Energy balance

Work

When a force is applied to a system and causes a displacement, then work has been done on that system. By convention the numerical value of work W is positive when net -work is performed by the system on the surroundings. Thus, $W > 0$ means that the system has performed work on the surroundings such that the energy remaining in the system has decreased. If $W < 0$, then surroundings have performed net -work on the system so as to increase the system's energy. Work has units of energy (e.g. J, cal).

Is work a state function? *You can provide two examples of a system undergoing work interactions with its surroundings.*

Rates vs Amounts

Chemical processes use process streams to transport material from one point to another. Consider a stream with a mass flowrate m (note that we could equivalently have used molar units). The material in the stream carries its kinetic, potential, and internal energy with it. Therefore, the mass transport is perforce accompanied by energy transport. The rates of energy transport (units: energy/time, e.g. Joules/sec) that accompany the material flow in a process stream can be calculated as follows:

$$\dot{E}_k = \frac{1}{2}\dot{m}u^2 \qquad \dot{E}_p = \dot{m}gz \qquad \dot{U} = \dot{m}\hat{U} \qquad (5)$$

Remember these initials from the last lecture? Good.

Heat transport and work can be also expressed as rates, with symbols Q_o and W_o, respectively. The units of Q_o and W_o are energy/time. Note that units of energy against time are equivalently called units of **power**.

The General Energy Balance

"Black Box" Analysis: This method of analysis, in the context of process modeling, does not concern itself with how individual process units work. The input and output streams are instead analyzed by applying constraints imposed by nature, namely conservation of mass and conservation of energy. The inner workings of the physical apparatus are not relevant. This course treats process units as black boxes. Future courses will go into detail of how different process units work.

The **First Law of Thermodynamics** is a statement of energy conservation. Although energy cannot be created or destroyed, it can be converted from one form to another (for example, internal energy stored in molecular bonds can be converted into kinetic energy; potential energy can be converted to kinetic or to internal energy, etc.). Energy can also be transferred from one point to another, or from one body to a second body. Energy transfer can occur by flow of heat, by transport of mass (transport of mass is otherwise known as convection), or by performance of work. We'll see examples of these modes of energy transport below. The general energy balance for a process can be expressed in words as:

$$\textit{Accumulation of Energy in System} = \textit{Input of Energy into System} - \textit{Output of Energy from System} \qquad (6)$$

Now the total energy of a system, as considered above, is composed of kinetic, potential, and internal energies. These energies can be transferred into or out of the system by flow of mass through process streams that bring the various forms of energy with them. In addition, they can be transferred by performance of work, or by flow of heat. Equation 6, after expressing all terms as rates, thus becomes: (please write this down if you haven't opened the script for the audio as it is technical but not to worry, we will expand the equation as we go thro)

$$\textit{Rate of Energy Accumulation in System} = \sum_{\text{input streams}} \dot{m}_j \left(\hat{U}_j + \frac{u_j^2}{2} + g z_j \right) - \sum_{\text{output streams}} \dot{m}_j \left(\hat{U}_j + \frac{u_j^2}{2} + g z_j \right) + \dot{Q} - \dot{W} \qquad (7)$$

In the first term on the right of equation 7, *j* runs over all incoming streams, and in the second it runs over all outgoing streams. Note that all terms in equation 7 have units of energy/time. Also, recall the conventions with regard to the sign of the heat and work terms.

What is the physical meaning of each of the terms in equation 7?

Equation 7 can be rewritten in various ways. Let us consider a stationary system (i.e. the system is not experiencing an overall movement in the frame of reference, although its boundary may be deformable). Such a system will in general experience two types of *contact* work interactions with the surroundings. The first type of work is called **shaft work** (symbol: W_s) and arises when a part of the boundary of the system is displaced. Shaft work takes place at moving parts of a system's boundary across which there is no mass transport. The force is often exerted by some form of machinery. For example, the surface of a rotating impeller exerts force on the fluid (the fluid being the system) as it stirs the fluid, and hence performs shaft work on the "system." Another example is that of a moving wall, such as a piston. The moving piston exerts force and thus performs shaft work on the contained fluid (the fluid again being the system).

A second classification of work that we will encounter is **flow work**. Flow work occurs at areas of a system's boundary across which there is material flowing. The flow work is associated with the force and displacement required to push the material into the system (input streams), or with the force and displacement required to push material out of the system (output streams). A fluid cannot flow unless it creates space for itself when it enters or exits a system. The forces that do the necessary pushing is exerted by particles of the flowing material inside the system on the particles of the material outside the system, and are evaluated at the stream inlets and outlets where the transfer of material into/out of the system takes place. These forces, expressed per area, are the pressure in the stream.

For systems with no significant heat exchange with surroundings $Q = 0$. Such a system is said to be **adiabatic**. The absence of any heat transfer can be due to perfect thermal insulation or the fact that the system and surroundings are at the same temperature.

Steam Tables

The **steam tables** are a tabulation of the thermodynamic parameters for water in liquid and vapor phases. Information is provided for **saturated liquid**, **saturated steam** (i.e. saturated water vapor), and for **superheated steam** (i.e. superheated water vapor). Saturated liquid and saturated steam can coexist in a vapor liquid equilibrium. Superheated steam would have to be cooled to its dew point to become saturated. The steam tables provide the following parameters:

(i) vapor pressure of saturated water as a function of temperature (equivalently, the boiling point of liquid water as a function of pressure)
(ii) the specific volume $\hat{V}$ of liquid water and of steam
(iii) the specific internal energies of liquid water and of steam relative to a reference state of liquid water at the triple point
(iv) the specific enthalpy of liquid water and of steam relative to a reference state of liquid water at the triple point
(v) the heat of vaporization of water, given by the difference between the enthalpies of the saturated steam and of the saturated liquid

This is just a summary but a lot of significant examples and publications are available for further research on the matter. This being an audio file, I can not get into much mathematical expressions without confusing you so much which is why I try to make this much more theoretical as I can without loosing the meaning of equations. So, once again, its been a pleasure. See you in lecture seven. Adios!!