**Conservation Equations**

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**Definitions**

**SYSTEM:**

- any specified collection of matter under study.

**WORK & HEAT TRANSFER:**

- thermodynamics deals with these properties of matter as a system interacts with its surroundings through work and heat transfer
CONSERVATION OF MASS

\[ \frac{d}{dt}(m_{CV}) = \dot{m}_{IN} - \dot{m}_{OUT} \]

where:

\[ m_{CV} = \int_V \rho \, dV \]
\[ \dot{m}_{IN} = (\rho \, v^* \, A)_{IN} \]
\[ \dot{m}_{OUT} = (\rho \, v^* \, A)_{OUT} \]

with \( v^* \) = average velocity

First Law of Thermodynamics

What is the difference between a closed and an open system?

- is there mass crossing the system boundary? YES: open system  NO: closed system
Control Mass (Closed System)

conservation of mass is inherently satisfied

CONSERVATION OF ENERGY:

• the energy content of an isolated system is constant

energy entering − energy leaving = change of energy within the system

Example: A Gas Compressor

Performing a 1st law energy balance:

\[
\begin{align*}
\left\{ \begin{array}{c}
\text{Initial Energy} \\
E_1
\end{array} \right\} & + \left\{ \begin{array}{c}
\text{Energy gain} W_{1-2} \\
\text{Energy loss} Q_{1-2}
\end{array} \right\} = \left\{ \begin{array}{c}
\text{Final Energy} \\
E_2
\end{array} \right\}
\end{align*}
\]
Control Volume Analysis (Open System)

CONSERVATION OF ENERGY:

\[ E_{CV}(t) + \Delta Q + \Delta W_{shaft} + (\Delta E_{IN} - \Delta E_{OUT}) + (\Delta W_{IN} - \Delta W_{OUT}) = E_{CV}(t + \Delta t) \]  

where:

\[ \Delta E_{IN} = e_{IN}\Delta m_{IN} \]

\[ \Delta E_{OUT} = e_{OUT}\Delta m_{OUT} \]

\[ \Delta W = \text{flow work} \]

\[ e = \frac{E}{m} = u_{\text{internal}} + \frac{(v^*)^2}{2} + g z \]

\[ \Delta E_{IN} = e_{IN}\Delta m_{IN} \]

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\[ e = \frac{E}{m} = u_{\text{internal}} + \frac{(v^*)^2}{2} + g z \]
What is flow work?

\[ \Delta m_{IN} = \rho_{IN} A_{IN} v_{IN}^* \Delta t \]

\[ \Delta W_{IN} = F \cdot \text{distance} = \frac{P_{IN} A_{IN}}{F} \cdot v_{IN}^* \Delta t = \frac{P_{IN} \Delta m_{IN}}{\rho_{IN}} \]

with \( v = 1/\rho \)

\[ \Delta W_{IN} = (P \cdot v \cdot \Delta m)_{IN} \rightarrow \text{flow work} \] (2)

Similarly

\[ \Delta W_{OUT} = (P \cdot v \cdot \Delta m)_{OUT} \] (3)

Substituting Eqs. 2 and 3 into Eq. 1 gives the 1st law for a control volume

\[ E_{CV}(t + \Delta t) - E_{CV}(t) = \Delta Q + \Delta W_{shaft} + \Delta m_{IN}(e + P v)_{IN} - \Delta m_{OUT}(e + P v)_{OUT} \] (4)

Equation 4 can also be written as a rate equation → divide through by \( \Delta t \) and take the limit as \( \Delta t \rightarrow 0 \)

\[ \frac{d}{dt} E_{CV} = \dot{Q} + \dot{W}_{shaft} + [\dot{m}(e + P v)]_{IN} - [\dot{m}(e + P v)]_{OUT} \]

where:

\[ \dot{m} = \rho \cdot v^* \cdot A \]
Second Law of Thermodynamics

Fundamentals

1. Like mass and energy, every system has entropy.

   Entropy is a measure of the degree of microscopic disorder and represents our uncertainty about the microscopic state.

