Energy requirement for heating materials

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1. Energy requirement for heating materials

The amount of energy needed to heat 1 kg of a substance by 1°C is known as the effective heat capacity (also specific heat) of the substance. The effective heat capacity depends on the physical condition of the substance (solid, liquid or gas) and on the temperature and pressure. The effective heat capacity of most materials, and also water, is highest in the liquid state.

The amount of heat energy per kg and per °C increase in temperature that is the effective heat capacity or specific heat is constant and depends on the material, its physical condition and to a small extent on its temperature and pressure. The symbol cp is usually used to denote this (c for capacity and p for pressure = constant), if the process takes place at constant pressure which is usually the case in everyday life.

2. Energy requirement for heating water

What happens, when heat energy is introduced to water?

Three different cases can be noticed:

- ice
- water
- water vapour

2.1 Ice

On the introduction of heat the temperature of ice first rises. (The cp values of ice, water and steam are listed in the table). The cp of ice is so strongly dependant on temperature that under circumstances an average value will have to be calculated or estimated for the specific temperature range. The temperature dependen-ce of cp for water and water vapour is usually negligible. About 170 kJ of energy is required to heat 1 kg of ice from – 100°C to 0°C.

On continuing to apply energy to the ice, the temperature does not increase at all at first (2), but the ice melts. The more the energy applied the more water is formed and less ice remains. The amount of heat needed to completely melt 1 kg of ice at 0°C to water at 0°C is called melting heat or enthalpy of fusion (the term en-thalpy indicates that the process takes place under constant pressure), the symbol used is Delta HSm. The Delta HSm for water at 0°C is 334 kJ/kg.

Therefore a quantity of energy of 334 kJ is required to completely melt 1 kg ice at 0°C to 1 kg water at 0°C. This is almost double the quantity needed to heat it from -100°C to 0°C.

2.2 Water

If the application of energy is further continued, the temperature of water starts increasing till the boiling point is reached (100°C at normal pressure). (Taking a cp-value of 4.2 kJ/kg/°C, about 420 kJ of energy is required per kg of water). The temperature then remains constant if the application of energy is continued till all the water has evaporated and is now present only in the form of steam.

The quantity of heat needed to completely convert 1 kg of water at 100°C to water vapour at 100°C is called the heat of condensation or heat of evaporation or evaporation enthalpy, and the symbol used is Delta HV. The Delta HV of water at 100°C is 2256 kJ/kg. Delta HV is temperature dependant and decreases with increasing temperature to zero at the critical temperature. The pressure dependency of Delta HV is very small and usually negligible.

2.3 Water vapour

If the water vapour does not disperse into the air, but is e.g. discharged through pipes, the temperature can be increased at random above the boiling temperature (="boiling point").

3 Examples

3.1 Example 1

70 kg of ice at a temperature of -20°C is to be converted into water at 40°C. What is the amount of energy (heat) Q required for the process?

1. **Heating the ice to melting temperature (0°C):**

   Q1 = m (ice) * cp(ice) * (0°C - -20°C) = 70kg * 2.0kJ/kg/°C * 20°C = 2800 kJ

2. **Melting the ice at melting temperature:**

   Q2 = m(ice) * DeltaHSm(Wa.) = 70kg * 334kJ/kg = 23380 kJ

3. **Heating the water from 0°C to 40°C:**

   Q3 = m(wa.) * cp(wa) * (40°C – 0°C) = 70kg * 4.2kJ/kg/°C = 11760 kJ

Total amount of heat required:

Q = Q1 + Q2 + Q3 = 37940 kJ

Conversion to kWh (1 kWh = 3600 kJ):

37940 kJ = 10.54 kWh

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3.2 Example 2:

70 kg of water at 20°C is to be heated to 70°C. What is the quantity of energy (heat) Q will be required for the process?

Heating the water to boiling point (100°C):

Q = m(wa) * cp(wa) * (70°C – 20°C) = 70kg * 4.2kJ/kg/°C * 50°C = 14700 kJ

Conversion to kWh (1 kWh = 3600 kJ):

14700 kJ = 4.08 kWh

3.3 Example 3:

70 kg of water at a temperature of 40°C is to be converted to water vapour at 170°C. Determine the quantity of energy (heat) Q required for the process?

1. **Heating the water to boiling point (100°C):**

   Q1 = m(wa) * cp(wa) * (100°C – 40°C) = 70kg * 4.2kJ/kg/°C * 60°C = 17640 kJ

2. **Evaporating the water at boiling point:**

   Q2 = m(wa) * DeltaHV(wa) = 70kg * 2256kJ/kg = 157920kJ

3. **Heating the steam from 100°C to 170°C:**

   Q3 = m(steam) * cp (steam) * (170°C – 100°C) = 70kg * 2.0kJ/kg/°C * 70°C = 9800 kJ

Total heat required:

Q = Q1 + Q2 + Q3 = 185360kJ

Conversion to kWh (1 kWh = 3600 kJ):

185360 kJ = 51.49 kWh

The thermal capacity of ice, water and water vapour at different temperatures is listed in the following:

Temperature in °C thermal capacity cp in kJ/kg/°C

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Ice

°C	kJ/kg/°C
-10	1.38
- 60	1.64
- 31	1.86
- 25	1.93
- 15	2.00
- 5	2.06
- 2	2.10

Water

°C	kJ/kg/°C
0	4.22
10	4.19
20	4.18
40	4.18
60	4.18
70	4.19
80	4.20
90	4.21
100	4.22

Steam

110	2.01
120	2.00
150	1.98
200	1.96
250	1.98
300	2.00
400	2.05
500	2.12

4 Heating air

The density of air at 0°C is 1.293 kg/m^3, the specific thermal capacity 0.715 – 1.004 kJ/kg x K depending on the condition without water, that is dry.

Example

The thermal capacity of air is about 1.0

The weight of 1L air is approx. 1.3g = 1m^3 approx. 1.3 kg

This gives the increase at 1°C: 1.3KJ = 0.000367 kwh

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5 Heating of other materials

The thermal capacity of other materials at common surrounding temperatures are shown in the table

Material/substance	thermal capacity cp in kJ/kg/°C
Alcohol	2.46
Alcohol vapour	1.43
Iron	0.45
Aluminium	0.90
Zink	0.39
Copper	0.39
Sulfur	0.74
Mercury	0.14
Oakwood	2.40
Pinewood	2.40
Paper	1.20
Sand, dry	0.80
Glass	0.80
Rubber	1.40
Compost (dry)	1.90
Organic substance	1.70
Mineral substance	0.70

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Example:

1000 kg decomposition material comprising of 65% water and 35% dry mass. 75% of the dry mass is organic matter and 25% mineral substances. The decomposition material is to be heated from 20°C to 70°C.

- m_w 65.000%
- m_{org} 26.25%
- mmin 8.75%

Q1 = m_w * cp(water) **Δ**T = 650*4.18*(70 – 20) = 135,850 KJ

Q2 = m_{org} * cp(org. substance) * ΔT = 262.5*1.7*(70 – 20) = 22,312 KJ

Q3 = m_{min} * cp(min substance) * ΔT = 87.5*0.7* (70 – 20) = 3.063 KJ

Q = Q1 + Q2 + Q3 = 135,850 + 22,312 + 3,063 = 161,225 KJ

Conversion to kWh (1 kWh = 3600 kJ):

161,225 kJ = 44.78 kWh

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