Chapter 4 - Energy Analysis for a Control Volume

Lecture 25

Sections 4.3-4.4

MEMS 0051 Introduction to Thermodynamics

Mechanical Engineering and Materials Science Department
University of Pittsburgh

Student Learning Objectives

At the end of the lecture, students should be able to:

- Apply the Conservation of Energy and Conservation of Mass to steady state nozzles, diffusers and throttles
- Understand and apply the Conservation of Energy for an open system

Steady States

- Steady state implies the following:
  1. The C.$\forall$. is fixed with respect to our coordinate frame
  2. Mass at each point in the C.$\forall$. is invariant with respect to time
  3. The state of and mass flux crossing the C.S. into the C.$\forall$. is invariant with respect to time

$$\implies \frac{d\,m}{dt} = 0 \quad \text{and} \quad \frac{d\,E}{dt} = 0$$

Conservation Equations for Steady State

- Therefore, our continuity equation for steady state becomes

$$\sum_{i=1}^{N} \dot{m}_i = \sum_{j=1}^{M} \dot{m}_j$$

- The Conservation of Energy becomes

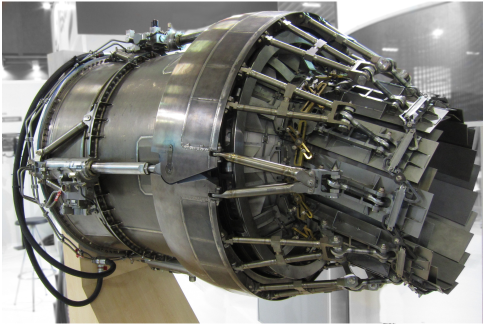
$$\dot{Q}+\sum_{i=1}^{N} \dot{m}_i \left(h_i + \frac{V_i^2}{2} + g z_i \right) = \dot{W} + \sum_{j=1}^{M} \dot{m}_j \left(h_j + \frac{V_j^2}{2} + g z_j \right)$$

- Or, on a per mass basis for a single stream device

$$q + h_1 + \frac{V_1^2}{2} + g z_1 = w + h_2 + \frac{V_2^2}{2} + g z_2$$

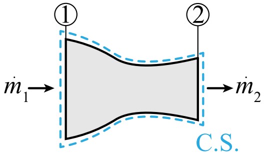
Nozzles

- Nozzles convert pressure energy into kinetic energy
- There are a variety of designs; convergent and convergent-divergent for Ma>1



Example #1

- Consider a steady state converging-diverging nozzle in which 2 [kg/s] of steam enters at 4,000 [kPa] and a temperature of 400°C and a velocity of 10 [m/s]. It exhausts to a pressure of 1,500 [kPa] with a velocity of 665 [m/s]. Determine the exit cross-sectional flow area.



Example #1

Example #1

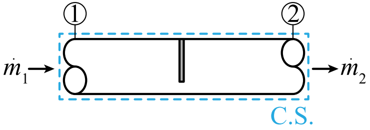
Example #1

Diffusers and Throttles

- Diffusers convert kinetic energy to pressure energy - the opposite of a nozzle
- Due to the similarity with a nozzle, we will forgo an analysis of a diffuser

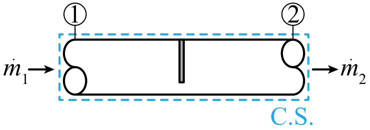
Throttles

- Throttles reduce pressure energy of the system by placing a restriction within the flow
- For a throttle, we assume single stream, no heat loss or work, and the same cross-sectional flow area



Example #2

- Construct the C.o.E. equation for an incompressible fluid flowing through throttle, with constant cross-sectional area, operating under steady state

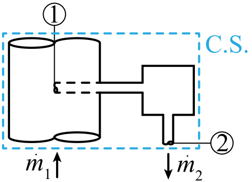


Example #2

Example #3

- A two-phase mixture of liquid and vapor steam at 2,000 [kPa] is being transported through a pipe. Some steam is throttled through a calorimeter (a device that is used to measure quality) which is then exhausted to atmosphere, i.e. 100 [kPa]. The steam exiting to atmosphere has a temperature of 120°C. Determine the quality of the steam in the pipe.

Example #3



Example #3

Example #3

Student Learning Objectives

At the end of the lecture, students should be able to:

- Apply the Conservation of Energy and Conservation of Mass to steady state nozzles, diffusers and throttles
  - Nozzles are devices that convert pressure energy to kinetic energy - the enthalpy at the outlet is increased above the inlet enthalpy by the difference of the inlet and exit kinetic energies
- Understand and apply the Conservation of Energy for an open system
  - The C.o.E. is reduced to reflect the specifics of the problem at hand, and is usually combined with the continuity equation

Suggested Problems

- 4.20, 4.21, 4.23, 4.25, 4.27, 4.28, 4.31, 4.36