ESO 201A: Thermodynamics

2016-2017-I semester

Energy Analysis of Closed Systems: part 3

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Learning objective

- Examine the moving boundary work or $P\,dV$ work commonly encountered in reciprocating devices such as automotive engines and compressors.
- Identify the first law of thermodynamics as simply a statement of the conservation of energy principle for closed (fixed mass) systems.
- Develop the general energy balance applied to closed systems.
- Define the specific heat at constant volume and the specific heat at constant pressure.
- Relate the specific heats to the calculation of the changes in internal energy and enthalpy of ideal gases.
- Describe incompressible substances and determine the changes in their internal energy and enthalpy.
- Solve energy balance problems for closed (fixed mass) systems that involve heat and work interactions for general pure substances, ideal gases, and incompressible substances.

Energy balance for closed systems

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc., energies}}} \quad \text{(kJ)}$$

Energy balance for any system undergoing any process

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt}_{\substack{\text{Rate of change in internal,} \\ \text{kinetic, potential, etc., energies}}} \quad \text{(kW)}$$

Energy balance in the rate form

The total quantities are related to the quantities per unit time is

$$Q = \dot{Q}\,\Delta t, \quad W = \dot{W}\,\Delta t, \quad \text{and} \quad \Delta E = (dE/dt)\Delta t \quad \text{(kJ)}$$

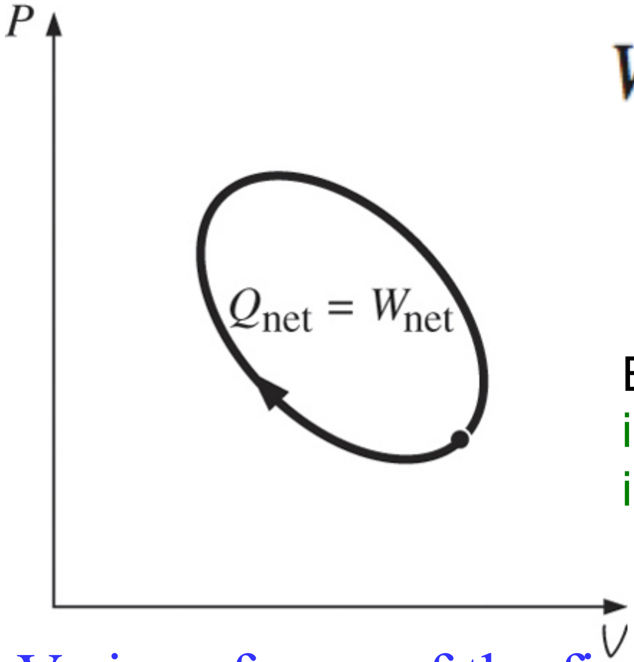
$$e_{in} - e_{out} = \Delta e_{system} \quad \text{(kJ/kg)}$$

Energy balance per unit mass basis

$$\delta E_{in} - \delta E_{out} = dE_{system} \quad \text{or} \quad \delta e_{in} - \delta e_{out} = de_{system}$$

Energy balance in differential form

Energy balance for closed systems



$$W_{net,out} = Q_{net,in} \quad \text{or} \quad \dot{W}_{net,out} = \dot{Q}_{net,in}$$

$$Q = Q_{net,in} = Q_{in} - Q_{out}$$
$$W = W_{net,out} = W_{out} - W_{in}$$

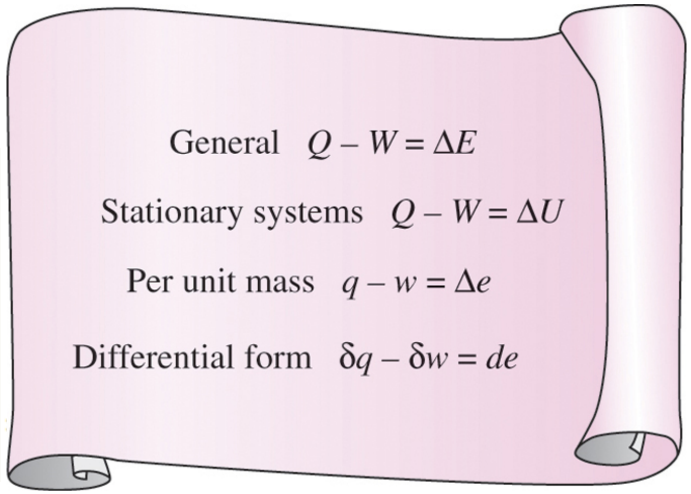
Energy balance when sign convention is used (i.e., heat input and work output are positive; heat output and work input are negative).

$$Q_{net,in} - W_{net,out} = \Delta E_{system} \quad \text{or} \quad Q - W = \Delta E$$

Various forms of the first-law relation for closed systems when sign convention is used.

For a cycle $\Delta E = 0$, thus $Q = W$.

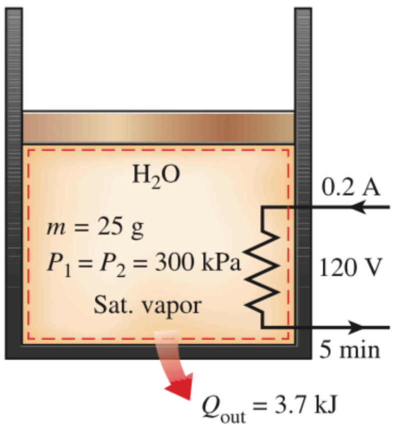
The first law cannot be proven mathematically, but no process in nature is known to have violated the first law, and this should be taken as sufficient proof.



