Before discussing what is Energy Balance, we need to remember some terms:

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>System</td>
<td>The quantity of matter or region of space chosen for study enclosed by a boundary.</td>
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<tr>
<td>Surroundings</td>
<td>Everything outside the system boundary.</td>
</tr>
<tr>
<td>Boundary</td>
<td>The surface that separates the system from the surroundings. It may be a real or imaginary surface, either ridged or movable.</td>
</tr>
<tr>
<td>Open system (flow system)</td>
<td>A system that is open to interchange of mass with the surroundings. Heat and work can also be exchanged.</td>
</tr>
<tr>
<td>Closed system (nonflow system)</td>
<td>A system that does not interchange mass with the surroundings. But heat and work can be exchanged.</td>
</tr>
<tr>
<td>Property</td>
<td>Observable (or calculable) characteristic of the system such as pressure, temperature, volume, etc.</td>
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<tr>
<td>State</td>
<td>Conditions of the system (specified by the values of temperature, pressure, composition, etc.)</td>
</tr>
<tr>
<td>Steady state</td>
<td>The accumulation in the system is zero, the flows in and out are constant, and the properties of the system are invariant.</td>
</tr>
<tr>
<td>Unsteady state (transient)</td>
<td>The system is not in the steady state</td>
</tr>
<tr>
<td>Equilibrium (state)</td>
<td>The properties of the system are invariant; implies a state of balance. Types are thermal, mechanical, phase, and chemical equilibrium.</td>
</tr>
<tr>
<td>Phase</td>
<td>A part (or whole) of the system that is physically distinct, and macroscopically homogeneous of fixed or variable composition, such as gas, liquid, or solid.</td>
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</table>
**System**

A “system” is an object or a collection of objects that an analysis is done on. The system has a definite boundary, called the system boundary that is chosen and specified at the BEGINNING of the analysis. Once a system is defined, through the choice of a system boundary, everything external to it is called the surroundings. All energy and material that are transferred out of the system enter the surroundings, and vice versa. In the general case there are very few restrictions on what a system is; a system can have a nonzero velocity, a nonzero acceleration, and a system can even change in size with time.

**An isolated system** is a system that does not exchange heat, work, or material with the surroundings. 

If heat and work are exchanged across a system’s boundary, but material is not, it is a **closed system.** An **open system** can exchange heat, work, and material with the surroundings.

**HWs.** Discuss each situation below as approximating an isolated, a closed, or an open system.

(i) A river.
(ii) The interior of a closed can of soda.
(iii) The interior of a closed refrigerator that is turned on.
(iv) The interior of a closed refrigerator that is turned off.

**State of a System**

Once a system is defined, a certain number of variables will specify its state fully. For example, one may need to provide the temperature, pressure, composition, total amount of material, velocity, and position in order to specify a system’s “state.” The exact information that is needed to specify the state of a system depends on the type of system and the analysis to be performed.

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Adiabatic system</td>
<td>A system that does not exchange heat with the surroundings during a process (perfectly insulated).</td>
</tr>
<tr>
<td>Isothermal system</td>
<td>A system in which the temperature is invariant during a process.</td>
</tr>
<tr>
<td>Isobaric system</td>
<td>A system in which the pressure is constant during a process.</td>
</tr>
<tr>
<td>Isochoric system</td>
<td>A system in which the volume is invariant during a process.</td>
</tr>
<tr>
<td>State variable</td>
<td>Any variable (function) whose value depends only on the state of the system and not upon its previous history (e.g., internal energy).</td>
</tr>
<tr>
<td>Path variable</td>
<td>Any variable (function) whose value depends on how the process takes place, and can differ for different histories (e.g., heat and work).</td>
</tr>
</tbody>
</table>
State Functions and State Properties
The state of a system can be changed, for example by increasing its temperature or changing its composition. Properties of the system, whose change depends only on the initial (before) and final states of the system, but not on the manner used to realize the change from the initial to the final state, are referred to as state properties or state functions. In other words, the change in a state function or state property $X$, between some final (state 2) and initial (state 1) situations, can be expressed as

$$\Delta X = X_{\text{state 2}} - X_{\text{state 1}} = X_{\text{final}} - X_{\text{initial}}$$

In the equation, $X_{\text{final}}$ only depends on the final state of the system, and $X_{\text{initial}}$ only on the initial state of the system. The equation does not require any information whatsoever as to how the system got from the initial to the final state, since $X$ does not depend on the details of the path followed.

Path Functions
The path followed by the system is important. Any variable (function) whose value depend on how the process takes place, and can differ for different histories (e.g. heat and work).

Example. Which of the below examples represent changes in state functions?

(i). Work done to climb from the bottom (state 1) to the top (state 2) of a mountain.
(ii). Change in gravitational energy of an object when it is raised from the bottom (state 1) to the top (state 2) of a mountain.
(iii). Change in density of water in a pot when it is heated from 20°C (state 1) to 50°C (state 2).
(iv) Amount of heat liberated from burning gas in a stove in order to realize a temperature change of the water in a pot from 20°C (state 1) to 50°C (state 2).
(v) You are invited to a wedding ceremony which will be in Istanbul Çıragan Saray, there which dress you will wear, which travelling method (by flight, by car, by bus …..) you will use, and how much time and money you need; these are all important factors in your plan. Think which one of them is/are state function(s).

It is important to understand the process types:
There are three major classifications of processes:

**Batch Process:** In a batch process, material is placed in the vessel at the start and (only) removed at the end -- no material is exchanged with the surroundings during the process. Batch Examples: baking cookies, fermentations, small-scale chemicals (pharmaceuticals)

**Continuous process:** In a continuous process, material flows into and out of the process during the entire duration. Continuous Examples: pool filter, distillation processes.

**Semi-batch process or semi-continuous process:** A semi-batch process is one that does not neatly fit into either of the other categories (i.e., it is a catch-all classification). Semi-Batch Examples: washing machine, fermentation with purge.
Each of the above classes of process may be further distinguished by their mode of operation with respect to time.

Continuous processes may be run at **steady-state (SS)**, none of the process variables change with time (if we ignore small, random fluctuations). It means if a process starts and reaches an equilibrium, nothing changes (process variables amount of streams, T, P..... are all constant until the process is over).

Batch processes may be run at unsteady-state (USS), the process variables change with time. (One class of unsteady-state processes is oscillatory, where they process variables change with time in a regular way). Cooking a meal is an example of USS, putting all ingredients into a pan wait for cook, and take and eat it, everything is time dependent, nothing same!

So let’s understand what SS is:

![Image of steady-state system](image)

- **Figure 1.** The open and steady state conditions showing system and in and out flows

The system is a steady-state process or a steady-state system because

1) the conditions inside the process (specifically the amount of water in the vessel remain unchanged with time
2) the conditions of the flowing streams remain constant with time

Thus, in a steady-state process, by definition all of the conditions in the process (e.g., temperature, pressure, mass of material, flow rate, etc.) remain constant with time. A continuous process is one in which material enters and/or leaves the system without interruption. After how much time is passed without changing flow rates of inlet and outlet, we will have the same amount of water in the system; this means it is a SS process.

Unsteady-state system:

Figure 2b shows the system after 2 h of accumulation (2 h of accumulation at 10 kg/h amounts to 20 kg of total accumulation). Because the amount of water in the system changes with time, the process and system are deemed to be an unsteady-state (transient) process or system. For an unsteady-state process, not all of the conditions in the process (e.g., temperature, pressure, mass of material, etc.) remain constant with time, and/or the flows in and out of the system can vary with time.

