# Refrigeration and Air conditioning Engineering.

# 3rd year – refrigeration and Air conditioning Course

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# FROZEN-FOOD PROPERTIES
# &
# Freezing Time of Food

## Lecture -14 -

**M.Sc. Zahraa F. Hussain**

# 6-1 INTRODUCTION:

## Traditional methods in food preservation

- Drying
- Salting
- Sugar and brine solution
- Cooling and freezing

- The freezing process has a dramatic influence on the thermal properties of the food product.
- Because of the significant amount of water in most foods
- and the influence of phase change on properties of water,
- the properties of the food product change in a proportional manner.

- **As the water within the product changes from liquid to solid, the**
- **density**
- **thermal conductivity**
- **heat content (enthalpy)**
- **and apparent specific heat of the product**

**change gradually as the temperature decreases below the initial freezing point for water in the food.**

## Table (6-1) Unfrozen Composition Data, Initial Freezing Point and Specific Heats of Foods

| Food Item | Moisture Content, % $x_{wo}$ | Protein, % $x_p$ | Fat, % $x_f$ | Carbohydrate, % $x_c$ | Fiber, % $x_{fb}$ | Ash, % $x_a$ | Initial Freezing Point, °C | Specific Heat Above Freezing, kJ/(kg·K) | Specific Heat Below Freezing kJ/(kg·K) |
|---|---|---|---|---|---|---|---|---|---|
| Blackberries | 85.6 | 0.72 | 0.39 | 12.76 | 5.30 | 0.48 | −0.8 | 3.68 | 1.68 |
| Blueberries | 84.6 | 0.67 | 0.38 | 14.13 | 2.70 | 0.21 | −1.6 | 3.60 | 1.88 |
| Cantaloupes | 89.8 | 0.88 | 0.28 | 8.36 | 0.80 | 0.71 | −1.2 | 3.94 | 2.01 |
| Cherries, Sour | 86.1 | 1.00 | 0.30 | 12.18 | 1.60 | 0.40 | −1.7 | 3.65 | 1.89 |
| Cherries, Sweet | 80.8 | 1.20 | 0.96 | 16.55 | 2.30 | 0.53 | −1.8 | 3.65 | 1.89 |
| Cranberries | 86.5 | 0.39 | 0.20 | 12.68 | 4.20 | 0.19 | −0.9 | 3.77 | 1.93 |
| Currants, European Black | 82.0 | 1.40 | 0.41 | 15.38 | 0.00 | 0.86 | −1.0 | 3.80 | 1.91 |
| Currants, Red and White | 84.0 | 1.40 | 0.20 | 13.80 | 4.30 | 0.66 | −1.0 | 3.80 | 1.91 |
| Dates, Cured | 22.5 | 1.97 | 0.45 | 73.51 | 7.50 | 1.58 | −15.7 | 1.51 | 1.09 |
| Figs, Fresh | 79.1 | 0.75 | 0.30 | 19.18 | 3.30 | 0.66 | −2.4 | 3.43 | 1.80 |
| Figs, Dried | 28.4 | 3.05 | 1.17 | 65.35 | 9.30 | 2.01 | — | 1.63 | 1.13 |
| Gooseberries | 87.9 | 0.88 | 0.58 | 10.18 | 4.30 | 0.49 | −1.1 | 3.77 | 1.93 |

# 6-2 Thermal properties of frozen food:

- **6-2-1 Ice fraction**
- To predict the thermos-physical properties of frozen foods, which depend strongly on the
- 1. fraction of ice in the food,
- 2. the mass fraction of water that has crystallized must be determined as follows.

Table (6-1) Unfrozen Composition Data, Initial Freezing Point and Specific Heats of Foods

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| Blackberries | 85.6 | 0.72 | 0.39 | 12.76 | 5.30 | 0.48 | −0.8 | 3.68 | 1.68 |
| Blueberries | 84.6 | 0.67 | 0.38 | 14.13 | 2.70 | 0.21 | −1.6 | 3.60 | 1.88 |
| Cantaloupes | 89.8 | 0.88 | 0.28 | 8.36 | 0.80 | 0.71 | −1.2 | 3.94 | 2.01 |
| Cherries, Sour | 86.1 | 1.00 | 0.30 | 12.18 | 1.60 | 0.40 | −1.7 | 3.65 | 1.89 |
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| Figs, Fresh | 79.1 | 0.75 | 0.30 | 19.18 | 3.30 | 0.66 | −2.4 | 3.43 | 1.80 |
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| Gooseberries | 87.9 | 0.88 | 0.58 | 10.18 | 4.30 | 0.49 | −1.1 | 3.77 | 1.93 |

- $$x_{ice} = \frac{1.105\, x_{wo}}{1 + \frac{0.7138}{\ln(t_f - t + 1)}}$$
- Where:
- $x_{ice}$: Ice fraction
- $x_{wo}$: Mass fraction of water in the unfrozen food (table 6-1)
- $t_f$: Initial freezing point of food, (table 6-1), °C
- $t$: Food temperature, °C

- **Example 1.** A 150 kg beef carcass is to be frozen to –20°C. What are the masses of the frozen and unfrozen water at –20°C?

Table 6-1 Unfrozen Composition Data, Initial Freezing Point and Specific Heats of Foods

| Food Item | Moisture Content, % $x_{wo}$ | Protein, % $x_p$ | Fat, % $x_f$ | Carbohydrate, % $x_c$ | Fiber, % $x_{fb}$ | Ash, % $x_a$ | Initial Freezing Point, °C | Specific Heat Above Freezing, kJ/(kg·K) | Specific Heat Below Freezing, kJ/(kg·K) |
|---|---|---|---|---|---|---|---|---|---|
| **Beef** | | | | | | | | | |
| Brisket | 55.2 | 16.94 | 26.54 | 0.0 | 0.0 | 0.80 | — | — | — |
| Carcass, Choice | 57.3 | 17.32 | 24.05 | 0.0 | 0.0 | 0.81 | −2.2 | — | — |
| Carcass, Select | 58.2 | 17.48 | 22.55 | 0.0 | 0.0 | 0.82 | −1.7 | — | — |

- From Table (6-1), the mass fraction of water in the beef carcass is 0.582 and the initial freezing point for the beef carcass is –1.7°C. Using Equation (6-1), the mass fraction of ice is:

- $$\boldsymbol{x_{ice} = \frac{1.105\, x_{wo}}{1+\frac{0.7138}{\ln(t_f - t+1)}}}$$

- $$x_{ice} = \frac{1.105\, x_{wo}}{1+\frac{0.7138}{\ln(t_f - t+1)}} = \frac{1.105\times 0.58}{1+\frac{0.7138}{\ln(-1.7+20+1)}} = 0.52$$

- The mass fraction of unfrozen water is:
- $x_{wo}$=0.58, $x_{ice=}$ 0.52
- $x_u = x_{wo} - x_{ice} = 0.58 - 0.52 = 0.06$
- The mass of frozen water at –20°C is:
- $x_{ice} \times 150$ kg $= 0.52 \times 150 = 78$ kg
- The mass of unfrozen water at –20°C is:
- $x_u \times 150$ kg $= 0.06 \times 150 = 9$ kg

# 6-2-2 Density:

- Modeling the density of foods and beverages requires knowledge of the food porosity, as well as the mass fraction and density of the food components. The density ρ of foods and beverages can be calculated accordingly:

$$\boldsymbol{\rho = \frac{1-\varepsilon}{\sum \frac{x_i}{\rho_i}}}$$

Where:

ε: Porosity,

Porosity ε is required to model the density of granular foods stored in bulk, such as grains and rice. For other foods, ε is zero.

xi Mass fraction of the food constituents.

ρi: Density of the food constituents.

| | | |
|---|---|---|
| Density, kg/m$^3$ | Protein | $\rho = 1.3299 \times 10^3 - 5.1840 \times 10^{-1}t$ |
| | Fat | $\rho = 9.2559 \times 10^2 - 4.1757 \times 10^{-1}t$ |
| | Carbohydrate | $\rho = 1.5991 \times 10^3 - 3.1046 \times 10^{-1}t$ |
| | Fiber | $\rho = 1.3115 \times 10^3 - 3.6589 \times 10^{-1}t$ |
| | Ash | $\rho = 2.4238 \times 10^3 - 2.8063 \times 10^{-1}t$ |

# 6-2-3 Specific heat:

- Specific heat is a measure of the energy required to change the temperature of a food by one degree. Therefore, the specific heat of foods or beverages can be used to calculate the heat load imposed on the refrigeration equipment by the cooling or freezing of foods and beverages.

