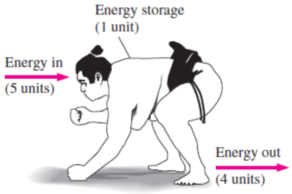
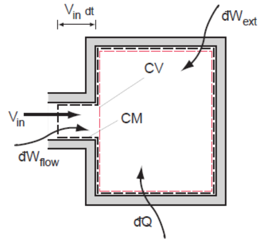
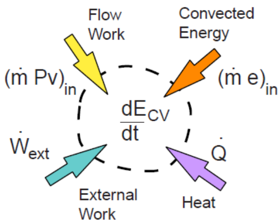
University Of Jordan
Faculty of Engineering and Technology
Department of Chemical Engineering

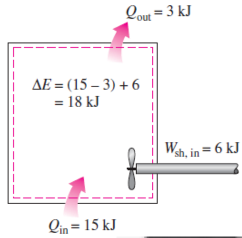


Thermodynamics I



Energy and General Energy analysis





Dr.-Eng. Zayed Al-Hamamre

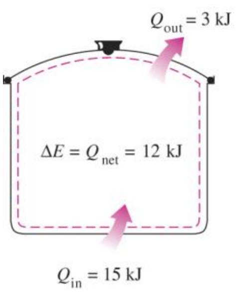
Content

- The first law of thermodynamics
  - Energy balance
  - Energy change of a system
  - Mechanisms of energy transfer (heat, work, mass flow)
- Energy conversion efficiencies
  - Efficiencies of mechanical and electrical devices (turbines, pumps)
- Energy and environment

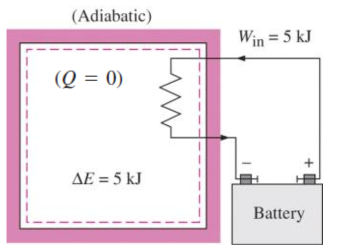
The First Law of Thermodynamics

- ✓ **The *first law of thermodynamics* (*the conservation of energy principle*)** provides a sound basis for studying the relationships among the various forms of energy and energy interactions.
- ✓ The first law states that ***energy can be neither created nor destroyed during a process; it can only change forms***.
- ✓ **The *First Law:*** For all adiabatic processes between two specified states of a closed system, the net work done is the same regardless of the nature of the closed system and the details of the process.
  - The net work must depend on the end states of the system only, represented by the total energy (E).
  - The change in the total energy during an adiabatic process must be equal to the net work done.

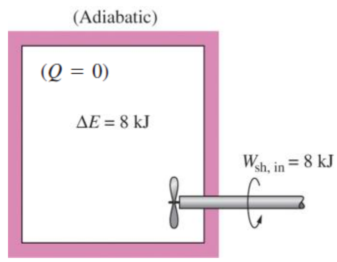
The First Law of Thermodynamics



In the absence of any work interactions, the energy change of a system is equal to the net heat transfer.



The work (electrical) done on an adiabatic system is equal to the increase in the energy of the system.



The work (shaft) done on an adiabatic system is equal to the increase in the energy of the system.

Energy Balance

- *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.*

$$\begin{pmatrix}\text{Total energy}\\ \text{entering the system}\end{pmatrix} - \begin{pmatrix}\text{Total energy}\\ \text{leaving the system}\end{pmatrix} = \begin{pmatrix}\text{Change in the total}\\ \text{energy of the system}\end{pmatrix}$$

$$\Delta E_{\text{system}} = E_{\text{final}} - E_{\text{initial}} = E_2 - E_1$$ **Energy balance**

$$\Delta E = \Delta U + \Delta \text{KE} + \Delta \text{PE}$$

Where $\Delta U = m(u_2 - u_1)$ $\quad \Delta \text{KE} = \frac{1}{2} m(V_2^2 - V_1^2)$ $\quad \Delta \text{PE} = mg(z_2 - z_1)$

- u_1 and u_2 can be determined directly from the property tables or thermodynamic property relations

