Ministry of Higher Education
Higher Institute for Engineering and Technology at Manzala
Electronics Engineering Dept.

Thermodynamics and Heat Transfer (MEC121)

Lecture 3: 1st Law of Thermodynamics

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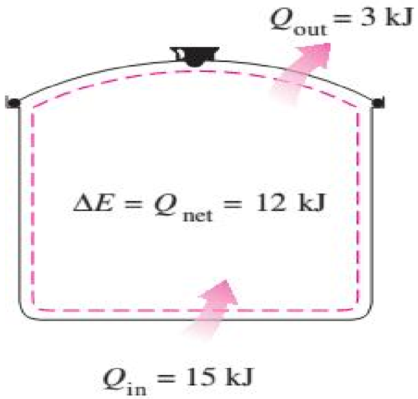
1st Law of Thermodynamics

- The **first law of thermodynamics**, also known as the **conservation of energy principle**, provides relationships between the various forms of energy, such as E, Q and W and their interactions.

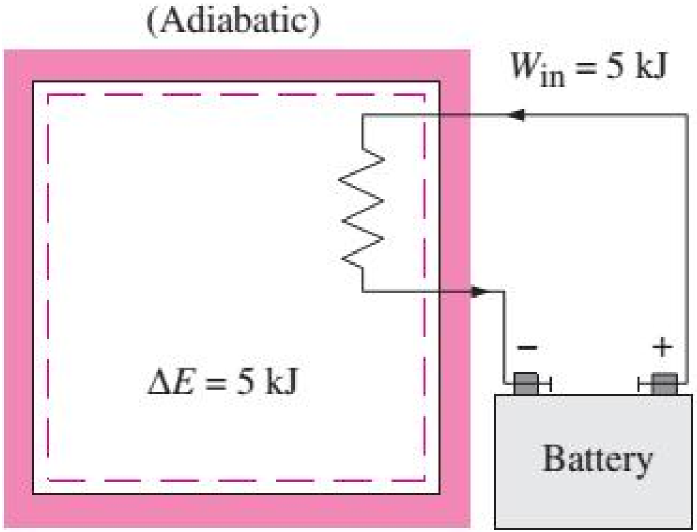
- The first law of thermodynamics states that **energy can be neither created nor destroyed during a process; it can only change from one form to another**.

- As an example, consider the heating of water in a pot. If 15 kJ of heat is transferred to the water from the heating element and 3 kJ of it is lost from the water to the surrounding air (as water vapor), the increase in energy of the water is equal to the net heat transfer to water, which is 12 kJ.



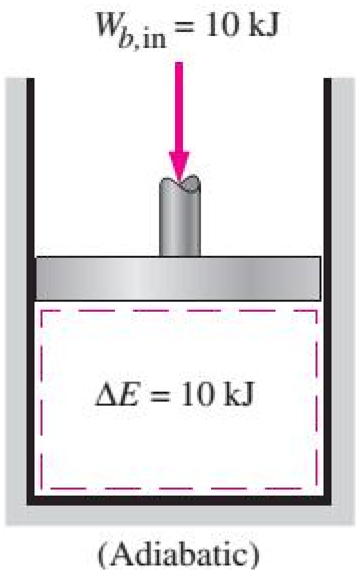
1^{st} Law of Thermodynamics

- Now consider a well-insulated room heated by an electric heater as our system. As a result of electrical work done, the energy of the system increases. Since the system is insulated and cannot have any heat transfer to or from the surroundings (Q=0), then the electrical work done on the system must equal the increase in energy of the system.



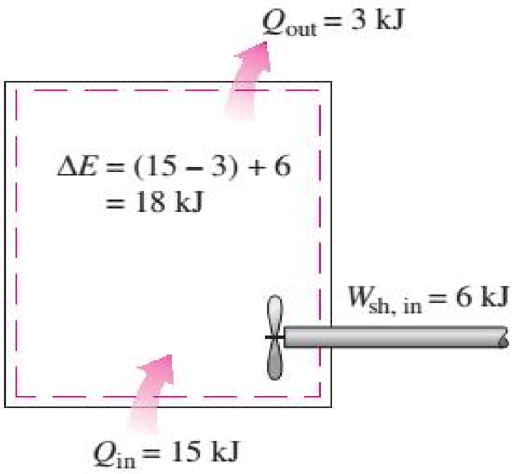
1st Law of Thermodynamics

- The temperature of air rises when it is compressed (air compressor ضاغط الهواء). This is because energy is transferred to the air from the boundary work done. In the absence of any heat transfer (Q = 0), the entire work will be stored in the air (increases its total energy).