# Unfrozen food:

- A simpler model for the specific heat of an unfrozen food can be calculated from equation bellows:
- $\boldsymbol{C_u = 4.19 - 2.3x_s - 0.628x_s^3}$
- *Cu:* Specific heat of the unfrozen food in kJ/(kg·K).
- $x_s$ Mass fraction of the solids in the food.
- The mass fraction of solids is the total mass of product – the mass foe water in the product

# Frozen food:

- Below the food's freezing point, sensible heat from temperature change and latent heat from the fusion of water must be considered.
- The following equation can be used to calculate the specific heat of frozen food.

- $\boldsymbol{c_a = 1.55 + 1.26x_s + \frac{(x_{wo} - x_b).L_o.t_f}{t^2}}$
- Where:
- $c_a$ = apparent specific heat, (kJ/kg·K).
- $t$ = food temperature, °C
- $L_o$: Heat of fusion of water (333 kJ/kg/K)
- $x_b$: The mass fraction of bound water may be estimated as follows:
- $\boldsymbol{x_b = 0.4.x_p}$
- $\boldsymbol{x_p}$: Mass fraction of protein in the food

Table 6-1 Unfrozen Composition Data, Initial Freezing Point and Specific Heats of Foods

| Food Item | Moisture Content, % $x_{wo}$ | Protein, % $x_p$ | Fat, % $x_f$ | Carbohydrate, % $x_c$ | Fiber, % $x_{fb}$ | Ash, % $x_a$ | Initial Freezing Point, °C | Specific Heat Above Freezing, kJ/(kg·K) | Specific Heat Below Freezing kJ/(kg·K) |
|---|---|---|---|---|---|---|---|---|---|
| **Lamb** | | | | | | | | | |
| Composite of Cuts, Lean | 73.4 | 20.29 | 5.25 | 0.0 | 0.0 | 1.06 | −1.9 | 3.20 | 1.61 |
| Leg, Whole, Lean | 74.1 | 20.56 | 4.51 | 0.0 | 0.0 | 1.07 | — | 3.30 | 1.66 |

- **Example 2.** One hundred kilograms of lamb meat is to be cooled from 10°C to 0°C. Using the specific heat, determine the amount of heat that must be removed from the lamb.
- From Table (6-1), the composition of lamb is given as follows:
- $x_{wo} = 0.7342$, $x_p = 0.2029$, $x_{fat} = 0.0525$, $x_{ca} = 0$
- $x_f = 0.00$, $x_a = 0.0106$. $\boxed{t_f = -1.9\ ^oC}$

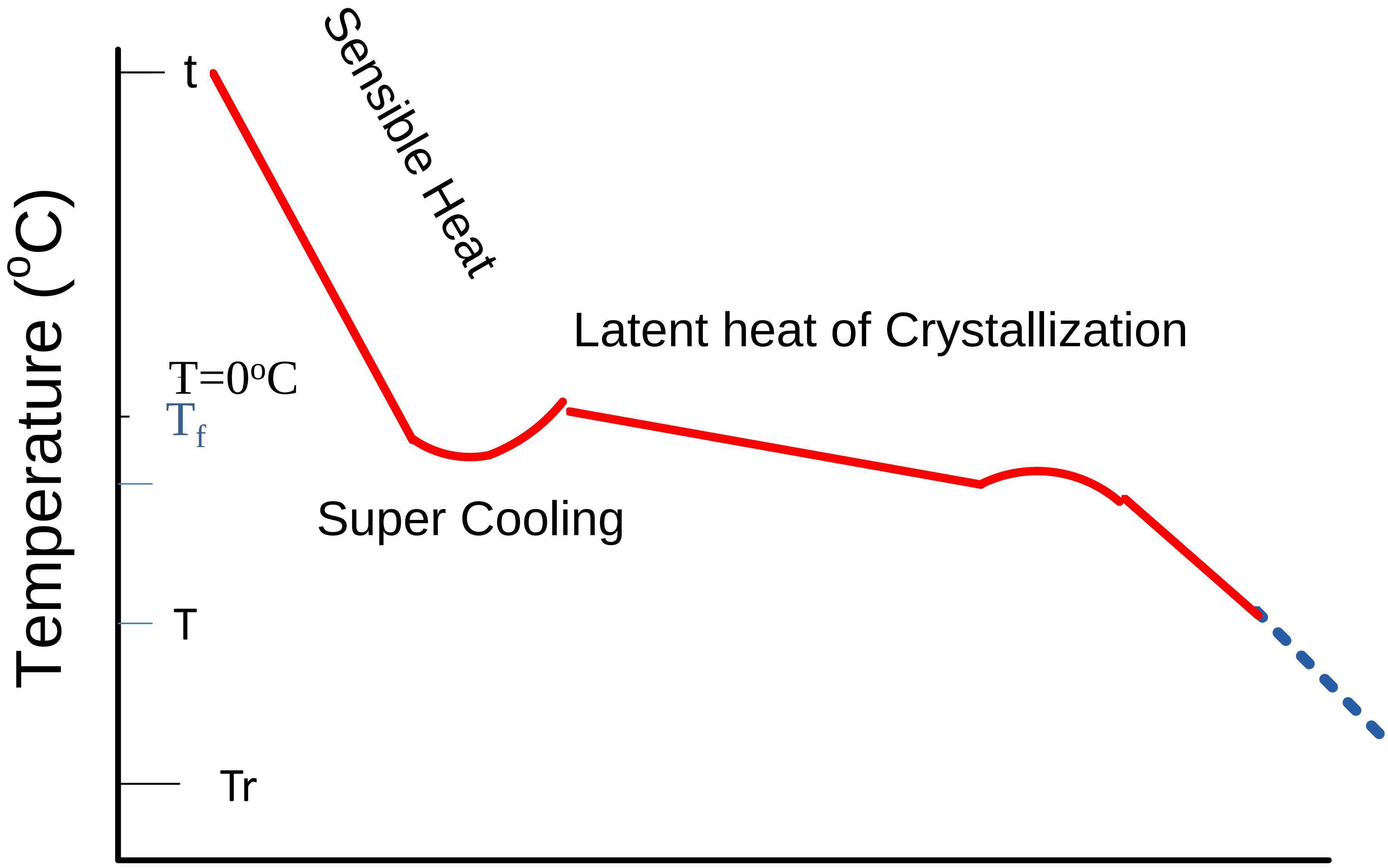
- Using the equation of unfrozen food, since the final temperature is greater that initial freezing point of the food ( -1.9 °C).

