Thermal Processing

Advanced Food Process Engineering

(PFE-503)

Lecture 2

Heat Transfer Considerations in Thermal Processing

- Typical processing time
- Sterilization of solid food (0.5 kg in a retort at 120°C for excess of one hour) - Net heating time for few minutes only to achieve the desired thermal death of the target microorganism .
- The long duration of the process is due to the slowness of **heat transfer (heat penetration)** to the **coldest point** of the can. It can be stated that in thermal process design, the rate of heat transfer rather than the thermal resistance of the microorganism often determines the duration of the process.

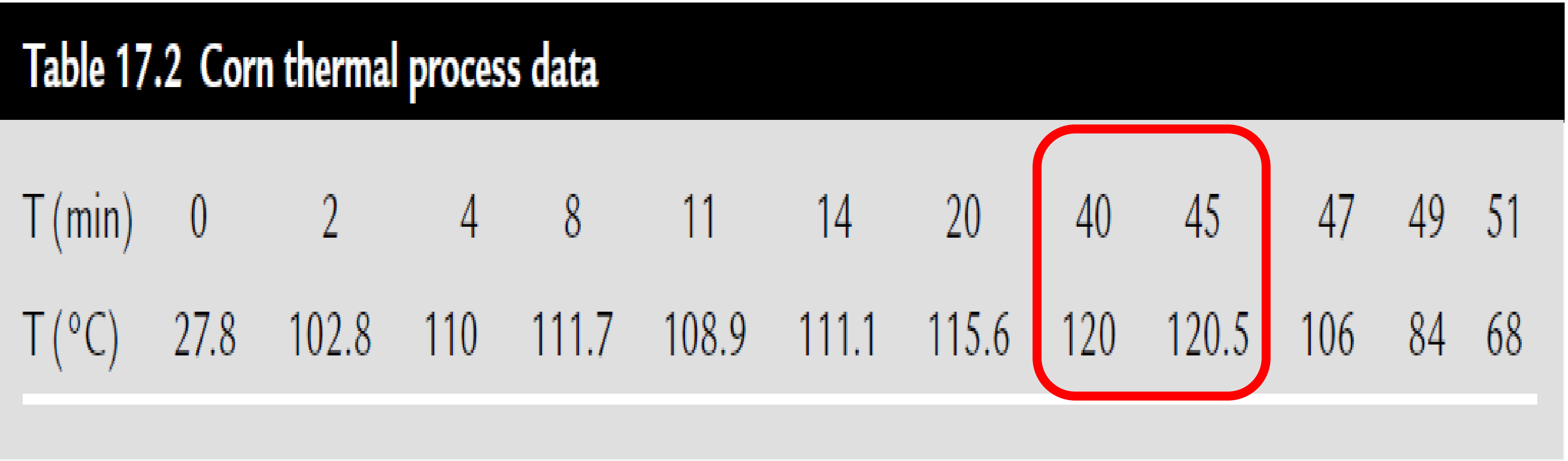


Table 17.2 Corn thermal process data

T (min)	0	2	4	8	11	14	20	40	45	47	49	51
T (°C)	27.8	102.8	110	111.7	108.9	111.1	115.6	120	120.5	106	84	68

1. **The heating medium**

- ***Saturated steam –*** *(high heat transfer coefficient, control of temperature through pressure, high heat content) – Not good for heat sensitive foods*
- ***Hot water –*** *less heat transfer, Good for heat sensitive foods*
- ***Steam–air mixture –*** *Common (Medium heat transfer)*
- ***Hot gas (combustion gases) –*** *Not preferred*

