ENERGY BALANCES

Energy

- Energy was first hypothesized by Newton.

- Newton was the first who expressed kinetic and potential energies.

Energy

- Potantial,
- Kinetic,
- Chemical,
- Mechanical,
- Electrical

Energy cannot be measured directly.

Potantial energy

- Energy of an object due to its **height**.

- P.E. = $m\,g\,h$

Kinetic energy

- Energy of an object due to its **velocity**.

- K.E. = $\frac{1}{2} m v^2$

Internal energy

- Atoms and molecules move constatntly in random direction. Atoms vibrate, rotate and collide with each other.

↓

- Energies related to all these movements are called as the **internal energy**.

During processing of food;

- One or two forms of energy are predominant, the others can be omitted.

Example-1

- Depositing of sugar beets from conveyor to the tank
- Potantial and kinetic energy changes,
- Chemical end electrical energies do not change

<u>Example-2</u>

- During heating of tomato juice in a heat exchanger,

- Potantial and kinetic energy do not change,

- **<u>Internal energy</u>** changes as a result of change in temperature

Total energy of a system or an object;

Can be omitted!

- $E_{Toplam} = E_{KE} + E_{PE} + E_{Electrical} + E_{Manyetic} + E_{Chemical} + \ldots + E_{Internal}$

$$\boxed{E_{Toplam} = E_{KE} + E_{PE} + E_{Internal}}$$

Energy

- Not static, always in flux.
- Even under steady-state conditions, an object absorbs energy from its surroundings and at the same time emits energy to its surroundings at the same rate.
- When there is imbalance between the energy absorbed and emitted, the steady-state is altered, molecular energy in the system may increase or new compounds may be formed.

First law of thermodynamics (law of conservation of energy);

- In an isolated system, overall energy does not change.
- Indicating that the energy do not form or disappear.
- Only the energy in one form can be converted to another form.

Energy balance equation:

- determined as in the case of mass balances.

Energy balance equation;

- Energy in = energy out + accumulation

In steady-state,

- Accumulation will be zero.

Energy balance equation;

- Energy entering the system = Energy leaving the system

If the system involves only an exchange of energy between two components;

Energy gain by component 1	=	Energy loss by component 2

Energy balances are done for;

- Identifying areas where energy conservation can be done.

- In designing heating or cooling systems to ensure the right amount of **fluids** used for heat exchange and the right size of **equipment** used to achieve the processing objectives.

Enthalpy

Sum of **internal energy** and the **multiplication of pressure and specific volume**

$$H = E + PV'$$

H: Enthalpy, kJ/kg

E: Internal energy, kJ/kg

P: Pressure, kPa

V': Specific volume, m^3/kg

- When the enthalpy of an air in a room is described, then this enthalpy includes the **internal energy**.
- If a liquid enters and leaves the open system, then the enthalpy will be equal to the **multiplication of pressure and specific volume** (flow energy).

Enthalpy

- Enthalpy cannot be measured directly.
- Enthalpy values should always be given on the reference conditions (in particular temperature).
- For steam tables, reference temperature is $0^{o}C$.

Heat

- A form of energy.
- “Heat exchange occurs between a system and its surroundings because of **temperature difference**.
- Heat transfers from a hot object to a cold one.

- Heat is used in many food applications, particularly in cooking and preservation (pasteurization and sterilization).

- Common heat units are **calorie, kilo-calorie, BTU and joule**.

Heat (Q);

- The sign of Q shows the flux of heat.

If heat transfers from a system to its surroundings → ***Q* is negative**

if heat transfers from the surroundings into a system (heating of potato) → ***Q* is positive**

Specific heat

- Amount of heat gained or lost for a unit mass of a substance, accompanying a unit change in temperature of the substance but not involving with phase change.
- Specific heat of **solids** and **liquids** are constant over a fairly wide temperature range.
- Specific heat of **gases** varies with temperature.

c_p ve c_v değerleri;

- c_p and c_v are similar for solids and liquids.

- c_p and c_v are different for gases.

- Since most food processes are carried out **under constant pressure**, the specific heat values under constant pressure are used for food processing calculations.