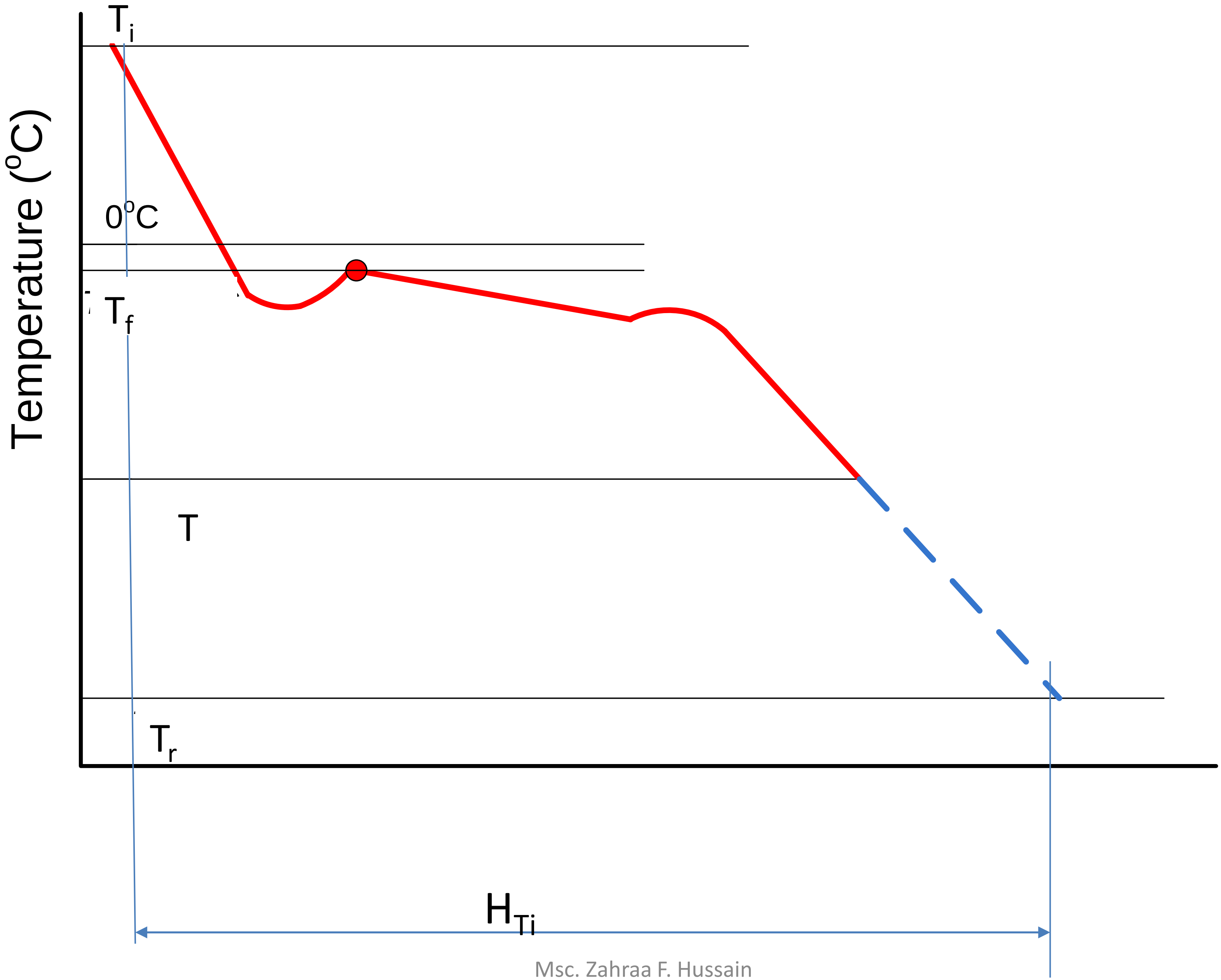
- $C_u = 4.19 - 2.3x_s - 0.628x_s^3$

- $x_s = 1 - x_{wo}$
- $x_{wo} = 0.7342$
- $x_s = = 1 - 0.7342 = 0.2658$
- $C_u = 4.19 - 2.3x_s - 0.628x_s^3$
- $C_u = 3.567 \frac{kJ}{kg.K}$
- $Q = m.C_u.\Delta T = 100 \times 3.567 \times (10 - 0) = 3567\ kJ$

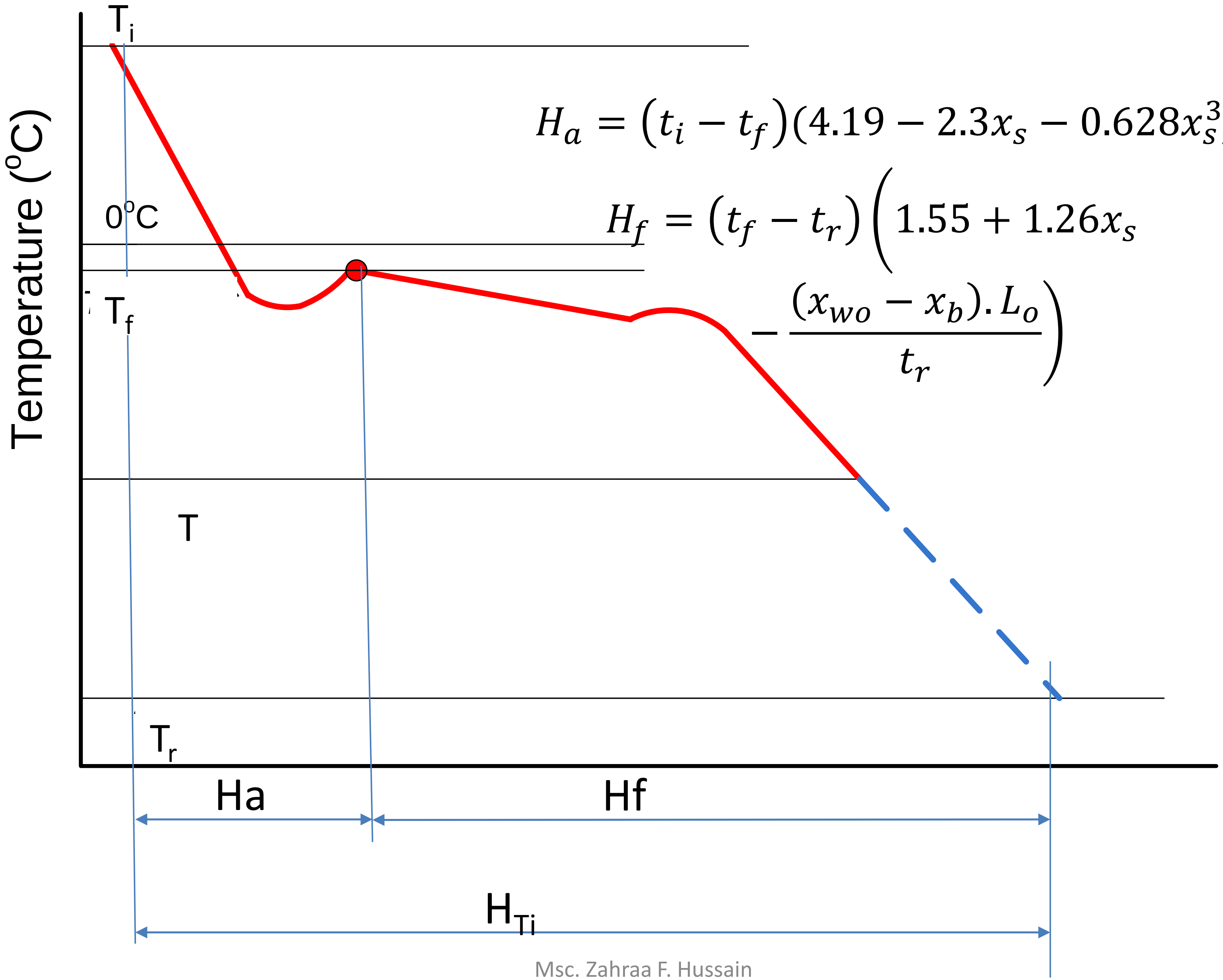
# 6-2-4 Enthalpy:

- The change in a food's enthalpy can be used to estimate the energy that must be added or removed to effect a temperature change.
- Above the freezing point, enthalpy consists of sensible energy;
- Below the freezing point, enthalpy consists of both sensible and latent energy.
- Enthalpy may be obtained from the definition of constant-pressure specific heat:


Temperature (°C)
t
Sensible Heat
Latent heat of Crystallization
T=0°C
Tf
Super Cooling
T
Tr