1st Law of Thermodynamics

- Another form of 1st law of thermodynamics is that the net change (increase or decrease) in the total energy of the system during a process is equal to the difference between the total energy entering and the total energy leaving the system during that process. التغير فى طاقة السيستم تساوى مجموع الطاقات الداخلة – الطاقات الخارجة



- **For Closed System:**

$$\boxed{E_2 - E_1 = \Delta E = \sum Q - \sum W} \quad \ldots\ldots\ldots (19)$$

$$\boxed{(U + KE + PE)_{sys2} - (U + KE + PE)_{sys1} = \Delta E = \sum Q - \sum W} \quad \ldots\ldots\ldots (20)$$

1st Law for Closed System

- **For Closed System:**

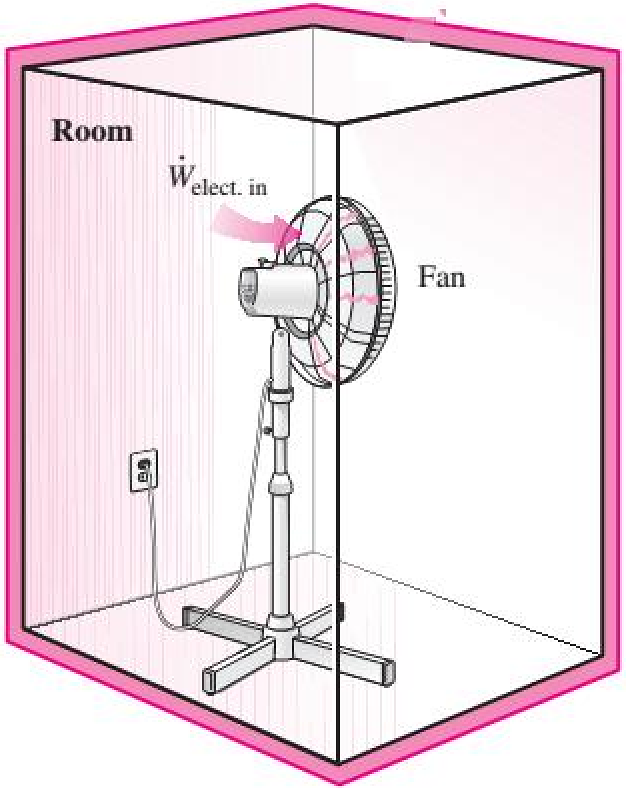
$$m(u+ke+pe)_{sys2} - m(u+ke+pe)_{sys1} = m\Delta e = \sum Q - \sum W$$

$$m\left[\left(u_{sys2}-u_{sys1}\right)+\left(ke_{sys2}-ke_{sys1}\right)+\left(pe_{sys2}-pe_{sys1}\right)\right] = m\Delta e = \sum Q - \sum W$$

$$\boxed{\mathbf{m\left[\left(u_{sys2}-u_{sys1}\right)+\left(\frac{V_{sys2}^2-V_{sys1}^2}{2}\right)+g\left(z_{sys2}-z_{sys1}\right)\right] = m\Delta e = \sum Q - \sum W}} \quad \text{---------} \quad (20)$$

Example

On a hot summer day, a student turns his fan on when he leaves his room in the morning. When he returns in the evening, will the room be warmer or cooler than the neighboring rooms? Why? Assume all the doors and windows are kept closed.