Forms of heat

Sensible heat;
energy associated to change in the temperature of system or object (food)

Laten heat;
energy associated with phase transitions (no temperature changes)

Sensible heat of foods

$$Q = m\, C_p\, (\Delta T)$$

Q : Sensible heat gained by food, kJ

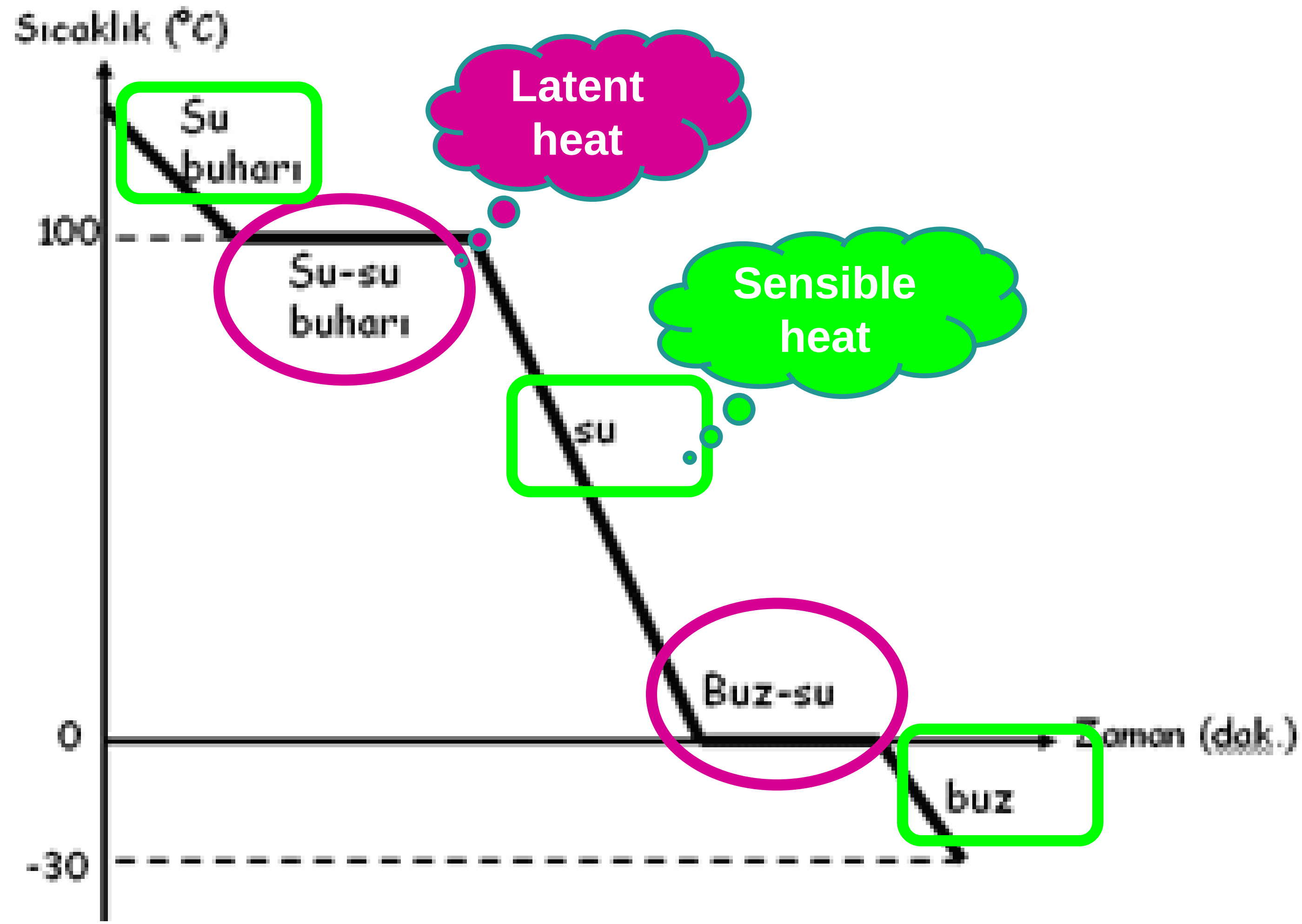
m : Mass of food, kg

C_p : Specific heat of food, kJ/kg °C

Δ T : Change in temp of food, °C

- **Example 4.1:** Calculate the enthalpy change during heating of 3 kg water from 20°C to 90°C.

