SCHOOL OF ENGINEERING
MECHANICAL ENGINEERING

Thermodynamics and energetics I: Exercise 10

In this exercise you apply the 1st and 2nd law of thermodynamics to open systems and calculate entropy production of components. Additionally, you will apply the notion of exergy and evaluate exergy balances of closed systems.

Useful information:
$\widetilde{R} = 8.314$ kJ/(kmol · K), $M_{\text{air}} = 29$ kg/kmol, $M_{\text{O}_2} = 32$ kg/kmol, $M_{\text{CO}_2} = 44$ kg/kmol, $c_{\text{water}} = 4.185$ kJ/(kg · K)

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1. A volume flow rate of 1 m^3/min of air at a pressure of 4 bar and 35 °C enters a compressor operating under steady state conditions. The outlet pressure is 18 bar. Assume no internal irreversibilities in the compressor and isothermal compression. Assume that air behaves as an ideal gas and neglect changes in kinetic and potential energy. Calculate:

   (a) the rate of work absorbed by the compressor and the heat transfer. Firstly consider a control volume which only includes the working fluid (air).

   (b) the entropy production for an enlarged control volume (including the compressor and its imminent environment). In this case, the heat transfer takes place at 17 °C.

   (c) Comment on the differences.

2. Oxygen enters a stationary operating nozzle at 3.8 MPa, 650 K, 10 m/s. The outlet conditions are 150 kPa, 310 K and 750 m/s. Assume that oxygen behaves as perfect gas ($c_v = 2.5R$) and neglect potential energy changes. Determine:

   (a) The specific heat transfer and the specific entropy change. Only include the nozzle in the control volume.

   (b) What additional information is necessary to determine the specific entropy production?

   (c) The specific entropy production for an enlarged control volume (including the nozzle and its imminent environment) where the heat transfer takes place at 17 °C.

   Note: In this case, the change in kinetic energy is not negligible.

3. Consider 1 kg of steam initially at 240 °C and 20 bar. Assume the environmental temperature at 290 K and 1 bar. Ignore kinetic and potential energy changes. Draw the Tv diagram and determine the change in exergy for each of the following processes:

   (a) the system heated at constant pressure until the volume doubles.

   (b) the system expands isothermally until the volume doubles.

   Note: Try to use CoolProp (documentation page) to obtain the specific steam properties when you need to. Feel free to use Gen AI tools such as ChatGPT to generate your code, but be sure to do a few verification tests (example code).

4. 1 kmol of CO_2 is contained within a 7 m^3 rigid, insulated vessel initially at 4 bar. An electrical resistor (of negligible mass) transfers energy to the gas at a constant rate of 12 kW during a time period of one minute. Employing the perfect gas ($c_v = 3.5R$) and ignoring kinetic and potential energy changes, determine:

   (a) the electrical work.

   (b) the change in exergy of the gas assuming that environment is at $T_0 = 20$ °C and $p_0 =$ 1 bar.

   (c) the exergy destruction.