What if you make a change in the process so that the flow out of the system is instantaneously reduced to a constant 90 kg/h? Figure 2a shows the initial condition in the vessel. Because
water accumulates at the rate of 10 kg/h (100 kg/h-90 kg/h) in the system, the amount of water present in the vessel will depend on the interval of time for which the rate of accumulation is maintained.

**Figure 2.** The open and unsteady state conditions showing system and in and out flows (this is an example for positive accumulation)

a) In the system just we have 100 kg water

b) Then water is allowed to enter and leave with a different rate; inlet: 100 kg H\(_2\)O/hr and outlet 90 kg H\(_2\)O/hr after 2 hour is passed, we will have 120 kg water in the system

**Figure 3.** The open and unsteady state conditions showing system and in and out flows (this is an example for negative accumulation)

a) In the system just we have 100 kg water

b) Then water is allowed to enter and leave with a different rate; inlet: 90 kg H\(_2\)O/hr and outlet 100 kg H\(_2\)O/hr after 2 hour is passed, we will have 80 kg water in the system

**Energy terms**

Energy is often categorized as:
A. Kinetic Energy
B. Potential Energy
C. Internal Energy

**Kinetic Energy**
A system’s kinetic energy is associated with directed motion (e.g. translation, rotation) of the system. Translation refers to straight line motion. The kinetic energy \(E_K\) of a moving object of mass \(m\) and travelling with speed \(v\) is given by, \((1/gc)\) is generally not represented in SI however it is unforgettable in AES.

\[ E_K = \frac{1}{2} m v^2 \frac{1}{g_c} \]

Specific kinetic energy is shown with \(\bar{E}_K\)
\[ \bar{E}_K = \frac{1}{2} v^2 \frac{1}{g_c} \]

Note that \( v \) is measured relative to a **frame of reference** that defines what is “stationary”. \( E_K \) has units of energy, \( m \) of mass, and \( v \) of length/time. How could the kinetic energy of a system change?

Is kinetic energy a state function?

Example: Water is pumped from a storage tank through a tube of 3.00 µm inner diameter at a rate of 0.001 m³/s. See Figure. What is the specific kinetic energy of the water in the tube?

Basis: 1 second

If we need mass of water we can find calculate of water using volumetric flow rate and either density or specific volume (which is inverse of density from steam table) if you know \( T \). Specific \( E_K \) is asked so no need to calculate mass of water. In order to find velocity, let’s calculate area of the pipe, \( r = \frac{1}{2} (3.0) \text{ cm} = 1.5 \text{ cm} \)

\[ v = \frac{0.001 \text{ m}^3}{s} \frac{10000 \text{ cm}^2}{\pi (1.5)^2 \text{ cm}^2} = 1.415 \text{ m/s} \]

\[ E_K = \frac{1}{2} \left[ \left( \frac{1.415 \text{ m/s}}{s} \right)^2 \frac{1 \text{ (N)(s^2)}}{1 \text{ (kg)(m)}} \frac{1}{1 \text{ (N)(m)}} \right] \text{0.1 J/kg} \]

**Potential Energy**

Potential energy of a system is due to the position of the system in a potential field. There are various forms of potential energy, but only gravitational potential energy will be considered in this course. The gravitational potential energy of an object of mass \( m \) at an elevation \( z \) in a gravitational field, relative to its gravitational potential energy at a reference elevation \( z_0 \), is given by

\[ E_p = m h \frac{g}{g_c} \]

Specific potential energy is shown with \( \bar{E}_p \)

\[ \bar{E}_p = h \frac{g}{g_c} \]

The quantity \( g \) is the gravitational acceleration that defines the strength of the gravitational field. Often, the earth’s surface is used as the reference and assigned \( h_0 = 0 \), in which case \( mgh \) represents the gravitational potential energy of the object relative to its potential energy if it rested on the earth’s surface. \( E_p \) has units of energy, \( m \) of mass, \( g \) of length/time², and \( h \) of length.
(1/gc) is generally not represented in SI however it is unforgettable in AES.

How could the gravitational potential energy of a system change?

Is gravitational potential energy a state function?

**Example:** Calculation of potential energy change of water

Water is pumped from one tank to another 300 ft away, as shown in Fig. The water level in the 2nd tank is 40 ft above the water level of the 1st tank. What is the increase in specific potential energy of the water in Btu/lb\(_m\)? In AES \( \frac{\theta}{g_c} = \frac{32.2 \text{ ft/s}^2}{32.174 \text{ (lbm)/(ft)}(\text{s}^2)} \approx 1 \frac{\text{lb}_f}{\text{lb}_m} \)

\[
\bar{E}_p = \frac{\theta}{g_c} = (40 \text{ ft})(1 \frac{\text{lb}_f}{\text{lb}_m})(\frac{1 \text{ Btu}}{778.2 \text{ (ft)(lb}_f))} = 0.0514\text{Btu/lb}_m
\]

**Internal Energy**

All the energy associated with a system that does not fall under the above definitions of kinetic or potential energy is internal energy. More specifically, internal energy is the energy due to all molecular, atomic, and subatomic motions and interactions. Usually, the complexity of these various contributions means that no simple analytical expression is available from which internal energy can be readily calculated. The internal energy will be represented by the symbol \( U \). Internal energy has units of energy (e.g. J, cal, BTU).

\( U = m\bar{U} \)

What types of events would bring about a change in a system’s internal energy?

Is internal energy a state function?

Internal energy is a function of temperature (T) and specific volume (\( \bar{V} \)) for single phase and single component

\( \bar{U}=f(T, \bar{V}) \)

By taking total derivative to see effect of them:

\[
d\bar{U} = \left[ \frac{\partial \bar{U}}{\partial T} \right]_{\bar{V}} dT + \left[ \frac{\partial \bar{U}}{\partial \bar{V}} \right]_{T} d \bar{V}
\]
The numerical value of \[\frac{\partial U}{\partial T}\] is so lower than \[\frac{\partial U}{\partial T}\] that so it is negligible (since the mathematics we use here just addition as an example if we add 1000 with 0.001, 0.001 is negligible).

By definition \[\frac{\partial U}{\partial T}\] is the heat capacity (specific heat) at constant volume, \(C_V\).

Heat capacity can be defined to be the amount of heat necessary to raise the T of one kilogram of substance by one degree in a closed system, and so has the SI units of J/(kg)(K)

\[\Delta U = \int_{T_1}^{T_2} C_V dT\]

For an IG, at constant volume this equation is valid (if no phase change occurs).

Careful the temperature dependency of \(C_V\), it is not constant while T changes its value changes, however in a narrow range of T studied in the most cases we are handling it as constant.

If there is more than one component in the system we need to calculate total internal energy as:

\[U_{tot} = m_1 U_1 + m_2 U_2 + m_3 U_3 + \ldots\]

Example: What is the change in internal energy when 10 kg mol of air is cooled from 60°C to 30°C in a constant volume process? Find the \(C_V\) of air valid at this T range from handbooks, it is 2.1 x10^4 J/(kg mol)(K). It can be written as 21 kJ/(kg mol)(°C).

\[\Delta U = n (\hat{U}_2 - \hat{U}_1) = n \int_{T_1}^{T_2} C_V dT = 10 \text{ kg mol} \left(21 \frac{kJ}{(\text{kg mol})(°C)}\right)(30 - 60)°C\]

\[\Delta U = -6.3 \text{ kJ}\]

**HW 2:** Figure below shows two different possible paths taken by a gas in a process. For which path, will \(\Delta U\) be the greatest, path A or Path B?