Sensible and latent heat:



- If we continue to heat water, temperature of water will also increase and finally water boils (**Sensible heat**).
- If we still heat boiling water, water molecules will start to transfer to vapor phase. During this process, temperature of vapor will still be 100°C (just phase transition). In order to evaporate the water molecules, we need to give the **latent heat of vaporization**.

Latent heat of condensation is equal to *latent heat of evaporation*.

- Condensation is the phase change from vapor phase to liquid phase.

- If heat is removed from vapor, then distance between vapor molecules will decrease and vapor molecules will condensate in droplets. Heat removed during this process is called as **latent heat of condensation**.

- If water in liquid state changes to solid phase, heat released will be *latent heat of freezing*.

- During melting of a frozen material, the same amount of heat absorbed and this heat is called as *latent heat of fusion*.

- Boiling point of water depends on the pressure.
- At 1 atm, water boils at 100°C.
- If pressure is increased, then boiling point will also increase.
- **Latent heat of vaporization** of water also depends on boiling point of water.
- The relationship between pressure, boiling water and **latent heat of vaporization** is given in Table 4.1.

Pressure (atm)	**Boling point of water (°C)**	***Latent heat of vaporization* (kcal/kg)**
1	100	540
1.5	110	532.5
0.2	60	563

- **Example 4.2:** 3 kg of water at 20°C was boiled under 1.5 atm of pressure and 110°C, and then transformed to vapor. Calculate the enthalpy change for the vapor 110°C.

- **Example 4.3:** The temperature of 2 kg water at 20°C increases to 110°C after heating under 1.5 atmosphere constant pressure. After continuous heating, the temperature of the resulting vapor at 110°C increases to 125°C. The specific heat of vapor is **0.445 kcal/kg °C**.

a) Calculate the enthalpy change during transforming 2 kg water to vapor at 125°C.

b) Calculate the entalphy of vapor at 125°C.

- Final enthalpy (629.2) is not the enthalpy of vapor at 125°C.
- It is the total heat needed to transfer 1 kg water to 1 kg vapor at 125°C.
- If we want to calculate enthalpy of vapor at 125°C, we need to take into consideration of enthalpy of water between 0° and 20°C. The reference point in enthalpy calculation is 0°C.
  Q = (1 kg) (1 kcal/kg °C) (20 – 0)°C = 20 kcal
- Enthalpy of vapor at 125°C will be the sum of "20 + 629.2 = 649.2 kcal."

- **Example 4.4:** The ice at –10°C was melted by heating and then under normal atmospheric pressure, the resulting water molecules were transferred to vapor at 100°C. Calculate the enthalpy change during transforming 5 kg ice to vapor. The specific heat of ice is 0.5 kcal/kg °C and *latent heat of fusion* is 80 kcal/kg.

- **Example 4.5:** The fruit at 25°C is frozen to –20°C. The specific heat of fruit above freezing point is 0.95 kcal/kg °C and the freezing point of fruit is -3°C, the specific heat of fruit below freezing point is 0.460 kcal/kg °C and latent heat of freezing is 68 kcal/kg. Calculate the enthalpy change during freezing of 8 kg fruit from 25°C to –20°C.

Answer

- **Example 4.6:** 6 kg of water at 25°C was boiled to 104°C under 1.1 atm of pressure. And then, the steam was heated to 130°C.

a) Find out the enthalpy change in "kcals" during the heating of water at 25°C to vapor at 130°C.
b) Find out the enthalpy of vapor at 130°C in **SI** unit system by taking into consideration of enthalpy calculations for water.

Data

- latent heat of evaporation of water; 540 kcal/kg at 100°C, 532.5 kcal/kg at 110°C.
- specific heat of vapor, 1886 J/kg K at 125°C and 1891 J/kg K at 150°C.

Answer

- E = 3766 kcal (entalphy change from 25^{o}C to 130°C)

- $E_{130°C}$= 3916 kcal (entalphy at 130^{o}C)

Specific heat

- Amount of heat gained or lost for a unit mass of a substance, accompanying a unit change in temperature but not involving with phase change.

$$C_p = \frac{Q}{m\,(\Delta T)}$$

- Most solids and liquids have a constant specific heat over a fairly wide temperature range above freezing point.

- Specific heat of gases varies with temperature.

Specific heat of foods;

- Depends on **composition** and **mostly water content**.

