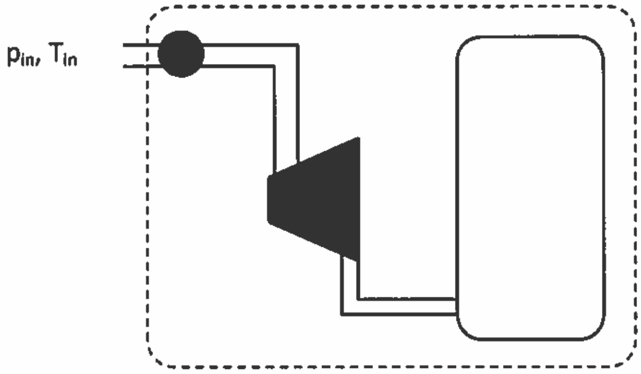
Problem 1

Consider an intermittent duty pneumatic hybrid power train that uses brake energy to compress a working gas, in this case nitrogen, into a reservoir and then recovers the stored energy by expanding the gas through a turbine. When additional powertrain work is required, a valve is opened from the reservoir (time t_1) and flows through the turbine into a collection tank. Assume that the brake energy driven compression process creates an infinite reservoir of nitrogen gas at 300°C and 10 bar and the collection tank is initially evacuated (at the valve opening time.) The valve is closed when the pressure in the collection tank reaches the reservoir pressure (time t_2), at which point the temperature of the nitrogen in the collection tank is 250°C. The expansion process provides an additional 45kJ of work to the drivetrain per kilogram of nitrogen flowing in to the tank during this process. Calculate the heat transfer entering the control volume (shown below) per kilogram of nitrogen entering the tank.



Problem 2

A can containing 350 cm³ of compressed air at 10 bar, 20 °C is placed inside a closed, rigid, insulated, and evacuated chamber. The valve on the can fails and the air inside rapidly fills the entire chamber. During this process, 4 J/K of entropy is produced. Determine the volume of the chamber and the final pressure of the air inside the chamber. Assume that air is an ideal gas with constant specific heat $c_p = 1.004$ kJ/(kg.K). Neglect any changes in potential and kinetic energy. Neglect the volume of the solid parts of the can.

Problem 3

Helium is the working fluid in a Brayton cycle with concentrated solar irradiation as the heat input. The cycle is schematically depicted in Figure C. The pressure, temperature, and volumetric flow rate of the flow entering the well-insulated compressor are $p_1 = 1$ bar, $T_1 = 300$ K, and $\left(A\overline{V}\right)_1 = 10.0\ \mathrm{m^3/s}$, respectively. The pressure ratio of the compressor is $r = p_2/p_1 = 10$, and the compressor has an isentropic efficiency of $\eta_C = 85\%$. A solar receiver is maintained at a constant temperature T_{sr}. Concentrated solar radiative heat flux equal to 2500 $\mathrm{kW{\cdot}m^{-2}}$ enters the solar receiver through a quartz window with an aperture area of $A_{sr} = 4\ \mathrm{m^2}$ and impinges directly upon a reticular porous ceramic (rpc) material. This type of material efficiently absorbs solar irradiation and effectively transfers heat via convection to the flow due to very high specific surface area. Thus, the flow exiting the solar receiver is at T_{sr}. The effective solar absorptivity and emissivity of the solar receiver are $\alpha_s = 0.9$ and $\varepsilon = 0.8$, respectively. The flow leaving the solar receiver expands across a well-insulated turbine to produce work and exits at a pressure of 1 bar. The isentropic efficiency of the turbine equals $\eta_T = 90\%$. After exiting the turbine, heat is rejected to the surrounding as it moves through a heat exchanger until it reaches T_1.

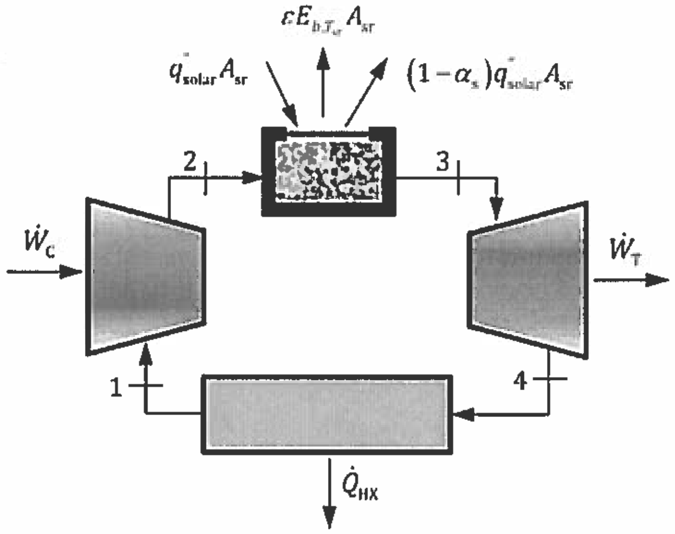


Figure C.

Assume the following:

1) Steady-state
2) Ideal gas behavior
3) Negligible kinetic and potential energy effects
4) Negligible heat losses in the solar receiver except for the radiative emissiver power
5) Neglible pressure losses across the solar receiver and heat exchanger
6) A uniform and constant temperature in the solar receiver
7) Dead state temperature and pressure are $T_0 = 298.15$ K and $p_0 = 1$ bar, respectively

Given the specfic heat and gas constant for helium are $c_{p,He} = (5/2)R_{He}$ and $R_{He} = 2.0785\ \mathrm{kJ/kg{\cdot}K}$, respectively, and the Stefan-Boltzmann constant equals $\sigma = 5.67\times10^{-11}\ \mathrm{kW{\cdot}m^{-2}{\cdot}K^{-4}}$, determine the following:

a) The mass flowrate at the exit of the compressor in kg/s.
b) The solar receiver temperature, T_{sr}, in K (Hint: iteration may be required and $E_b = \sigma T^4$).
c) The cycle efficiency.
d) The rate of exergy destruction across the solar receiver in kW