5.3 First law for open systems

Name: _____ Class: _____ Date: _____ **Total: 14 marks**

KEY WORDS control volume • enthalpy • nozzle

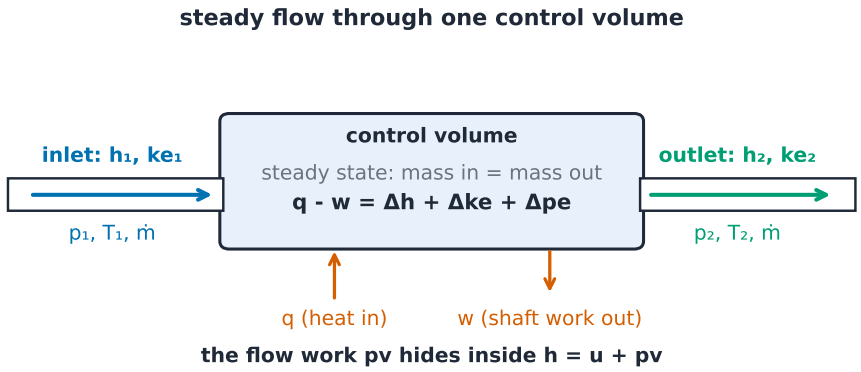
Objective

Run the steady-flow energy equation across real devices: enthalpy at the ports, the turbine two-step, pump work and nozzle kinetic energy.

1 Key knowledge and worked examples

■ **One equation, three devices**

$q - w = \Delta h + \Delta ke + \Delta pe$; $h = u + pv$ absorbs the flow work. Turbine: isentropic leg, then η_t. Pump: $w_p \approx v\,\Delta p$.



*Enthalpy in, enthalpy out, shaft work and heat at the ports

■ **Worked example. The turbine two-step**

$s_{2s} = s_1$: $x_{2s} = 0.8966$, $h_{2s} = 2407.4$; $w_s = 823.5$; with $\eta_t = 0.85$: $w = 0.85 \times 823.5 = 700.0$ kJ/kg ✓, $h_2 = 3230.9 - 700.0 = 2530.9$.

2 Practice

All devices run at steady state; take $g\,\Delta z$ as negligible.

2.1 An adiabatic compressor takes air from $h_1 = 295.2$ to $h_2 = 480.5$ kJ/kg: the shaft work per kilogram (one decimal, kJ/kg, sign stated) and the power at a mass flow of 1.5 kg/s (one decimal, kW). [4]

2.2 A pump lifts liquid water ($v = 0.001005$ m^3/kg) from 800 kPa to 5.0 MPa: the work input (two decimals, kJ/kg). [3]

2.3 An adiabatic nozzle accelerates air from 20 to 320 m/s with no shaft work: the enthalpy change (one decimal, kJ/kg) and the direction of the change. [4]

2.4 One sentence each: why is the kinetic-energy term kept for a nozzle and dropped for a pump, and why does the open-system ledger run on h rather than u? [3]

Solutions

2.1

- $w = h_1 - h_2 = 295.2 - 480.5 = \mathbf{-185.3}$ kJ/kg - negative because it is work input.
- $\dot{W} = \dot{m}\,|w| = 1.5 \times 185.3 = \mathbf{278.0}$ kW.

2.2

- $w_p = v\,\Delta p = 0.001005 \times (5000 - 800) = \mathbf{4.22}$ kJ/kg.

2.3

- $\Delta ke = (320^2 - 20^2)/2 = 51{,}000$ J/kg $= \mathbf{51.0}$ kJ/kg.
- $q = w = 0$ gives $\Delta h = -\Delta ke = \mathbf{-51.0}$ kJ/kg: enthalpy falls ✓.

2.4

- The nozzle's product IS velocity, so Δke is the point of the device; a pump moves slow liquid, so Δke is negligible against $v\,\Delta p$.
- Pushing each kilogram through a port costs pv of flow work; absorbing it into u gives h, so ports balance in h.

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