Energy is a property

Mechanisms of Energy Transfer, E_{in} and E_{out}

$$E_{\text{in}} - E_{\text{out}} = (Q_{\text{in}} - Q_{\text{out}}) + (W_{\text{in}} - W_{\text{out}}) + (E_{\text{mass,in}} - E_{\text{mass,out}}) = \Delta E_{\text{system}}$$

Heat transfer
Work transfer
Mass flow

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc., energies}}} \quad (\text{kJ})$$

In the **rate form**

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{\text{system}}/dt}_{\substack{\text{Rate of change in internal,}\\ \text{kinetic, potential, etc., energies}}} \quad (\text{kW})$$

$$e_{\text{in}} - e_{\text{out}} = \Delta e_{\text{system}} \quad (\text{kJ/kg})$$

$$\delta E_{\text{in}} - \delta E_{\text{out}} = dE_{\text{system}} \qquad \delta e_{\text{in}} - \delta e_{\text{out}} = de_{\text{system}}$$

Mechanisms of Energy Transfer, E_{in} and E_{out}

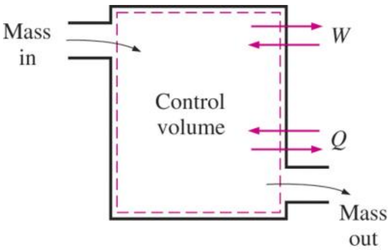
- For constant rates, the total quantities during a time interval Δt are related to the quantities per unit time as

$$Q = \dot{Q}\,\Delta t \quad \text{(kJ)}$$

$$W = \dot{W}\,\Delta t$$

$$\Delta E = (dE/dt)\,\Delta t$$

A closed mass involves only *heat transfer* and *work.*



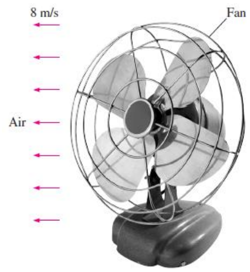
- The energy content of a control volume can be changed by mass flow as well as heat and work interactions.

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.

Example

A fan that consumes 20 W of electric power when operating is claimed to discharge air from a ventilated room at a rate of 0.25 kg/s at a discharge velocity of 8 m/s. Determine if this claim is reasonable.



Example

Annual Lighting Cost of a Classroom

The lighting needs of a classroom are met by 30 fluorescent lamps, each consuming 80 W of electricity. The lights in the classroom are kept on for 12 hours a day and 250 days a year. For a unit electricity cost of 7 cents per kWh, determine annual energy cost of lighting for this classroom. Also, discuss the effect of lighting on the heating and air-conditioning requirements of

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Example cont.

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Energy Conversion Efficiency

✓ ***Efficiency*** indicates how well an energy conversion or transfer process is accomplished.

$$\text{Performance} = \frac{\text{Desired output}}{\text{Required output}}$$

➢ **Efficiency of a water heater:** The ratio of the energy delivered to the house by hot water to the energy supplied to the water heater.

Type	Efficiency
Gas, conventional	55%
Gas, high-efficiency	62%
Electric, conventional	90%
Electric, high-efficiency	94%

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Energy Conversion Efficiency

- Then the performance of combustion equipment can be characterized by **combustion efficiency,**

$$\eta_{\text{combustion}} = \frac{Q}{\text{HV}} = \frac{\text{Amount of heat released during combustion}}{\text{Heating value of the fuel burned}}$$

- An efficiency definition should make it clear whether it is based on the higher or lower heating value of the fuel.
- Efficiencies of cars and jet engines are normally based on *lower heating values* since water normally leaves as a vapor in the exhaust gases.
- Efficiencies of furnaces, on the other hand, are based on *higher heating values*.

$$HHV = LHV + n\,\Delta\hat{H}_v(\text{H}_2\text{O},\ 25°\text{C})$$

Where $\Delta\hat{H}_v(\text{H}_2\text{O},\ 25°\text{C})$ the heat of vaporization of water at 25°C is

$$\Delta\hat{H}_v(\text{H}_2\text{O},\ 25°\text{C}) = 44.013\ \text{kJ/mol} = 18{,}934\ \text{Btu/lb-mole}$$