---

**Enthalpy**

The enthalpy \(H\) of a system is defined by
\[ H = U + PV \]

\[ H = m \hat{H} \]

where \( P \) is the pressure and \( V \) is volume. Let’s think about the \( PV \) term. We know that \( PA \), where \( A \) is the area subjected to a pressure \( P \), is the force acting on that area. If a fluid inside a system is displaced through a distance \( h \) by the force \( PA \), then the resultant work \( W \) done on the system can be calculated as the product of this force times the displacement. In other words, \( W = PAh \). Now note that \( Ah = V \), the volume swept out by the displacement. Thus, an alternate way to write the displacement work is \( W = PV \). This type of work, where pressure results in the displacement of a fluid, will be referred to as flow work. If an amount of fluid of volume \( V \) is inserted into a system against a pressure \( P \), the work required to accomplish this is \( PV \). Enthalpy, therefore, can be viewed as the sum of the internal energy of this fluid volume added to the system plus the flow work performed on the system in order to insert the fluid. Enthalpy has units of energy (e.g. J, cal, BTU).

What types of events would bring about a change in a system’s enthalpy?

Is enthalpy a state function?

In order to calculate the specific enthalpy like in the case of internal energy, we use the property that the enthalpy is an exact differential. The state for the enthalpy for a single phase and single component can be completely specified by two intensive variables; temperature and pressure.

\[ \hat{H} = f(T, P) \]

By taking total derivative to see effect of them:

\[ d\hat{H} = \left[ \frac{\partial \hat{H}}{\partial T} \right]_P dT + \left[ \frac{\partial \hat{H}}{\partial P} \right]_T dP \]

The numerical value of \( \left[ \frac{\partial \hat{H}}{\partial P} \right]_T \) is so lower than \( \left[ \frac{\partial \hat{H}}{\partial P} \right]_P \) then so it is negligible (since the mathematics we use here just addition as an example if we add 1000 with 0.001, 0.001 is negligible).

By definition \( \left[ \frac{\partial \hat{H}}{\partial T} \right]_P \) is the heat capacity (specific heat) at constant pressure, \( C_P \).

\[ \Delta \hat{H} = \hat{H}_2 - \hat{H}_1 = \int_{\hat{H}_1}^{\hat{H}_2} d\hat{H} = \int_{T_1}^{T_2} C_P dT \]

Careful the temperature dependency of \( C_P \), it is not constant while \( T \) changes its value changes, however in a narrow range of \( T \) studied in the most cases we are handling it as constant.

If there is more than one component in the system we need to calculate total internal energy as:

\[ H_{tot} = m_1 \hat{H}_1^+ + m_2 \hat{H}_2^+ + m_3 \hat{H}_3^+ \cdots \]
Enthalpy has no absolute value only changes in the enthalpy can be calculated like in the case of internal energy. The enthalpy values in the Tables (like steam tables) are $\Delta \hat{H}$ values with respect to common reference conditions like liquid water at 0°C and its vapor pressure. This means not the enthalpy at this condition is zero however enthalpy has arbitrarily been assigned zero under these conditions. Since in calculation of enthalpy change reference conditions are cancelled out, no mistakes present in calculation. Careful that reference is generally initial conditions.

Initial state of the system (1) \hspace{1cm} Final state of the system (2)

Enthalpy=$\hat{H}_1 - \hat{H}_{ref}$ \hspace{1cm} Enthalpy=$\hat{H}_2 - \hat{H}_{ref}$

Net enthalpy change $\Delta \hat{H} = (\hat{H}_2 - \hat{H}_{ref}) - (\hat{H}_1 - \hat{H}_{ref}) = \hat{H}_2 - \hat{H}_1$

Enthalpy changes of a pure substance as a function of $T$.

By forming Equation from solid to vapor state:

$\Delta \hat{H} = \int_{T_{ref}}^{T_{fusion}} C_{P_{solid}} dT + \Delta \hat{H}_{fusion} at T_{fusion} + \int_{T_{fusion}}^{T_{vaporization}} C_{P_{liquid}} dT + \Delta \hat{H}_{vaporization at T_{boiling point}} + \int_{T_{boiling}}^{T_{vaporization}} C_{P_{vapor}} dT$

Vaporization (Latent heat)

(sensible heat)

(blue colored lines show sensible heats)

**Example:** What is $\Delta H$ for 1 kg water from ice at 0°C to vapor at 120°C and 100 kPa?

$C_{P_{liq}} = 4.186 \text{kJ/(kg)(K)}$, $C_{P_{vap}} = 1.88 \text{J/(g)(K)}$, $C_{P_{ice}} = 2.09 \text{kJ/(kg)(°C)}$

$\Delta H_{fusion} = 3.34 \text{kJ/kg}$, $\Delta H_{vap} = 2255 \text{kJ/kg}$

$\Delta H = 3.34 \text{kJ/kg} + [4.186 \text{kJ/(kg)(K)}](100-0) \text{ °C} + 2255 \text{kJ/kg} + [1.88 \text{kJ/(kg)(K)}](120-100) \text{ °C}$
ΔH=3044.6 kJ/kg

Specific Properties
The total internal energy, enthalpy, kinetic energy, and potential energy of a system are extensive properties. An extensive property depends on the total number of molecules present in the system and on the system’s total size. Often, it is more convenient to refer to the amount of a property per mass of the system. For example, if the system is a fluid phase, one may want to express the amount of internal energy or enthalpy contained in a unit mass of the fluid. If one refers to an amount of a property per mass, one is speaking about a specific property. Specific properties are intensive. Thus, specific volume is volume per mass, specific internal energy is internal energy per mass, and specific enthalpy is enthalpy per mass. Specific properties will be identified by a “^” symbol above them; thus, \( \tilde{V} \) = specific volume (units: volume/mass; e.g. m³/kg, ft³/lbm), \( \tilde{H} \) = specific internal energy (units: energy/mass; e.g. J/kg, BTU/lbm), \( \tilde{H} \) = \( \tilde{H} \) + P\( \tilde{V} \) = specific enthalpy (units: energy/mass; e.g. J/kg, cal/g), etc.

Reference States
The specific internal energy and specific enthalpy of a material are always defined relative to a reference state. The reference state can be chosen to refer to any set of conditions, although often it is chosen to be 0°C and 1 atm. Then, one speaks of \( \tilde{H} \) or \( \tilde{H} \) of a material relative to the value of \( \tilde{H} \) or \( \tilde{H} \) of that material in the reference state.

What is the value of \( \tilde{H} \) or \( \tilde{H} \) for the material in its reference state?

Now imagine that a system passes from state 1 to state 2. In general, \( \tilde{H} \) or \( \tilde{H} \) will change when the state of the system changes, with the difference being

\[ \Delta \tilde{H} = \tilde{H}_2 - \tilde{H}_1 \] and \[ \Delta \tilde{H} = \tilde{H}_2 - \tilde{H}_1 \]

Does the choice of a reference state affect the value of \( \Delta \tilde{H} \) or \( \Delta \tilde{H} \)?

Note that, in calculations, we will only be interested in how much the internal energy or enthalpy changed. That is, we will only need to calculate \( \Delta \tilde{H} \) and \( \Delta \tilde{H} \), but not the absolute values of internal energy or enthalpy.

Heat
When there is a difference in temperature between two points, heat is transferred (flows) from high temperature to the low temperature. By convention the numerical value of heat transferred is positive when it is transferred into the system, thereby increasing the energy contained in the system. That is, if \( Q \) is the heat transferred from the surroundings to the system, then \( Q > 0 \) means (positive for system) that net heat is transferred to the system so as to increase the energy of the system. If \( Q < 0 \) (negative for system), then net heat is transferred from the system to the surroundings, and the system has lost energy. Note that \( Q \) has units of energy (e.g. J, BTU, cal).

Is the heat transferred in going from state 1 to state 2 a state function?