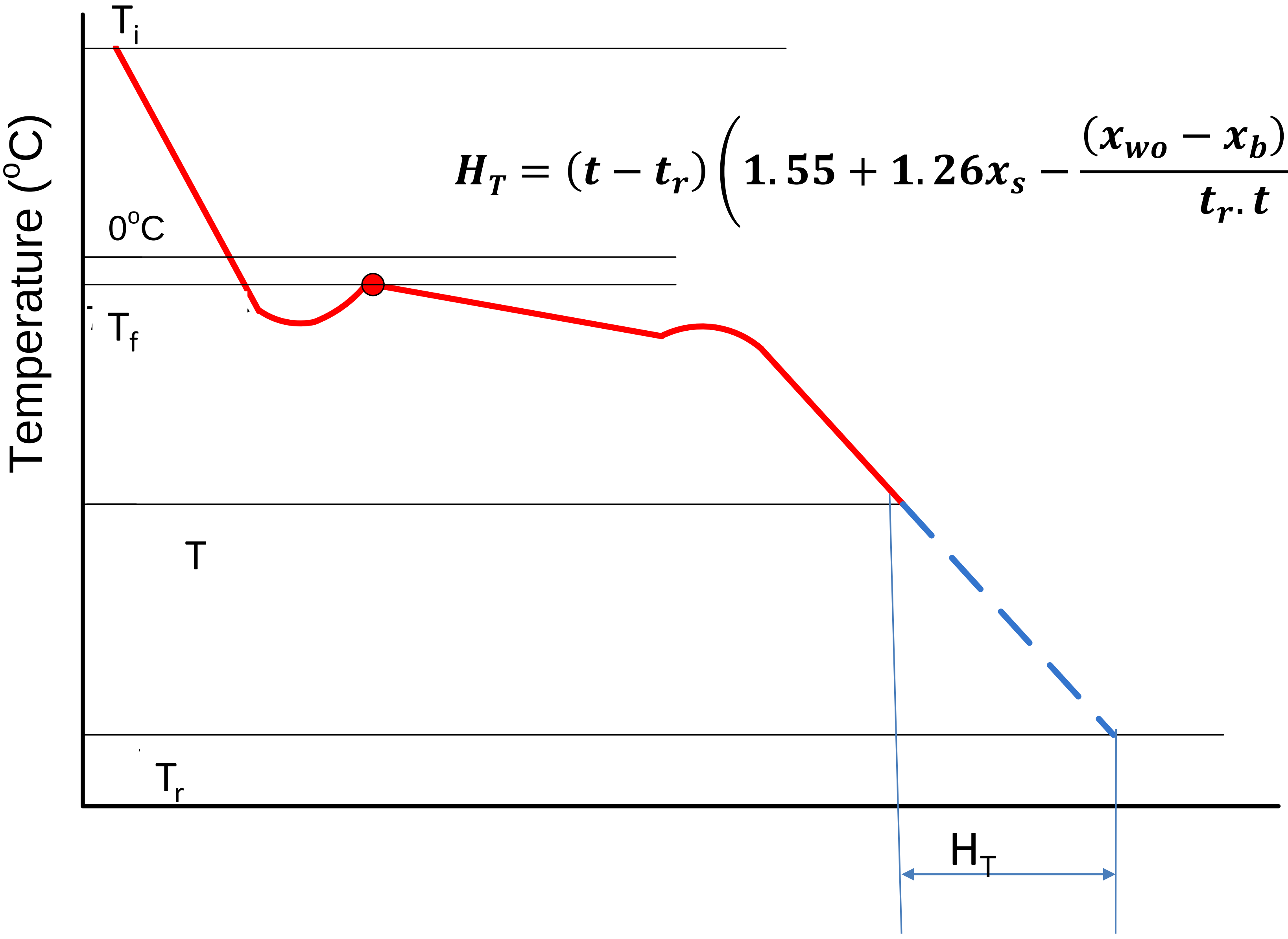
Temperature (°C)
T_i
0°C
T_f
T
T_r
H_Ti




$$H_a = \left(t_i - t_f\right)\left(4.19 - 2.3x_s - 0.628x_s^3\right)$$

$$H_f = \left(t_f - t_r\right)\left(1.55 + 1.26x_s - \frac{(x_{wo} - x_b).L_o}{t_r}\right)$$

$$H_T = (t - t_r)\left(1.55 + 1.26x_s - \frac{(x_{wo} - x_b).L_o t_f}{t_r.t}\right)$$



# Unfrozen and frozen food:

- The enthalpy of an **unfrozen food** may be obtained as follows:
- $H_u = H_a + H_f$ ( Over all enthalpy of food)
- $H_a = (t_i - t_f).C_u.$ (unfrozen food)
- $H_a = (t_i - t_f).(4.19 - 2.3x_s - 0.628x_s^3)$
- $H_f = (t_f - t_r).c_a.$ (frozen food)
- $H_f = (t_f - t_r)\left(1.55 + 1.26x_s - \frac{(x_{wo} - x_b).L_o}{t_r}\right)$
- $t_r$: Reference freezing point equals (-40 °C)

# frozen food:

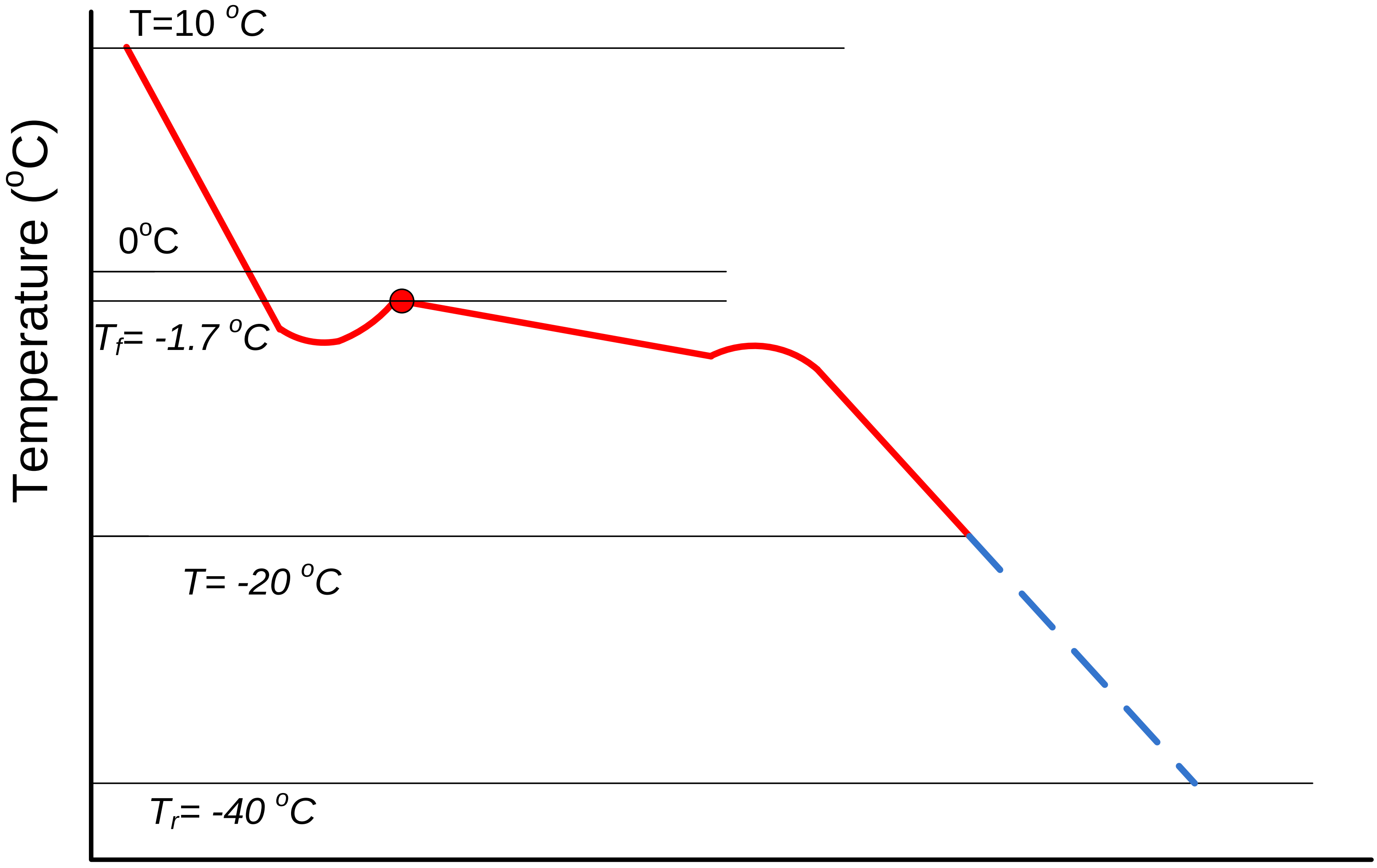
- The enthalpy of an **frozen food** may be obtained as follows:
- $$H_T = (t - t_r)\left(1.55 + 1.26x_s - \frac{(x_{wo} - x_b).L_o t_f}{t_r.t}\right)$$
- $t_r$: Reference freezing point equals (-40 °C)

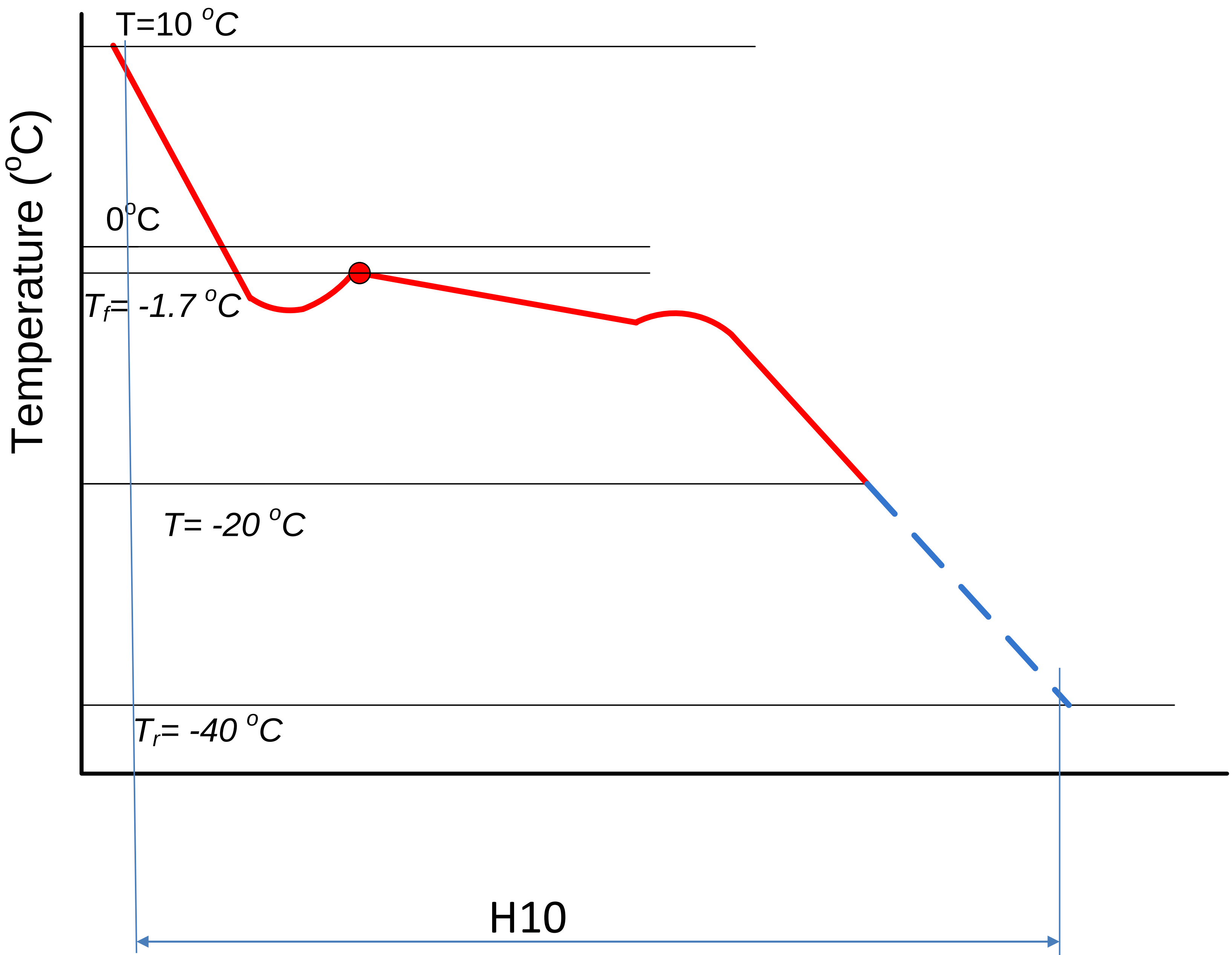
- Example 3: A 150 kg beef carcass is to be frozen to a temperature of –20°C. The initial temperature of the beef carcass is 10°C. How much heat must be removed from the beef carcass during this process?

