MEC511

Thermodynamics & Fluids

Chapter02

Energy and the First Law of Thermodynamics

Toronto Metropolitan University

Lecture 08

NOTE!

2.4 Energy Transfer by Heat

2.4.1 Sign Convention, Notation, and Heat Transfer Rate

The symbol Q denotes an amount of energy transferred across the boundary of a system in a heat interaction with the system's surroundings.

$Q > 0$: heat transfer *to* the system

$Q < 0$: heat transfer *from* the system

- **heat is not a property**
- **The amount of energy transfer by heat for a process is given by the integral** $Q = \int_1^2 \delta Q$
- **The net rate of heat transfer is denoted by $\dot{Q}$**
- **The amount of energy transfer by heat during a period of time can be found by integrating from time t_1 to time t_2:**

$$Q = \int_{t_1}^{t_2} \dot{Q}\, dt$$

- ***In some cases it is convenient to use the heat flux, $\dot{q}$, which is the heat transfer rate per unit of system surface area (W/m^2). The net rate of heat transfer, $\dot{Q}$, is related to the heat flux $\dot{q}$ by the integral:***

$$\dot{Q} = \int_{A} \dot{q}\, dA$$

2.5 Energy Accounting: Energy Balance for Closed Systems

First law of thermodynamics

$$\begin{bmatrix} \textit{change} \text{ in the amount} \\ \text{of energy contained} \\ \text{within a system} \\ \text{during some time} \\ \text{interval} \end{bmatrix} = \begin{bmatrix} \textit{net} \text{ amount of energy} \\ \text{transferred } \textit{in} \text{ across} \\ \text{the system boundary by} \\ \textit{heat} \text{ transfer during} \\ \text{the time interval} \end{bmatrix} - \begin{bmatrix} \textit{net} \text{ amount of energy} \\ \text{transferred } \textit{out} \text{ across} \\ \text{the system boundary} \\ \text{by } \textit{work} \text{ during the} \\ \text{time interval} \end{bmatrix}$$

$$E_2 - E_1 = Q - W$$

$$\boxed{\Delta KE + \Delta PE + \Delta U = Q - W}$$

2.5 Energy Accounting: Energy Balance for Closed Systems

Other form of First Law of Thermodynamics

$$dE = \delta Q - \delta W$$

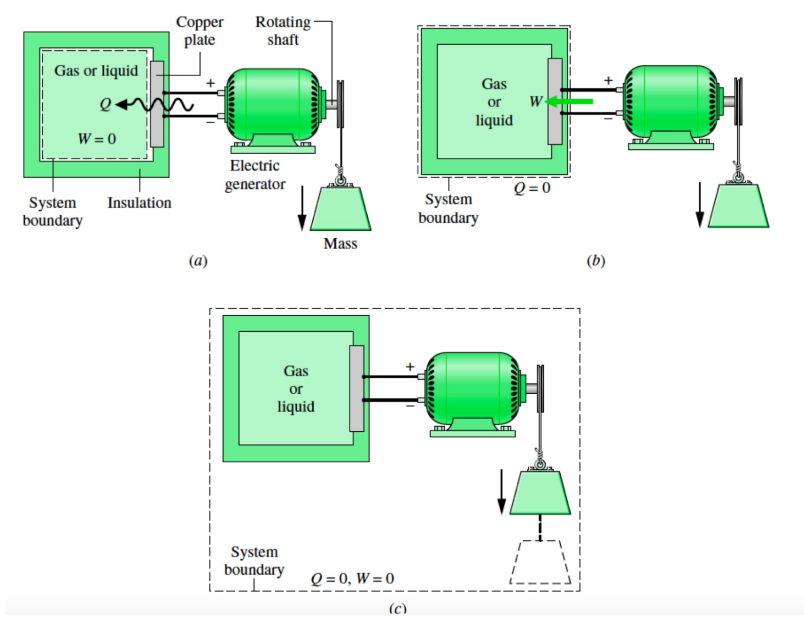
$$\frac{dE}{dt} = \dot{Q} - \dot{W}$$ **time rate form of the energy balance**

$$\frac{dE}{dt} = \frac{dKE}{dt} + \frac{dPE}{dt} + \frac{dU}{dt}$$

$$\frac{dKE}{dt} + \frac{dPE}{dt} + \frac{dU}{dt} = \dot{Q} - \dot{W}$$

2.5 Energy Accounting: Energy Balance for Closed Systems

Illustration of alternative choices for system boundaries.