What does “transfer of heat” mean, physically? That is, what are the molecular level processes that give rise to heat transfer?
Basically heat can be classified as sensible heat and latent heat. Sensible heat is sensed with a temperature change (ΔT≠0). Latent heat is heat used for a phase change (ΔT=0).

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 \( W < 0 \), surroundings have performed net work on the system. Work has units of energy (e.g. J, cal, BTU). [This point needs further discussion, just the opposite of W sign is accepted by some engineers (Himmelblau and some other books) with an assumption that work is a kind of energy and losing energy for a system should cause negativity, so if you see that don’t worry the GEB will be changed if so]

Is work a state function?

Example: Suppose that an IG at 27°C and 200 kPa is enclosed in a cylinder by a frictionless piston, and the gas slowly forces so that the volume of gas expands from 0.1 to 0.1 m³. See the Figure. Calculate the work done by the gas on the piston if two different paths are used to go from the initial state to the final state:

Path A: the expansion occurs at constant pressure (isobaric)

Path B: the expansion occurs at constant temperature (isothermal)

The piston should be assumed to be frictionless and ideal process, otherwise the solution given below is not so correct. You will see them in some other further courses. System is IG, basis: IG at 27°C and 200 kPa
We can calculate the moles of gas, using PV=nRT

\[ n = \frac{(200 \text{ kPa})(0.1 \text{ m}^3)}{300 \text{ K}} \frac{(\text{kg mol})(K)}{8.314 (\text{kPa})(\text{m}^3)} = 0.00802 \text{ kg mol} \]

For isobaric process, \( W = + \int_{V_1}^{V_2} PdV \) (positive because work done by the system)

\[ W = P(V_2-V_1) = 200 \text{ kPa} (0.2 - 0.1)\text{ m}^3 \frac{\text{kJ}}{(\text{kPa})(\text{m}^3)} = 20 \text{ kJ} \]

For isothermal process; \( P=\frac{nRT}{V} \)

\[ W = + \int_{V_1}^{V_2} \frac{nRT}{V} dV = nRT \int \frac{1}{V} dV = nRT \ln\left(\frac{V_2}{V_1}\right) \]

\[ W = (0.0802 \text{ kg mol})\left(\frac{8.314 (\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})}\right)(300 \text{ K}) \ln\left(\frac{0.2}{0.1}\right) = 13.86 \text{ kJ} \]

This example is from Himmelblau but in the book mentioned the results were negative, here are positive. (No problem this difference will be overcome using different sign before W term in the GEB; we will discuss)

**RATES VS AMOUNTS**

Chemical processes use process streams to transport material from one point to another. Consider a stream with a mass flow rate \( m \) (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 perfected accompanied by energy transport. The rates of energy transport (units: energy/time, e.g. J/s, BTU/h) that accompany the material flow in a process stream can be calculated as follows:

\[ E_K = \frac{1}{2} m u^2 \frac{1}{8c} \quad \& \quad E_P = m \frac{g}{8c} \quad \& \quad U = m\dot{H} \text{ & flow work } mP\dot{V} \]

hence total of internal energy and flow work is enthalpy so
Heat transport and work can be also expressed as rates, with symbols $Q$ and $\dot{W}$, respectively. The units of $Q$ and $\dot{W}$ are energy/time.

Note that units of energy/time are equivalently called units of **power**.

**Problems:**

1. Water flows into a process unit through a 2 cm diameter pipe at a volumetric flow rate of 2.00 m$^3$/h.
   (i) Calculate the rate $E_K$ at which the water stream brings kinetic energy in J/s.
   (ii) What is the reference “state” used for kinetic energy?
   (iii) If the pipe is at an elevation $h = 100$ m (relative to the reference elevation $h_o$), what is the rate at which the stream brings potential energy into the process unit, in J/s?

2. A can of soda at room temperature is put into the refrigerator so that it will cool. Would you model the can of soft drink as a closed system or as an open system? Explain.

3. Suppose that a constant force of 40.0 N is exerted to move an object for 6.00 m. What is the work accomplished (on an ideal system) expressed in the following:
   (a) joules (c) cal
   (b) (ft)(lb) (d) Btu

4. A rigid tank contains air at 400 kPa and 600°C. As a result of heat transfer to the surroundings, the temperature and pressure inside the tank drop to 100°C and 200 kPa, respectively. Calculate the work done during this process.

**CALCULATION OF ENTHALPY CHANGES**

In order to calculate enthalpy change it was noted that there are several techniques, here using of specific heats enthalpy calculation of food systems will be discussed.

**Specific Heat of Solids and Liquids**

The specific heat ($C_p$) is the amount of heat that accompanies a unit change in temperature for a unit mass. The specific heat, which varies with temperature, is more variable for gases compared with liquids or solids. Most solids and liquids have a constant specific heat over a fairly wide temperature range. The enthalpy change of a material with mass $m$ is:

$$\Delta H = m \int_{T_1}^{T_2} C_p \, dT \quad (\text{Eq. xx})$$

Handbook tables give specific heats averaged over a range of temperature. When average specific heats are given, Equation (xx) becomes:

$$q = m C_{\text{avg}} (T_2 - T_1) \quad (\text{Eq. Xx})$$

For solids and liquids, Equations (xx) and (Xx) are valid over the range of temperatures encountered in food processing systems.
Table 5.1 shows the average specific heats of various solids and liquids.

![Table 5.1 Specific Heat of Food Products.](image)


For fat-free fruits and vegetables, purees and concentrates of plant origin, Siebel (1918) observed that the specific heat varies with moisture content and that the specific heat can be determined as the weighted mean of the specific heat of water and the specific heat of the solids.

For a fat-free plant material with a mass fraction of water \( w_{H_2O} \), the specific heat of water above freezing is 1 BTU/(lb)(°F) or 4.186 kJ/(kg)(K), and that of non-fat solids is 0.2 BTU/(lb)(°F) or 0.837 kJ/(kg)(K).

Because the mass fraction of non-fat solids is \( w_{SNF} = 1 - w_{H_2O} \), the weighted average specific heat for unit mass of material above freezing is:

\[
C_{avg} = 1(w_{H_2O}^F) + 0.2(1 - w_{H_2O}^F) = (1 - 0.2)w_{H_2O}^F + 0.2 = 0.8w_{H_2O}^F + 0.2 \text{ in BTU/(lb)(°F)}
\]

In SI:

\[
C_{avg} = 3.349w_{H_2O}^F + 0.837 \text{ in kJ/(kg)(K)}
\]

When fat is present, the specific heat above freezing may be estimated from the mass fraction fat \( w_{fat} \), mass fraction solids non-fat \( w_{SNF} \), and mass fraction moisture \( w_{H_2O} \), as follows:

\[
C_{avg} = 0.4 w_{fat} + 0.2 w_{SNF} + w_{H_2O} \text{ in Btu/(lb)(°F)}
\]

\[
C_{avg} = (1.674)(w_{fat}) + (0.836)(w_{SNF}) + (4.186)(w_{H_2O}) \text{ in kJ/(kg)(K)}
\]

Below freezing, it is not suitable to use specific heats for the whole mixture because the amounts of frozen and unfrozen water vary at different temperatures. It will be necessary to consider the latent heat of fusion of water, and sensible heats of liquid water and ice should be
evaluated separately. Refer to another course, Food Operation 382, “Enthalpy Changes in Foods during Freezing” later.