Energy Conversion Efficiency

- The efficiency of space heating systems of residential and commercial buildings is usually expressed in terms of the **Annual Fuel Utilization Efficiency (AFUE)**, which accounts for the combustion efficiency as well as other losses such as heat losses to unheated areas and start-up and cooldown losses.
- **Generator:** A device that converts mechanical energy to electrical energy.
- **Generator efficiency:** The ratio of the electrical power output to the mechanical power input.
- **Thermal efficiency of a power plant:** The ratio of the net electrical power output to the rate of fuel energy input.

$$\eta_{\text{overall}} = \eta_{\text{combustion}}\,\eta_{\text{thermal}}\,\eta_{\text{generator}} = \frac{\dot{W}_{\text{net,electric}}}{\text{HHV} \times \dot{m}_{\text{net}}}$$

Overall efficiency of a power plant

- The overall efficiencies are about
  - 26–30 percent for gasoline automotive engines,
  - 34–40 percent for diesel engines, and
  - 40–60 percent for large power plants.

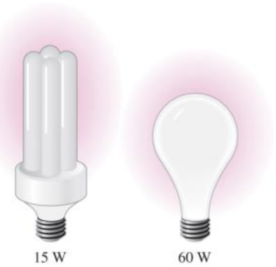
Energy Conversion Efficiency

The efficacy of different lighting systems

Type of lighting	Efficacy, lumens/W
Combustion	
Candle	0.2
Incandescent	
Ordinary	6–20
Halogen	16–25
Fluorescent	
Ordinary	40–60
High output	70–90
Compact	50–80
High-intensity discharge	
Mercury vapor	50–60
Metal halide	56–125
High-pressure sodium	100–150
Low-pressure sodium	up to 200

Lighting efficacy: The amount of light output in lumens per W of electricity consumed.

A 15-W compact fluorescent lamp provides as much light as a 60-W incandescent lamp.



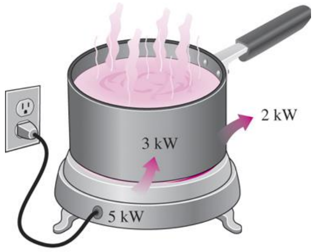
Energy Conversion Efficiency

- Cooking appliances convert electrical or chemical energy to heat for cooking.
- The **efficiency of a cooking appliance** can be defined as the ratio of the *useful energy transferred to the food to the energy consumed by the appliance*

Energy costs of cooking a casserole with different appliances*
[From A. Wilson and J. Morril, *Consumer Guide to Home Energy Savings*, Washington, DC: American Council for an Energy-Efficient Economy, 1996, p. 192.]

Cooking appliance	Cooking temperature	Cooking time	Energy used	Cost of energy
Electric oven	350°F (177°C)	1 h	2.0 kWh	$0.16
Convection oven (elect.)	325°F (163°C)	45 min	1.39 kWh	$0.11
Gas oven	350°F (177°C)	1 h	0.112 therm	$0.07
Frying pan	420°F (216°C)	1 h	0.9 kWh	$0.07
Toaster oven	425°F (218°C)	50 min	0.95 kWh	$0.08
Electric slow cooker	200°F (93°C)	7 h	0.7 kWh	$0.06
Microwave oven	"High"	15 min	0.36 kWh	$0.03

*Assumes a unit cost of $0.08/kWh for electricity and $0.60/therm for gas.



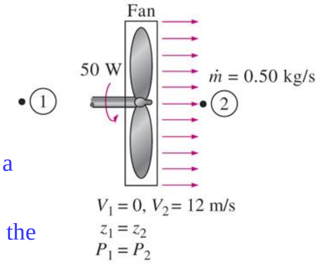
$$\text{Efficiency} = \frac{\text{Energy utilized}}{\text{Energy supplied to appliance}}$$

$$= \frac{3\ \text{kWh}}{5\ \text{kWh}} = 0.60$$

Efficiencies of Mechanical and Electrical Devices

Mechanical efficiency

$$\eta_{mech} = \frac{\text{Mechanical energy output}}{\text{Mechanical energy input}} = \frac{E_{mech,out}}{E_{mech,in}} = 1 - \frac{E_{mech,loss}}{E_{mech,in}}$$



