FIRST LAW of THERMODYNAMICS – Open Systems

An Open System is one where mass crosses the boundary of the system.
They may be divided into two situations: –

Unsteady Flow systems – where the mass in/out does **not** equal the mass out/in; or

Steady Flow systems where mass flow in equals mass flow out.

In unsteady flow systems parameters such as pressure, mass, temperature etc. will change with time. (hence 'unsteady')

In steady flow systems parameters such as pressure, mass, temperature etc. will remain constant with time. (hence 'steady')

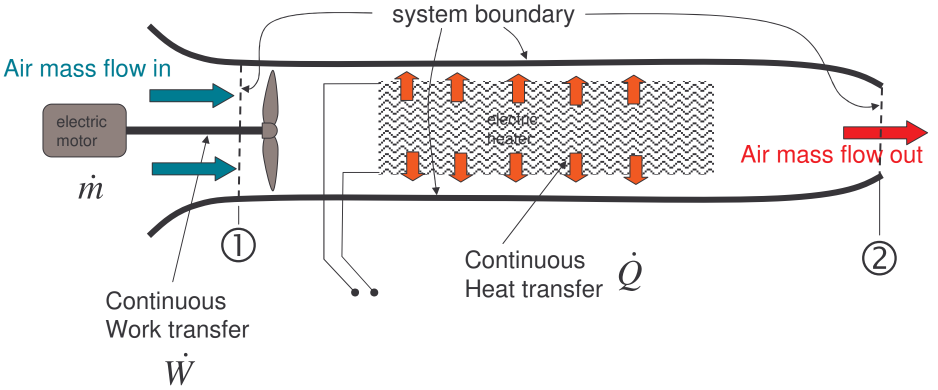
In most real systems both situations are present – and typically when a system goes from one steady state condition to another there is an unsteady period between them. This is why, when testing or experimenting, we usually have wait for a while until steady state conditions are achieved before we can take reliable measurements.
e.g. an engine going from 'idle' to 'full power'.

With closed systems the time taken for heat or work to transfer in to or out of the system was not very important (although we noted that it often characterises certain processes).

In steady flow systems there will be a definite rate at which heat and/or work transfers in to or out of the system.

