FDE449
Physical Properties of Foods

Thermal properties of foods

Content
*Specific heat
*Enthalpy, sensible and latent heat
*Thermal diffusivity

Sensible and latent heat changes

- Specific heat, latent heat and specific enthalpy play an important role in heat transfer problems when heating or cooling foods.
- It is necessary to know the specific heat to determine the quantity of energy that needs to be added or removed.
- This will give an indication of the energy costs involved and in a continuous process will have an influence on the size of the equipment.
- Latent heat values, which are associated with phase changes, play an important role in freezing, crystallization, evaporation and dehydration processes.

Specific heat

- The specific heat of a material is a measure of the amount of energy required to raise unit mass by unit temperature rise.
- Specific heat is temperature dependent. However, for the purpose of many engineering calculations, these variations are small and an average specific heat value is used for the temperature range considered.

The units of specific heat

- kJ / kg K or kcal / kg K or
- Btu / Ib ^{o}F).

From the definitions of the different thermal units, the specific heat of water in the respective units is

1.0. kcal / kg K or 4.18 kJ /kg K or 1 Btu /Ib ^{o}F

Specific heat

- In a batch heating or cooling process, the amount of heat (energy) Q require or removed is given by

  Q= mass x average specific heat x temperature change

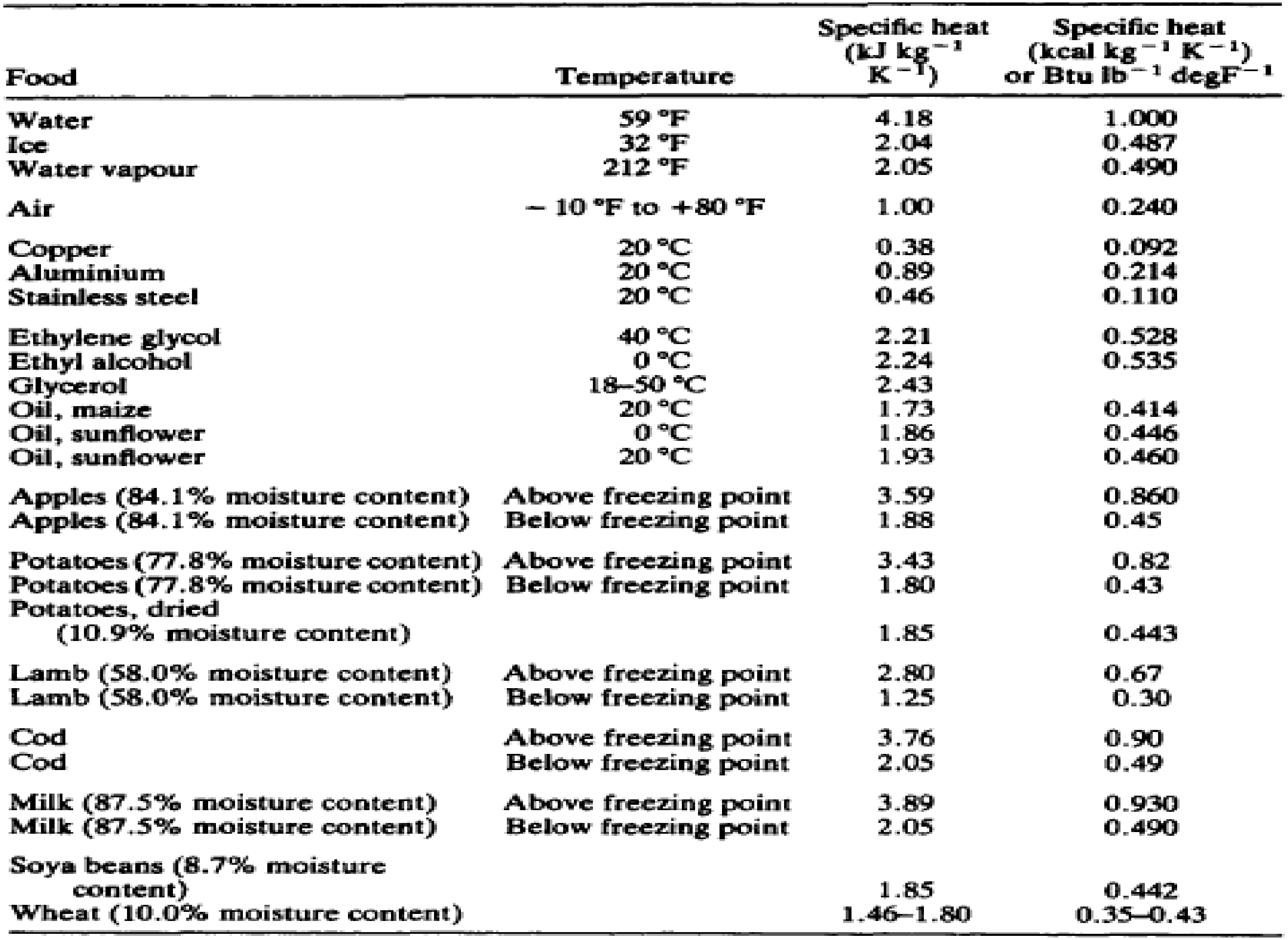
  $= m\ c\ \Delta T$

- ❑ Liquid water has an extremely high specific heat value, much higher than most other liquids.
- ❑ This is why it is so widely used as a cooling medium. The addition of ethylene glycol (antifreeze) will lower the specific heat and consequently the cooling efficiency. When water freezes, the specific heat capacity is drastically reduced, by a factor of approximately 2.
- ❑ Since water has a much higher specific heat than most other food constituents, the specific heat of a food is significantly affected by the amount of water present and the physical state of the water.
