Lecture 23

Modeling Real Devices
Thermodynamic Problem Solving

1. **Sketch** System & Boundary
2. Identify **Unknowns** (put them on sketch)
3. Classify the **System** (open, closed, isolated)
4. Identify **Processes/States**
5. Write Governing **Equations** (including auxiliary eqns)
6. Algebraically **Solve**
7. **Calculate** Values (carrying units w/numbers)
8. **Check** Results (eqns, algebra, calculations, signs, units)
9. **Reflect** (on the problem, on the solution, and/or on the problem solving process)
The Laws of the Universe

Conservation of Mass – The Continuity Equation

\[ \sum_{i} \dot{m}_i - \sum_{e} \dot{m}_e = \frac{dm_{\text{sys}}}{dt} \]

Conservation of Energy – The First Law of Thermodynamics

\[ \dot{Q} - \dot{W} + \sum_{i} \dot{m}_i \left( h_i + \frac{V_i^2}{2g_c} + \frac{g}{g_c} z_i \right) - \sum_{e} \dot{m}_e \left( h_e + \frac{V_e^2}{2g_c} + \frac{g}{g_c} z_e \right) = \frac{dE_{\text{sys}}}{dt} \]

The Entropy Balance – The Second Law of Thermodynamics

\[ \sum_{k} \frac{\dot{Q}_k}{T_k} + \sum_{i} \dot{m}_i s_i - \sum_{e} \dot{m}_e s_e + \dot{S}_p = \frac{dS_{\text{sys}}}{dt} \]
Alternate Forms: 1st Law for Closed Systems

The First Law over a finite period of time is (making a movie),

\[ Q - W = (U_2 - U_1) + \frac{m}{2g_c} (V_2^2 - V_1^2) + \frac{mg}{g_c} (z_2 - z_1) \]

\[ q - w = (u_2 - u_1) + \frac{(V_2^2 - V_1^2)}{2g_c} + \frac{g (z_2 - z_1)}{g_c} \]

The First Law at an instant in time is (taking a picture),

\[ \dot{E}_T = \dot{E}_G = \frac{dE_{sys}}{dt} \]

\[ \dot{Q} - \dot{W} = \frac{dE_{sys}}{dt} = \frac{d}{dt} \left[ U + \frac{mV^2}{2g_c} + \frac{mgz}{g_c} \right] \]
Isentropic Efficiency of Turbines

\[ \eta_t = \frac{\dot{W}_t}{\dot{W}_{t,s}} \]
Isentropic Efficiency of Compressors

\[ \eta_c = \frac{\dot{W}_{c,s}}{\dot{W}_c} \]

The figure illustrates the isentropic process of a compressor. The efficiency is defined as the ratio of the isentropic work input \(\dot{W}_{c,s}\) to the actual work input \(\dot{W}_c\).
Isentropic Efficiency of Pumps

\[ \eta_p = \frac{\dot{W}_{p,s}}{\dot{W}_p} \]

\[ \dot{S}_p / \dot{m} \]

\[ P_1 \]

\[ P_2 \]

\[ L \]

\[ L+V \]
Turbocharger Problem

**Given:** A turbocharger used to boost the inlet air pressure to the combustion process in an automobile engine as shown. As a first estimate, the turbine and compressor can be considered isentropic.

**Find:**

(a) The turbine exit temperature and power delivery
(b) The compressor exit pressure and temperature
(c) Repeat parts (a) and (b) for the case where the turbine has an isentropic efficiency of 85% and the compressor has an isentropic efficiency of 80%.

![Diagram of turbocharger system with labels and conditions:](image)
Vortex Tube Problem

From the vortex tube performance chart on the previous slide

Air
$T_1 = 70^\circ\text{F}$
$P_1 = 100 \text{ psig}$

$m_2 / m_1 = 0.70$

$T_2 = (T_1 - 71)^\circ\text{F} = -1^\circ\text{F}$

$P_2 = 0 \text{ psig}$

$T_3 = (T_1 + 151)^\circ\text{F} = 221^\circ\text{F}$

$P_3 = 0 \text{ psig}$

Is this possible, or is this a caveat emptor scenario?
Vortex Tubes

A company called Vortec sells a device known as a vortex tube. The company claims that the device operates as shown below,
The table below shows approximate temperature drop and rise achieved by vortex tubes when adjusted to various Cold Fractions. A Cold Fraction is the percentage of cold air produced versus total filtered compressed air consumed by any Vortex Tube.

Table Baseline: Compressed air temperature: 70°F/21°C
Pressure Dew Point: -100°F/-56°C (dry air)
Backpressure: not to exceed 5 PSIG/0.4 Bar
Numbers on the Blue Bar: Temperature Drop
Numbers on the White Bar: Temperature Rise

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<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
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<td>C°</td>
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