Table 6-1) Unfrozen Composition Data, Initial Freezing Point and Specific Heats of Foods

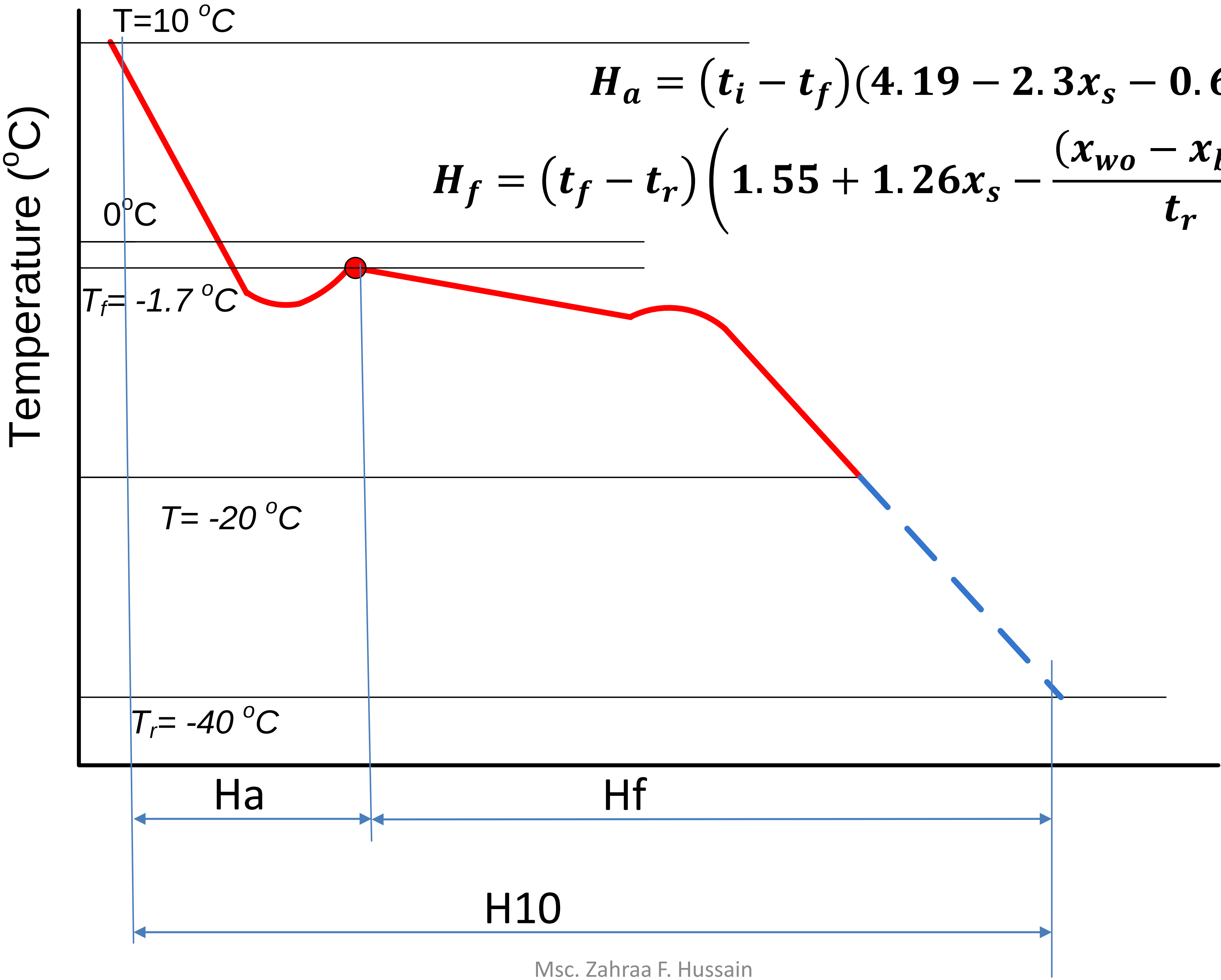
| Food Item | Moisture Content, % $x_{wo}$ | Protein, % $x_p$ | Fat, % $x_f$ | Carbohydrate, % $x_c$ | Fiber, % $x_{fb}$ | Ash, % $x_a$ | Initial Freezing Point, °C | Specific Heat Above Freezing, kJ/(kg·K) | Specific Heat Below Freezing kJ/(kg·K) |
|---|---|---|---|---|---|---|---|---|---|
| **Beef** | | | | | | | | | |
| Brisket | 55.2 | 16.94 | 26.54 | 0.0 | 0.0 | 0.80 | — | — | — |
| Carcass, Choice | 57.3 | 17.32 | 24.05 | 0.0 | 0.0 | 0.81 | −2.2 | — | — |
| Carcass, Select | 58.2 | 17.48 | 22.55 | 0.0 | 0.0 | 0.82 | −1.7 | — | — |

- **Solution:**
  From Table (6-1), the mass fraction of water in the beef carcass is 0.5821, the mass fraction of protein in the beef carcass is 0.1748, and the initial freezing point of the beef carcass is –1.7°C. The mass fraction of solids in the beef carcass is:


T=10 $^oC$
Temperature ($^oC$)
$0^oC$
$T_f$= -1.7 $^oC$
T= -20 $^oC$
$T_r$= -40 $^oC$