2. The packages

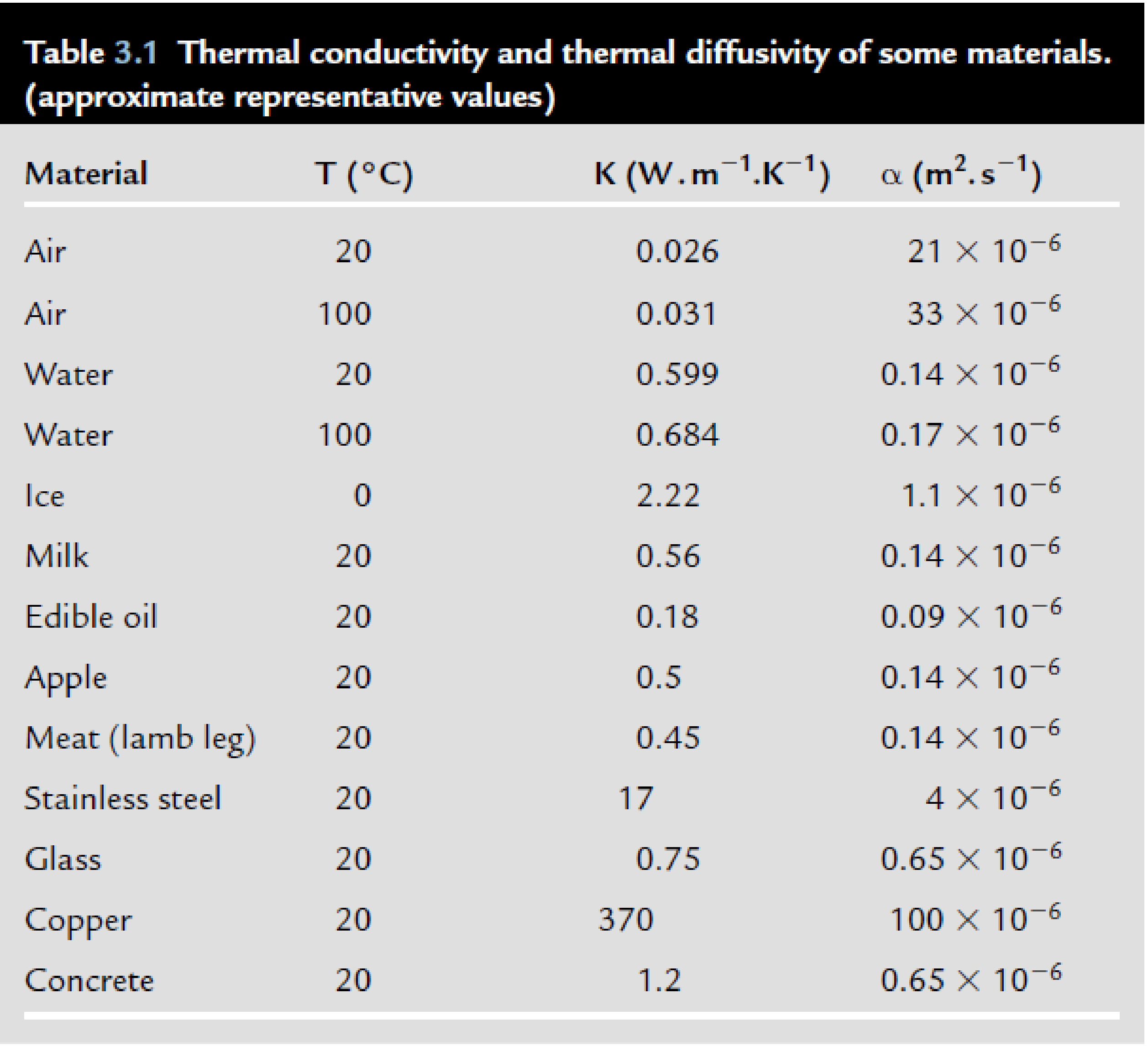


Table 3.1 Thermal conductivity and thermal diffusivity of some materials. (approximate representative values)

Material	T (°C)	K ($W.m^{-1}.K^{-1}$)	α ($m^2.s^{-1}$)
Air	20	0.026	21×10^{-6}
Air	100	0.031	33×10^{-6}
Water	20	0.599	0.14×10^{-6}
Water	100	0.684	0.17×10^{-6}
Ice	0	2.22	1.1×10^{-6}
Milk	20	0.56	0.14×10^{-6}
Edible oil	20	0.18	0.09×10^{-6}
Apple	20	0.5	0.14×10^{-6}
Meat (lamb leg)	20	0.45	0.14×10^{-6}
Stainless steel	20	17	4×10^{-6}
Glass	20	0.75	0.65×10^{-6}
Copper	20	370	100×10^{-6}
Concrete	20	1.2	0.65×10^{-6}

