Thermodynamics

Caution: Students please read before starting

(1) You should be provided with a set of thermodynamics properties tables for use during this exam.

(2) The exam consists of three (3) problems on three (3) separate pages. Check NOW to verify that your exam is complete.

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If you are missing the properties tables or any of the three (3) exam pages stop work NOW and advise your proctor immediately.

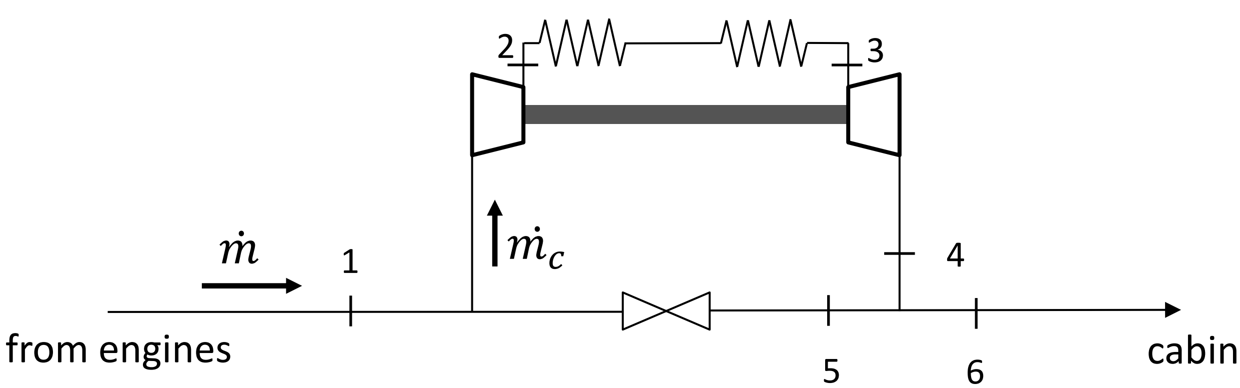
Problem 1

The diagram below represents schematically one of the four equivalent air-based refrigeration cycles used for air conditioning in the hypersonic airplane Concorde. A mass flow rate of $\dot{m} = 0.34\ kg/s$ is extracted from the compressor (in the propulsion engines) at stage 1 (*P_1=2.24 bar, T_1=200 ℃)*. One part of this flow, $\dot{m}_c$, is further adibatically compressed to *P_2= 4 bar,* with an isentropic efficiency $\eta_{ic} = 0.75$, in the compressor unit of the air conditioning unit. Subsequently, it is cooled isobarically (constant pressure), to a temperature *T_3=87 ℃* in two heat exchangers in series, and it is finally expanded adiabatically in a turbine to the cabin pressure, *P_4=P_6=0.9 bar.*

The power obtained in the expansion at the turbine stage is fully utilized for the earlier compressor stage. At the exit of the turbine, the mass flow rate $\dot{m}_c$ is mixed with the remaining flow rate (from the extracted amount in the propulsion engines), which is sent through a simple throttling device to reduce the pressure from conditions in *1* to *P_5=P_6.* The temperature of the air flowing to the cabin is automatically regulated through the extracted flow rate , $\dot{m}_c$.

Assuming air as an ideal gas with constant specific heats (*k=1.4*):

1) Draw the T-s diagram of the process;
2) Determine the isentropic efficiency of the turbine, η_{it}
3) The relative mass flow rates through the throttling device and the heat exchangers, in case the air is injected in the cabin at *T_6= -10 ℃* (supersonic flight at high altitude).