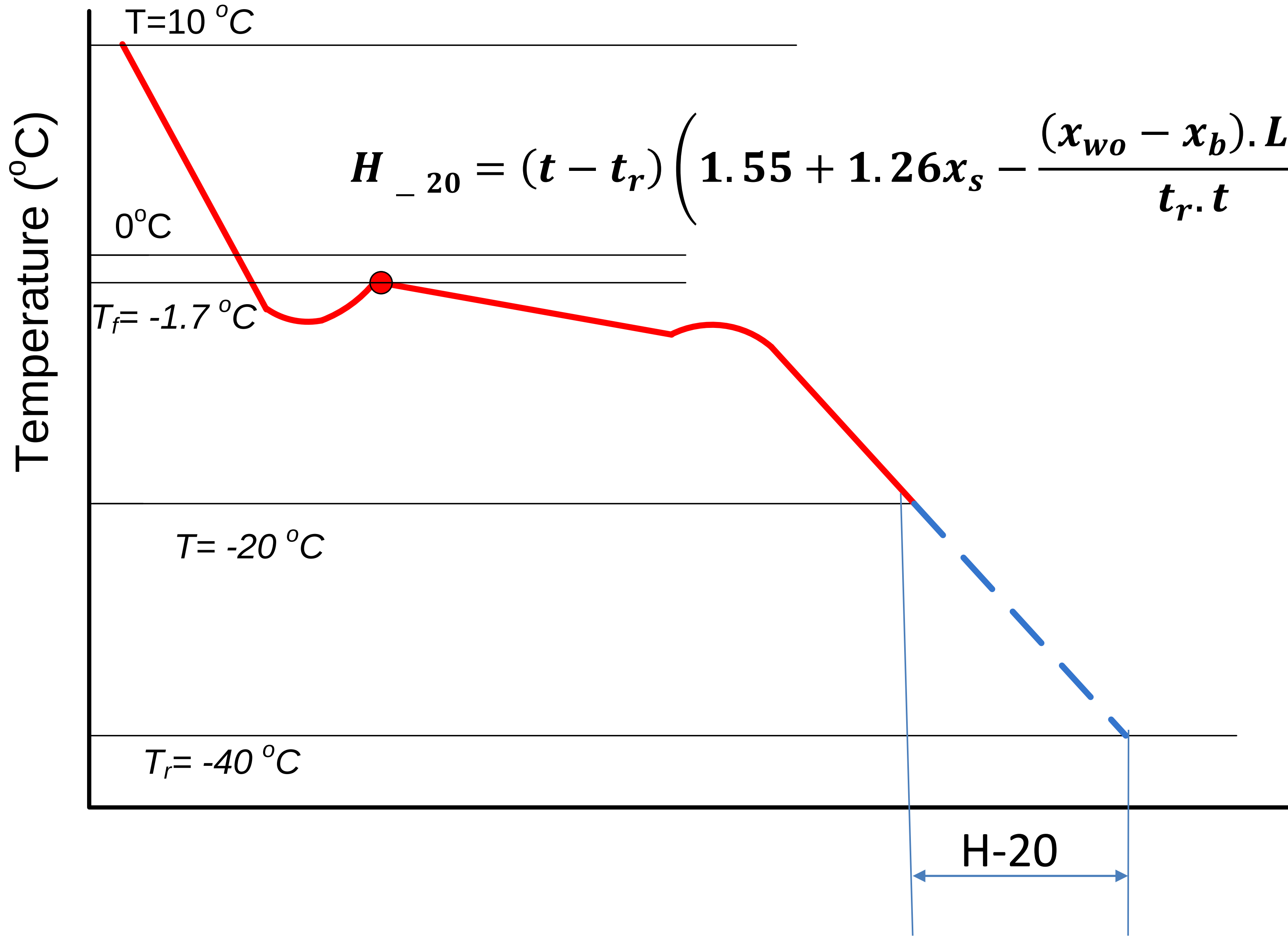
T=10 °C
0°C
$T_f$= -1.7 °C
T= -20 °C
$T_r$= -40 °C
Temperature (°C)
H10

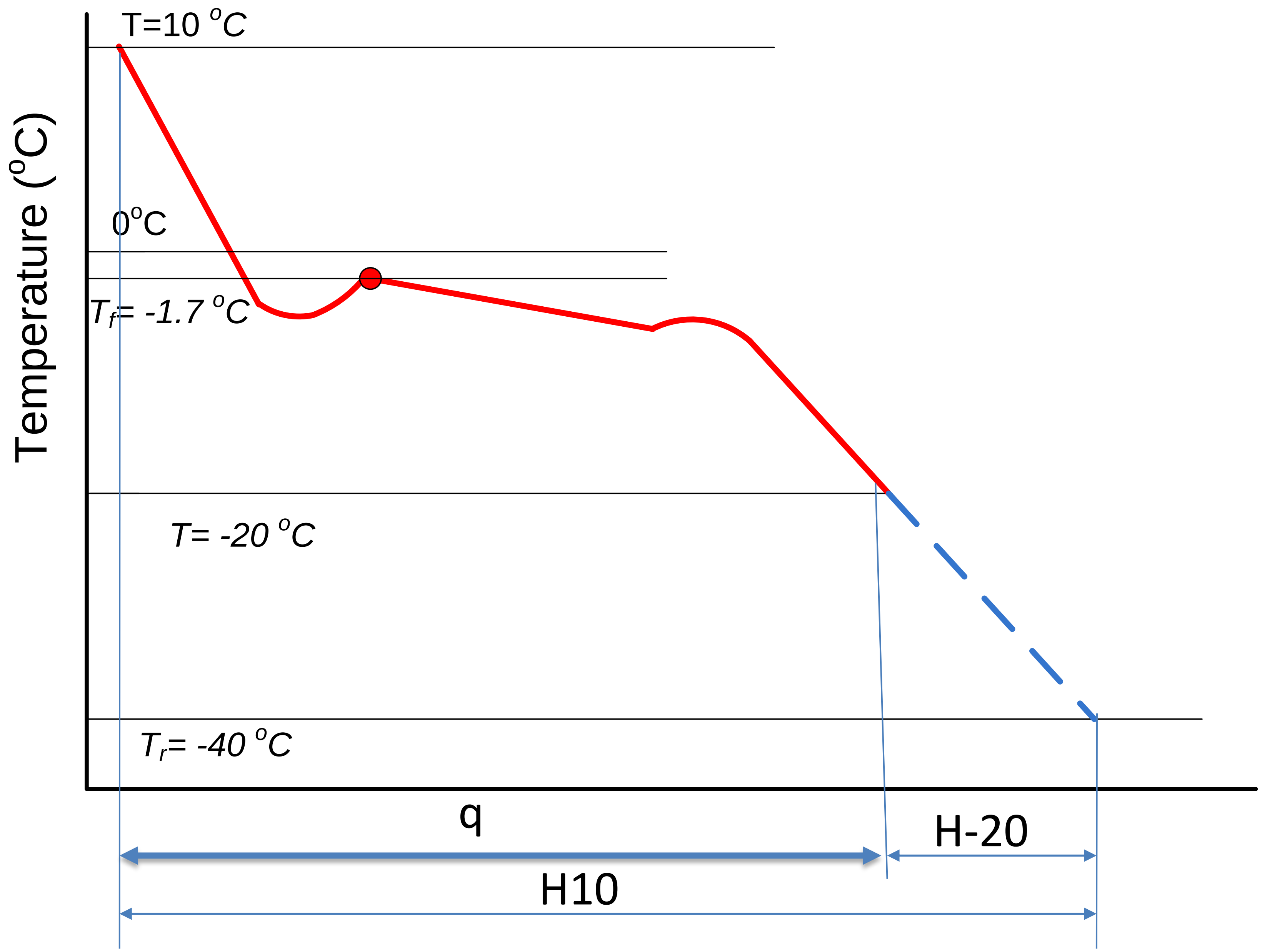



$$H_a = (t_i - t_f)(4.19 - 2.3x_s - 0.628x_s^3)$$

$$H_f = (t_f - t_r)\left(1.55 + 1.26x_s - \frac{(x_{wo} - x_b).L_o}{t_r}\right)$$

$$H_{-20} = (t - t_r)\left(1.55 + 1.26x_s - \frac{(x_{wo} - x_b).L_o t_f}{t_r.t}\right)$$




T=10 °C
Temperature (°C)
0°C
T_f= -1.7 °C
T= -20 °C
T_r= -40 °C
q
H-20
H10

- $x_s = 1 - x_{wo} = 1 - 0.5821 = 0.4179$
- $x_b = 0.4.x_p = 0.4 \times 0.1748 = 0.06992$
- $H_T == (t - t_r)\left(1.55 + 1.26x_s - \frac{(x_{wo} - x_b).L_o t_f}{t_r.t}\right)$

$$H_{\_20} = (t - t_r)\left(1.55 + 1.26x_s - \frac{(x_{wo} - x_b).L_o t_f}{t_r.t}\right)$$

- $H_{-20}$
$= ((-20) - (-40))\left(1.55 + 1.26 \times 0.4179 - \frac{(0.5821 - 0.06992).333.6 \times (-1.7)}{-40 \times (-20)}\right)$
- $H_{-20} = 48.79 \frac{kJ}{kg}$

- **The enthalpy of unfrozen food is:**
- $H_{10} = H_f + \mathrm{H_a}$
- $H_f = (t_f - t_r)\left(1.55 + 1.26x_s - \frac{(x_{wo} - x_b).L_o}{t_r}\right)$
- $H_f = (-1.7 - (-40))(1.55 + 1.26 \times 0.4179) - \frac{(0.5821 - 0.06992).333.6}{-40} = 243.14\,\frac{kJ}{kg}$
- $H_{10} = H_f + (t - t_f)(4.19 - 2.3x_s - 0.628x_s^3)$
- $H_{10} = 243.14 + (10 + 1.7)(4.19 - 2.3 \times 0.4179 - 0.628 \times 0.4179^3)$
- $H_{10} = 280.38\,\frac{kJ}{kg}$
- $Q = m.(H_{10} - H_{-20}) = 150 \times (280.38 - 48.79)$**=34739kJ**