- High thermal conductivity – tin, aluminum

- Low thermal conductivity - glass

3. Internal heat transfer

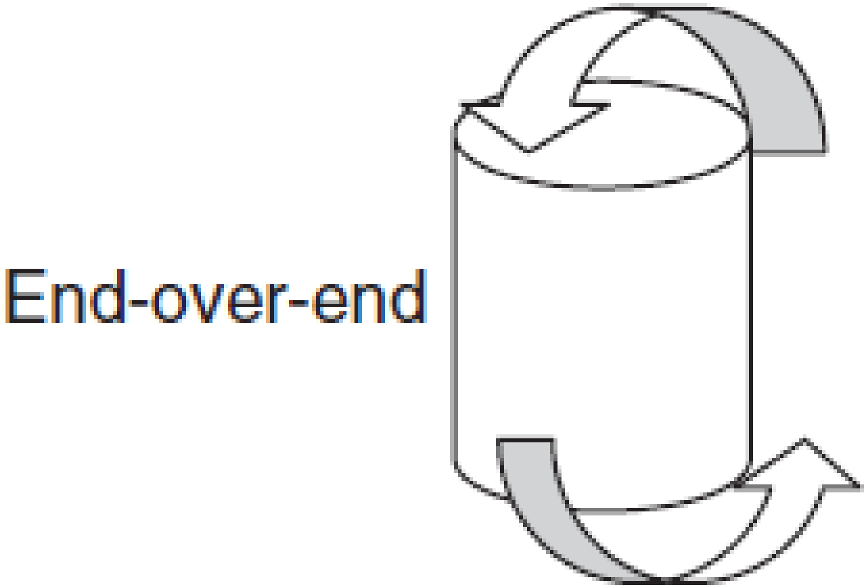
- Heat transfer through the product may be by convection, by conduction or both.
  - In solid foods – conduction predominates
  - In liquid food – convection predominates

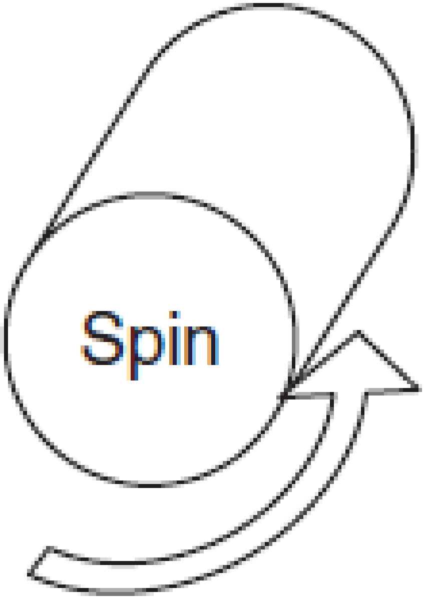
S. No.	Mode	Coldest point
1.	Conductive	Geometric center
2.	Convective transfer without agitation in a vertical can	One-third the height from the bottom
3.	large solid particles in a low viscosity liquid medium	At the center of the solid particles.