Example

Consider a room that is initially at the outdoor temperature of 20°C. The room contains a 100-W light bulb, a 110-W TV, a 200-W refrigerator, and a 1000-W iron. Assuming no heat transfer through the walls, determine the rate of increase of the energy of the room when all of these electric devices are on. **(Ans. 1410 W)**

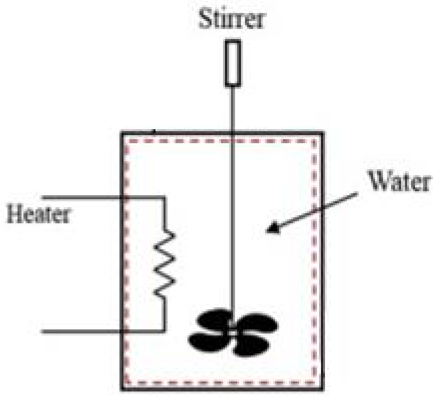
Example

A fan is to accelerate silent air to a velocity of 10 m/s at a rate of 4 m^3/s. Determine the minimum power that must be supplied to the fan. Take the density of air to be 1.18 kg/m^3.

(Ans. -236 W)

Example

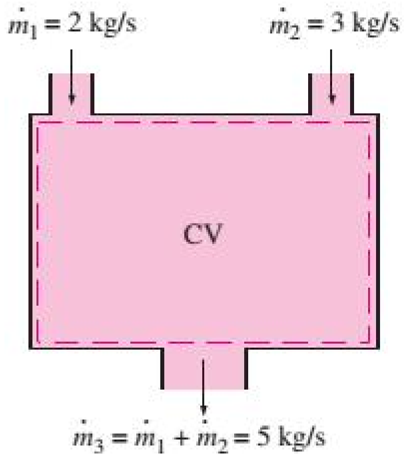
A rigid tank contains a hot fluid that is cooled while being stirred by a paddle wheel. Initially, the internal energy of the fluid is 800 kJ. During the cooling process, the fluid loses 500 kJ of heat, and the paddle wheel does 100 kJ of work on the fluid. Determine the final internal energy of the fluid. Neglect the energy stored in the paddle wheel. **(Answer: U_2= 400kJ)**



1st Law for Open System

Open System (There is a mass flow across the system boundary)

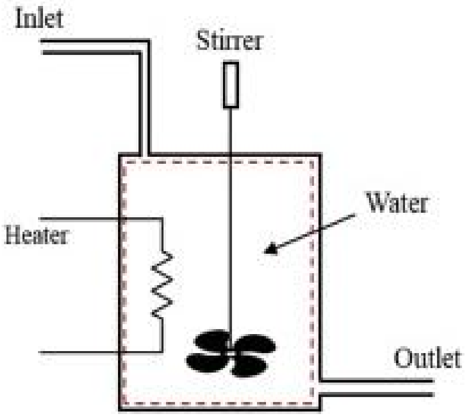
Steady Flow System

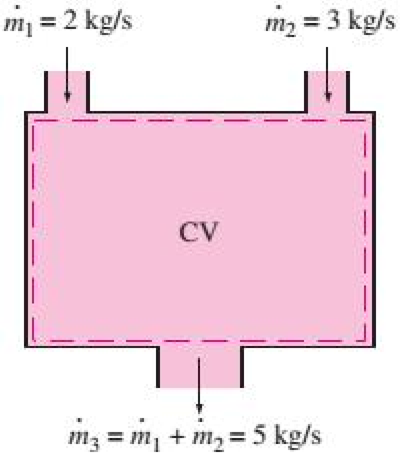


Unsteady-Flow System (such as charging and discharging systems)

Steady Flow System

In a **steady-flow system**, flows of mass and energy that cross the system boundary are constant. Accordingly, this system should achieve the mass and energy conservation principle.مبدأ ثبات الكتلة و الطاقة



