DTU

47201 Engineering thermodynamics

Lecture 3a: First law for open systems (Ch 4.13-4.16)

Review: Real world thermodynamics example

https://www.youtube.com/watch?v=gOMibx876A4

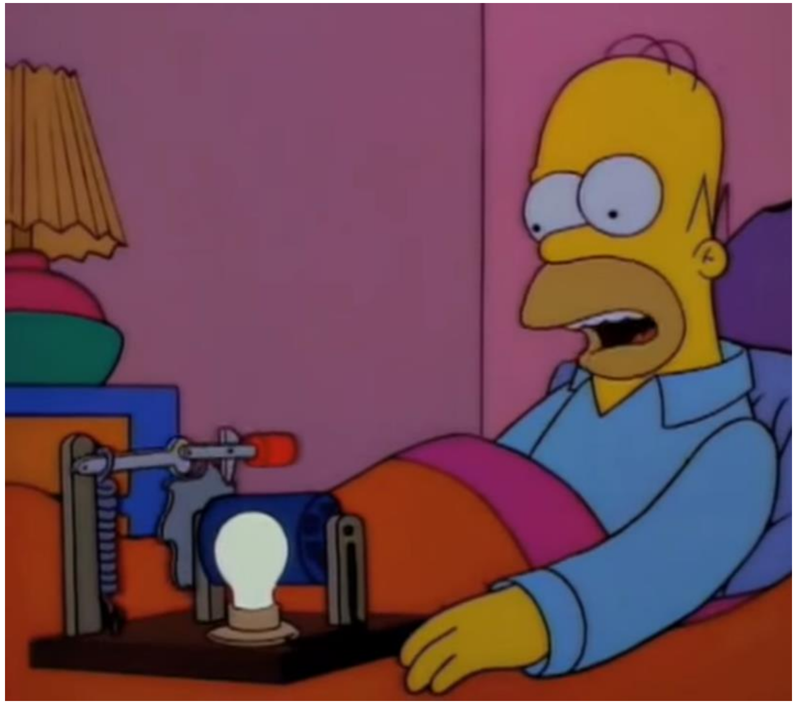
Did Lisa violate the laws of thermodynamics?

Given:

- Perpetual motion machine – started with some initial kinetic energy
- There was a light bulb – some work output