- ❑ Frozen foods with high water contents will have specific heat values approximately half that of their fresh counterparts.

Specific heat

- Metals have very low specific heat values compared with those of foods.
- Oils and fats again have specific heats about half that for water.
- Dried grain and food powders also have very low specific heat values.
- Specific heats are temperature dependent;
- for most substances, there is a slight increase in the specific heat as the temperature rises.
- Since specific heats are dependent on moisture content and temperature, these are often recorded in more detail.
- Table gives further specific heat values for a range of foods, together with a selection of data sources.

Specific heat of some foods and food processing materials



Food	Temperature	Specific heat (kJ kg^{-1} K^{-1})	Specific heat (kcal kg^{-1} K^{-1}) or Btu lb^{-1} degF^{-1}
Water	59 °F	4.18	1.000
Ice	32 °F	2.04	0.487
Water vapour	212 °F	2.05	0.490
Air	− 10 °F to +80 °F	1.00	0.240
Copper	20 °C	0.38	0.092
Aluminium	20 °C	0.89	0.214
Stainless steel	20 °C	0.46	0.110
Ethylene glycol	40 °C	2.21	0.528
Ethyl alcohol	0 °C	2.24	0.535
Glycerol	18–50 °C	2.43	
Oil, maize	20 °C	1.73	0.414
Oil, sunflower	0 °C	1.86	0.446
Oil, sunflower	20 °C	1.93	0.460
Apples (84.1% moisture content)	Above freezing point	3.59	0.860
Apples (84.1% moisture content)	Below freezing point	1.88	0.45
Potatoes (77.8% moisture content)	Above freezing point	3.43	0.82
Potatoes (77.8% moisture content)	Below freezing point	1.80	0.43
Potatoes, dried (10.9% moisture content)		1.85	0.443
Lamb (58.0% moisture content)	Above freezing point	2.80	0.67
Lamb (58.0% moisture content)	Below freezing point	1.25	0.30
Cod	Above freezing point	3.76	0.90
Cod	Below freezing point	2.05	0.49
Milk (87.5% moisture content)	Above freezing point	3.89	0.930
Milk (87.5% moisture content)	Below freezing point	2.05	0.490
Soya beans (8.7% moisture content)		1.85	0.442
Wheat (10.0% moisture content)		1.46–1.80	0.35–0.43

Specific heat

- Therefore, the specific heat of foods is different above and below the freezing point.