2. Unlike mass and energy, entropy can be produced but it can never be destroyed. That is, the entropy of a system plus its surroundings (i.e. an isolated system) can never decrease (2nd law).

\[
\mathcal{P}_m = m_2 - m_1 = 0 \text{ (conservation of mass)}
\]

\[
\mathcal{P}_E = E_2 - E_1 = 0 \text{ (conservation of energy)} \rightarrow 1\text{st law}
\]

\[
\mathcal{P}_S = S_{gen} = S_2 - S_1 \geq 0 \rightarrow 2\text{nd law}
\]

The second law states:

\[
(\Delta S)_{system} + (\Delta S)_{surr.} \geq 0
\]

where \(\Delta \equiv final - initial\)

3. Reference: In a perfect crystal of a pure substance at \(T = 0 \, K\), the molecules are completely motionless and are stacked precisely in accordance with the crystal structure. Since entropy is a measure of microscopic disorder, then in this case \(S = 0\). That is, there is no uncertainty about the microscopic state.

4. Relationship to Work: For a given system, an increase in the microscopic disorder (that is an increase in entropy) results in a loss of ability to do useful work.

5. Heat: Energy transfer as heat takes place as work at the microscopic level but in a random, disorganized way. This type of energy transfer carries with it some chaos and thus results in entropy flow in or out of the system.

6. Work: Energy transfer by work is microscopically organized and therefore entropy-free.
Definitions

Example: Slow adiabatic compression of a gas

**Reversible Process:** A process $1 \to 2$ is said to be reversible if the reverse process $2 \to 1$ restores the system to its original state without leaving any change in either the system or its surroundings.

$\Rightarrow \text{idealization where } S_2 = S_1 \Rightarrow S_{\text{gen}} = 0$

**Adiabatic Process:** A process is adiabatic where there is no energy in the form of heat crossing the boundary.

**Isentropic Process:** An isentropic process exhibits no change in the entropy of the state between an initial and final condition. Note: since entropy can be produced as well as transferred, it is important to assess the net result of both mechanisms.

\[
\begin{align*}
\text{Reversible} & \quad + \quad \text{Adiabatic Process} & \Rightarrow & \quad \text{Isentropic Process} \\
S_{\text{gen}} &= 0 & Q &= 0 & S_1 &= S_2
\end{align*}
\]

But does:

\[
\text{Isentropic Process} \Rightarrow \text{Reversible} + \text{Adiabatic}
\]
Second Law Analysis for a Control Mass

- control mass is uniformly at $T_{TER}$ at all times
- control mass has a fixed size ($V = constant$)

From Gibb’s equation

$$T_{TER} \, dS = dU + P \, dV^0$$

From the 1st law

$$dU = dQ$$

Therefore for a reversible process

$$dS = \frac{dQ}{T_{TER}}$$

We integrate to give

$$S_2 - S_1 = \frac{Q_{1-2}}{T_{TER}}$$

and for a non-reversible process

$$dS = \frac{dQ}{T_{TER}} + dS_{gen}$$

We integrate to give

$$S_2 - S_1 = \frac{Q_{1-2}}{T_{TER}} + S_{gen \, 1-2}$$
Second Law Analysis for a Control Volume

For the isolated system

\[(\Delta S)_{sys} + (\Delta S)_{sur} = S_{gen} \geq 0\]

\[
\Delta S_{CV} - s_A m_{1-2}^A + s_B m_{1-2}^B - \frac{Q_{1-2}^A}{T_{TER}^A} + \frac{Q_{1-2}^B}{T_{TER}^B} = \mathcal{P}_{s_{1-2}} = S_{gen}
\]

or as a rate equation

\[
\left(\frac{dS}{dt}\right)_{CV} = \left(sm + \frac{\dot{Q}}{T_{TER}}\right)_{IN} - \left(sm + \frac{\dot{Q}}{T_{TER}}\right)_{OUT} + \dot{S}_{gen}
\]
**PROBLEM STATEMENT:**

A bicycle tire has a volume of 1200 cm$^3$ which is considered to be constant during “inflation”. Initially the tire contains air at atmospheric conditions given as $P_0 = 100$ kPa and $T_0 = 20 ^\circ C$. A student then hooks up a bicycle pump and begins to force air from the atmosphere into the tire. After pumping stops and a new equilibrium is reached, the tire pressure is 600 kPa and the air temperature in the tire is 20 $^\circ C$.

a) Determine the mass [kg] of air added to the tire.

b) Determine the minimum amount of work [kJ] required to reach this end state.

c) If more than the minimum work is actually used, where does this extra energy go? That is what becomes of the extra energy?