@ *t* = 0 $E_0 = KE_0 - \dot{W}_{light}dt$

So the kinetic energy should reduce with time due to the work to power the light

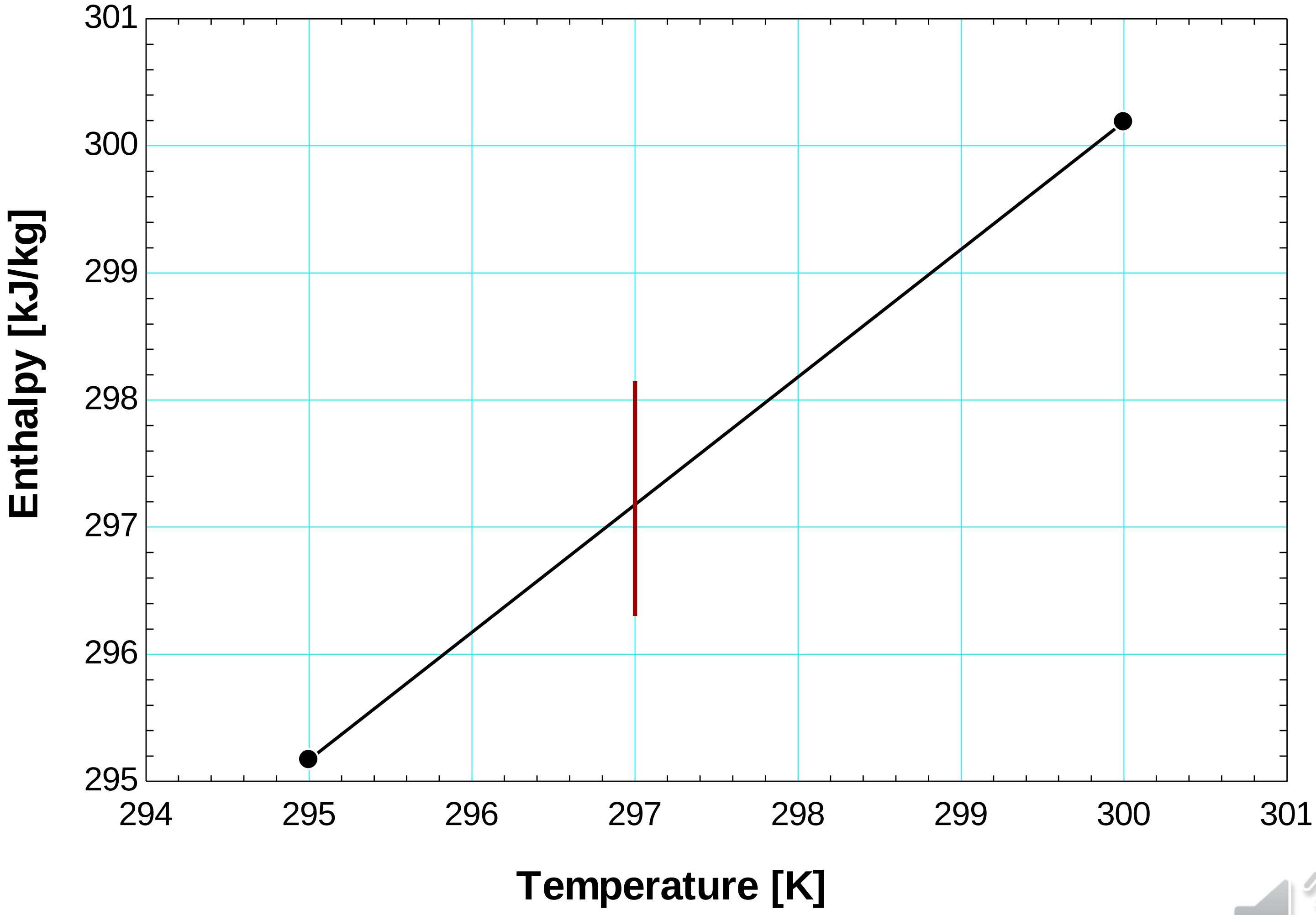


However, Homer says that it keeps going faster – so the kinetic energy keeps increasing. Therefore, Lisa has violated the first law of thermodynamics

Interpolating properties from tables

- You will often need properties at conditions (temperature, pressure, etc.) that are not given in the tables. When that happens, you need to interpolate values
  – Tables are set up to give properties at small enough intervals that linear interpolation gives an excellent estimate of the real values

- The technique is to fit a line between two points and find the intermediate value



Interpolation example

Find the enthalpy, *h*, of air at 297 K

– From Appendix 7: Ideal Gas Properties for Air we get:

T, K	h, kJ/kg	P_r	u, kJ/kg	v_r	s^o, kJ/kgK
200	199.97	0.3363	142.56	1707.0	1.29559
210	209.97	0.3987	149.69	1512.0	1.34444
220	219.97	0.4690	156.82	1346.0	1.39105
230	230.02	0.5477	164.00	1205.0	1.43557
240	240.02	0.6355	171.13	1084.0	1.47824
250	250.05	0.7329	178.28	979.0	1.51917
260	260.09	0.8405	185.45	887.8	1.55848
270	270.11	0.9590	192.60	808.0	1.59634
280	280.13	1.0889	199.75	738.0	1.63279
285	285.14	1.1584	203.33	706.1	1.65055
290	290.16	1.2311	206.91	676.1	1.66802
295	295.17	1.3068	210.49	647.9	1.68515
300	300.19	1.3860	214.07	621.2	1.70203