- Specific heat above or below freezing point is calculated by Siebel equtions:
  - $c= 3.349m_w + 0.83736$ above freezing point
  - $c= 1.256\ m_w + 0,83736$ below freezing point

m_w: mass fraction of water

Relationship between specific heat and composition

- It would be possible to predict the specific heat of a food from a knowledge of its composition.
- For example the specific heat of skim-milk would be slightly lower than that of water because of the presence of milk solids. As the fat content increases, one would expect the specific heat to decrease (substitution of water or fat).
- The simplest form of equation for estimating the approximate specific heat *c* of food is as follows:

$$c = m_w c_w + m_s c_s \text{ (kJ/kg K)}$$

Where

m_w: mass fraction of water,

c_w: 4.18 kJ/kg K, the specific heat of water

m_s: mass fraction of solids

c_s : 1.46 kJ/kg K, the specific heat of solids

- An alternative form distinguishes between fat and other solids.
- The equation given is:

$$c = (0.5m_f + 0.3m_{snf} + m_w) \times 4.18 \text{ (kJ/ kg K)}$$

Where;

m_f , m_{snf} and m_w : mass fractions of fat, solids non-fat and water, respectively.

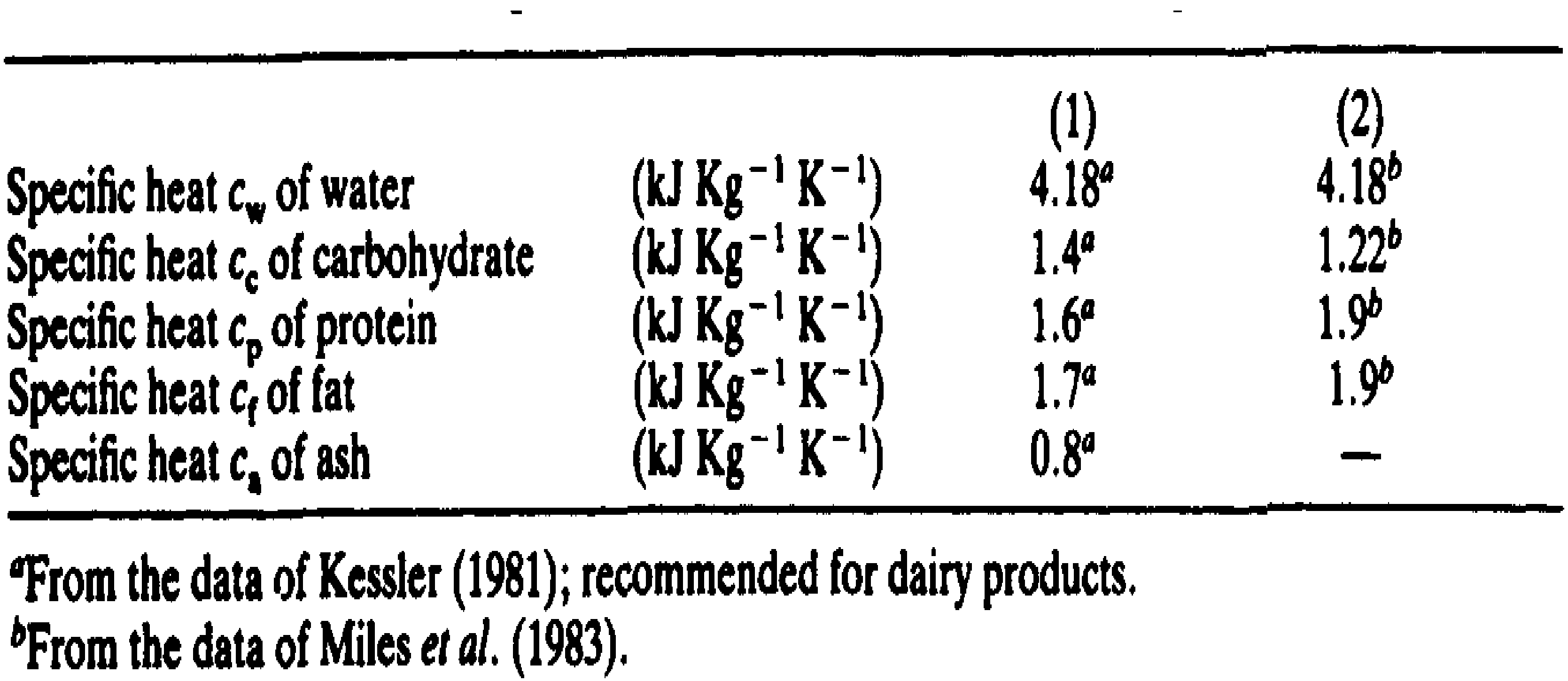
- If the approximate analysis for the material is available, the following equation can be used:

$$\underset{(water)}{m_w c_w} + \underset{(carbohydrate)}{m_c c_c} + \underset{(protein)}{m_p c_p} + \underset{(fat)}{m_f c_f} + \underset{(ash)}{m_a c_a}$$

Where; m_w , m_c , m_p , m_f and m_a the mass fractions of the respective components

c_w , c_c, c_p , c_f *and* c_a the specific heats of the respective components

Specific heat values for food components



		(1)	(2)
Specific heat c_w of water	(kJ Kg^{-1} K^{-1})	4.18[a]	4.18[b]
Specific heat c_c of carbohydrate	(kJ Kg^{-1} K^{-1})	1.4[a]	1.22[b]
Specific heat c_p of protein	(kJ Kg^{-1} K^{-1})	1.6[a]	1.9[b]
Specific heat c_f of fat	(kJ Kg^{-1} K^{-1})	1.7[a]	1.9[b]
Specific heat c_a of ash	(kJ Kg^{-1} K^{-1})	0.8[a]	—

[a] From the data of Kessler (1981); recommended for dairy products.

[b] From the data of Miles *et al*. (1983).

Enthalpy and latent heat

- Enthalpy (*H*), is a thermodynamic property, is the sum of the system's internal energy and the product of its pressure and volume
- Unit in SI system: J/kg,

in Imperial system: kcal/kg

Changes in enthalpy during heating and cooling operations are important; the change in enthalpy *ΔH* is given by:

$$H = U + pV$$

U= Internal energy

If the temperature of a substance has increased, it has gained heat; on the contrary, if its temperature has decreased, it has lost heat.

Enthalpy

- Changes in enthalpy during heating or cooling operations are important; The change in the enthalpy ΔH is given by

$$\Delta H = \Delta U + \Delta (pV)$$

$$\Delta H = \Delta U + p\Delta V + V\Delta p$$

Where Δ indicates the final minus the initial value. If the process takes place at constant pressure (i.e. $\Delta p = 0$), *then*

$$\Delta H = \Delta U + p\Delta V$$

From the first law of thermodynamics, $q = \Delta U + p\Delta V$, *then*

$$q = \Delta H$$

Latent heat

- The gain or loss of heat of a substance does not always cause a change in its temperature.
- In some cases, a gain or loss in internal energy causes a phase change without causing a temperature change in that substance.
- The heat that causes a change in the temperature of a substance is called "sensible heat".
- On the other hand, the heat that allows a substance to change phase without causing a change in its temperature is called "latent heat".

Latent heat

- e.g.:
- The heat required for water to change from liquid to vapor at its boiling point,
- The heat that must be removed for water at 0^oC to turn into ice at 0^oC
- In many food processes, there is a phase change.
- Phase change means energy change.
- These phases can be solid, liquid and gas.

