Energy, Work, Heat

Last time we introduced systems & balances. We found that with a carefully defined system we could balance just about anything.

Today we will begin to quantify & balance Energy = 1st Law of Thermodynamics.

What is Energy? Well, what forms of energy are there?

Thermal, potential, kinetic, mechanical, electrical, chemical, nuclear....

All of these forms are quantifiable, relative to a reference state & can be included in thermodynamic systems. Energy has units of J=Nm

There are many definitions for energy. My definition:

Energy is a gradient moving a system to a different state. Ex: heat defines energy as the potential to produce change.

These forms of energy can be divided into categories:

Internal: dependent on the atoms & molecules of the material in the system. ⇒ Thermal, Chemical, Nuclear

External: dependent on the system & surroundings/referenced state. ⇒ Potential, Kinetic, Electrical, Mechanical, etc.

Can energy transfer between forms? Yes!

Can energy transfer between systems? Yes! but how?

Heat: energy transfer through a temperature differential

Work: energy transfer across a system boundary as a result of a difference in any potential other than temperature.
We need to balance energy for a system that includes all of the ways that energy changes.

\[ \text{Closed system:} \quad E_{\text{in}} - E_{\text{out}} + E_{\text{stored}} = 0 \]

Balance: \( E_{\text{in}} - E_{\text{out}} + E_{\text{stored}} = 0 \) 

Is energy produced or destroyed? No, it's conserved.

\[ E_{\text{in}} = E_{\text{out}} + E_{\text{stored}} \quad \text{where} \quad E_{\text{in}} = Q_{\text{in}} + W_{\text{in}}, \quad E_{\text{out}} = Q_{\text{out}} + W_{\text{out}} \]

\[ AE_{\text{stored}} = ? \]

Thermal = \( \Delta U \) internal energy of a system

Potential = \( \Delta PE = mg \Delta z \)

Kinetic = \( \Delta KE = \frac{1}{2} m v^2 \)

Our energy balance on a closed system is then

\[ Q_{\text{in}} + W_{\text{in}} = Q_{\text{out}} + W_{\text{out}} + \Delta U + \Delta PE + \Delta KE \]

On a rate basis for a closed system

\[ \dot{Q}_{\text{in}} + \dot{W}_{\text{in}} = \dot{Q}_{\text{out}} + \dot{W}_{\text{out}} + \frac{dU}{dt} + \frac{dPE}{dt} + \frac{dKE}{dt} \]

Rate of Energy in \quad Rate of Energy out \quad Rate change of energy stored

Let's work through some examples
For the purposes of this class, heat transfer will either be

1) Adiabatic means no heat transfer

2) Specified given to you

3) The body that is being calculated in the balance

Simple enough. How else can we transfer energy to the system?

→ Work = how lets add a shaft with a propeller. The shaft trades mechanical energy via torque-speed to the fluid.

How do we spin the shaft with one of our energy forms?

Potential: Falling weight. How do we find the work transferred by the falling weight? Work has units of J = /kg*m, force * distance.

\[ W = \int F\,dz \Rightarrow W_{fz} = F(z_2 - z_1) \Rightarrow W_{fz} = mg(z_2 - z_1) \]

So our fluid energy balance becomes \( E_i = E_{out} + \Delta E_{stored} \)

\[ Q_{in} + W_{in} = \Delta U + \Delta E_{int} + \Delta P \Rightarrow W_{in} = \Delta U \Rightarrow \Delta U = mg(z_2 - z_1) \]

Kinetic: Snowball hitting target.

Newton's 2nd Law: \( F = m\frac{dv}{dt} \) where \( v = \frac{dx}{dt} \) applying chain rule \( \frac{dv}{dt} = \frac{dv}{dx} \frac{dx}{dt} \)

\( F = m\frac{dv}{dx} \frac{dx}{dt} \Rightarrow F = mv\frac{dv}{dx} \Rightarrow W_{fz} = \int F\,dx \Rightarrow W_{fz} = \int m\frac{dv}{dx} \,dx \Rightarrow W_{fz} = \int m\left( v^2 - v_1^2 \right) \,dx \Rightarrow W_{fz} = \frac{m}{2}(v_2^2 - v_1^2) = \Delta U \text{ imbalance} \)
Mechanical: Spring & String: Hooke's Law \( F = kx \),

So \( W_{1 \to 2} = \int F \, dx \Rightarrow \int_{x_1}^{x_2} kx \, dx = \int \frac{k}{2} (x_2^2 - x_1^2) \)

Electrical: Motor: usually measured by power meter,

\[ W_{\text{motor}} = \frac{1}{2} \int F \, dx \Rightarrow W_{1 \to 2} = \int_{x_1}^{x_2} \frac{1}{2} \dot{V} \, dt = \Delta U \]

Your book has many more!!

Is there another way to do work on the system besides the shaft?

What happens if the piston moves? Our system volume changes size?

\[ W_{1 \to 2} = \int F \, dx \text{ where } F = PA \Rightarrow W_{1 \to 2} = \int_{x_1}^{x_2} P \, dA \text{ and } dT = dV / V \]

\[ W_{1 \to 2} = \int P \, dV \]

To solve this, we need a relationship for pressure as a function of volume for our fluid.

We don't know how to do this yet. Moreover, it in all these properties are related yet! Moreover, in all of these cases: \( W = \Delta U \) → What is internal energy? How is it related to the other properties? Like \( T \) & \( P \)?

We will discuss this next week! Discussion & Vibe Wednesday.