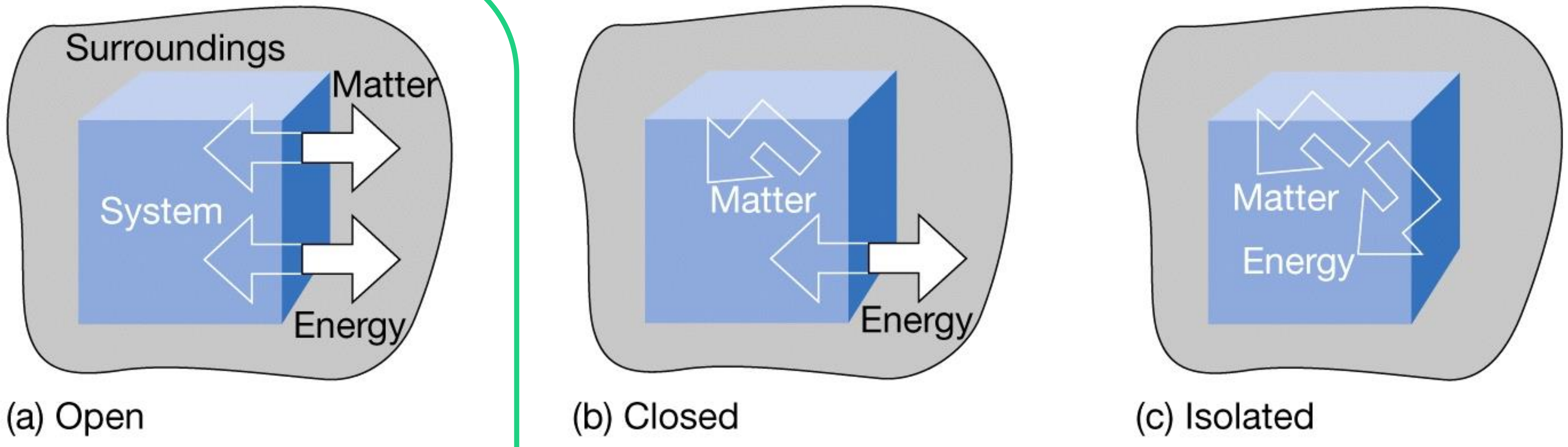
- Let's call point *1* 295 K and point *2* 300 K. Then the equation of the line will be:

$$h(T) = \frac{h_2 - h_1}{T_2 - T_1}(T - T_1) + h_1$$

- Then for a temperature of 297 K we can calculate the enthalpy

$$h(297\ K) = \frac{300.19\ \frac{kJ}{kg} - 295.17\ \frac{kJ}{kg}}{300\ K - 295\ K}(297\ K - 295\ K) + 295.17\frac{kJ}{kg} = 297.18\frac{kJ}{kg}$$

