_o\) from a relationship analogous to eqn (14.2) of Example 14.2.

\[ \frac{C}{C_o} = \] 

Exercise 14.4

Experimental data from various sources presented in Ref. 12 indicate that the energy of activation for thermal destruction of vitamin \(B_1\) in certain vegetables
and meat is in the range of 26–28 kcal/mol based on k values between 70.5 °C and 149 °C with $k_{100} = 0.0063 \text{ min}^{-1}$. Calculate the loss of vitamin B$_1$ due to thermal destruction in the case of cooking the meat for 90 min at 100 °C or alternatively for 30 min in a pressure cooker at 115 °C.

**Solution**

Step 1
Calculate the z value and $D_{109}$ value:

$$z = \text{..........................................................}$$

$$D_{109} = \text{..........................................................}$$

Step 2
Calculate the $D_{100}$ and $D_{115}$ values:

$$D_{100} = \text{..........................................................}$$

$$D_{115} = \text{..........................................................}$$

Step 3
Calculate the vitamin loss at 100 °C and 115 °C:

$$\left( \frac{C}{C_0} \right)_{100\degree C} = \text{..........................................................}$$

$$\left( \frac{C}{C_0} \right)_{115\degree C} = \text{..........................................................}$$

**Exercise 14.5**

For an initial spore load equal to 20 spores per can and a food spoilage microorganism with $D_{121} = 1 \text{ min}$, calculate the spoilage probability if an F equivalent to $F_{121} = 6 \text{ min}$ was applied.

**Solution**

Calculate N from eqn (14.2):

$$N = \text{..........................................................}$$

Therefore, the spoilage probability is:

..........................................................................................................................

or 1 can in ......................... cans.
A low acid solid food product was sterilized in a can with 76 mm diameter and 112 mm height. The autoclave temperature varied with time as given in the table below. An $F_o = 3$ min has been established in the laboratory as a minimum process sterilizing value for the slowest heating point of the can in order for this product to be safe. Determine if the applied thermal treatment is adequate to deliver an equivalent lethality of $F_o = 3$ min. It is given that the thermal diffusivity and the initial temperature of the product are $1.3 \times 10^{-7}$ m$^2$/s and 30 °C respectively. If this thermal treatment is not enough, decide when the cooling period should start so that the lethality achieved is at least 3 min. Study the effect of steam temperature and cooling water temperature on the $F$ value.

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<thead>
<tr>
<th>Time (min)</th>
<th>Temperature (°C)</th>
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Solution

Step 1
State your assumptions:

Step 2
The temperature in the center of the can vs. time will be calculated using the partial differential equation for a finite cylinder, eqn (14.5). The explicit finite differences method will be used for the solution of eqn (14.5) since there is not an analytical solution for the conditions applied:

$$\frac{\partial T}{\partial r} = \alpha \left( \frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial y^2} \right)$$ (14.5)

If the temperature in the center is known, the lethality of the process for the time-temperature history of the geometric center of the can (the slowest heating point) can be calculated with eqn (14.6):

$$F = \int_0^t 10^\frac{T-T_R}{z} \, dt \approx \sum_{0}^{t} 10^\frac{T-T_R}{z} \Delta t$$ (14.6)

The values $T_R = 121.1 \, ^\circ C$ and $z = 10 \, ^\circ C$ will be used, since the $F_o$ value is given.

Step 3
The solution outlined in step 2 is shown in the spreadsheet program *Can sterilization.xls*. To solve the problem, read the instructions, insert the input data, and iterate until a constant $F$ value is reached. Observe in the plot that the maximum temperature at the center is reached after the onset of the cooling period. Explain this.

Step 4
If the $F$ calculated is lower than 3 min ($F_o$ given), increase the value of t for the “Onset of cooling period” to delay the beginning of cooling. This change will increase the heating period. Rerun the program (turn the SWITCH OFF, change the value of t, turn the SWITCH ON and iterate). Repeat step 3 until $F \geq 3$ min. Observe the sensitivity of $F$ to $t$.

Step 5
Use the initial time for the “onset of cooling period” ($t = 40$ min). Change the steam temperature and rerun the program until $F \geq 3$ min. Observe the sensitivity of $F$ to the steam temperature. Observe that low temperatures contribute little to sterilization (observe the minimum temperature at the center which gives an appreciable change in $F$).
Step 6
Use the initial values for the steam temperature and the time for the onset of cooling. Change the cooling water temperature and rerun the program until $F \geq 3$ min. Observe the sensitivity of $F$ to the cooling water temperature. What problem might arise if the cooling water temperature is too low?

**Exercise 14.7**

Use your own time-temperature data for the autoclave and re-solve the previous problem.

*Solution*

Insert a sheet in the spreadsheet *Can sterilization.xls* (On the **Insert menu** select **Sheet**).
Write your own time-temperature values in the new sheet.
Change cell H10 accordingly to read the new data.
Run the program.

**Exercise 14.8**

For the destruction of microorganisms in whole milk that will be used as a substrate for yoghurt starter manufacture in a dairy, the milk is heated to 95 °C in an agitated jacketed tank, held at this temperature for 15 min, and then cooled to 45 °C before inoculation. If the mass of milk is 1000 kg, the heat transfer area in the jacket is 4 m$^2$, the overall heat transfer coefficient between heating medium and milk is 300 W/m$^2$°C, the heat capacity of milk is 3.9 kJ/kg°C, and the heating medium temperature is 130 °C, calculate the number of log cycles reduction of a mesophilic microorganism with $D_{121} = 1$ min and of a thermophilic microorganism with $D_{121} = 6$ min. Assume that $z$ is 10 °C for both microorganisms and neglect the lethal effect of the cooling period.

*Solution*

Step 1
Calculate the change of temperature of the milk with time during heating (remember that heating of an agitated liquid can be treated as heating of a body with negligible internal resistance).

Step 2
Insert the data in the spreadsheet *General method.xls*. Run the program and calculate $F$.

Step 3
Convert $F$ to log cycles reduction using $D$. 
Exercise 14.9

Assume that the acceptable level of spoilage risk for a canned food is 1 can in 100000 (spoilage probability of \(10^{-5}\)). Calculate the required F value if the initial microbiological load is 50 spores per can with \(D_{121} = 1\) min.

Exercise 14.10

Beer is pasteurized at 71 °C for 15 s or 74 °C for 10 s. Calculate z.

Exercise 14.11

The minimum pasteurization requirement in the USA for liquid eggs according to Ref. 14 is 60 °C for 3.5 min, while in Great Britain it is 64.4 °C for 2.5 min. Assuming that these treatments are equivalent, calculate the required time for an equivalent treatment in Denmark, where the pasteurization temperature could be up to 69 °C.