# 6-2-5: Thermal conductivity

The simplest model of thermal conductivity is given by the following equation:

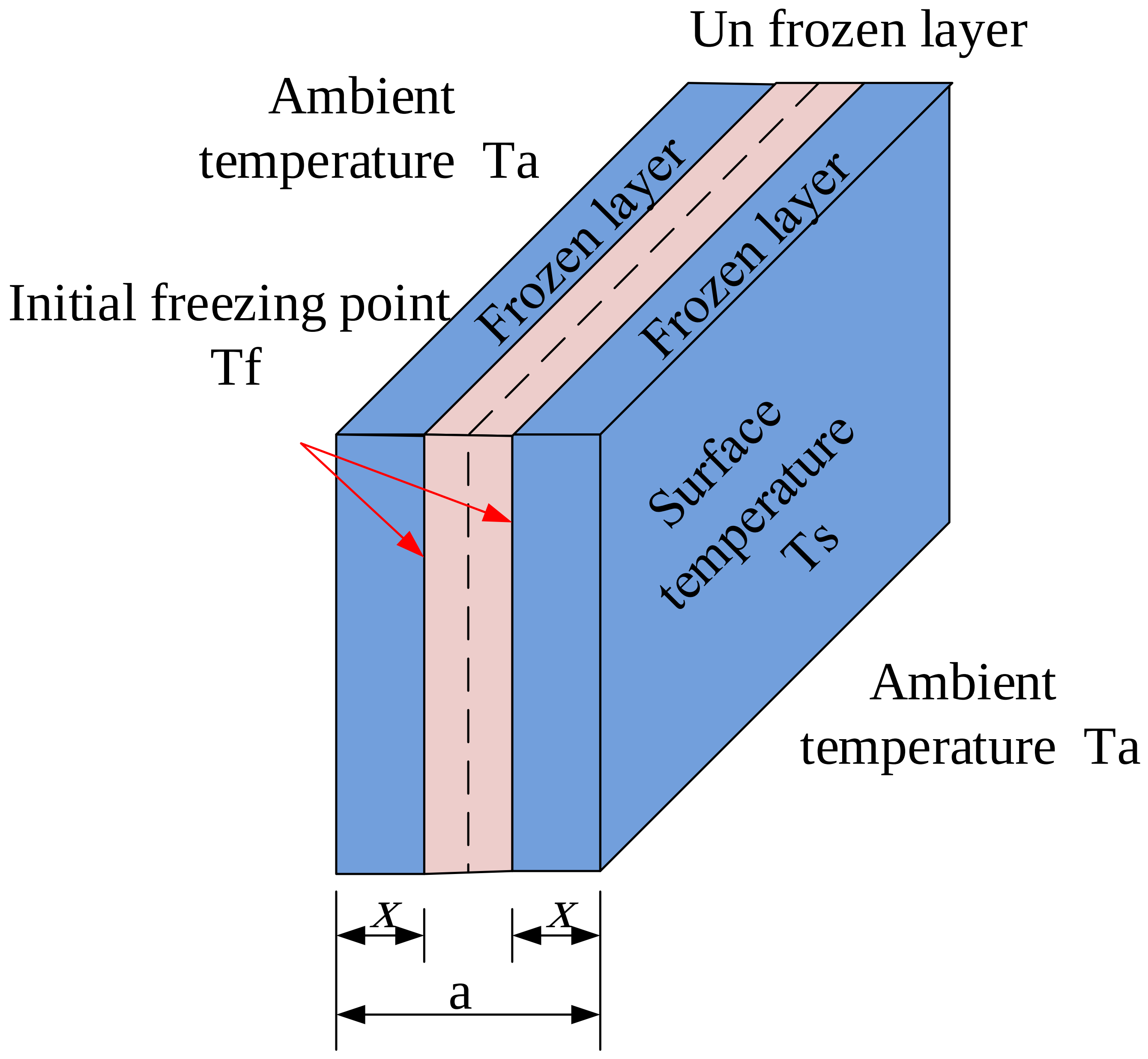
$$k = 0.155x_p + 0.25x_h + 0.16x_f + 0.135x_a + 0.58x_w$$

# 6-3 Freezing time of food:

- A key calculation in the design of a freezing process is the determination of freezing time.
- Three distinct periods are noticeable at any location within a food undergoing freezing:
- 1- pre-freezing,
- 2- phase change, and
- 2- post-freezing.

## 6-3-1 Plank's Equation:

**Plank's** equation describes only the phase change period of the freezing process. Consider an infinite slab ( Fig 6.1) of thickness
*a*. We assume that the material constituting the slab is pure water.
Because this method ignores the pre-freezing step, the initial temperature of the slab is the same as the initial freezing point of the material, $T_f$.


Un frozen layer
Ambient temperature Ta
Frozen layer
Frozen layer
Initial freezing point Tf
Surface temperature Ts
Ambient temperature Ta
X
X
a

- With water, the initial freezing point is 0°C.
- The slab is exposed to a freezing medium at temperature *T*a.
- The heat transfer is one-dimensional.
- After some duration of time, there will be three layers:
- two frozen layers each of thickness *x* and a middle unfrozen layer.
- Consider the right half of the slab A moving front inside the slab separates the frozen from the unfrozen region.
- As water is converted into ice at the moving front, latent heat of fusion, *L*, is generated.

$$t_f = \frac{\rho_f . L_f}{T_f - T_a}\left[\frac{\grave{P}.a}{h} + \frac{\grave{R}a^2}{k_f}\right]$$

- $\rho_f$ : Density of the frozen material.
- $L_f$: Change in the latent heat of the food (kJ/kg).
- $L_f = x_{wo}.L$ **(6-10)**
- $T_f$: Freezing temperature (°C).
- $T_a$: Freezer air temperature (°C).
- *h:* Convective heat transfer coefficient at the surface of the material (W/m$^2$°C).
- *a:* Thickness/diameter of the object (m)
- *k:* is the thermal conductivity of the frozen material (W/m°C).

Table (6-2) Constants of equation (6-9)

| | Sphere | Cylinder | Slab |
|---|---|---|---|
| P̀ | 1/6 | 1/4 | 1/2 |
| R̀ | 1/24 | 1/16 | 1/8 |

- **Example 4:**
- A spherical piece of liver to be frozen in the air blast freezer, the initial temperature is 10 $^{o}C$ , the air temperature equals -40 $^{o}C$. The radius of the Spherical liver equals 7cm. Assume that the density of the liver is equal to 1000 $kg/m^3$, heat transfer coefficient and convection equals to $50 W/m^2.K$. Estimate the time required for freezing.

| Food Item | Moisture Content, % $x_{wo}$ | Protein, % $x_p$ | Fat, % $x_f$ | Carbohydrate, % $x_c$ | Fiber, % $x_{fb}$ | Ash, % $x_a$ | Initial Freezing Point, °C | Specific Heat Above Freezing, kJ/(kg·K) | Specific Heat Below Freezing kJ/(kg·K) |
|---|---|---|---|---|---|---|---|---|---|
| Liver | 69.0 | 20.00 | 3.85 | 5.82 | 0.0 | 1.34 | −1.7 | 3.43 | 1.72 |

- Find the thermal conductivity of the liver:
- $k = 0.155x_p + 0.25x_h + 0.16x_f + 0.135x_a + 0.58x_w$
- $k = 0.155(0.2) + 0.25(0.0582) + 0.16(0.0385) + 0.135(0.0134) + 0.58(0.69) = 0.4537\,\frac{\mathrm{W}}{\mathrm{m\,K}}$

Table (6-2) Constants of equation (6-9)

| | Sphere | Cylinder | Slab |
|---|---|---|---|
| Ṕ | 1/6 | 1/4 | 1/2 |
| Ŕ | 1/24 | 1/16 | 1/8 |

- The time required for freezing is:
- $t_f = \frac{\rho_f . L_f}{T_f - T_a}\left[\frac{\grave{P}.a}{h} + \frac{\grave{R}a^2}{k_f}\right]$
- From table (6-2) find the values of $\grave{P}$ is (1/6) and $\grave{R}$ is (1/24) and **a** equals to the sphere diameter (0.07 m)
- $L_f = x_{wo}.L = 0.69 \times 333.6 = 230.18$
- $t_f = \frac{1000 \times 230.18 \times 1000}{-1.7-(-40)}\left[\frac{\frac{1}{6}(0.07)}{50} + \frac{\frac{1}{24}(0.07^2)}{0.4537}\right] = 4107s$
  $= 1.141hr.$

## 6.4 Food microbiology

- Refrigeration overall application is the prevention or retardation of microbial, physiological, and chemical changes in foods. Even at temperatures near the freezing point, foods may deteriorate through the growth of microorganisms, through changes caused by enzymes, or through chemical reactions. Holding foods at low temperatures merely reduces the rate at which these changes take place. Refrigeration also plays a major role in maintaining a safe food supply.
- **6-4.1 Basic microbiology:** Microorganisms play several roles in a food production facility. They can causes to food: 1- spoilage, 2-producing off-odors and 3- flavors, 4-or product texture or appearance through slime production and pigment formation. Microorganisms fall into four categories—1-bacteria, 2-yeasts, 3-molds, and 4- viruses.

