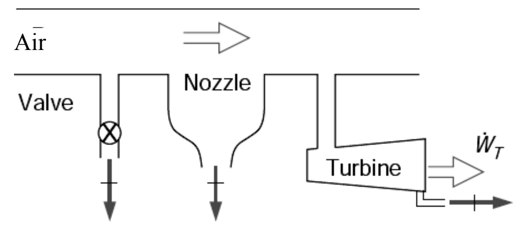
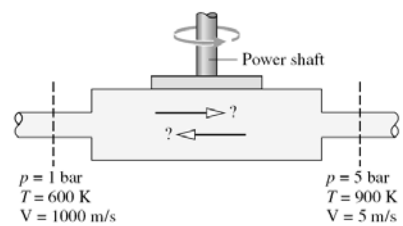
Problem Sheet: 2^{nd} Law for flow systems

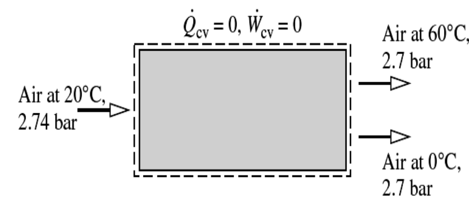
1. A large supply line has a steady air flow at 500 K, 200 kPa. It is used in three different adiabatic devices shown in the figure on the right: a throttle flow, an ideal nozzle, and an ideal turbine. All the exit flows are at 100 kPa. (a) Find the exit temperature and specific entropy generation for each device and the exit velocity of the nozzle. Consider C_p = 1.04 kJ/kgK for air. **(b)** Find the same when the inlet air temperature is 2500 K and use the air tables.



2. The figure on right shows steady-state operating data for a well-insulated device with air entering at one location and exiting at another with a mass flow rate of 10 kg/s. Assuming ideal gas behavior and negligible potential energy effects, determine the direction of flow and the power, in kW.

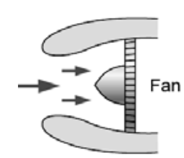


3. An inventor claims to have developed a device requiring no work input or heat transfer, yet able to produce at steady state hot and cold air streams as shown in the figure on right. Employing the ideal gas model for air and ignoring kinetic and potential energy effects, evaluate this claim.

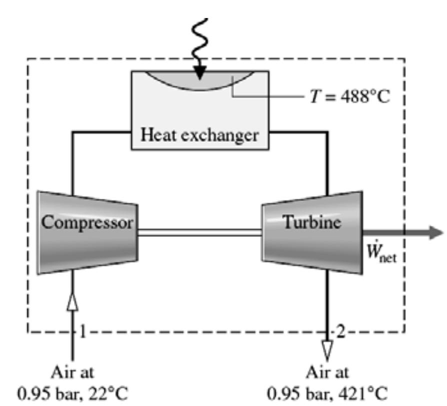


4. Consider the design of a nozzle in which nitrogen gas flowing in a pipe at 500 kPa, 200 °C at a velocity of 10 m/s is expanded to produce a velocity of 300 m/s. Determine the exit pressure and cross sectional area of the nozzle if the air flow rate is 0.15 kg/s and the expansion is reversible and adiabatic.

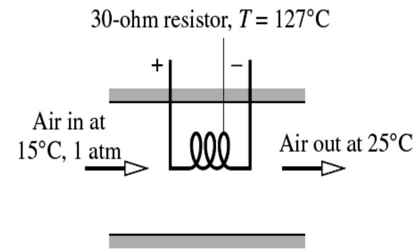
5. Atmospheric air at −45°C, 60 kPa enters the front diffuser of a jet engine, shown in the figure on the right, with a velocity of 900 km/h and a frontal area of 1 m^2. After leaving the adiabatic diffuser, the velocity is 20 m/s. Find the diffuser exit temperature and the maximum pressure possible. Assume the C_p of air as 1.04 kJ/kgK and k = 1.4.



6. Figure on the right shows a gas turbine power plant operating at steady state consisting of a compressor, a heat exchanger, and Turbine. Air enters the compressor with a mass flow rate of 3.9 kg/s at 0.95 bar, 22 °C and exits the turbine at 0.95 bar, 421 °C. Heat transfer to the air as it flows through the heat exchanger occurs at an average temperature of 488 °C. The compressor and turbine operate adiabatically. Using the ideal gas model for the air, and neglecting kinetic and potential energy effects, determine the maximum theoretical value for the *net* power that can be developed by the power plant, in MW.