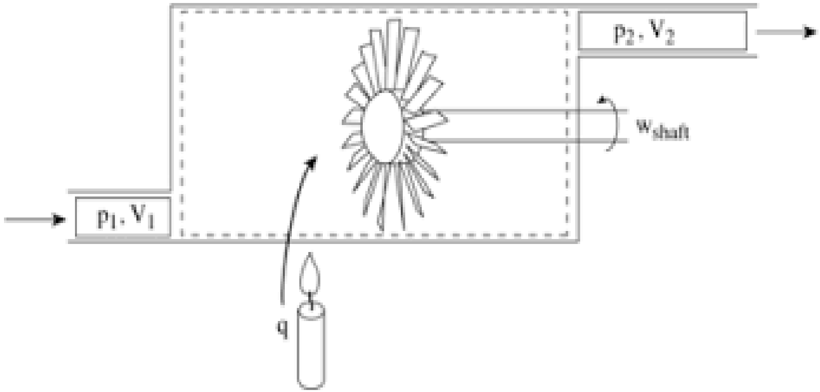


$\sum_{in} \dot{Energy} = \sum_{out} \dot{Energy}$

$\sum_{in} \dot{m} = \sum_{out} \dot{m}$

Flow Energy & Enthalpy

As the fluid is flowing, it has a **flow energy** which is equal to pressure (p) multiplied by volume (V).



$$\boxed{FE = pV \ \ (J)} \ \ldots\ldots\ldots$$

Enthalpy is a property of the system that is equal to the addition of internal energy (U) and flow energy (pV).

$$\boxed{H = U + pV \ \ (J)} \ \ldots\ldots\ldots \ 21$$

$$\boxed{h = u + pv \ \ (J/kg)} \ \ldots\ldots\ldots \ 22$$

1st Law for Open System

- **For Open System:**

$$\boxed{\sum_{out} \dot{m}\,(h + ke + pe) - \sum_{in} \dot{m}\,(h + ke + pe) = \sum \dot{Q} - \sum \dot{W}} \quad \ldots\ldots\ldots \quad (21)$$

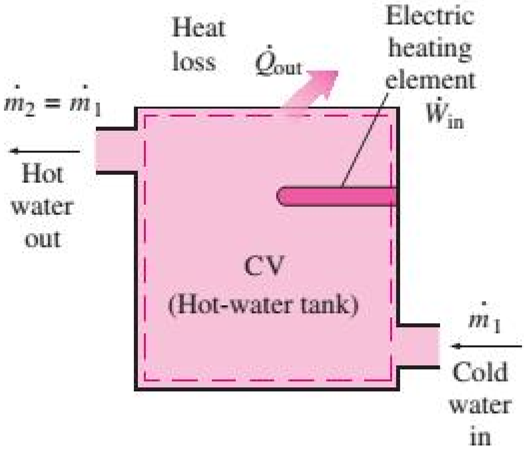
Example:

$$\dot{m}_2\,(h_2 + ke_2 + pe_2) - \dot{m}_1(h_1 + ke_1 + pe_1) = \dot{Q}_{out} - \dot{W}_{in}$$

Since $\dot{m}_2 = \dot{m}_1 = \dot{m}$ Because it is a steady-flow system

$$\dot{m}\,[(h_2 - h_1) + (ke_2 - ke_1) + (pe_2 - pe_1)] = \dot{Q}_{out} - \dot{W}_{in}$$

$$\dot{m}\left[(h_2 - h_1) + \left(\frac{V_2^2 - V_1^2}{2}\right) + g(z_2 - z_1)\right] = \dot{Q}_{out} - \dot{W}_{in}$$



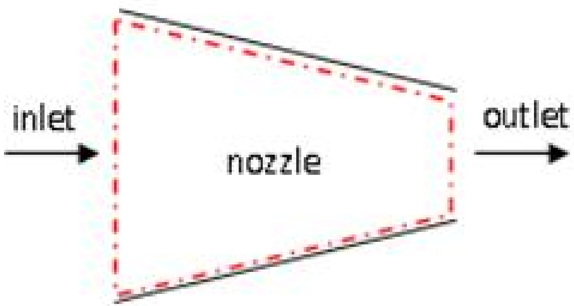
Some Steady-Flow Engineering Devices

Nozzle & Diffuser

- **Nozzles** and **diffusers** are commonly utilized in jet engines, rockets, and even garden hoses.
- The nozzle and diffuser perform opposite tasks.