**Example.** Calculate the specific heat of orange juice concentrate having a solids content of 45%.

**Solution:**

Using Siebel’s equation: Calculating a weighted average specific heat:

$$C_{avg} = 0.2(0.45) + 1(0.55) = 0.64 \text{ BTU/(lb)(◦F)}$$

$$C_{avg} = 837.36(0.45) + 4186.8(0.55) = 2679 \text{ J/(kg)(K)}$$

**Example.** Calculate the specific heat of beef roast containing 15% protein, 20% fat, and 65% water.

**Solution:**

$$C_{avg} = 0.15(0.2) + 0.20(0.4) + 0.65(1) = 0.76 \text{ BTU/(lb)(◦F)}$$

$$C_{avg} = 0.15(0.837) + 0.2(1.674) + 0.65(4.186) = 3.182 \text{ J/(kg)(K)}$$

**Example.** Calculate the heat required to raise the temperature of a 4.535 kg (10 lb) roast containing 15% protein, 20% fat, and 65% water from 4.44◦C (40◦F) to 65.55◦C (150◦F). Express this energy in (a) BTU, (b) joules.

**Solution:**

Cavg from previous Example = 0.76 BTU/(lb)(◦F)

(a) $$q = m C_{avg} (T_2 - T_1) = 10 \text{ lb} \times 0.76 \text{ BTUlb · ◦F} (150 - 40)\text{◦F} = 836 \text{ BTU}$$

(b) Use Cavg from previous Example = 3.182 kJ/(kg · K)

$$q = 4.535 \text{ kg}[3.182 \text{ kJ/(kg)(K)}] (65.55 - 4.44)\text{◦C} = 882 \text{ kJ}$$

**Example.** Calculate the specific heat of a formulated food product that contains 15% protein, 20% starch, 1% fiber, 0.5% ash, 20% fat, and 43.5% water at 25◦C.

**Solution:**

The specific heat in kJ/(kg)(◦C), are $$C_{protein} = 2.036; C_{fat} = 2.018; C_{starch} = 1.594; C_{ash} = 1.891; C_{water} = 4.186$$

Substituting them in Equation (in SI)

$$C_{mean} = 0.15(2.037) + 0.2(1.594) + 0.01(1.891) + 0.005(1.373) + 0.2(2.018) + 0.435(4.186) = \Delta 2.870 \text{ kJ/(kg)(K)}$$

**INTRODUCTION TO ENERGY BALANCES FOR PROCESSES WITHOUT REACTION**

Energy balance is a mathematical or numerical expression of 'Conservation of energy' (also called first law of thermodynamics). Energy balance and mass balance are encountered often in the problems related to process design and operation. Principle of conservation of energy states that energy is indestructible, but can be transformed to other forms of energy and the total amount of energy entering any system must be exactly equal to that of leaving plus any accumulation within this system.

Energy out = Energy in + generation − consumption − accumulation
For steady state process the accumulation of both mass and energy will be zero. In mass balance, the total mass flow into a process unit is generally equal to the flow out at the steady-state except in biomass formation within a bioreactor where generation is concerned. In energy balance, the total enthalpy of the outlet streams will not be equal to that of the inlet streams if energy is generated (exothermic) or consumed (endothermic).

Careful that we are interested with the system and its states. Initially (at time \( t_1 \)) if there is a material in a system, the material has ENERGY formed by internal energy (it has to have internal energy, this is certain no doubt about it), and possibly kinetic and potential energies due to the conditions. Finally (at time \( t_2 \)) if there is a material in a system, the material has ENERGY formed by internal energy (it has to have internal energy), and possibly kinetic and potential energies due to the conditions.

As you can see accumulation is formed with the \((U + E_K + E_P)\) energies of the material within the system. If no change of these energies from \( t_1 \) to \( t_2 \), (if no change in amount of material, no velocity change and latitude change defined) \( \Delta E = 0 \). If accumulation term, \( \Delta E = 0 \) system is SS and if accumulation term, \( \Delta E \neq 0 \) system is USS. If the system is open we may have energy flow in and energy flow out as:

\[
\begin{align*}
\text{At time } t_1 & \quad E_{t_1} = (U + E_K + E_P)_{t_1} \\
\text{At time } t_2 & \quad E_{t_2} = (U + E_K + E_P)_{t_2} \\
\Delta E & = E_{t_2} - E_{t_1}
\end{align*}
\]

Energy Balances

Let us understand the GMB. There is a system and if the system is open, there may be some flow in and out of the system, and there may be some reactions causing generation of new compounds and/or consumption of some reactants. Due to these flows and or due to the reactions, there may be some changes within the system with respect to process time \((t)\),
hence for a process time $dt$, and $dF_A$ shows the change in materials present in the system. Therefore GMB is

$$(F_{Ain}) - (F(f_x)_{Aused}) + (F(f_x)_{Agenerated}) - (F_{Aout}) = \left(\frac{dF_A}{dt}\right)$$

Flow terms Accumulation/time dependency

If we have no reaction used and generated terms become equal to zero, then the equation:

$$\{\text{Total flow into the system}\} - \{\text{Total flow out of the system}\} = \{\text{Accumulation of material within the system}\} = \left(\frac{dF_A}{dt}\right)$$

The $EB \rightarrow (F_{Ain}) - (F_{Aout}) = \left(\frac{dF_A}{dt}\right)$

If the system is at SS, accumulation term equals to zero, $\left(\frac{dF_A}{dt}\right) = 0$.

The $EB \rightarrow (F_{Ain}) = (F_{Aout})$

If the system is at USS, accumulation term does not equal to zero, $\left(\frac{dF_A}{dt}\right) \neq 0$.

The $EB \rightarrow (F_{Ain}) - (F_{Aout}) = \left(\frac{dF_A}{dt}\right)$

Or we can describe as:

Within the system changes with respect to time:

\[
\{F_{\text{Final material in the system at } t_2}\} - \{F_{\text{Initial material in the system at } t_1}\} = \{\text{Accumulation}\} \quad \text{Eq. 1}
\]

“Flow of anything in minus flow of anything out” forms “accumulation” within the system:

\[
\{\text{Flow into the system from } t_1 \text{ to } t_2\} - \{\text{Flow out of the system from } t_1 \text{ to } t_2\} = \{\text{Accumulation}\} \quad \text{Eq. 2}
\]

So Eq. 1 and Eq. 2 they are equal to each other

\[
\{F_{\text{Final material in the system at } t_2}\} - \{F_{\text{Initial material in the system at } t_1}\} = \{\text{Flow into the system from } t_1 \text{ to } t_2\} - \{\text{Flow out of the system from } t_1 \text{ to } t_2\}
\]

You will understand if the process is SS or USS from explanations of the system, and although not every time it is valid, if you have a variable given per time, it will be SS; NOT EVERYTIME BUT MOSTLY. As you can see from the Figures 1-3, all streams’ quantities are given per time. In Figure 1, it is SS and in the others USS. Assume the
process is SS and try to solve the problem, and you realize that it is not SS, then change your assumption to USS. The steps of EB writing:

"When a sailor doesn't know what harbor he is looking for" advised by the Roman philosopher Seneca, "no wind is the right wind"

1. Choose the system, identify its boundary, and then decide whether the system is open or closed. Write the decision down. Change it if your first decision proves to be a poor one.
2. Decide if the system is steady state or unsteady state. Write the decision down.
3. Write down the general energy balance (GMB) for the system (one for each system if you pick multiple systems) along with the other equations.
4. Simplify the general energy balance as much as possible by using information the problem statement and reasonable assumptions based on your understanding of the process.
5. Choose a reference state for your calculations, usually the specification of temperature and pressure, but other variables may be substituted. Sometimes the reference state will be the initial state conditions.
6. Based on the reference state, get any needed physical property data ($T, p, V, U, H$) and add the values of the data to the sketch of the process, be sure to include phase changes.
7. Solve the energy balance alone or in conjunction with the material balances.

