THE UNIVERSITY *of* EDINBURGH
School of Engineering

Tutorial 4: Mass & Energy Analysis of Steady State Processes and Devices

Note: numerical solution are based on one approach to solving the tutorial questions. Other approaches can also be correct and could lead to slightly different numerical answers.

Conceptual Questions:

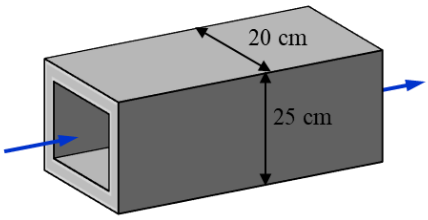
1. Can a steady-state device have boundary work?

2. Apply the energy balance for throttling process. Does the gas temperature change during the throttling process when the working fluid is an ideal gas?

3. How does a nozzle or spray head generate kinetic energy

Problem Solving Questions:

4. Air (ρ=1.225 kg/m^(3)) travels in a rectangular duct with height 25 cm and width of 20 cm. The average velocity of 5 m/s. Determine the mass flow rate.

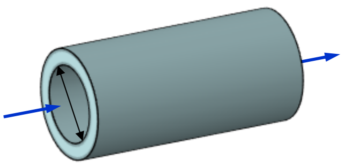


[ans: 0.306 kg/s]

5. Air at 100 kPa, 50°C, flows through a pipe with a volume flow rate of 40 m^3/min. Assuming ideal gas and constant velocity,

a. Determine the mass flow rate through the pipe in kg/s.

b. Determine the average velocity ($\vec{V}_{avg}$) in m/s if the pipe has a cross sectional area with diameter 30 cm.

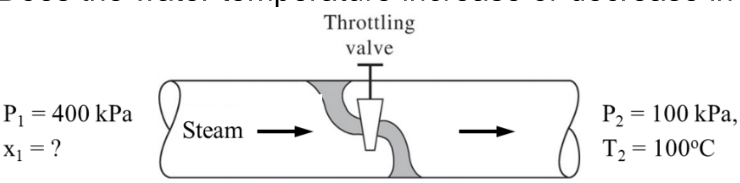


[ans: (a) $\dot{m}$ = 0.719 kg/s , (b) $\vec{V}_{avg}$ = 9.43 m/s]

6. One way to determine the quality of saturated steam is to throttle the steam to a low enough pressure that it exists as a superheated vapor. Saturated steam at 400 kPa and quality x_1 is throttled to 100 kPa, 100°C.

a. Determine the initial quality of the steam at 400 kPa.

b. Does the water temperature increase or decrease in this process?

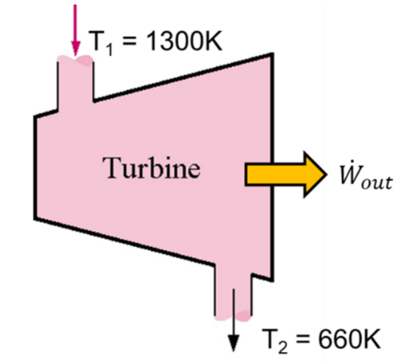


[ans: (a) x = 0.971 , (b) temperature decreases]

7. High pressure air at 1300K flows into an aircraft gas turbine and undergoes a steady-state, steady-flow, adiabatic process to the turbine exit at 660K.

a. Calculate the work done per unit mass of air flowing through the turbine using $C_{p,ave}$ = 1.138 kJ/kg·K.

b. Calculate the work done per unit mass when using the ideal gas air tables in the back of the book (i.e. Table A7.1 (Borgnakke & Sonntag).

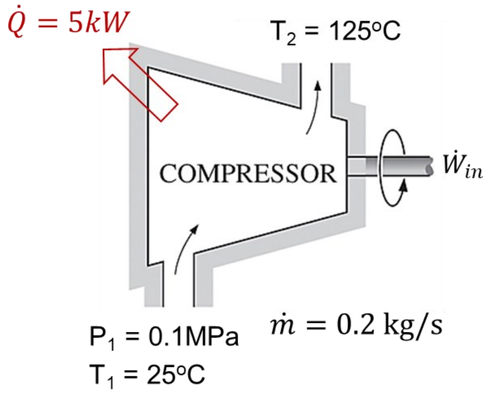


[ans: (a) $\dot{w}_{out}$= 728.3 kJ/kg, (b) $\dot{w}_{out}$= 725.1 kJ/kg]

8. Nitrogen gas is compressed in a steady-state, steady-flow, adiabatic process from 0.1MPa, 25°C. During the compression process the temperature becomes 125°C. The mass flow rate of nitrogen is 0.2 kg/s. Assume ideal gas with constant specific heat C_p = 1.039 kJ/kg·K

a. Determine the work done on the nitrogen, in kW.

b. If heat is lost to the surroundings at 5 kW, determine the work done on the nitrogen, in kW



[ans: (a) $\dot{W}_{in}$= 20.8 kW ,(b) $\dot{W}_{in}$= 25.8 kW]

9. Apply the conservation of energy equation to a pump and include the change in kinetic and potential energy of the fluid streams entering and leaving the system. Show that if we remove the pumping work, we will arrive at the Bernoulli's equation for frictionless, incompressible fluid flow through a pipe.

Conservation of energy: $\dot{Q}_{net} + \dot{m}_i\left(h_1 + \frac{\vec{V_1}^2}{2} + gz_1\right) = \dot{W}_{net} + \dot{m}_2\left(h_2 + \frac{\vec{V_2}^2}{2} + gz_2\right)$

Bernoulli's Equation: $\frac{P_2}{\rho} + \frac{\vec{V}_2^2}{2} + gz_2 = \frac{P_1}{\rho} + \frac{\vec{V}_1^2}{2} + gz_1$