Open systems

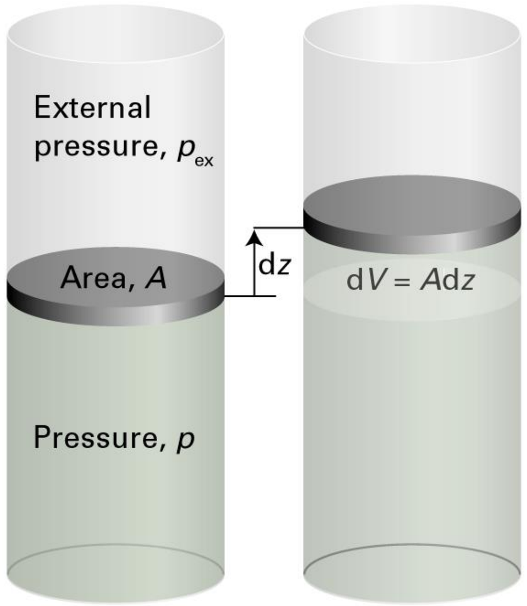


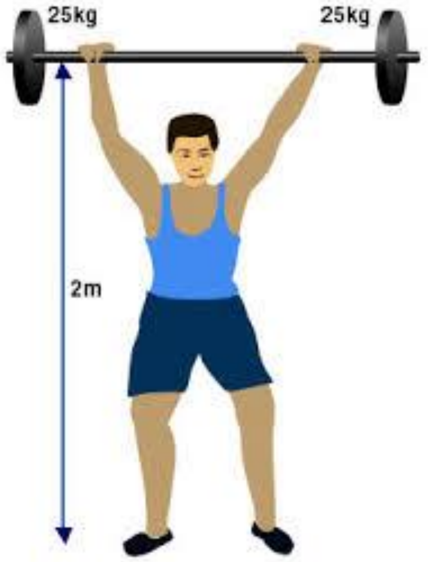
Control volume

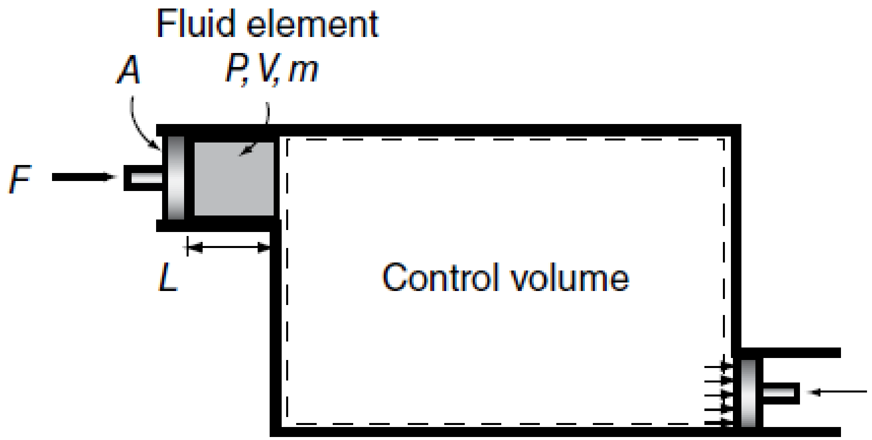
Control mass

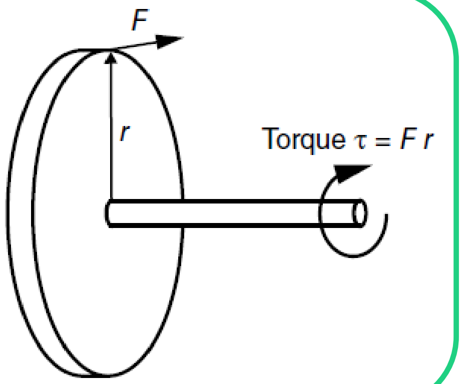
- Rather than a control mass, we have a control volume where mass enters and exits
- There can be heat and work interaction with the surroundings