- Since the food composition changes depending on many factors, most accurate way of calculating specific heat of foods is to do **experiment**.

- In practice, specific heat of foods is calculated using the equations, **if the composition of foods (mass fractions) is known,**

- One of the most important compositional compound of foods is **water**.
- Specific of heat of water in **liquid** and **solid** phase is very **different.**

Therefore, specific heat of foods,

- Above freezing point
- Below freezing point, are very **different.**

Above freezing point (Siebel equation)

$$C_p = 1\,m_s + 0.2\,(1 - m_s)$$

m_s : Mass fraction of water in food

1: Specific heat of water, kcal $kg^{-1}\,°C^{-1}$ or BTU $lb_m^{-1}\,°F^{-1}$

0.2: Specific heat of nonfat solids, kcal $kg^{-1}\,°C^{-1}$ or BTU $lb_m^{-1}\,°F^{-1}$

$1 - m_s$: Mass fraction of nonfat solids in food containing no fat

C_p: Specific heat, kcal $kg^{-1}\,°C^{-1}$ or BTU $lb_m^{-1}\,°F^{-1}$

Arranging the equation:

$$C_p = 1\ m_s + 0.2 - 0.2\ m_s$$

$$C_p = m_s - 0.2\ m_s + 0.2$$

$$C_p = (1 - 0.2)\ m_s + 0.2$$

$$\boxed{C_p = 0.8\ m_s + 0.2 \text{ (English, mks and cgs)}}$$

Arranging the equation ın SI unit system

$$C_p = 3.349\ m_s\ +\ 0.83736$$

$0.8\ (4.1868) = 3.349$

$0.2\ (4.1868) = 0.83736$

C_p : Specific heat above freezing point, kJ $kg^{-1}\ K^{-1}$

m_s : Mass fraction of water in food

Effect of fat content on specific heat:

- For the animal based products which contain considerable **amount of fat**, the specific heat of food should be estimated by taking into consideration of the **mass fraction of fat (F)**.

Specific heat of foods containing fats above freezing point

C_p = 0.4 F + 0.2 NFS + 1 M (English, mks and cgs)

C_p = 1.67472 F + 0.83736 NFS+ 4.1868 M (SI)

C_p: Specific heat of food containing considerable amount of fat above freezing point, kJ/kg K

F : Mass fraction of fat in food

NFS : Mass fraction of non-fat solid in food

M : Mass fraction of water in food

Taking into consideration of carbohydrate, protein and ash:

$$C_{p\ (food)} = 1.424\,\mathbf{C} + 1.549\,\mathbf{P} + 1.675\,\mathbf{F} + 0.837\,\mathbf{A} + 4.187\,\mathbf{M}$$

- $C_{p\ (food)}$: **kJ/kg K**

- **Note:** (1) C, P, F, A and M is denoted for carbohydrate, protein, fat, ash and water, respectively.

  (2) Numbers in front of mass fractions of food constituents is the actual specific heat of each constituent.

- **Example 4.7:** Calculate the specific heat of orange juice concentrate having a solid content of 45% in **SI** unit system.

Answer

- $C_{\text{orange juice}} = 0.64\ \text{BTU}/(\text{lb}_m\ °\text{F})$
- $C_{\text{orange juice}} = 0.64\ \text{cal}/(\text{g}\ °\text{C})$
- $C_{\text{orange juice}} = 0.64\ \text{kcal}/(\text{kg}\ °\text{C})$

- **Example 4.9:** Calculate the specific heat of beef roast containing 15% protein, 20% fat and 65% water in **SI** unit system.

Answer

- $C_{roast\ beef} = 0.76\ kcal/(kg\ °C)$
- $\mathbf{C_{roast\ beef} = 3181.4\ J/(kg\ K)}$

- **Example 4.10:** Calculate the specific heat of food containing 30% of carbohydrate, 10% of protein, no fat, 0.4% of ash, 56% of water in **SI** unit system.

Answer

$$C_{food} = 1.424\,C + 1.549\,P + 1.675\,F + 0.837A + 4.187\,W$$

$$C_{food} = 1.424\,(0.3) + 1.549\,(0.1) + 0.837\,(0.004) + 4.187\,(0.56)$$

- $\mathbf{C_{food} = 2.93\ kJ/(kg\ K)}$