Agitation for effective Internal heat transfer

1. End-over-end agitation

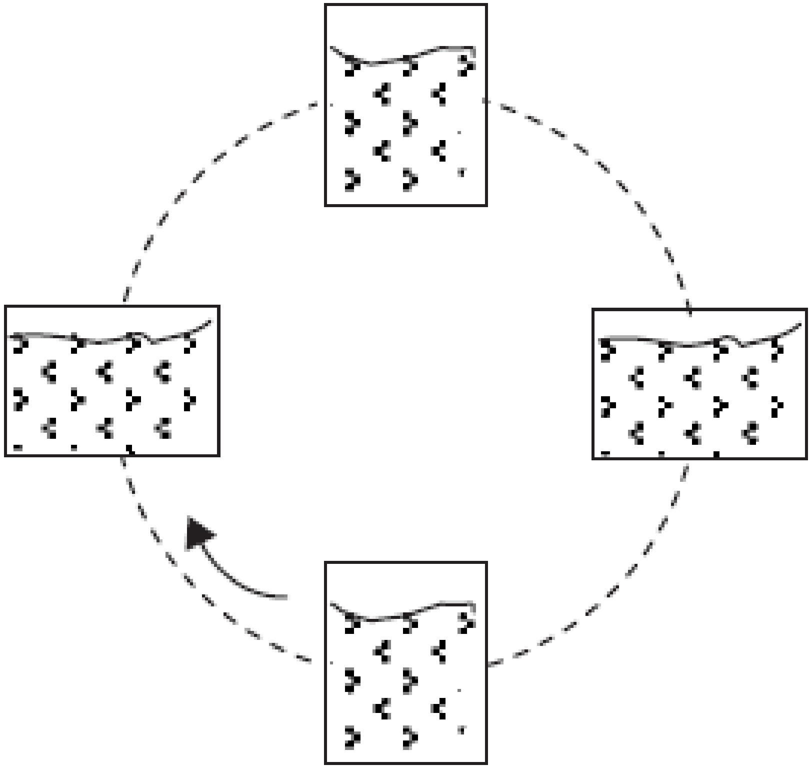
2. Spin agitation



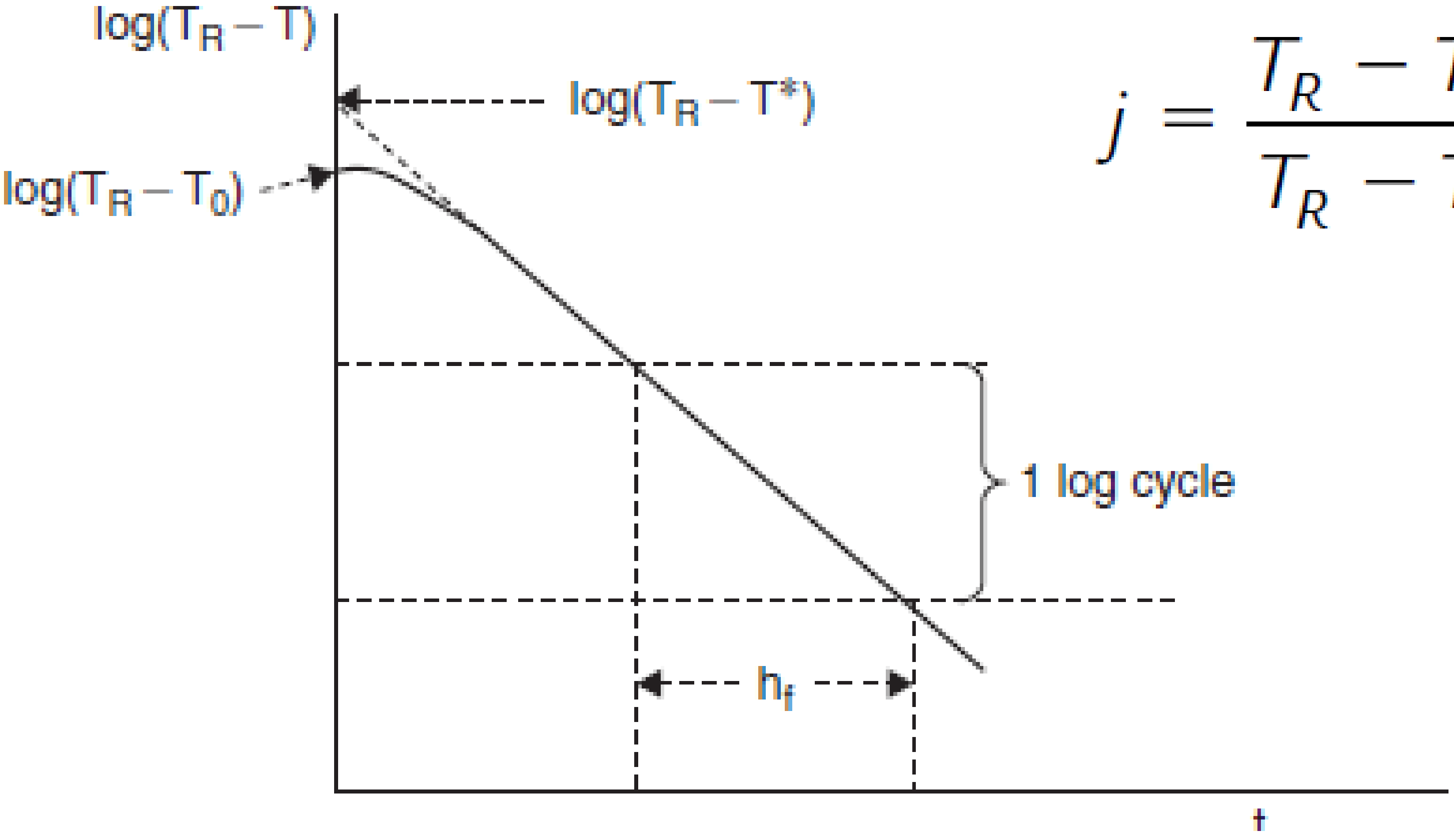


Agitation for effective Internal heat transfer

- *End-over-end method – Optimal speed*



Heating lag factor



$$j = \frac{T_R - T^*}{T_R - T_0}$$

The temperature of every particle = T; Temperature of the heating medium = T_R ; The imaginary initial temperature = T *, The initial temperature = T_0