**a- Bacteria:** Bacteria are the most common food-borne pathogens. Bacterial growth rates, under optimum conditions, are generally faster than those of yeasts and molds, making bacteria a prime cause of spoilage, especially in refrigerated, moist foods. Bacteria have many shapes, including spheres (cocci), rods, or spirals, that are usually between 0.3 and 5 to 10 mm in size. Bacteria are capable of growth in a wide range of environments.

**b- Yeasts and molds** become important in situations that restrict the growth of bacteria, such as in acidic or dry products. Yeasts can cause gas formation in juices and slime formation on fermented products. Mildew (black mold) on humid surfaces and mold formation on spoiled foods are also common.

**c- Viruses:** Human viruses, such as Hepatitis A ) , ( التهاب الكبد cannot multiply outside the human body. Design features must include facilities for good employee hand washing and sanitation practices to minimize potential for product contamination.

### 6.4.3 Microbial Growth:

All microbial populations follow a generalized growth curve (Figure 6-2). **Lag phase —The** period immediately following inoculation to fresh media in which little or no growth occurs. A time of intense metabolic activity as the cells gear up for reproduction. **Log or exponential phase —The** period of growth in which cellular reproduction is most active. Generation time is at a minimum. Numbers can double as fast as every 20 to 30 min. under optimum conditions. **Stationary phase —The** number of new cells being produced equals the number of cell deaths. **Death phase —The** number of dead cells exceeds the number of living cells until only a small portion of the population exists or the population dies out completely.

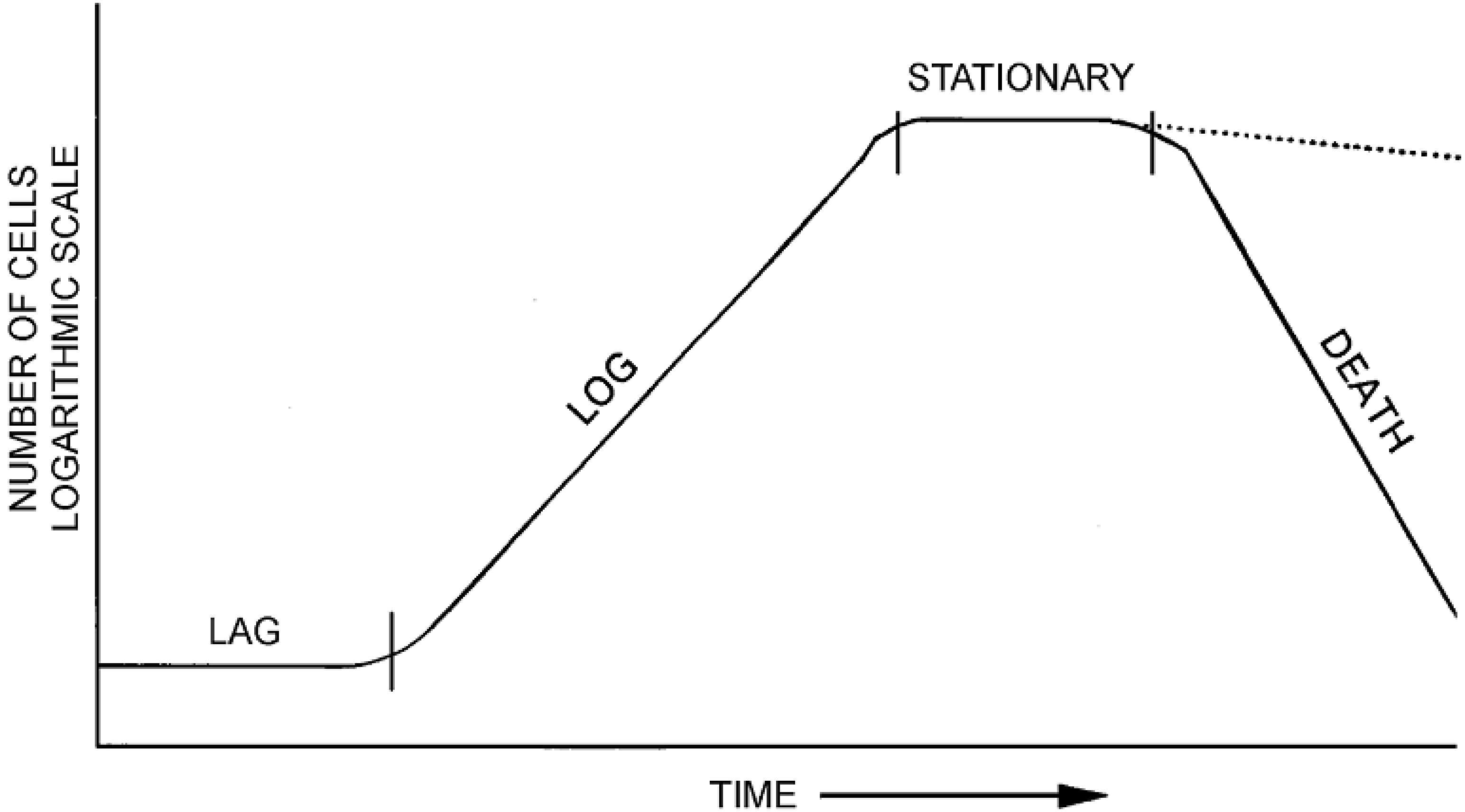



Fig. (6-2) Typical Microbial Growth Curve

## 6-5 Design for control of microorganisms:

Microorganisms can be controlled by one of three mechanisms:

**6.5.1 Prevention of Contamination:** To prevent the entry of microorganisms into food production areas, Ventilation systems must provide adequately clean air. Because bacteria are generally transported through air on dust particles, 95% filters are sufficient to remove most microorganisms. High-efficiency particulate air (HEPA) filters provide sterile air and are used for cleanrooms. Air-filtering materials must remain dry. Wet filters in ventilation systems support microbial growth, and organisms are transported throughout the production facility in the air. Positive pressure in the production environment prevents the entry of airborne contamination from sources other than ventilation ducts. Traffic flow through a production facility should be planned to minimize contact between raw and cooked products.

**6.5.2Prevention of Growth:** Water control is one of the most effective and most frequently overlooked means of inhibiting microbial growth. All ventilation systems, piping, equipment, and floors must be designed to drain completely. Condensation on ceilings and chilled pipes also supports microbial growth and may drip onto product contact surfaces that are not adequately protected. Insulation of pipe and/or dehumidifying systems may be necessary, particularly in chilled rooms. Increased airflow may also be useful in removing residual moisture. Maintenance of 70% rh prevents the growth of all but the most microorganisms; less than 60% rh prevents all microbial growth on facility surfaces. Controlling relative humidity is not always possible. For example, the aging of meat carcasses requires relative humidifies of 90 to 95% to prevent excessive drying of the tissue. In these cases, temperatures just above the product freezing point should be used to inhibit microbial deterioration. Temperatures below 5°C inhibit the most common organisms that cause foodborne illness. Since no microbial growth occurs in frozen foods, as long as a product remains below its freezing point, microbial safety issues are nonexistent. Frozen foods must be stored below −20°C for legal and quality reasons.

### 6.5.3 Destruction of Organisms:

High temperature is an effective means of inactivating microorganisms and is used extensively in blanching, pasteurization, and canning. Moist heat is far more effective than dry heat. High temperatures (77°C) may also be used for sanitation when chemicals are not used. While hot water sanitation is effective against vegetative forms of bacteria, spores are not affected. In addition to heat, gases such as ethylene oxide and methyl bromide, irradiation, ultraviolet light, and sanitation chemicals are effective in destroying microorganisms.

## 6-6 The role of HACCP

Many of the procedures for the control of microorganisms are managed by the Hazard Analysis and Critical Control Point (HACCP) system of food safety. Developed in the food industry since the 1960s, HACCP is now accepted by food manufacturers and regulators. The HACCP system is used to manage physical and chemical hazards as well as biological hazards. The approach to HACCP is described in the seven principles:

1. Conduct a hazard analysis and identify control measures.
2. 2. Identify critical control points.
3. 3. Establish critical limits.
4. 4. Establish monitoring procedures.
5. 5. Establish corrective actions.
6. 6. Establish verification procedures.
7. 7. Establish record keeping and documentation procedures.