Nozzle & Diffuser

The cross-sectional area of a **nozzle** decreases in the flow direction. This device increases the velocity of a fluid at the expense of pressure. على حساب الضغط

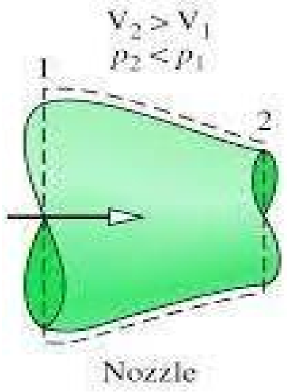


By applying 1st law of thermodynamics:

$$\dot{m}\left[(h_2 - h_1) + \left(\frac{V_2^2 - V_1^2}{2}\right) + \underbrace{g(z_2 - z_1)}_{0}\right] = \underbrace{\dot{Q}_{out}}_{0} - \underbrace{\dot{W}_{in}}_{0}$$

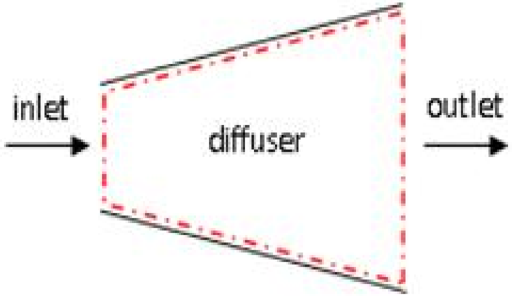
$$\left(\frac{V_2^2 - V_1^2}{2}\right) = -\,(h_2 - h_1)$$

$$\boxed{V_2 = \sqrt{V_1^2 - 2(h_2 - h_1)}} \quad \ldots\ldots\ldots \text{(22)}$$



Nozzle & Diffuser

The cross-sectional area of a **<u>diffuser</u>** increases in the flow direction. This device increases the pressure of a fluid by slowing it down (decreasing its velocity).

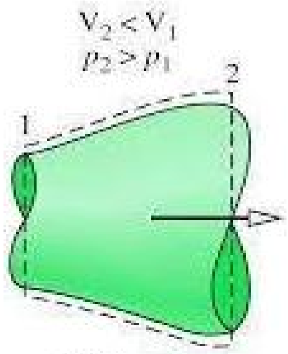


<u>By applying 1st law of thermodynamics</u>:

$$\dot{m}\left[(h_2-h_1)+\left(\frac{V_2^2-V_1^2}{2}\right)+\underbrace{g(z_2-z_1)}_{0}\right] = \underbrace{\dot{Q}_{out}}_{0} - \underbrace{\dot{W}_{in}}_{0}$$

$$\left(\frac{V_2^2-V_1^2}{2}\right) = -\,(h_2-h_1)$$

$$\boxed{h_2 = h_1 - \left(\frac{V_2^2-V_1^2}{2}\right)} \quad \ldots\ldots\ldots 23$$



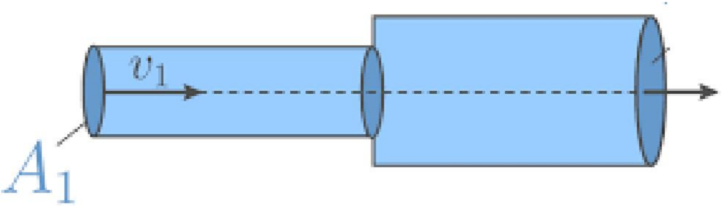
Diffuser

Nozzle & Diffuser

To calculate the mass flow rate of a fluid flowing into any cross-sectional area:

$$\boxed{\dot{m} = \rho A V \quad \left(\frac{kg}{s}\right)} \quad \ldots\ldots (24)$$

Where V is the velocity of the fluid and A is the cross-sectional area. V is always the velocity perpendicular to the cross-sectional area.



Example

Air at 10°C and 80 kPa (with a density of 0.98 kg/m^3) enters the diffuser of a jet engine steadily with a velocity of 200 m/s and an enthalpy of 10 kJ/kg. The inlet area of the diffuser is 0.4 m^2. The air leaves the diffuser with a velocity that is very small compared with the inlet velocity. Determine (a) the mass flow rate of the air and (b) the enthalpy of the air leaving the diffuser. **(Ans. 78.4 kg/s, 30 kJ/kg)**

Discussion About

- Any questions?