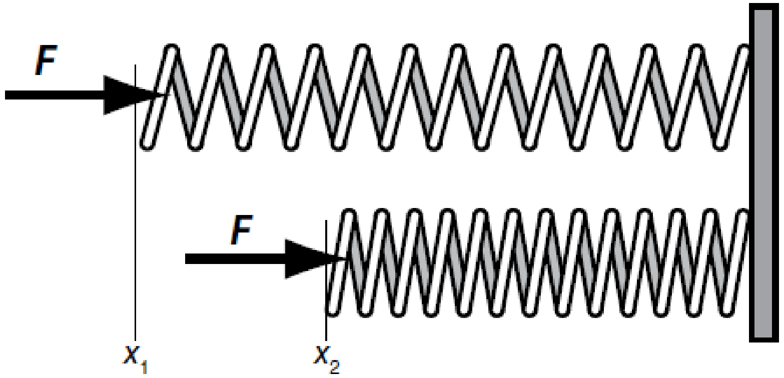
Types of work

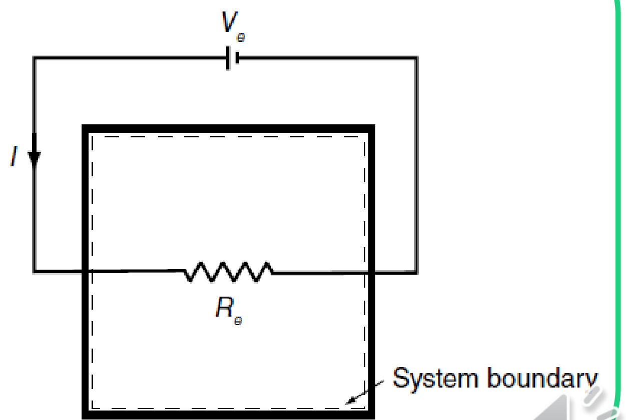








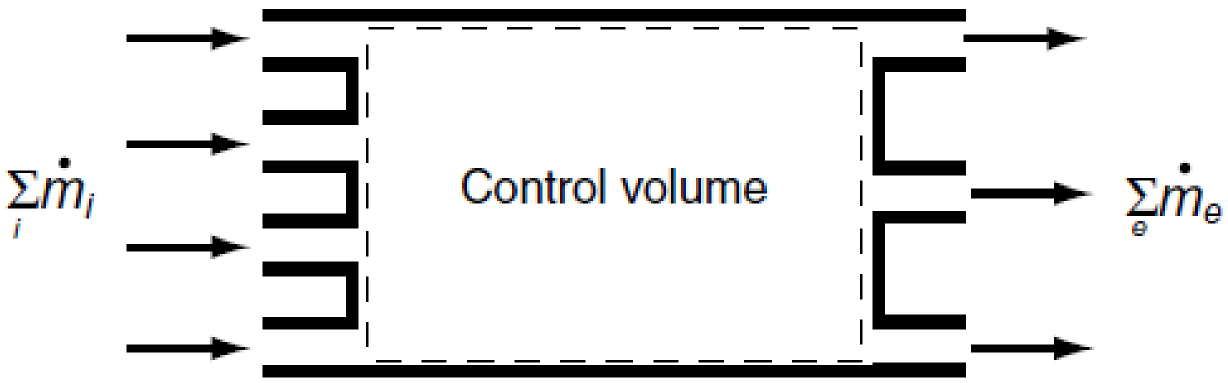




Open systems – mass balance

- The difference between an open and closed system is that there is a mass flow into and out of the control volume
  - There will be flow work and a mass balance is also required

- We will focus on steady state operation where the flow and work interactions have gone on long enough that the control volume remains constant with time