Example:

A closed system of mass 3kg undergoing a process in which there is a heat transfer of 150 kJ from the system to the surroundings. The work done on the system is 75 kJ. If the initial specific internal energy of the system is 450 kJ/kg, what is the final specific internal energy, in kJ/kg? Neglect changes in kinetic and gravitational potential energy.

Example: Each line of the following table gives data, in Btu, for a process of a closed system. Determine the missing table entries, in Btu.

Process	Q	W	E_1	E_2	ΔE
a	+40		+15		+15
b		+5	+7	+22	
c	−4	+10		−8	
d	−10		−10		+20
e	+3	−3	+8		

Example:

A gas expands in a piston-cylinder assembly from p_1=8.2 bar, V_1=0.0136 m^3 to p_2=3.4 bar in a process during which the relation between pressure and volume is $pV^{1.2}$=constant. The mass of the gas is 0.183 kg. if the specific internal energy of the gas decreases by 29.8 kJ/kg during the process, determine the heat transfer, in kJ. Kinetic and gravitational potential energy effects are negligible.

2.6 Energy Analysis of Cycles

- **A thermodynamic cycle is a sequence of processes that begins and ends at the same state.**
- **At the conclusion of a cycle all properties have the same values they had at the beginning.**

2.6 Energy Analysis of Cycles

2.6.1 Cycle Energy Balance :

$$\Delta E_{cycle} = Q_{cycle} - W_{cycle}$$

Since the system is returned to its initial state after the cycle, there is no net change in its energy.

$$\Delta E_{cycle} = 0$$

$$W_{cycle} = Q_{cycle}$$

2.6 Energy Analysis of Cycles

2.6.2 Power Cycles

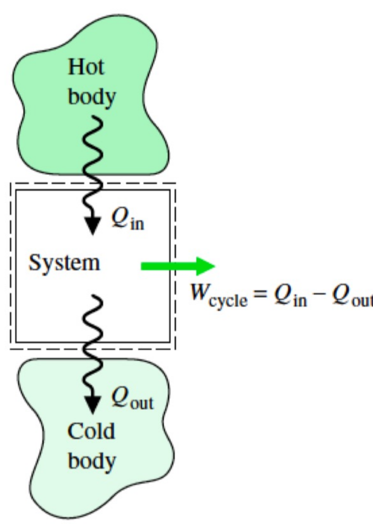
$$W_{cycle} = Q_{in} - Q_{out}$$

Thermal Efficiency

The performance of a system undergoing a power cycle can be described in terms of the extent to which the energy added by heat, Q_{in} , is converted to a net work output, W_{cycle} .

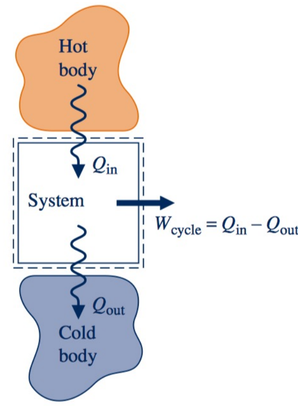
$$\eta = \frac{W_{cycle}}{Q_{in}}$$

$$\eta = \frac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$$



Example:

A system undergoing a power cycle requires an energy input by heat transfer of 1.0551x10^4 kJ for each kW.h of net work developed. Determine the thermal efficiency.



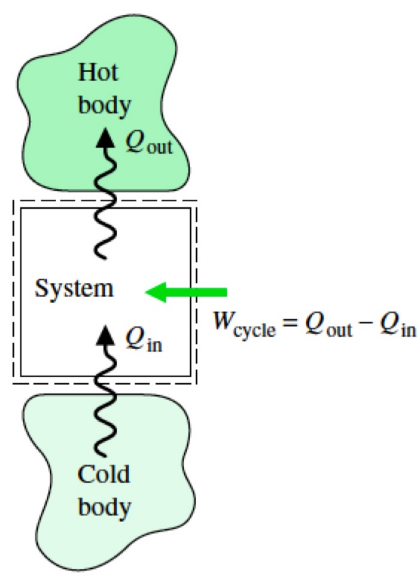
2.6 Energy Analysis of Cycles

2.6.3 Refrigeration Cycles

$$W_{cycle} = Q_{out} - Q_{in}$$

The objective of a refrigeration cycle is to cool a refrigerated space or to maintain the temperature within a dwelling or other building below that of the surroundings.