EXAMPLE 17.6

The temperature at the center of cans of corn in water was measured in the course of still retorting. The readings are shown in Table 17.2. The retort temperature was constant at 121°C. The first measurement was taken when the temperature of the retort stabilized. The steam was cut-off at 45 min and the cooling water valve was open at 47 min.

a. Calculate the F_0 of the process.
b. At what moment should the heating be stopped in order to have $F_0 = 8$ min?
c. From the data, plot the heat penetration curve ($\log(T_R - T)$ versus t). Assuming that you believe the data, how would you explain the deviation from the theoretical straight line?

Table 17.2 Corn thermal process data

T (min)	0	2	4	8	11	14	20	40	45	47	49	51
T (°C)	27.8	102.8	110	111.7	108.9	111.1	115.6	120	120.5	106	84	68

Solution:

a. The F_0 of the process is given by Eq. (17.11):

$$F_0 = \int_0^t 10^{\frac{T-121}{10}} dt$$

Since the time-temperature history of the food is not given in analytical form, the integral will be calculated empirically. Equation (17.10) is written as follows:

$$F_0 = \sum_0^t 10^{\frac{T-121}{10}} \Delta t$$

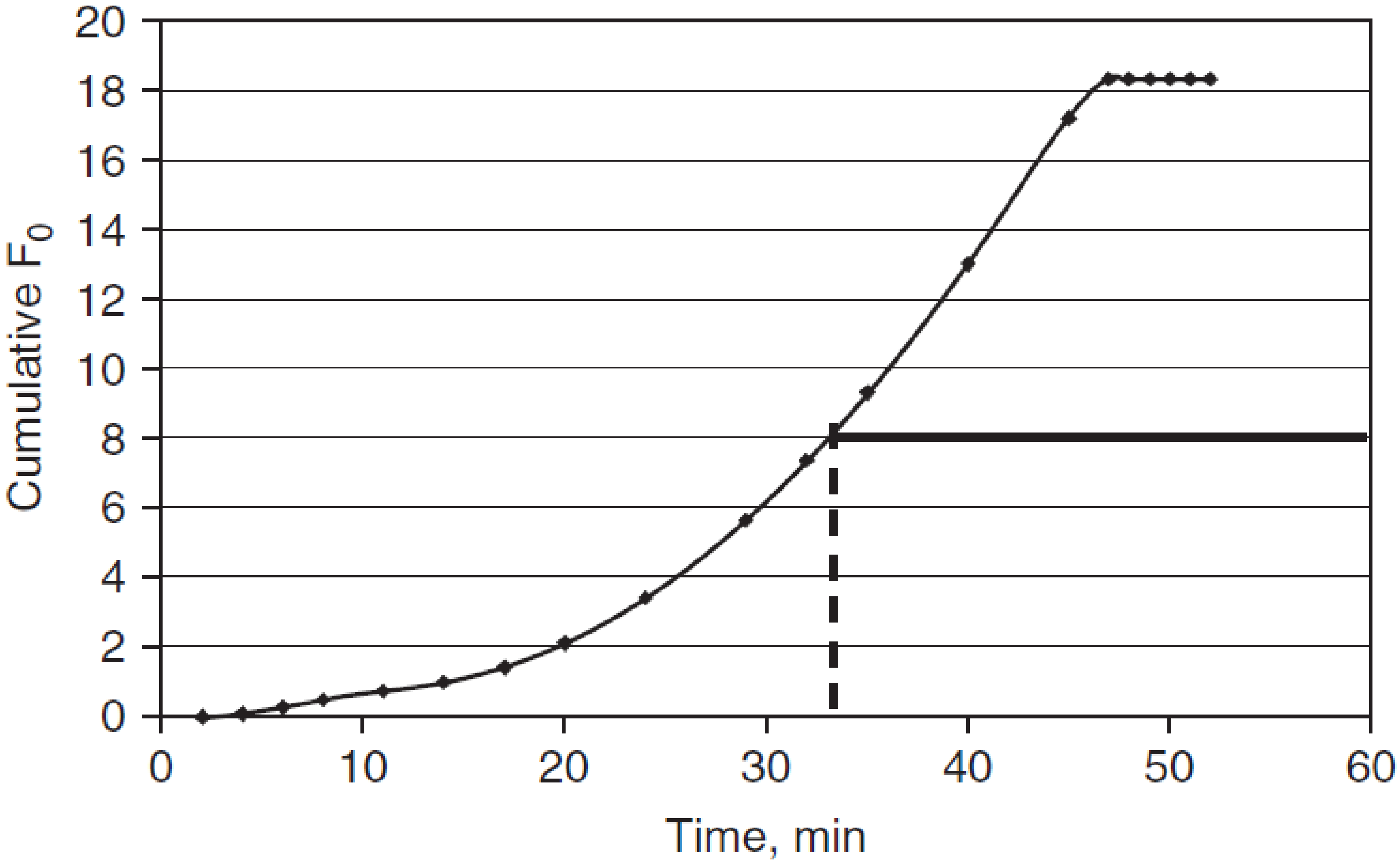
Table 17.2 is expanded as follows:

- The time is divided to intervals. For each interval, the average (mid-point) temperature T is calculated.
- For each time interval Δt, the expression $10^{\frac{T-121}{10}} \Delta t$ is calculated. This is the contribution of the given interval to the F_0 of the process.
- The F_0 of the entire process is the sum of the contributions.

Figure 17.7 is a plot of the lethality F_0 versus t.
The result is: $F_0 = 17.3$ min.

b. The required process time for $F_0 = 8$ min:
The contribution of the cooling period to the total F_0 is 0.43 min. Therefore the steam should be cut-off when the $F_0 = 8 - 0.43 = 7.57$ min. Going back to Table 17.2, we find that this occurs at t = 32 min. The steam should be cut-off at t = 32 min.

c. Figure 17.8 is a plot of $\log(T_R - T)$ versus t. The plot is far from linear and can be represented, at best, as two straight lines with widely different slopes.


20
18
16
14
12
10
8
6
4
2
0
Cumulative F_0
0
10
20
30
40
50
60
Time, min

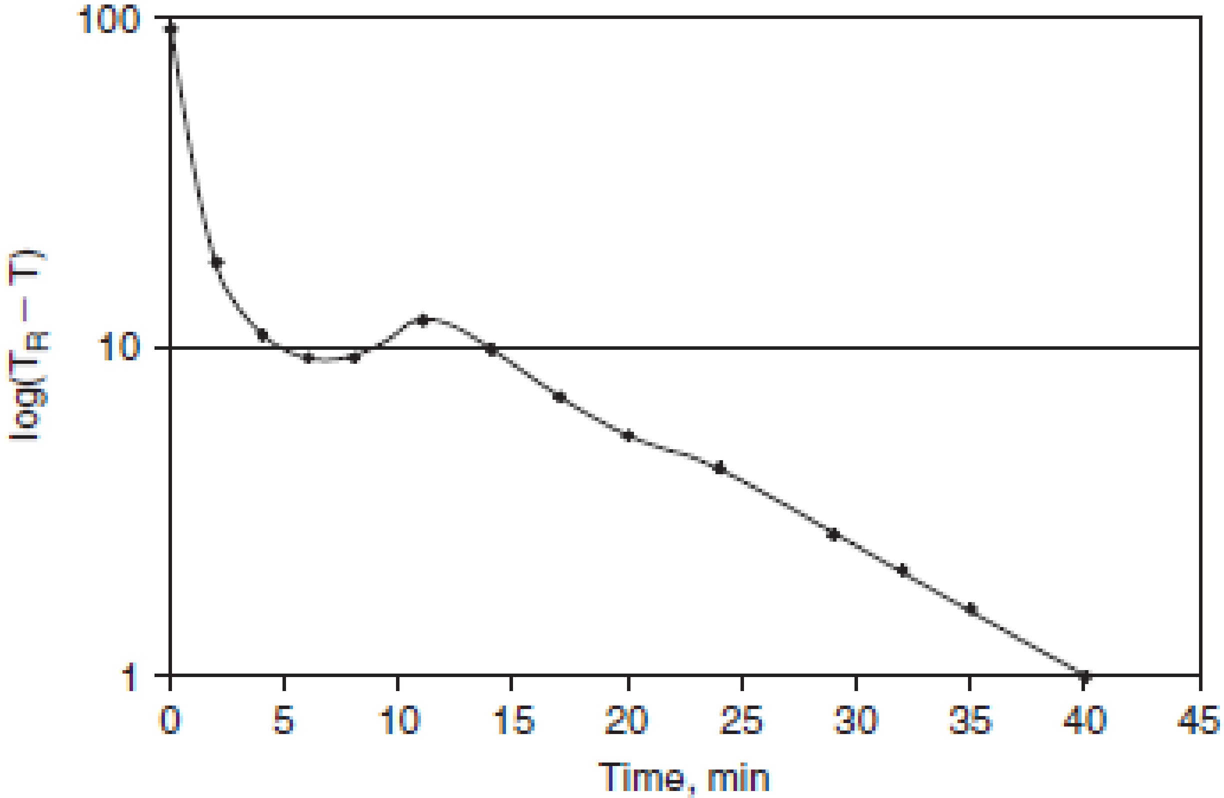
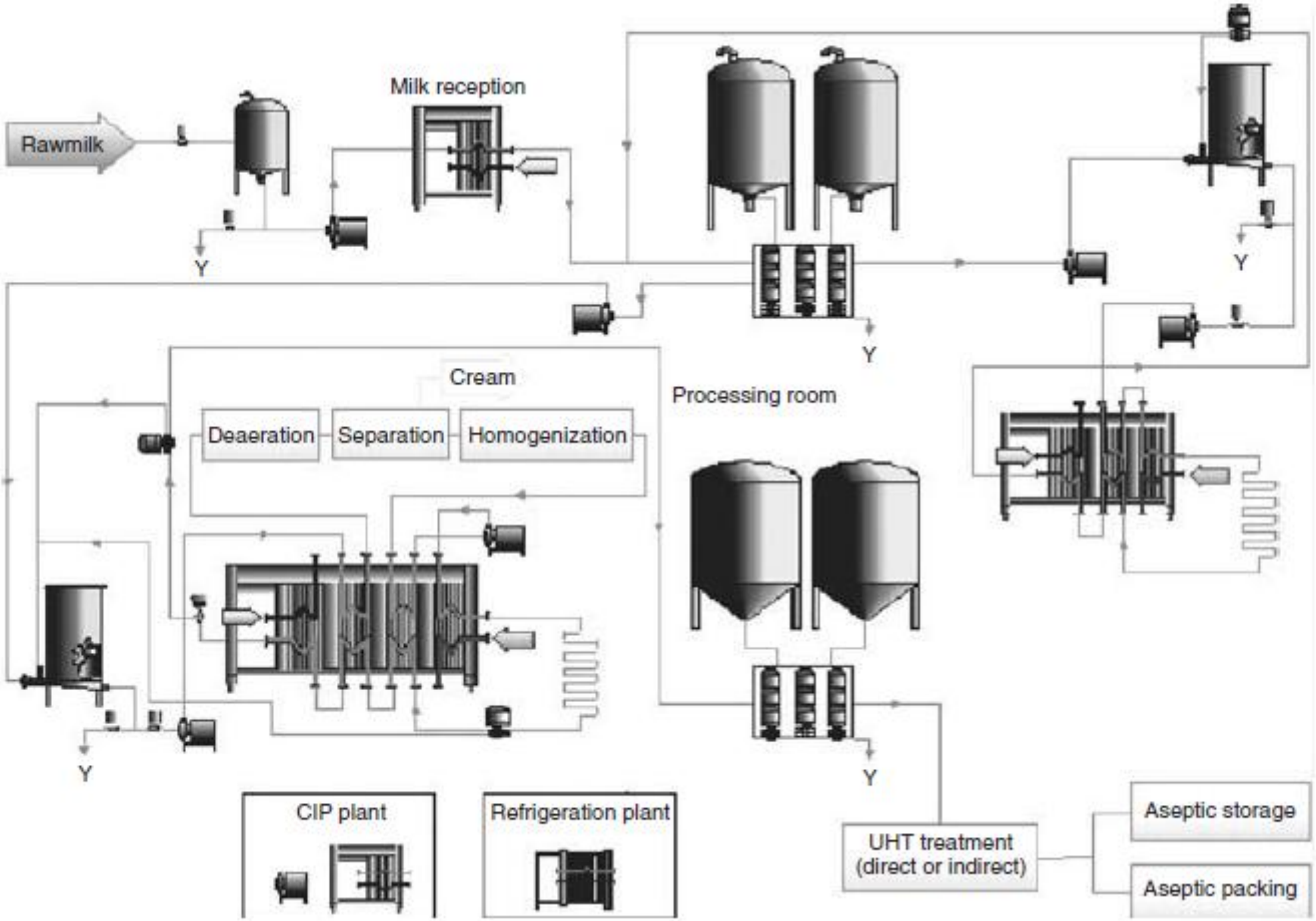