$$\dot{m} = \rho\, V\, A_c$$

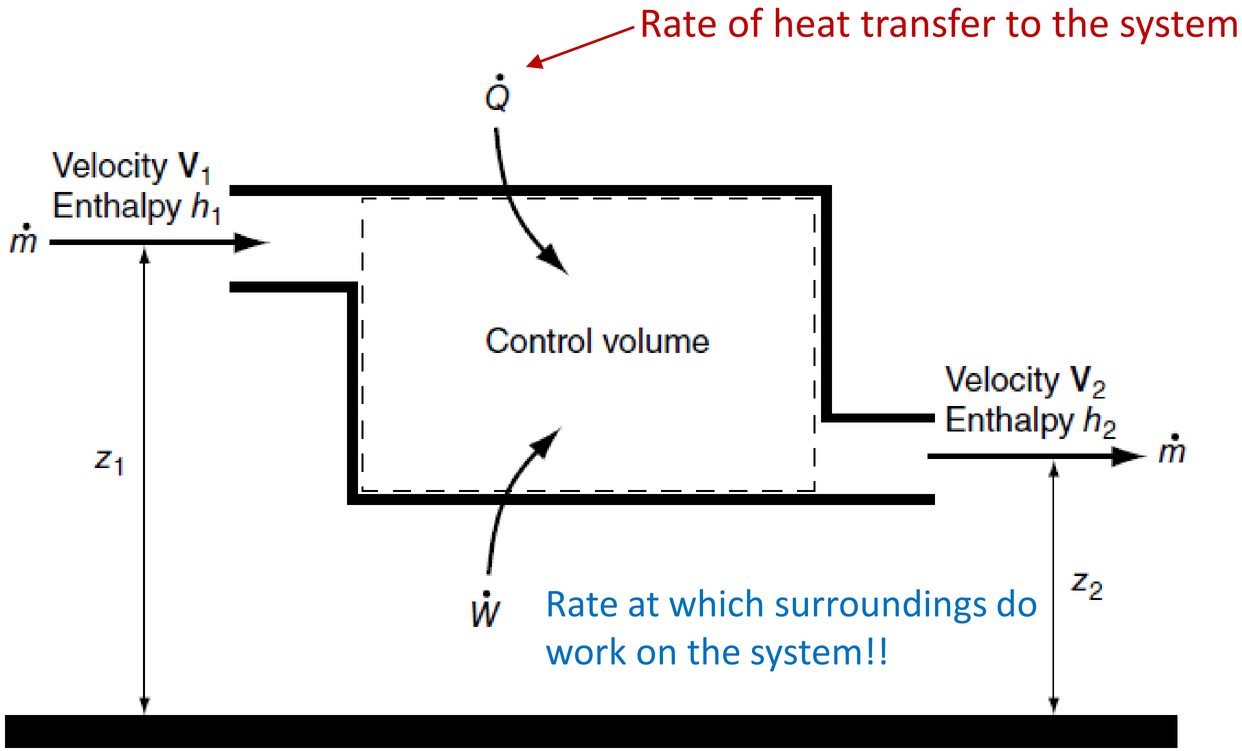
Where $\dot{m}$ is mass flow rate, ρ is the fluid density, V is the average velocity and A_c is the cross sectional area.

$$\sum \dot{m}_i = \sum \dot{m}_e$$

Applying the 1st Law to a single inlet/single outlet control volume

- The energy balance concept for an open system is exactly the same as for a closed system – we just need to account for mass flow

- At steady state, mass flowing into the system equal the mass flowing out and the energy entering the control volume is the same as the energy leaving the control volume