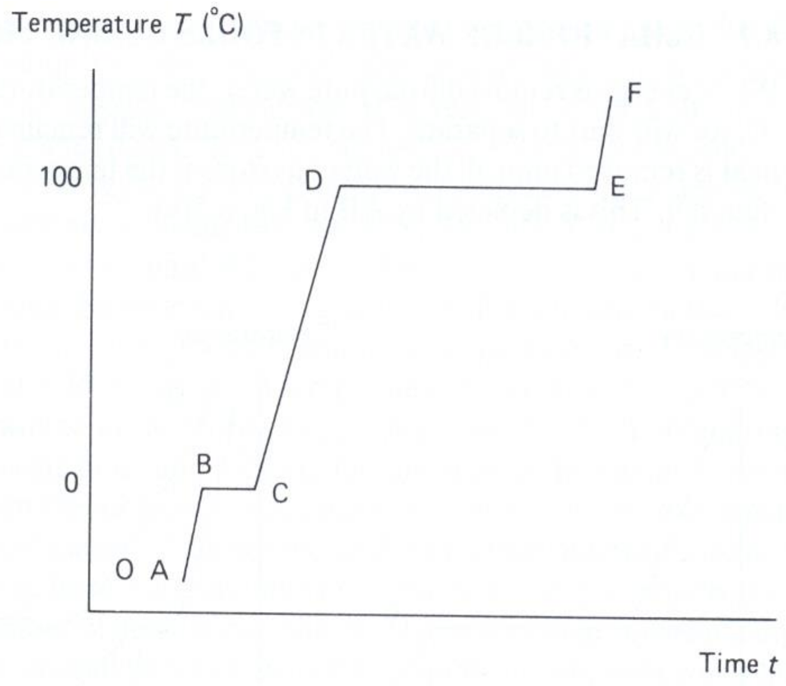
Latent heat

- in many food-processing operations, we encounter a change in phase; associated with these phase changes are energy changes.
- The phases involved are the solid, liquid and vapour phases.
- Water can exist as a solid, a liquid, a vapour or a combination

of these phases in equilibrium. If the pressure and temperature are fixed, it is

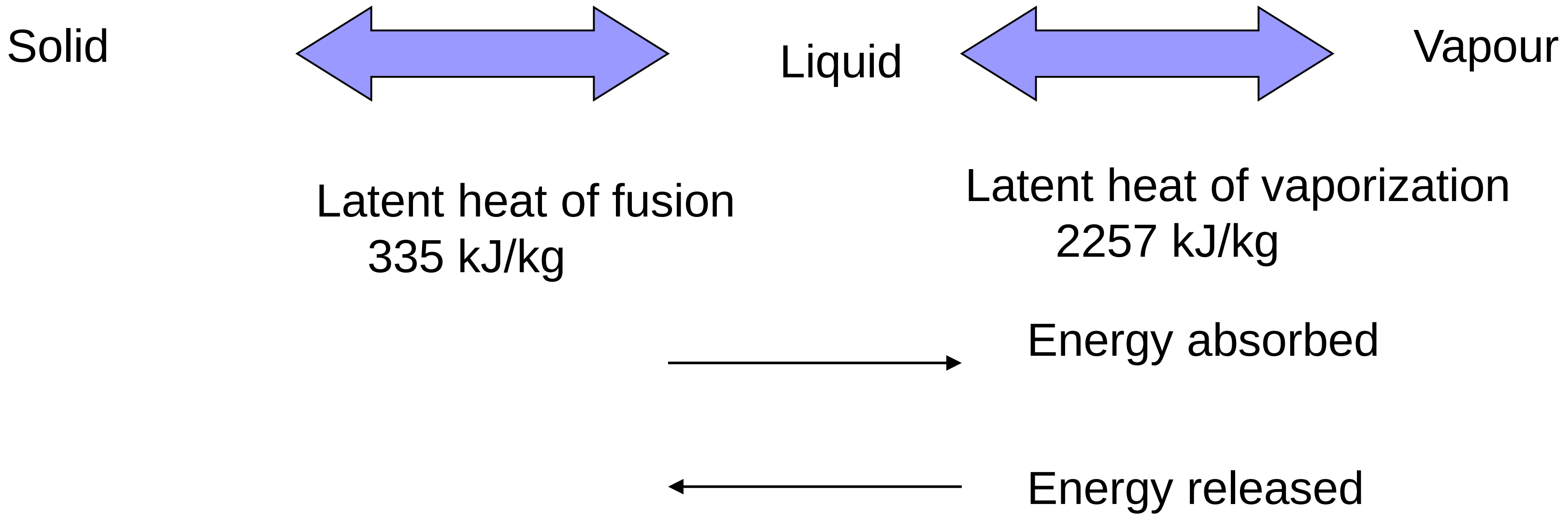
- If the pressure and temperature are fixed, it is possible to predict what state the water will be in.
- The most usual form that phase diagrams take is pressure plotted against temperature