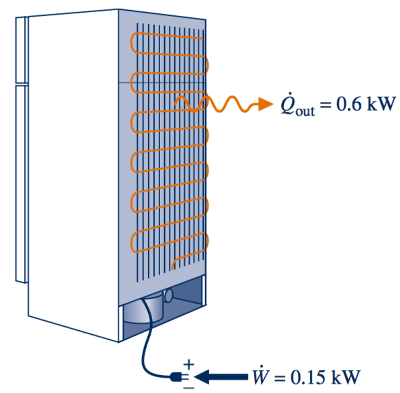
The performance of refrigeration cycles can be described as the ratio of the amount of energy received by the system undergoing the cycle from the cold body, Q_{in}, to the net work into the system to accomplish this effect, W_{cycle}. Thus, the coefficient of performance, β, is



$$\beta = \frac{Q_{in}}{W_{cycle}} \qquad \beta = \frac{Q_{in}}{Q_{out} - Q_{in}}$$

Example:

The refrigerator shown in the figure steadily receives a power input of 0.15 kW while rejecting energy by heat transfer to the surroundings at a rate of 0.6 kW. Determine the rate at which energy is removed by heat transfer from the refrigerated space, in kW, and the refrigerator's coefficient of performance.



2.6 Energy Analysis of Cycles

2.6.3 Heat Pump Cycles

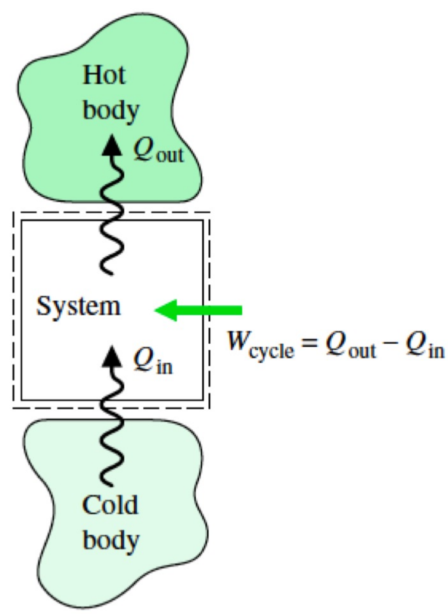
$$W_{cycle} = Q_{out} - Q_{in}$$

The objective of a heat pump is to maintain the temperature within a dwelling or other building above that of the surroundings or to provide heating for certain industrial processes that occur at elevated temperatures.

The performance of heat pumps can be described as the ratio of the amount of energy discharged from the system undergoing the cycle to the hot body, Q_{out}, to the net work into the system to accomplish this effect, Wcycle. Thus, the coefficient of performance, γ, is

$$\gamma = \frac{Q_{out}}{W_{cycle}}$$

$$\gamma = \frac{Q_{out}}{Q_{out} - Q_{in}}$$

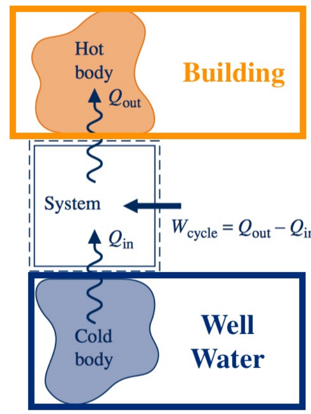


Example:

A heat pump cycle operating at steady state receives energy by heat transfer from well water at 10°C and discharges energy by heat transfer to a building at the rate of 1.2 x 10^5 kJ/h. Over a period of 14 days, an electric meter records that 1490 kW.h of electricity is provided to the heat pump. These are the only energy transfers involved. Determine;

(a) the amount of energy that the heat pump receives over the 14-day period from the well water by heat transfer, in kJ.

(b) the heat pump's coefficient of performance.



Example:

As shown in the below figure, a gas within a piston–cylinder assembly undergoes a thermodynamic cycle consisting of three processes in series:

Process 1–2: Compression with $U_2 = U_1$.

Process 2–3: Constant-volume cooling to p_3 = 140 kPa, V_3 = 0.028 m³.

Process 3–1: Constant-pressure expansion with W_{31} = 10.5 kJ.

For the cycle, W_{cycle} = -8.3 kJ. There are no changes in kinetic or potential energy.

Determine:

a) the volume at state$_1$, in m³.

b) the work and heat transfer for process 1–2, each in kJ.

c) can this be a power cycle? A refrigeration cycle?