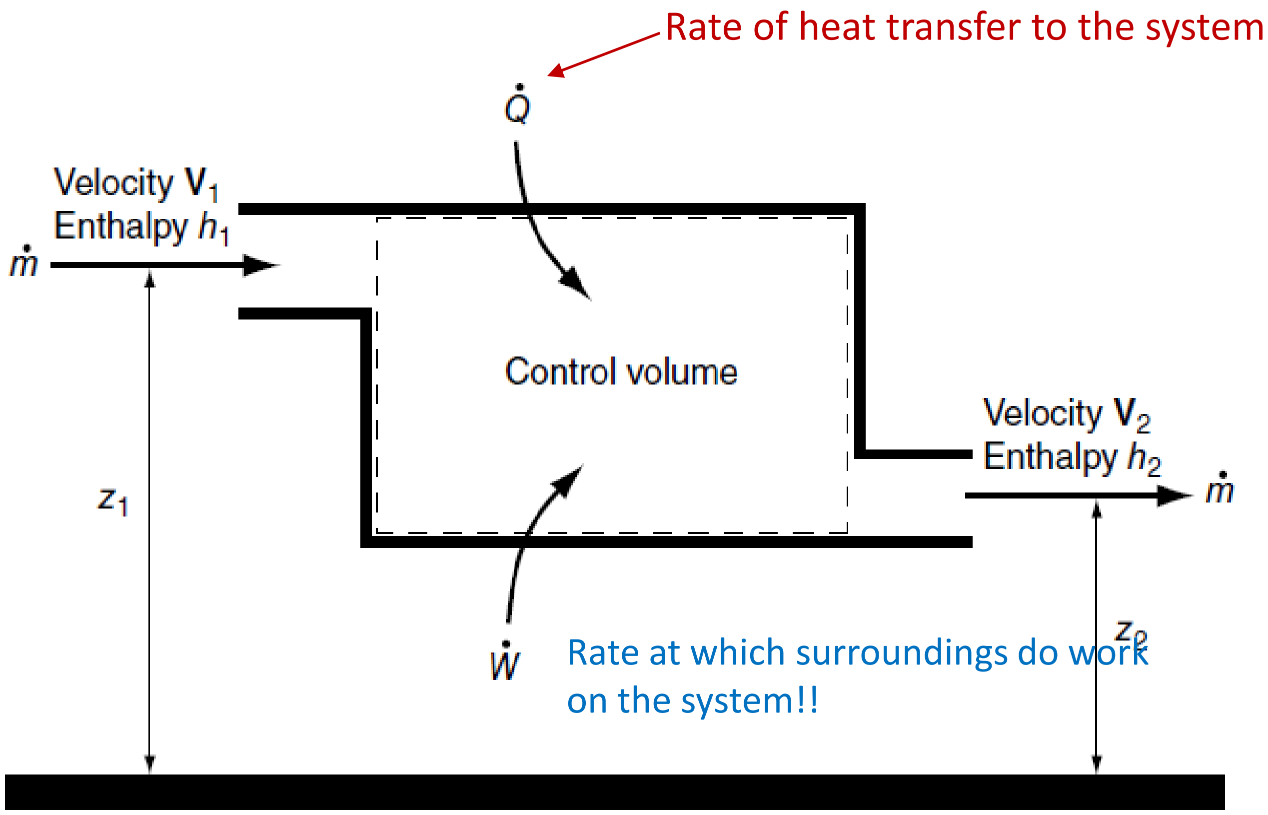
$$\frac{dE_{in}}{dt} = \frac{dE_{out}}{dt}$$

1^{st} Law energy balance: single inlet/single outlet control volume

- At steady state, the energy in is the same as the energy out. Accounting for all forms over energy entering and exiting the system gives the energy balance for an open system

- For a single inlet, single outlet $\dot{m}_{in} = \dot{m}_{out} = \dot{m}$

$$\dot{Q}_{in} + \dot{W}_{in} + \dot{m}\left(u + P\,v + \frac{V^2}{2} + gz\right)_{in} = \dot{Q}_{out} + \dot{W}_{out} + \dot{m}\left(u + P\,v + \frac{V^2}{2} + gz\right)_{out}$$



Enthalpy

- Enthalpy a property that is convenient to use when analyzing open systems. It is referred to as *h* for specific enthalpy and *H* for total enthalpy. The definition of specific enthalpy is given by Eq. 4.48

$$h = u + P\,v$$

- There is a separate specific heat that corresponds to enthalpy and that is the specific heat at constant pressure, c_p. It is defined in Eq. 4.58 as

$$c_p \equiv \left(\frac{\partial h}{\partial T}\right)_p$$

- When you want to calculate the change in internal energy, use c_v and when you want to calculate the change in enthalpy, use c_p

1^{st} Law energy balance using enthalpy

- The first law for an open system is usually stated in terms of enthalpy, where we substitute $u + P\,v = h$

- Then for a single inlet and a single outlet, the energy balance becomes:

$$\dot{Q}_{in} + \dot{W}_{in} + \dot{m}\left(h + \frac{V^2}{2} + gz\right)_{in} = \dot{Q}_{out} + \dot{W}_{out} + \dot{m}\left(h + \frac{V^2}{2} + gz\right)_{out}$$

Problems 3a

4.60

4.66

4.68

4.82

Problems 3a - solutions

4.60 Heater power is 80.9 kW

4.66 0.646 kg/s

4.68 311 K

4.82 Heat loss is 9.83 kW