Energy

1 Introduction to Energy

One of the most fundamental laws of nature is the **conservation of energy principle**. In fact, this is the first law of thermodynamics. Energy can not be created or destroyed. It can only change form. But what is energy? That's what we'll look at in this chapter.

There are multiple types of energy (think of kinetic energy, potential energy, thermal energy, and so on). The sum of all these energy types forms the **total energy** E. The total energy per unit mass is $e = E/m$ (with m the mass of the system).

All energy types can be split up in two groups, being the macroscopic types and the microscopic types. **Macroscopic** forms of energy depend on the reference frame. Examples are kinetic energy and potential energy. **Microscopic** forms of energy are related to the molecular structure of a system. The sum of all microscopic forms of energy in a system is called the **internal energy** U.

2 Macroscopic Energy

Let's take a closer look at the macroscopic forms of energy. We already mentioned **kinetic energy**. Its magnitude for a particle moving with velocity ν can be found using

$$KE = \frac{1}{2}m\nu^2, \qquad ke = \frac{1}{2}\nu^2. \tag{2.1}$$

Note that, next to the total kinetic energy KE, we have also mentioned the kinetic energy per unit mass ke. The **potential energy** due to a gravitational field can be found using

$$PE = mgz, \qquad pe = gz. \tag{2.2}$$

If we ignore other more complicated types of energy (like electrical energy, magnetic energy, etcetera), we can find the total energy to be

$$E = U + KE + PE = U + \frac{1}{2}m\nu^2 + mgz, \qquad e = u + ke + pe = u + \frac{1}{2}\nu^2 + gz. \tag{2.3}$$

3 Microscopic Energy

Now let's take a closer look at the microscopic forms of energy. To do that, we have to look at the molecules of a substance. These molecules move. The kinetic energy associated with this is the **sensible energy**.

Internal forces act between molecules. If sufficient energy is added, these internal forces are overcome. This may cause the substance to change its phase (for example from liquid to gas). When the phase changes back, energy is released again. This energy, related to the phase, is called the **latent energy**.

In real life, we usually refer to sensible and latent energy as heat. However, in thermodynamics we use the term **thermal energy** (to prevent confusion).

Finally there are also **chemical energy**, associated with bonds within a molecule, and **nuclear energy**, associated with the nucleus of the atom itself. Although the magnitude of these energies can be big, they are generally hard to access.

4 Energy Transfer

Energy can be transferred between systems in multiple ways. **Heat** is the form of energy that is transferred between systems due to a temperature difference. If there is no heat transfer in a process, then the process is an **adiabatic process**. Heat can be transferred by three mechanisms. In **conduction** the transfer occurs due to interaction between adjacent particles. **Convection** is the heat transfer between a solid surface and an adjacent moving fluid. Finally **radiation** is the transfer of energy due to the emission of electromagnetic waves.

The **work** W is the energy transfer caused by a force acting through a distance. Work done per unit time is called **power**. Usually the amount of work performed can be calculated using

$$W = \int_1^2 F\,ds, \tag{4.1}$$

where s is the distance moved. But sometimes there isn't a clear force. When a shaft is rotating, due to a torque T, the amount of work done is equal to

$$W_{shaft} = \int_1^2 T\,d\phi, \tag{4.2}$$

where ϕ is the angle over which the shaft is rotated. Another example is a spring. Here the force depends on the displacement, according to $F = kx$. So now we have as work done

$$W_{spring} = \int_1^2 kx\,dx = \frac{1}{2}k\left(x_2^2 - x_1^2\right). \tag{4.3}$$

The last way in which energy can be transferred is by a mass flow. Let's consider the case where an amount of mass enters the system. This mass has internal energy. Therefore the total energy of the system rises. Identically, when mass is removed, the total energy decreases.

5 Mechanical Energy

Mechanical energy is the form of energy that can be converted to work completely. While kinetic and potential energy are types of mechanical energy, thermal energy is not.

Now let's consider pressure. Pressure itself isn't an energy. But it can produce work, called **flow work**. The magnitude of flow work (per unit mass) can be found using P/ρ. The mechanical energy per unit mass therefore becomes

$$e_{mech} = \frac{P}{\rho} + \frac{1}{2}\nu^2 + gz. \tag{5.1}$$

6 Performance

The **efficiency** of a system is defined as

$$\eta = \text{efficiency} = \frac{\text{Desired output}}{\text{Required input}} = 1 - \frac{\text{Loss}}{\text{Required input}}. \tag{6.1}$$

We can think of awfully many types of efficiencies. Examples are the **combustion efficiency** and the **mechanical efficiency**. These are defined as

$$\eta_{combustion} = \frac{\text{Heat released during combustion}}{\text{Heating value of the fuel burned}}, \qquad \eta_{mechanical} = \frac{\text{Mechanical energy output}}{\text{Mechanical energy input}}. \tag{6.2}$$

Sometimes multiple efficiencies need to be combined (multiplied) to find the **overall efficiency** of a system. This efficiency is an indication of how well the system performs its job.