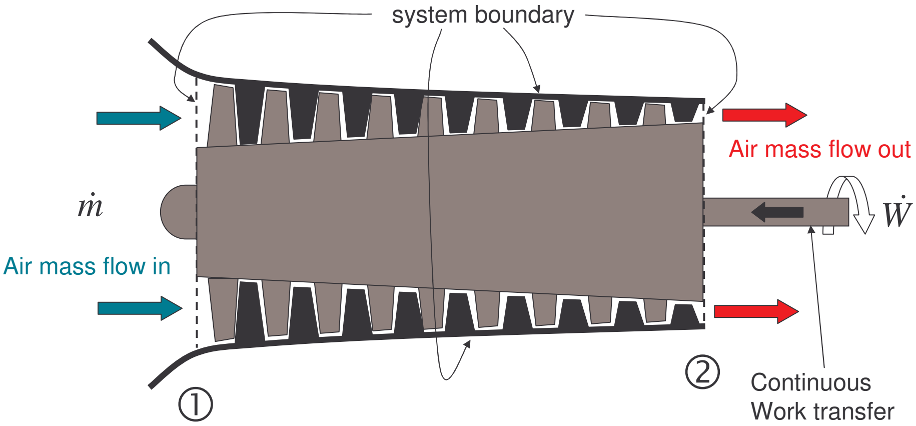
Examples of Steady Flow systems

1. A room air heater or hair dryer



Examples of Steady Flow systems

2. The Compressor of a Gas Turbine

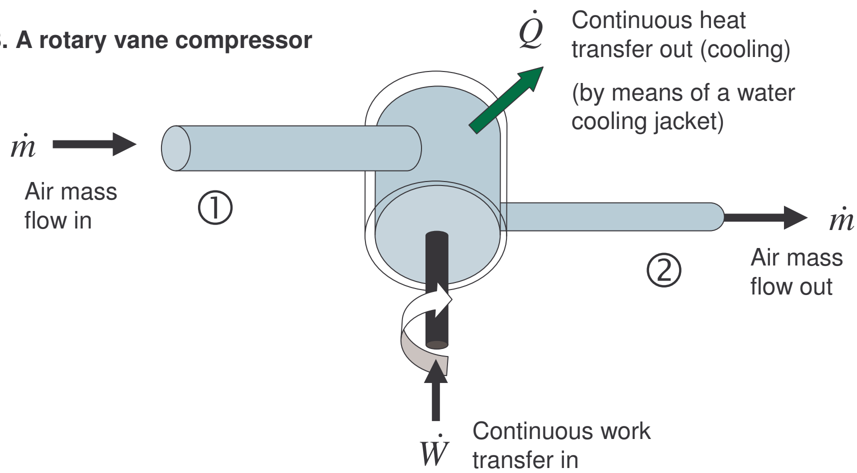


In this case there is little or no heat transfer from the air as it passes through the compressor (an adiabatic process)