In writing EB, we need to specify whether the system is OPEN or CLOSED and whether the system is SS or USS; then four different combinations are possible, CLOSED and USS, CLOSED and SS, OPEN and SS, and OPEN and USS.

Let’s analyze each condition separately:

For closed and USS

If there is a closed system, means no input and output streams. No flow terms we have in the EB. However we may (or not) have heat and work exchanged between the system and its surroundings.

The EB is

$$Q - W = \{\text{Accumulation of material within the system}\} = \Delta(U + E_K + E_P) \quad \text{Eq. 3}$$

(hint: Himmelblau using $Q+W$, since they sign W oppositely)

Example: Figure illustrates three examples of applying GEB to closed, unsteady-state systems. In Figure a, 10 kJ of heat is transferred through the fixed boundary (bottom) of a vessel with 2 kJ being transferred out at the top during the same time period. Thus, $\Delta U$ increases by 8 kJ and accumulation changed by 8 kJ (no change in potential and kinetic energies of the system, only internal energy is changed then $\Delta E = \Delta U$). In Figure b, a piston does 5 kJ of work on a gas whose internal energy increases by 5 kJ. In Figure c, the voltage difference between the system and surroundings forces a current into a system in which no heat transfer occurs because of the insulation on the system.
Fig. Examples of closed, unsteady state systems that involve energy changes.

Problems:

1. A closed system undergoes three successive stages in which the respective heat transfers are: \( Q_1 = +10 \text{ kJ} \), \( Q_2 = +30 \text{ kJ} \), and \( Q_3 = -5 \text{ kJ} \), respectively. In the first stage, \( \Delta E = +20 \text{ kJ} \), and in the third stage \( \Delta E = -20 \text{ kJ} \). a) What is the work in the second stage, and b) the net \( W \) output of all three stages? (ans (b) -35 kJ)

2. A closed tank contains 20 lb of water. If 200 Btu are added to the water, what is the change in internal energy of the water? (ans 200 Btu)

3. When a batch of hot water at 140°F is suddenly well mixed with cold water at 50°F, the water that results is at 110°F. What was the ratio of the hot water to the cold water? You can use the steam tables to get the data. (ans 2)

Recall that steady state means the accumulation in the system is zero, and that the flows of \( Q \) and \( W \) in and out of the system are constant. They can actually vary in the process, of course, but we are really interested only in their net cumulative values over a time interval, and look at only final and initial conditions for \( \Delta E \).

How should Eq. 3 be modified to analyze SS? All you have to do is realize that inside the system hence

\[
\Delta E_R = 0 \quad \Delta E_P = 0 \quad \Delta U = 0 \quad \Delta E = 0
\]

\[ Q - W = 0 \]

If you rearrange Equation you get \( W = Q \) meaning that all of the work done on a steady-state system (here value of the \( W \) is negative) must be transferred out as heat (is negative). However, ironically, the reverse is false, namely the heat added to a closed, steady system. \( Q \) does not always equal the work done by the system (\( W \)).
HW 3: Does the transfer of heat into a closed steady state system increase or decrease the internal energy in the system?

HW 4: Examine the Figure given below, find $\Delta E = \ ?$

**OPEN and USS**

If there is one or more than one input(s) or output(s) streams crossing the boundary; means the system is open system, we may have both input and/or outputs, hence flow terms should be presented in the EB.

In an open, unsteady-state system, the accumulation term $Q(t)$ in the energy balance can be nonzero because

1. the mass in the system changes,
2. the energy per unit mass in the system changes, and
3. both 1 and 2 occur.

You know that when mass flows in and out of a system the mass carries energy along with it. What types of energy? Just the same types that are associated with the mass inside the system, namely $U$, $PE$, and $KE$. All you have to do, then, is add these three types of energy associated
with each stream going in and out of the system to the energy transfers of $Q$ and $W$ in the energy balance. Don’t forget the presence of the FLOW WORK providing for flowing materials in and out.

$\Delta E$ will still correspond the final state within the system minus the initial state within the system.

\[
\begin{align*}
\{ \text{Total flow} \} & \quad \{ \text{Total flow} \} \\
\{ \text{into the system} \} & \quad \{ \text{out of the system} \} = \{ \text{Accumulation of material} \} \\
\{ \text{within the system} \} & \\
\end{align*}
\]

\[
\begin{align*}
\{ \text{Total flow} \} & = (U + E_K + E_p)_{in} + (H + E_K + E_p)_{in} \\
\{ \text{out of the system} \} & = (U + E_K + E_p)_{out} + (H + E_K + E_p)_{out} \\
\end{align*}
\]

\[
\begin{align*}
\{ \text{Total flow} \} & \quad \{ \text{Total flow} \} = Q - W + (H + E_K + E_p)_{in} - (H + E_K + E_p)_{out} \\
\{ \text{into the system} \} & \quad \{ \text{out of the system} \} = Q - W - \Delta(H + E_K + E_p)_{flow} \\
\end{align*}
\]

Since delta symbol ($\Delta$) used standing for a difference then has two different meanings
a) In $\Delta E$, $\Delta$ means final minus initial in time
b) In $\Delta(H + E_K + E_p)$, $\Delta$ means out of the system minus into the system
here “in – out” then we need “out – in” for using $\Delta$, hence $-(\text{out} – \text{in})$

For a specified time interval, you can assemble each of the terms that will be in the general energy balance using the symbols given in Table as follows:

Accumulation in the system from $t_1$ to $t_2$: with respect to time

\[
\{ \text{Accumulation of material} \} = \Delta \left[ (\dot{U} + \dot{E}_K + \dot{E}_p)_{t_2} m_{t_2} \right] - \Delta \left[ (\dot{U} + \dot{E}_K + \dot{E}_p)_{t_1} m_{t_1} \right] \\
= \Delta \left[ (\dot{U} + \dot{E}_K + \dot{E}_p) \right]_{time}
\]

Energy transfer in with mass from $t_1$ to $t_2$: $(\dot{U}_1 + \dot{E}_{K_1} + \dot{E}_{p_1}) m_1$

Energy transfer out with mass from $t_1$ to $t_2$: $(\dot{U}_2 + \dot{E}_{K_2} + \dot{E}_{p_2}) m_2$

Net energy transfer by heat transfer in and out from $t_1$ to $t_2$: $Q$

Net energy transfer by shaft, mechanical, or electrical work in and out from $t_1$ to $t_2$: $W$

Net energy transfer by work to introduce and remove mass from $t_1$ to $t_2$: $p_1 \dot{V}_1 m_1 - p_2 \dot{V}_2 m_2$
TABLE 22.1 Summary of the Symbols to be Used in the General Energy Balances

<table>
<thead>
<tr>
<th>Accumulation term (inside the system)</th>
<th>At time $t_1$</th>
<th>At time $t_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of energy in the system</td>
<td>$U_1$</td>
<td>$U_2$</td>
</tr>
<tr>
<td>Internal</td>
<td>$KE_{i1}$</td>
<td>$KE_{i2}$</td>
</tr>
<tr>
<td>Kinetic</td>
<td>$PE_{i1}$</td>
<td>$PE_{i2}$</td>
</tr>
<tr>
<td>Potential</td>
<td>$m_{i1}$</td>
<td>$m_{i2}$</td>
</tr>
<tr>
<td>Mass of the system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Energy accompanying mass transport (through the system boundary) during the time interval $t_1$ to $t_2$