The mechanical efficiency of a fan is the ratio of the kinetic energy of air at the fan exit to the mechanical power input.

$$\eta_{mech,\,fan} = \frac{\Delta \dot{E}_{mech,fluid}}{\dot{W}_{shaft,in}} = \frac{\dot{m}V_2^2/2}{\dot{W}_{shaft,in}} = \frac{(0.50\text{ kg/s})(12\text{ m/s})^2/2}{50\text{ W}} = 0.72$$

- The effectiveness of the conversion process between the mechanical work supplied or extracted and the mechanical energy of the fluid is expressed by the **pump efficiency** and **turbine efficiency**,

$$\eta_{pump} = \frac{\text{Mechanical energy increase of the fluid}}{\text{Mechanical energy input}} = \frac{\Delta \dot{E}_{mech,fluid}}{\dot{W}_{shaft,in}} = \frac{\dot{W}_{pump,u}}{\dot{W}_{pump}}$$

Efficiencies of Mechanical and Electrical Devices

$$\Delta \dot{E}_{mech,fluid} = \dot{E}_{mech,out} - \dot{E}_{mech,in}$$

$$\eta_{turbine} = \frac{\text{Mechanical energy output}}{\text{Mechanical energy decrease of the fluid}} = \frac{\dot{W}_{shaft,out}}{|\Delta \dot{E}_{mech,fluid}|} = \frac{\dot{W}_{turbine}}{\dot{W}_{turbine,e}}$$

$$|\Delta \dot{E}_{mech,fluid}| = \dot{E}_{mech,in} - \dot{E}_{mech,out}$$

- The mechanical efficiency should not be confused with the **motor efficiency** and the **generator efficiency,**

Motor: $$\eta_{motor} = \frac{\text{Mechanical power output}}{\text{Electric power input}} = \frac{\dot{W}_{shaft,out}}{\dot{W}_{elect,in}}$$

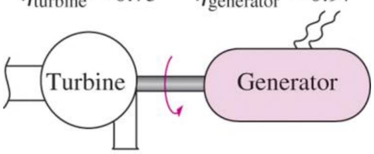
Generator: $$\eta_{generator} = \frac{\text{Electric power output}}{\text{Mechanical power input}} = \frac{\dot{W}_{elect,out}}{\dot{W}_{shaft,in}}$$

Efficiencies of Mechanical and Electrical Devices

$$\eta_{\text{pump-motor}} = \eta_{\text{pump}}\eta_{\text{motor}} = \frac{\dot{W}_{\text{pump},u}}{\dot{W}_{\text{elect,in}}} = \frac{\Delta \dot{E}_{\text{mech,fluid}}}{\dot{W}_{\text{elect,in}}}$$

$$\eta_{\text{turbine-gen}} = \eta_{\text{turbine}}\eta_{\text{generator}} = \frac{\dot{W}_{\text{elect,out}}}{\dot{W}_{\text{turbine},e}} = \frac{\dot{W}_{\text{elect,out}}}{|\Delta \dot{E}_{\text{mech,fluid}}|}$$

$\eta_{\text{turbine}} = 0.75$ $\eta_{\text{generator}} = 0.97$

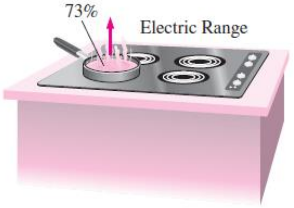


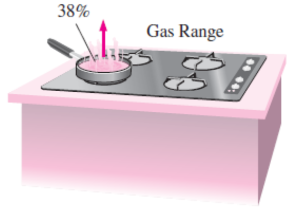
$$\eta_{\text{turbine-gen}} = \eta_{\text{turbine}}\eta_{\text{generator}} = 0.75 \times 0.97 = 0.73$$

The overall efficiency of a turbine–generator is the product of the efficiency of the turbine and the efficiency of the generator, and represents the fraction of the mechanical energy of the fluid converted to electric energy.