- A: Frozen water at any temperature below 0 C
- AB: The region where the temperature rises, sensible heat
- B: Melting point of frozen water
- BC: Latent heat
- CD: region where temperature rises, sensible heat
- D: boiling point of water, saturated water
- DE: Latent heat
- E: Saturated steam
- EF: zone of rising temperature, overheated steam, sensible heat



Heating curve for water, during the transition from ice to superheated water at atmospheric pressure

For water at atmospheric pressure



Solid

Liquid

Vapour

Latent heat of fusion
335 kJ/kg

Latent heat of vaporization
2257 kJ/kg

→ Energy absorbed

← Energy released

Latent heat values for foods (fusion)

- H_L=335 x m_{water} (kJ/kg) changes from ice to liquid or inverse
- H_L = 2257 x m_{water} (kJ/kg) (changes from liquid to vapour or reverse

where;

335: freezing latent heat of water(kJ/kg)

m_{water} : mass fraction of water

*Latent heat is affected by the moisture content of the food.

Example: Calculate the total amount of heat that should be removed during the cooling of 200 kg of apples from 25^oC to -20^oC.

*moisture content of apple: 82%

*Freezing point of apple: -1^oC

Enthalpy-Composition data

- For processes taking place at a constant pressure, heat changes can be associated with enthalpy changes.
- Therefore, if the enthalpy of the food is known at two temperatures, e.g. +25 "C and -20 "C, the amount of heat removed is simply obtained from the difference in values.
- Such enthalpy changes will account for both sensible and latent heat values.
- It is possible to measure enthalpy as a function experimentally.
- Rha (1975a) have provided a good
- table listing the enthalpy-temperature data for a wide variety of foods over the range from -40 ^{o}F (-40 ^{o} C) to 40 ^{o}F (4.5 ^{o} C), as well as enthalpy-composition diagrams for bread, egg white, whole egg, fish and potato starch.

- When available, such data are extremely useful. Fig. shows such a diagram for lean sea fish muscle.
- Enthalpy is plotted against moisture content;
- the other variables are temperature and percentage of frozen water.
- Enthalpy changes are evaluated as follows:

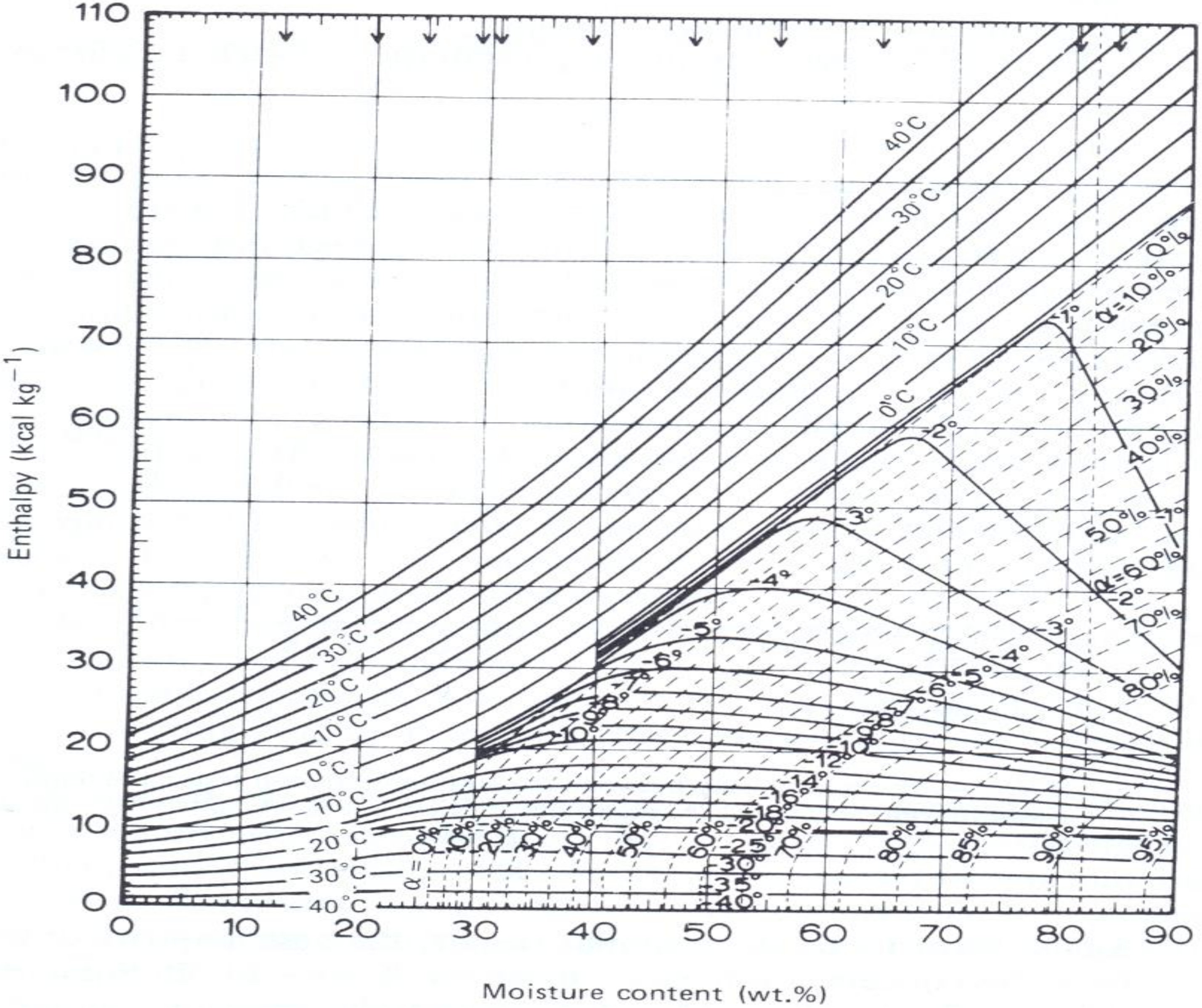


Fig. Enthalpy diagram for lean sea fish muscle, where α is the percentage of frozen water

- Fish with a moisture content of 80% at 25 ^{o}C would have an enthalpy value of 99.0 kcal/ kg. If this is reduced to -20 ^{o}C, the new enthalpy value is 10 kcal/ kg and the percentage of water frozen is 89%. Therefore,

  Enthalpy change: H_{25oC} –H_{-20oC}

$$99 – 10 = 89 \text{ kcal/kg}$$

Therefore, 89 kcal/kg needs to be removed to bring about this temperature change.

Thermal diffusivity(α)

- The thermal diffusivity a is the ratio of the thermal conductivity to the specific heat of the product multiplied by its density.
- The units of thermal diffusivity :m^2/s
- In physical terms, thermal diffusivity gives a measure of how quickly the temperature will change when it is heated or cooled.
- Materials with a high thermal diffusivity will heat or cool quickly; conversely, substances with a low thermal diffusivity will heat or cool slowly.
- Thus, thermal diffusivity is an important property when considering unsteady-state heat transfer situations.
- Thermal diffusivities can be determined experimentally or evaluated from a knowledge of the individual properties (Singh, 1982).

Thermal diffusivity(α)

- The thermal diffusivity of a substance is a value related to its thermal conductivity, specific heat and density and is calculated with the following equation:
  - $\alpha = \frac{k}{\rho c}$
- α = thermal diffusivity (m^2/s)
- k =thermal conductivity (j/s m K)
- ρ = density (kg/m^3)
- c = specific heat (J/kg K)

Thermal diffusivity

- The higher the thermal diffusivity, the higher the heat diffusion.
- The thermal diffusivity of metals are very high compared to the thermal diffusivity of liquids and gases.

- Therefore, metals heat up quickly and cool down quickly.

Thermal diffusivity

- The thermal diffusivity of water at 0^oC is $1.31x10^{-7}$ m^2/s, the thermal diffusivity coefficient of ice at 0^oC is $11.70x10^{-7}$ m^2/s
- According to these values, ice has a thermal diffusion coefficient approximately 9 times higher than water.
- This is why ice can heat and cool faster than water.
- The reason for the difference in freezing and thawing rates of foods is due to the different thermal diffusion coefficients of ice and water.