Figure 17.8 Heat penetration curve from data

This behavior may be due to the existence of two mechanisms of heat transfer (convection + conduction) and to internal changes in the properties of the contents (e.g. swelling and gelatinization of the free starch).

In-flow thermal processing



Heat exchangers are extensively used for the pasteurization or sterilization of pumpable products. Let us calculate the time–temperature relationship in a pumpable food product, passing through a tubular heat exchanger at a mass flow rate G (Figure 17.9).

The heat balance as the food passes over an element dA of heat transfer area gives:

$$U\frac{dA}{dt}(T_R - T) = GC_p\frac{dT}{dt} \tag{7.13}$$

where:

U = overall coefficient of heat transfer
T_R = temperature of the heating medium
dA/dt is related to the mass flow rate as follows:

$$\frac{dA}{dt} = \frac{4G}{D\rho} \tag{7.14}$$

Substitution gives:

$$\left(\frac{4U}{C_pD\rho}\right)(T_R - T) = \frac{dT}{dt} \tag{7.15}$$

Integration gives:

$$\ln\frac{T_R - T}{T_R - T_0} = -\left(\frac{4U}{C_pD\,\rho}\right)t \tag{7.16}$$

In-flow thermal processing

- Time–temperature relationship is log-linear, just as in the case of in-package heat penetration.
- It should be noted that T is the average temperature of the product.
- The actual temperature distribution depends on the degree of turbulence and on the physical structure of the product, as in the case of products consisting of solid particles in a liquid medium.
- In continuous in-flow heating, the temperature of the product usually rises **very rapidly** and **residence time** at the lethal temperature range is too short for complete sterilization or pasteurization

In-flow thermal processing

- It is therefore necessary to hold the heated product at high temperature for the required length of time, with no further heat transfer. This is usually done by installing a ***holding tube*** or a ***holding vessel of appropriate dimensions*** *after the heating section of the heat* exchanger.
- **Other option:** In-flow thermal processing is ohmic heating

Ohmic heating

- Ohmic heating is rapid, practically instantaneous and does not require heat transfer surfaces. There are no temperature gradients and there is no fouling.
- Theoretically, these features would make ohmic heating the preferred method of in-flow thermal processing, particularly for fluids containing solid particles.
- However, ohmic heating at its present state does not provide the uniformity and reliability required for thermal processing of low-acid foods. In addition, even though heating is rapid, cooling still depends on heat transfer through surfaces.
- For all these reasons, the application of ohmic heating is limited at present to the pasteurization of fruit juices and possibly liquid egg.

EXAMPLE 17.7

A food liquid is given a thermal treatment consisting of three consecutive stages:

a. Heating in a heat exchanger. The temperature increases linearly from 30 to 120°C in 90 seconds.
b. Holding at 120°C for 70 seconds.
c. Cooling in a heat exchanger. The temperature drops linearly from 120 to 10°C in 90 seconds.

Calculate the F_0 of each stage and of the entire process.

EXAMPLE 17.8

A liquid food is continuously heated in a heat exchanger from 70 to 130°C in 60 seconds. It is assumed that the temperature increase is linear with time. The purpose of the process is to inactivate a certain target microorganism. If the food contained originally 10^5 living cells of the target microorganism per gram, what will be the number of surviving cells per gram at the end of the process?

Data:

The heating time at a constant temperature of 110°C for a 12 log reduction of the target microorganism is 21 minutes. The z value is 9°C.

EXAMPLE 17.9

A dairy desert is rapidly heated to 121°C in a heat exchanger and then pumped into an insulated holding tube, 0.1 m in diameter and 10 m long. What is the maximum volumetric flow rate if the F_0 value of the holding must be 3 minutes at least? Assume perfect insulation.

Note: Considering the high viscosity of the product, it will be assumed that the flow regime will be laminar.