Example

The efficiency of cooking appliances affects the internal heat gain from them since an inefficient appliance consumes a greater amount of energy for the same task, and the excess energy consumed shows up as heat in the living space. The efficiency of open burners is determined to be 73 percent for electric units and 38 percent for gas units. Consider a 2-kW electric burner at a location where the unit costs of electricity and natural gas are $0.09/kWh and $0.55/therm, respectively. Determine the rate of energy consumption by the burner and the unit cost of utilized energy for both electric and gas burners.





Example Cont.

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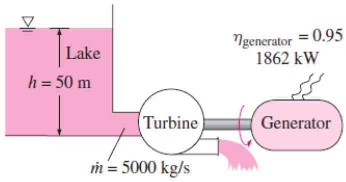
Example

The water in a large lake is to be used to generate electricity by the installation of a hydraulic turbine–generator at a location where the depth of the water is 50 m. Water is to be supplied at a rate of 5000 kg/s. If the electric power generated is measured to be 1862 kW and the generator efficiency is 95 percent, determine



(*a*) the overall efficiency of the turbine– generator, (*b*) the mechanical efficiency of the turbine, and (*c*) the shaft power supplied by the turbine to the generator.

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Example Cont.

Example

A 60-hp electric motor (a motor that delivers 60 hp of shaft power at full load) that has an efficiency of 89.0 percent is worn out and is to be replaced by a 93.2 percent efficient high-efficiency motor. The motor operates 3500 hours a year at full load. Taking the unit cost of electricity to be $0.08/kWh, determine the amount of energy and money saved as a result of installing the high-efficiency motor instead of the standard motor. Also, determine the simple payback period if the purchase prices of the standard and high-efficiency motors are $4520 and $5160, respectively.

Example Cont.

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Energy and Environment

- Using energy-efficient appliances conserve energy.
- It helps the **environment** by reducing the amount of pollutants emitted to the atmosphere during the combustion of fuel.
- The combustion of fuel produces
  - carbon dioxide, causes global warming
  - nitrogen oxides and hydrocarbons, cause smog
  - carbon monoxide, toxic
  - sulfur dioxide, causes acid rain.

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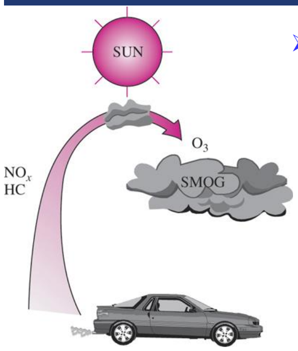
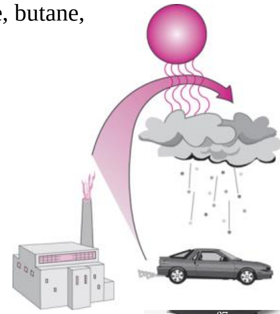
Energy and Environment



- Ground-level ozone, which is the primary component of smog, forms when HC and NO_x react in the presence of sunlight in hot calm days.
  - Smog also contains numerous other chemicals, including carbon monoxide (CO), particulate matter such as soot and dust, volatile organic compounds (VOCs) such as benzene, butane, and other hydrocarbons.
- **Sulfuric acid** and **nitric acid** are formed when sulfur oxides and nitric oxides react with water vapor and other chemicals high in the atmosphere in the presence of sunlight.



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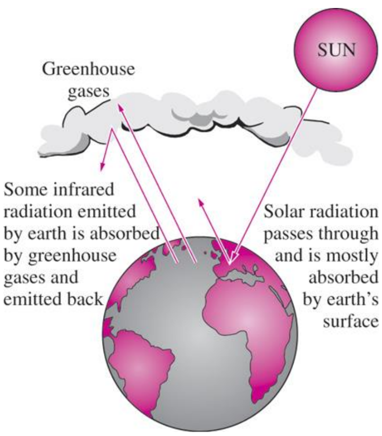
Energy and Environment



The greenhouse effect on earth.

- Greenhouse effect: Glass allows the solar radiation to enter freely but blocks the infrared radiation emitted by the interior surfaces. This causes a rise in the interior temperature as a result of the thermal energy buildup in a space (i.e., car).
- The surface of the earth, which warms up during the day as a result of the absorption of solar energy, cools down at night by radiating part of its energy into deep space as infrared radiation.

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