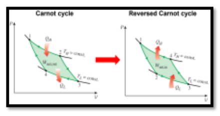
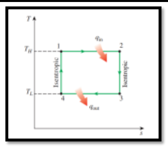
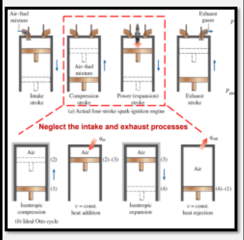
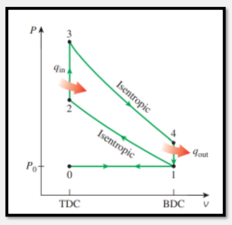
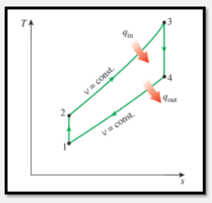
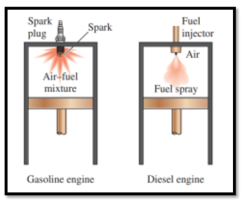
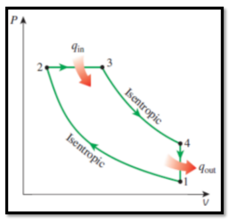
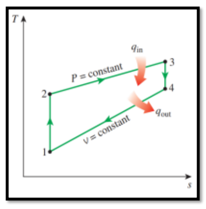
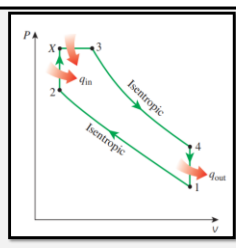
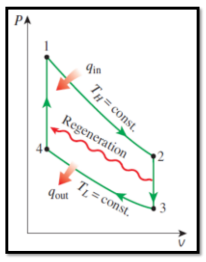
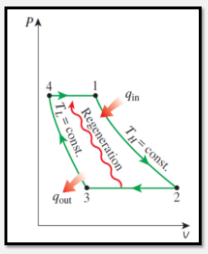
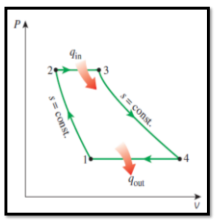
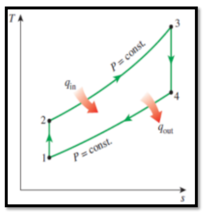
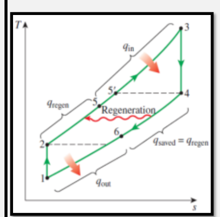
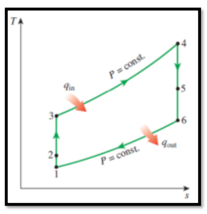
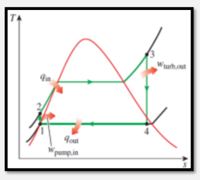
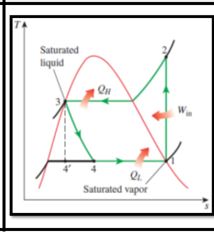
# Cycles in this course

| Thermodynamics Cycle | Purpose | Working Fluids | Key Processes | Application | Advantages | Disadvantages | Important Formulas | P-V | T-S |
|---|---|---|---|---|---|---|---|---|---|
| Carnot cycle | the highest thermal efficience among all heat engines | fluids | Reversible Isothermal Expansion<br>Reversible Adiabatic Expansion<br>Reversible Isothermal Compression<br>Reversible Adiabatic Compression | Carnot heat engine<br>Carnot refrigeration cycle | 1.The highest efficiency of cycle<br>2.Help design realistic machine | not practical | $\boxed{\eta_{th,Carnot} = 1 - \frac{T_L}{T_H}}$ |  |  |
| Otto Cycle | Ideal Cycle for Spark-Ignition Engines | combustion of the air–fuel mixture |  | Spark-Ignition Engines | 1.simple design and easy to use<br>2.working steadily | detonation cylinder | $r = \frac{V_{max}}{V_{min}} = \frac{V_{BDC}}{V_{TDC}}$<br>$\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{k-1}$<br>$\boxed{\eta_{th,Otto} = 1 - \frac{T_1}{T_2} = 1 - \frac{1}{r^{k-1}}}$ |  |  |
| Diesel Cycle | Ideal Cycle for Compression-Ignition Engines | air + fuel spray |  | Compression-Ignition Engines | 1.Diesel engines operate at much higher compression ratios and thus are usually more efficient than the spark ignition (gasoline) engin.<br>2.The diesel engines also burn the fuel more completely. | the same compression ratio<br>$\eta_{th,Otto} > \eta_{th,Diesel}$ | Cutoff ratio (定压预胀比): $r_c = \frac{V_3}{V_2}$<br>$\boxed{\eta_{th,Diesel} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right]}$ |  |  |
| Dual Cycle | A more realistic model for modern, high-speed compression ignition engines | | entire combustion process can better be modeled as a combination of constant-volume and constant-pressure processes | modern high-speed compression ignition engines | more realistic | | |  | |