<table>
<thead>
<tr>
<th>Type of energy</th>
<th>Transport in</th>
<th>Transport out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal</td>
<td>$U_1$</td>
<td>$U_2$</td>
</tr>
<tr>
<td>Kinetic</td>
<td>$KE_1$</td>
<td>$KE_2$</td>
</tr>
<tr>
<td>Potential</td>
<td>$PE_1$</td>
<td>$PE_2$</td>
</tr>
<tr>
<td>Mass of the flow</td>
<td>$m_1$</td>
<td>$m_2$</td>
</tr>
</tbody>
</table>

Net heat exchange between the system and the surroundings during the interval $t_1$ to $t_2$
$Q$

Work terms (exchange with the surroundings) during the interval $t_1$ to $t_2$

Net shaft, mechanical, and electrical work
$W$

Flow work done on the system to introduce material into the system
$m_1(p_1\dot{V}_1)$

Flow work done on the surroundings to remove material from the system
$-m_2(p_2\dot{V}_2)$

Hence

$$Q - W - \Delta(H + E_K + E_P)_\text{flow} = \Delta E_{\text{time}} = \Delta(\overline{U} + \overline{E}_K + \overline{E}_P)m_t$$

Flow terms | Accumulation

24.1 Simplifications of the General Energy Balance

Given problem statement, and often implied but not stated constraints, you can simplify the general energy balance. We reproduce it here using concise symbols as in GEB with "time or inside" and "flow" appended to refresh your memory about the system. "Inside" refers to the system inside the system boundary and time is shown time dependency both are used to define accumulation term. However "flow" refers to that cross the system boundary.

In most problems you do not have to use all of the terms of the general energy balance equation. Certain terms may by implication or judgment be zero or may be so small that they can be in comparison with the other terms. Other terms may state to small or zero. As a result, when you apply GEB to processes, you need to consider only certain terms in the equation, the three most commonly used applications of GEB are to:
1. closed systems
2. open systems with heat transfer into and out of the process
3. open, steady-state flow systems.
What follows is an analysis of each of these cases along with some physical examples:
1. Closed system. For closed or batch systems, no mass flow occurs in or out of the system (\( ml = m2 = 0 \)) so that: \( \Delta E = Q - W \)
If there is no accumulation (\( \Delta E = 0 \)), \( Q - W \)

An example is the initial heating to expand a hot air balloon

2. Open system with heat transfer. Many open, steady-state processes in the chemical processing industries exist, processes that are dominated by heat transfer, \( Q \). For these cases, \( \Delta E, W, \Delta PE, \) and \( \Delta KE \) can be neglected because they are small compared to \( Q \) and \( \Delta H \) or are zero. For these cases GEB becomes \( Q = \Delta \left[ m \left( \bar{H} \right) \right] = \Delta H \)
GEB can be applied to heat exchangers (i.e., devices transferring heat from a high temperature fluid to a lower temperature fluid) and distillation columns.
If no heat transfer takes place between the system and the surroundings. GEB reduces to
\( \Delta H = 0 \)

This equation is sometimes called the "enthalpy balance," and is used to model the mixing of fluids different temperatures, for pasteurization process in PHE.

3. Open, steady-state flow system. For steady-state (\( \Delta E = 0 \)) flow systems that do not involve significant transfer (\( Q = 0 \)), GEB reduces to
\( W = \Delta E_{K} + \Delta E_{P} \)
You can use the EB to size pumps or calculate the pressure drop through a piping network.

In addition to the three types processes listed above, other processes require the use of all of the terms in Equation (24.1). Sometimes both \( Q \) and \( \Delta E_{K} \) are simultaneously significant. In addition, you can also reach certain conclusions by inference from the nature of the material in the process and its conditions. For example for solids or liquids at constant temperature, \( \Delta U \approx 0 \). Similarly, for a near isothermal gas \( \Delta U \approx 0 \) and \( \Delta H \approx 0 \)

Some special process names associated with energy balance problems that we have mentioned in previous chapters are worth remembering:

a. Isothermal \( (dT = 0) \): constant temperature process
b. Isobaric \( (dp = 0) \): constant pressure process
c. Isometric or isochoric \( (dV = 0) \): constant volume process
d. Adiabatic \( (Q = 0) \): no heat interchange. If we inquire as to the circumstances under which a process can be called adiabatic, one the following is most likely:
(1) the system is insulated.
(2) \( Q \) very small in relation to the other in the energy equation and may be neglected.
(3) the process takes place so fast that there is no time for heat to be transferred.

Example: The system given and define the EB for each one of the following segments shown with numbers
Example: A rigid, well-insulated tank is connected to two valves. One valve goes to a steam line that has steam at 1000 kPa and 600 K, and the other to a vacuum pump. Both valves are initially closed. Then the valve to the vacuum pump is opened. The tank is evacuated, and the valve closed. Next the valve to the steam line is opened so that the steam enters the evacuated tank very slowly until the pressure in the tank: equals the pressure in the steam line. Calculate the final temperature of the steam in the tank.

Basis: 1 kg steam
System is tank, boundary is drawn with blue pen
At \( t=0 \), nothing is present in system it is evacuated, then steam starts to enter the system until eq. is reached. At \( t = t_{eq} \) in the tank we have steam at 1000 kPa (10 bar), but \( T \) is not known and it is the question asked. Now, no leaving stream presents. System is USS (nothing at the beginning steam present at the end). Open system, we have input stream, but no leaving stream. No change in KE and PE in the system and in flowing stream. No Work and Q exchanged. The m: 1 kg steam

Then GEB becomes

\[
Q = W - \Delta \left[ (\hat{U} + \hat{E}_K + \hat{E}_p) m \right]_{flow} = \Delta E_{time} = \Delta \left[ (\hat{U} + \hat{E}_K + \hat{E}_p) m \right]_{time}
\]

\[
-\Delta (H + \hat{E}_K + \hat{E}_p)_{flow} = \Delta \left[ (\hat{U} + \hat{E}_K + \hat{E}_p) m \right]_{time}
\]

\[
-\Delta (H)_{flow} = \Delta \left[ \hat{U} \right]_{time} = \Delta (H_{in} - H_{out}) = \Delta \left[ \hat{U}_{t_2} - \hat{U}_{t_1} \right]
\]

Since no mass at \( t_1 \), \( \hat{U}_{t_1} = 0 \), no output, \( H_{out} = 0 \)
EB becomes \( H_{in} = \hat{U}_{t_2} \)

We can find enthalpy of steam at 600 K (600-273=327°C) and 10 bar, it is equal to internal energy of steam at time \( t_2 \).
Example 22.4 Application of the Energy Balance to a Open, Steady-State System, a Heat Exchanger

Milk (essentially water) is heated from 15°C to 25°C by hot water that goes from 70°C to 35°C, as shown in Figure E22.4. What assumptions can you make to simplify Equation (22.8), and what is the rate of water flow in kg/min per kg/min of milk?