7. Figure on the right shows a 30-ohm electrical resistor located in an insulated duct carrying a stream of air. At steady state, an electric current of 15 amp passes through the resistor, whose temperature remains constant at 127 °C. The air enters the duct at 15 °C, 1 atm and exits at 25 °C with a negligible change in pressure. Kinetic and potential energy changes can be ignored. (a) For the resistor as the system, determine the rate of entropy production, in kW/K, (b) For a control volume enclosing the air in the duct and the resistor, determine the volumetric flow rate of the air entering the duct, in m^3/s, and rate of entropy production, in kW. Why do the entropy values in the two cases differ?



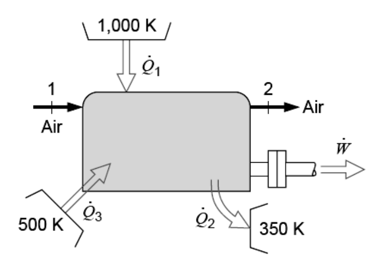
8. Air enters a compressor operating at steady state at 1 bar, 22 °C with a volumetric flow rate of 1 m3/min and is compressed to 4 bar, 177 °C. The power input is 3.5 kW. Employing the ideal gas model and ignoring kinetic and potential energy effects, obtain the following results: (a) For a control volume enclosing the compressor only, determine the heat transfer rate, in kW, and the change in specific entropy , in kW/K, from the inlet to exit. What additional information would be required to evaluate the rate of entropy production? (b) Calculate the rate of entropy production, in kW/K, for an enlarged control volume enclosing the compressor and a portion of its immediate surroundings so that heat transfer occurs at the ambient temperature, 22 °C.

9. Air is compressed in an axial-flow compressor operating at steady state from 27 °C, 1 bar to a pressure of 2.1 bar. The work input required is 94.6 kJ per kg of air flowing through the compressor. Heat transfer from the compressor occurs at the rate of 4 kJ per kg at a location on the compressor's surface where the temperature is 40 °C. Kinetic and potential energy changes can be ignored. Determine: **(a)** the temperature of the air at the exit, in °C, and **(b)** the rate at which entropy is produced within the compressor, in kJ/K per kg of air flowing.

10. Air enters an insulated compressor operating at steady state at 1 bar, 350 K with a mass flow rate of 1 kg/s and exits at 4 bar. The isentropic compressor efficiency is 82%. Determine the power input, in kW, and the rate of entropy production, in W/K, using the ideal gas model using (a) Air Table, and (b) considering a constant specific heat ratio of 1.39.

11. In a gas turbine operating at steady state, air enters the compressor with a mass flow rate of 5 kg/s at 0.95 bar and 22 °C and exits at 5.7 bar. The air then passes through a heat exchanger before entering the turbine at 1100 K, 5.7 bar. Air exits the turbine at 0.95 bar. The compressor and turbine operate adiabatically and kinetic and potential energy effects can be ignored. Determine the *net* power developed by the plant, in kW, if (a) the compressor and turbine operate without internal irreversibilities, and (b) the compressor and turbine isentropic efficiencies are 82 and 85%, respectively.

12. A reversible steady-state device receives a flow of 1 kg/s air at 400 K, 450 kPa, and the air leaves at 600 K, 100 kPa. Heat transfer of 800 kW is added from a 1000 K reservoir, 100 kW is rejected at 350 K, and some heat transfer takes place at 500 K. Find the heat transferred at 500 K and the rate of work produced.



13. Two flows of air are both at 200 kPa; one has 1 kg/s at 400 K, and the other has 2 kg/s at 290 K. The two lines exchange energy through a number of ideal heat engines, taking energy from the hot line and rejecting it to the colder line. The two flows then leave at the same temperature. Assume the whole setup is reversible and find the exit temperature and the total power out of the heat engines.

14. Air at 1000 kPa, 300Kis throttled to 500 kPa. What is the specific entropy generation?

15. A coflowing (same direction) heat exchanger, shown in the figure on the right, has one line with 0.25 kg/s oxygen at 17 ^{o}C, 200 kPa entering, and the other line has 0.6 kg/s nitrogen at 150 kPa, 500 K entering. The heat exchanger is long enough so that the two flows exit at the same temperature. Use constant heat capacities and find the exit temperature and the total rate of entropy generation.