Energy balance for a constant-pressure expansion or compression process

Example

A piston–cylinder device contains 25 g of saturated water vapor that is maintained at a constant pressure of 300 kPa. A resistance heater within the cylinder is turned on and passes a current of 0.2 A for 5 min from a 120-V source. At the same time, a heat loss of 3.7 kJ occurs. Determine the final temperature of the steam.



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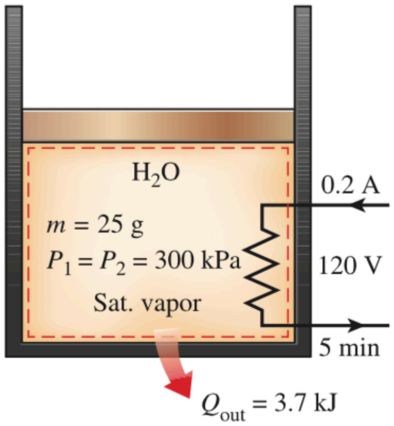
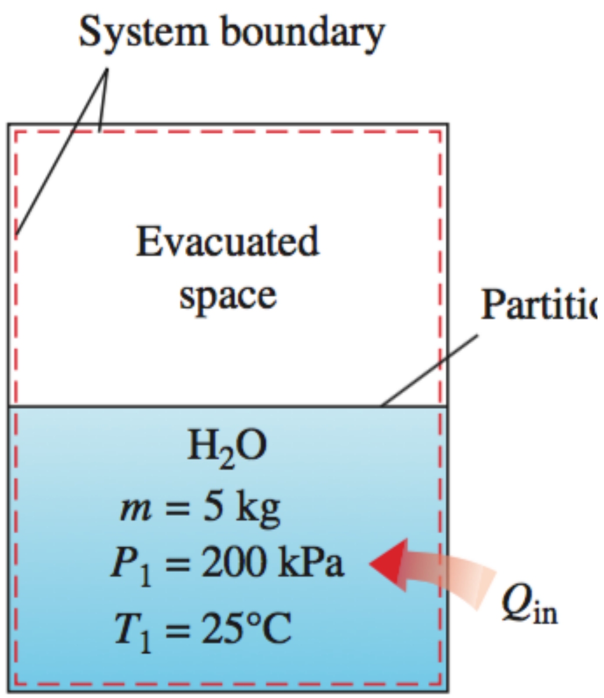


Unrestrained expansion

A rigid tank is divided into two equal parts by a partition. Initially, one side of the tank contains 5 kg of water at 200 kPa and 25°C, and the other side is evacuated. The partition is then removed, and the water expands into the entire tank. The water is allowed to exchange heat with its surroundings until the temperature in the tank returns to the initial value of 25°C. Determine (*a*) the volume of the tank, (*b*) the final pressure, and (*c*) the heat transfer for this process.



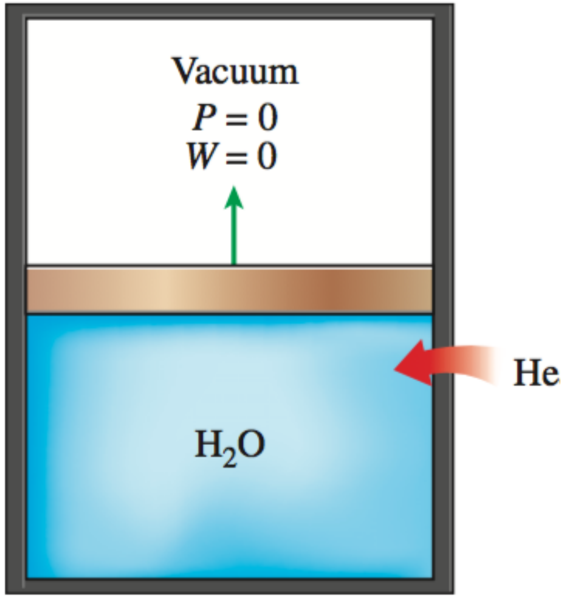
$$v_1 \cong v_{f\,@\,25^\circ C} = 0.001003 \text{ m}^3/\text{kg} \cong 0.001 \text{ m}^3/\text{kg}$$

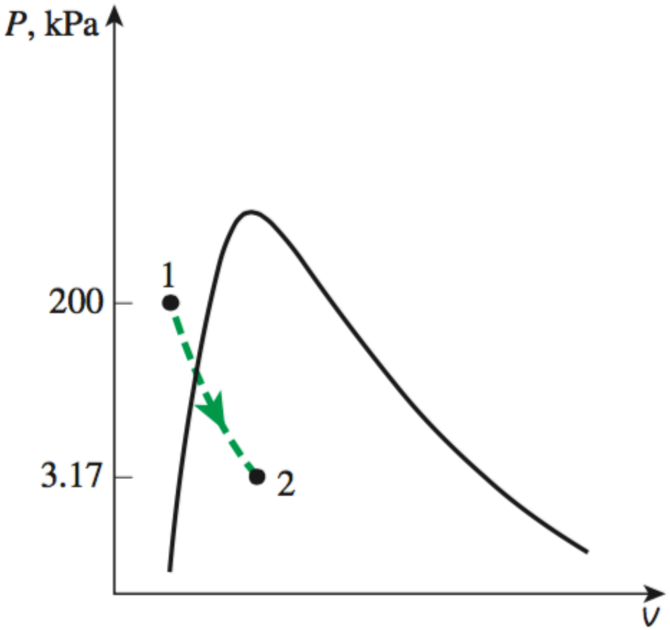
TABLE A–4

Saturated water—Temperature table

		Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg		
Temp., T °C	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5

Unrestrained expansion





Next lecture

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