

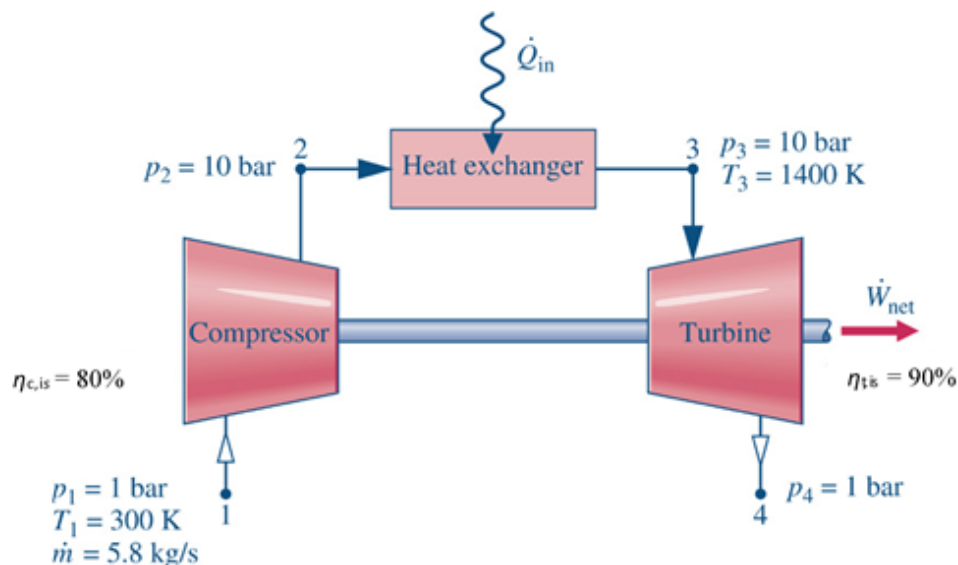
## Thermodynamics and energetics I: Exercise 9

The exercise deals with the 1st and 2nd law of thermodynamics. You get to apply them to open and closed systems.

1. A power system consists of three components in series; a compressor with isentropic efficiency of  $\eta_{c,s} = 80\%$ , a heat exchanger, and a turbine with isentropic efficiency of  $\eta_{t,s} = 90\%$ . Air enters (1) and exits (2) the compressor at the conditions given in the figure. The air is heated up in the heat exchanger and then enters the turbine at the given condition (3). The air exits the turbine at a pressure of  $p_4 = 1$  bar. Assume no heat losses in the compressor and the turbine and no work in the heat exchanger. Assume that air behaves as an **perfect gas**,  $c_v = 2.5R$ , and  $M_{\text{air}} = 29$  kg/kmol, with  $R$  being the specific gas constant.

Sketch the  $Ts$  diagram, then determine:

- (a) the power required by the compressor.
- (b) the power generated by the turbine.
- (c) the efficiency of the system.



2. Refrigerant 22 (R-22) with a volumetric flow rate of  $\dot{V}$  enters a compressor as saturated vapor at an inlet pressure  $p_1$ . The compressor operates in an ambient temperature  $T_b$ , with an exit pressure  $p_2 > p_1$ , and an isentropic efficiency of  $\eta$ . Assume that changes in kinetic energy and gravitational potential energy are negligible.
  - (a) Assume that the compressor is perfectly insulated (adiabatic).

You have one database that gives the thermodynamics properties of saturated R-22 vapor as a function of its pressure.

You have another database that allows you to calculate the specific enthalpy of R-22 as a function of pressure and specific entropy.

Determine the process for calculating the power required to drive the compressor, given the information provided. Use symbols to represent any thermodynamic properties that can be obtained from above databases.
  - (b) Under steady-state conditions, what additional criteria must be met to justify the assumption that a compressor operates isentropically? Express the condition for internal irreversibility  $\dot{\sigma}$ , based on the entropy balance of the system, and explain its significance.
    - (i) For an adiabatic compressor.
    - (ii) For a compressor without insulation.
3. A refrigerator cycle operating under stationary conditions with a coefficient of performance of 2.5 extracts 8000 kJ/h at a temperature of 0 °C and delivers the heating power to the environment at 20 °C.
  - (a) Determine the work rate required to drive the cooling cycle.
  - (b) Compare the calculated work rate to the work rate of a reversible cooling cycle operating between the same two reservoirs.