Water is pumped from a well (Figure E22.5) in which the water level is a constant 20 feet below the ground level. The water is discharged into a level pipe that is 5 feet above the ground at a rate of 0.50 ft³/s. Assume that negligible heat transfer occurs from the water during its flow. Calculate the electric power required by the pump if it is 100% efficient and you can neglect friction in the pipe and the pump.
System: milk + water in the tank

Assumptions:
1) \( \Delta KE + \Delta PE = 0 \) if milk or water is selected as system - you cannot but in order to simplify the solution
2) \( Q = 0 \) think the system is isolated, water loses heat milk gains - so not heat is evolved outside the system
3) \( W = 0 \) our boundary, no work done

So
\[
\Delta E = 0 = \Delta U - \Delta(H + KE + PE)
\]

\[
\Delta H = 0 \quad \Rightarrow \quad H_{out} - H_{in} = 0
\]

i.e.

\[
m_{milk} \frac{\Delta H_{milk}}{25^\circ C} + m_{H_2O} \frac{\Delta H_{H_2O}}{35^\circ C} = - \left( m_{milk} \frac{\Delta H_{milk}}{15^\circ C} + m_{H_2O} \frac{\Delta H_{H_2O}}{35^\circ C} \right)
\]

\[H_{milk} = \int C_p \, dT\]

\[m_{milk} \Delta H + m_{H_2O} \Delta H = 0\]

\[m_{milk} (55) - m_{H_2O} (35 - 25) = 0\]

\[C_p_{milk} = \frac{\rho_{milk} C_{p,milk} + \rho_f C_{p,water} + \rho_{surf} C_{p,surf}}{\rho_f + \rho_{surf}}\]

\[= 0.87 \left( \frac{4.18 \text{ kJ}}{\text{kg} \cdot \text{K}} \right) + 0.03 (0.694) + (0.873)(0.10)\]

\[= \frac{3.92 \text{ kJ}}{\text{kg} \cdot \text{K}}\]

From steam table

\[T \quad \Delta H \quad \frac{\Delta H}{\rho_f} \]

15 62.01 3.381
25 103.86 2.551
35 146.61 2.329
50 253.13 2.061
\[ \Delta H_{\text{milk}}^{15 \rightarrow 25^\circ C} = 3.77 \frac{\text{kJ}}{\text{kg} \cdot ^\circ C} \times (25 - 15)^\circ C = 37.7 \text{ kJ/kg} \]

\[ \Delta H_{\text{water}} = m \left( \Delta H_{25^\circ C} - \Delta H_{70^\circ C} \right) = (146.69 - 298.01) \text{ m}_\text{H}_2\text{O} \]

If instead of milk \( C_p \) (calorimetry), if we need to assume (since 87% \( H_2O \)) milk shows similar heat capacity with \( \text{water} \):

\[ \Delta H_{\text{milk}} = 1 \text{ kg} \times (103.86 - 62.01) = 41.85 \text{ kJ} \]

\[ m_{\text{milk}} \Delta H_{\text{milk}} = - (\Delta H_{\text{water}}) \text{ m}_\text{H}_2\text{O} \]

\[ m_{\text{H}_2\text{O}} = \frac{41.85 \text{ kJ}}{(-146.32) \frac{\text{kJ}}{\text{kg}}} = 0.286 \text{ kg} \]

\[ m_{\text{H}_2\text{O}} = \frac{41.85 \text{ kJ}}{-146.32 \frac{\text{kJ}}{\text{kg}}} = 0.286 \text{ kg} \]

For each one kg milk we need 0.286 kg water.
Ex: Water is pumped from a well in which the water level is a constant 20 ft below the ground level. The water is discharged into a level pipe that is 5 ft above the ground at a rate of 0.5 ft³/s. Assume that negligible heat transfer occurs from the water during its flow. Calculate the electric power required by the pump if it is 100% efficient & you can neglect friction in the pipe & the pump.

\[ Q = 0.5 \text{ ft}^3/\text{s} \]

\[ \Delta H \approx 0 \]

\[ \Delta KE = 0 \]

Open & SS system

\[ W = \Delta PE = mg \left( h_{out} - h_{in} \right) \]

\[ 0.5 \text{ ft}^3/\text{s} \times 62.4 \text{ lb/in}^3 = 31.2 \text{ lbm water/s} \]

\[ W = PE_{out} - PE_{in} = \frac{31.2 \text{ lbm} \cdot \text{H} \cdot \text{C}}{5} \frac{92.2 \text{ ft}}{32.2 \text{ ft/in}} \left( \frac{1.055 \text{ ft} \cdot \text{lb}}{798.2 \text{ lbm} \cdot \text{ft}^2/\text{s}^2} \right) = 1.06 \text{ kWh} \]

\[ Q - W = (\Delta H + \Delta KE + \Delta PE) \]

\[ Q - W = \Delta H - \Delta KE - \Delta PE = 0 \]

\[ - \left( h_{out} + h_{in} \right) \]
Water is being pumped from the 675.20
bottom of a well 15 ft deep at the rate of
250 gph into a vented storage tank to
maintain a level of water in a tank 165 ft
above the ground. To prevent freezing in
the winter a small heater puts 30,000
Btu/h into the water during its transfer from
the well to the storage tank. Heat is lost
from the whole system at the constant rate
of 2500 Btu/h. What is the T of the H2O
as it enters the storage tank, assuming that
the well water is at 85°F? A 2 hp pump
is being used to pump the water. About
55% of the rated horsepower goes into the
work of pumping & the rest is dissipated as
heat to the atmosphere.

\[ T_1 = 85°F \]

\[ T_2 = ? \]
Food Engineering Department, Engineering Faculty, Gaziantep University

\[ T_1 = 35^\circ F \]

\[ 200 \text{ gal} = 8.33 \text{ lb} \cdot \text{h} \]

\[ \Delta P = \rho \Delta h = 1666 \text{ lb} \cdot \text{in} \times \frac{32.24 \text{ ft}}{5 \text{ in}} = 18.31 \text{ ft} \cdot \text{lb} \]

\[ \Delta h = \frac{18.31 \text{ ft} \cdot \text{lb}}{32.24 \text{ ft} \cdot \text{lb} / \text{h}} \]

\[ Q = 20000 \text{ scf} = 25000 \text{ scf} \]

\[ W = 2 \text{ hp} \times 0.55 \times \frac{3000 \text{ lb} \cdot \text{ft}}{60 \text{ min} \cdot \text{hp} \cdot \text{h}} = 2800 \text{ lb} \cdot \text{ft} \]

\[ \Delta H = 25000 + 2800 = \Delta W + \Delta H \]

\[ \Delta H = 4992 \text{ scf} = \Delta W \]

\[ \Delta W = 3 \text{ scf} \]

\[ \Delta H = 7.45 \]

\[ T_f = 39.5^\circ F \]
24.19 Energy released by fruit & vegetables during cooling is called heat respiration.
For potatoes, the peak value is 3.5 mW/kg at 5°C. Suppose that in an insulated storage room,
52 pallets each containing 24 boxes of potatoes are stacked. Each box corresponds to 2.1 kg of
 cardboard & 2.2 kg of potatoes.

The respective specific heats are 1.7 kJ/kg°C for cardboard & 3.05 kJ/kg°C for potatoes.
If potatoes are cooled at the rate of 0.3°C/h, how much must be removed from the room
in kW. Neglect effect of air in room. Close basis: 1 box then a room. \( \Delta Q = \Delta H \)

\[
\begin{align*}
(2.1 \text{ kg} & \times 1.7 \frac{\text{kJ}}{\text{kg}^\circ\text{C}} + 20 \text{ kg} \times 3.05 \frac{\text{kJ}}{\text{kg}^\circ\text{C}}) (0.3 \frac{^\circ\text{C}}{\text{h}}) \\
= 19.37 \frac{\text{kJ}}{\text{h}} \times 24 \text{ box} \times 52 \text{ pallet} & = 24193.7 \frac{\text{kJ}}{\text{h}}
\end{align*}
\]

\[
\frac{24193.76 \frac{\text{kJ}}{\text{h}} \times \frac{\text{h}}{3600}}{= 6.714 \text{ kW}}
\]

The lowest heat for one kg potato is 35 mW.

35 \times 10^{-6} \text{ kW} \times \frac{20 \text{ kg}}{1 \text{ kg}} = \frac{24 \text{ box} \times 52 \text{ pallet}}{\text{a box pallet room}} = 0.8736 \text{ kW}

\[ Q = 6.7149 - 0.8736 = 5.84183 \text{ kW should be removed} \]