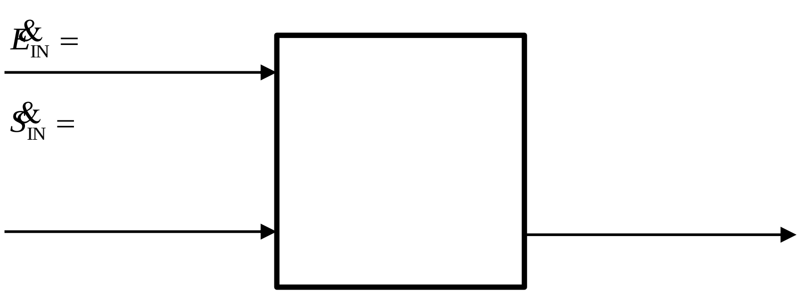


Problem 2

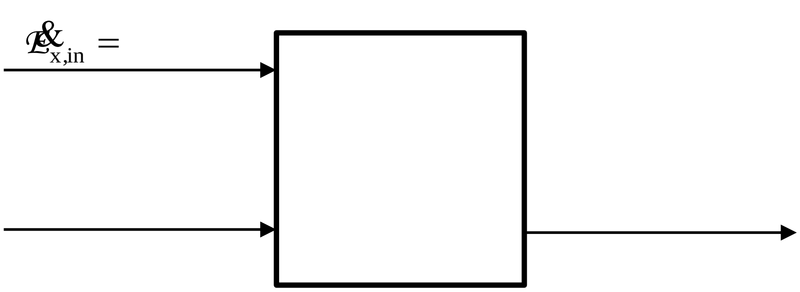
Two streams of the same incompressible liquid oil (constant specific heat = 2.0 kJ/kg-K and density = 800 kg/m^3 and negligible vapor pressure) enter an adiabatic and steady state mixing vessel. One stream flows at 10 kg/s and at 400 K, 100 kPa, and at 100 m/sec. The other steam flows at 5 kg/s and at 300 K, 100 kPa, and at 10 m/sec. The outlet flow is at 100 kPa and negligible velocity. The surrounding atmosphere is at 100 kPa and 300 K.

(a) Show, on the first diagram below, the energy flows (in W) and entropy flows (in W/K); and show the rate of entropy generation (if any) in the mixing vessel (the CV). Use 100 kPa and 300 K as the reference state for energy and entropy.
(b) Perform an exergy analysis and indicate on the second diagram the inlet stream exergy flow rates (such as $\dot{E}_{x,in}$), the exit stream exergy rate, and the exergy destruction rate in the CV, all in W. Ambient conditions are defined above.
(c) On following page, explain how the system could be modified (at least theoretically) to make this mixing process reversible.

Energy and Entropy Flow Diagram:

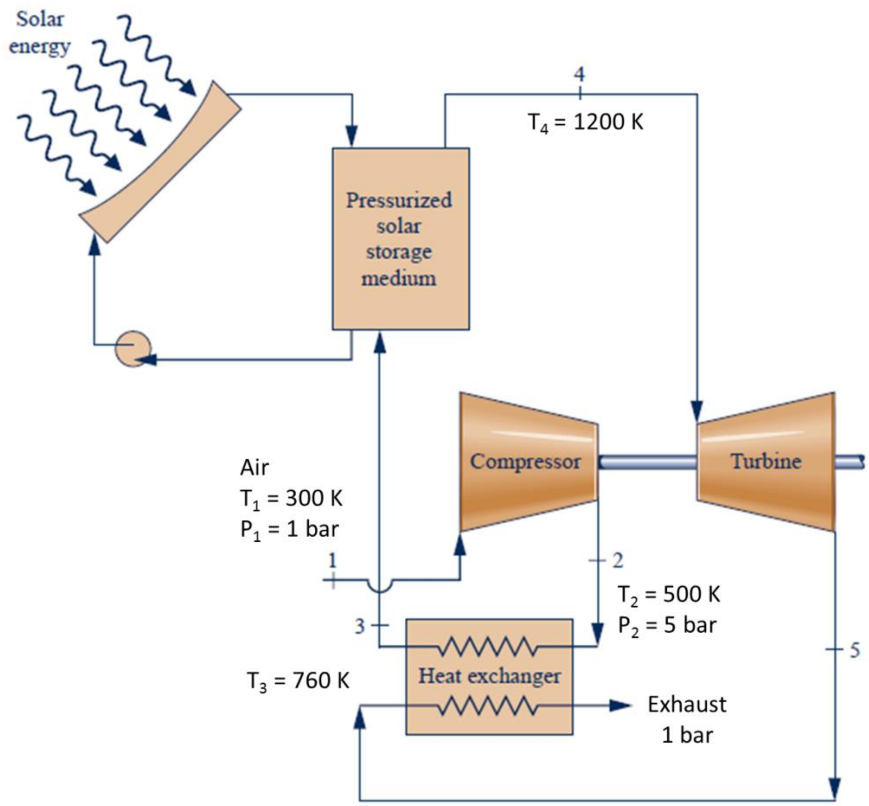


Exergy Flow Diagram



Problem 3

The figure below illustrates a gas turbine power plant that uses solar energy as the source of heat addition. Operating data are given on the figure and the thermal efficiency of the cycle is 30%. Model the cycle as a Brayton cycle, and assume no pressure drops in the heat exchanger or interconnecting piping.



Questions:

(a) Determine the turbine exit temperature (T_5).

(b) Determine the isentropic turbine efficiency.

(b) Determine the air mass flow rate, in kg/s, for a net power output of 1000 kW.

(c) Sketch the cycling processes on the T-s diagram.