$$\dot{Q} = 0$$

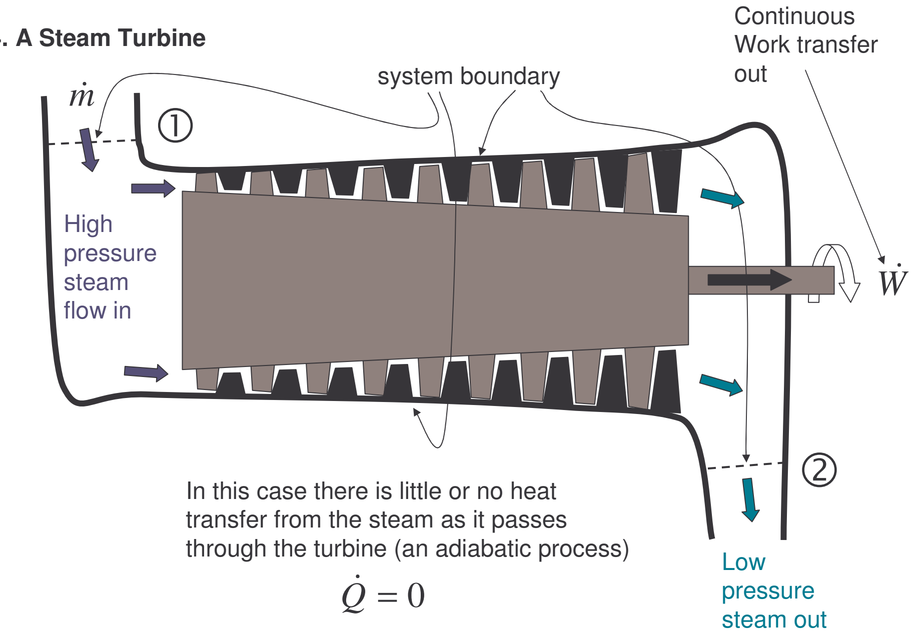
Examples of Steady Flow systems

3. A rotary vane compressor

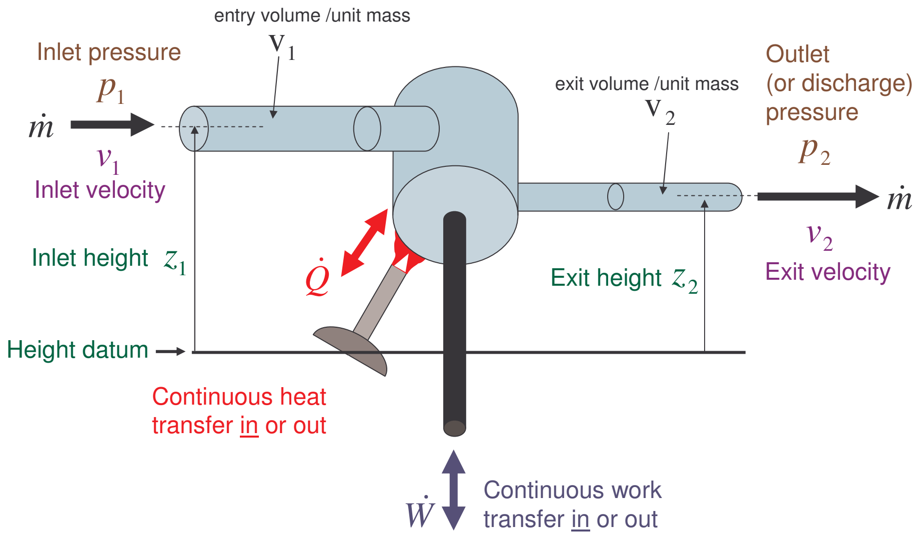


Examples of Steady Flow systems

4. A Steam Turbine



The Generalised Steady Flow system



If we have an open system, with mass continuously entering and leaving - three other forms of energy are carried in to or out of the system by virtue of the mass entering or leaving: they are:

Kinetic Energy $= \frac{1}{2} m v^2$

Potential Energy $= mgz$

and the energy required to 'force' mass in to (and out of) the system against the system's (and surroundings') pressure.

$$work / kg = pressure \times specific\ volume\,(in\ or\ out) = p\mathrm{v}$$

$$\therefore \text{for mass } m, \quad \text{energy} = mp\mathrm{v}$$

It follows that as well as changing the internal energy ($\boldsymbol{U}$) of the working fluid, its KE, PE and pV energy can also change because of the work and heat transfer in to or out of the system

For mass $\boldsymbol{m}$ entering and leaving the system:

$$change\ \ in\ \ KE = \tfrac{1}{2} m({v_2}^2 - {v_1}^2)$$

$$change\ \ in\ \ PE = mg\,(z_2 - z_1)$$

$$change\ \ in\ \ p\mathrm{V} = m(p_2\mathrm{v}_2 - p_1\mathrm{v}_1)$$

$$change\ \ in\ U = m(u_2 - u_1)$$

$$Q_m + W_m = \tfrac{1}{2} m({v_2}^2 - {v_1}^2) + mg\,(z_2 - z_1) + m(p_2\mathrm{v}_2 - p_1\mathrm{v}_1) + m(u_2 - u_1)$$

dividing each term by time to obtain rates of energy transfer and mass flow:

$$\dot{Q} + \dot{W} = \dot{m}[\tfrac{1}{2}({v_2}^2 - {v_1}^2) + g(z_2 - z_1) + (p_2\mathrm{v}_2 - p_1\mathrm{v}_1) + (u_2 - u_1)]$$

or $$\dot{Q} + \dot{W} = \dot{m}[\tfrac{1}{2}({v_2}^2 - {v_1}^2) + g(z_2 - z_1) + (\underline{p_2\mathrm{v}_2 + u_2}) - (\underline{p_1\mathrm{v}_1 + u_1})]$$

Because a fluid will always have a temperature and pressure at entry and exit – we combine the last two terms - to obtain the 'composite' property 'enthalpy':
(which we defined earlier under the section on Properties of Fluids)

$$h = p\mathrm{v} + u$$

we can write the equation very compactly as:

$$\dot{Q} + \dot{W} = \dot{m}\,\Delta\,[\tfrac{1}{2}v^2 + gz + h]$$

This is known as the steady flow energy equation (SFEE)

Δ means the 'difference in' and is always 'final'-'initial' or 'exit'-'entry'

$$\dot{Q} + \dot{W} = \dot{m}\,[(\frac{v_2^{\,2} - v_1^{\,2}}{2}) + g(z_2 - z_1) + (h_2 - h_1)]$$

In **Thermodynamics** because we are often using gases which are relatively low density fluids, and because the inlet and outlet velocities and heights are often similar we can often simplify the SFEE to:

$$\dot{Q} + \dot{W} = \dot{m}\,\Delta\,h$$

$$or \quad \dot{Q} + \dot{W} = \dot{m}\,(h_2 - h_1)$$

This is known as the simplified steady flow energy equation (SSFEE).

In **Fluid Dynamics** because we are often using liquids which are relatively high density fluids, and are often not transferring heat to or from the liquid or changing its internal energy content we can often simplify the SFEE to:

$$\dot{W} = \dot{m}\,\Delta\,[\tfrac{1}{2}v^2 + gz + p\mathrm{v}]$$

(We'll meet this form of the SFEE again when we study liquid flow in pipes and pumps.)