| Stirling Cycle | ideal models for external combustion engines | | The two isentropic processes in the Carnot cycle are replaced with two constant volume processes with regeneration | external combustion engine | (The advantages of external combustion engines:)<br>1. The combustion is more complete with more time and space, thus more energy extraction from the fuel and less air pollution.<br>2. Operate on closed loops, thus the working fluid that has the most desirable characteristics can be utilized.<br>3. A variety of fuels (even solar energy) can be used. | | $\boxed{\eta_{th,Stirling} = \eta_{th,Ericsson} = \eta_{th,Carnot} = 1 - \frac{T_L}{T_H}}$ |  | |
| Ericsson Cycle | ideal models for external combustion engines | | The two isentropic processes in the Carnot cycle are replaced with two constant pressure processes with regeneration | external combustion engine | (The advantages of external combustion engines:)<br>1. The combustion is more complete with more time and space, thus more energy extraction from the fuel and less air pollution.<br>2. Operate on closed loops, thus the working fluid that has the most desirable characteristics can be utilized.<br>3. A variety of fuels (even solar energy) can be used. | | $\boxed{\eta_{th,Stirling} = \eta_{th,Ericsson} = \eta_{th,Carnot} = 1 - \frac{T_L}{T_H}}$ |  | |
| Brayton Cycle | Ideal Cycle for Gas-Turbine Engines | fuel + air | 1-2 Isentropic compression (in a compressor)<br>2-3 Constant-pressure heat addition<br>3-4 Isentropic expansion (in a turbine)<br>4-1 Constant-pressure heat rejection | Gas-Turbine Engines | Today, it is used for gas turbines only where both the compression and expansion processes take place in rotating machinery | | Pressure ratio: $r_p = \frac{P_2}{P_1}$<br>$\boxed{\eta_{th,Brayton} = 1 - \frac{T_1}{T_2} = 1 - \frac{1}{r_p^{(k-1)/k}}}$<br>$\boxed{r_{p,\,max\,work} = \left(\frac{T_3}{T_1}\right)^{k/[2(k-1)]}}$ |  |  |
| The Brayton Cycle with Regeneration | to increase thermal efficiency | fuel + air | the air leaving the compressor can be first heated by the hot exhaust gas in a heat exchanger before getting into the combustion chamber | | 1.less fuel is used for the same work output<br>2.the thermal efficiency increases | | $\eta_{th,regen} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{h_6 - h_1}{h_3 - h_5}$<br>$\epsilon = \frac{q_{regen,act}}{q_{regen,max}} = \frac{h_5 - h_2}{h_4 - h_2}$<br>When $\varepsilon = 1$, $\eta_{th,regen} = 1 - (\frac{T_1}{T_3})(r_p)^{(k-1)/k}$ | |  |
| Jet-Propulsion Cycle | Gas-turbine engines are widely used to power aircraft | gas | The ideal jet-propulsion cycle differs from the ideal Brayton cycle in that the gas is expanded in the turbine to produce the power that is just sufficient to drive the compressor and the auxiliary equipment | Aircraft gas turbines | the net work output of an ideal jet-propulsion cycle is zero. The gas that exits the turbine at a relatively high pressure is subsequently accelerated in a nozzle to provide the thrust of the aircraft | | $F = (\dot{m}V)_{exit} - (\dot{m}V)_{inlet} = \dot{m}(V_{exit} - V_{inlet})$<br>$\dot{W}_P = FV_{aircraft} = \dot{m}(V_{exit} - V_{inlet})V_{aircraft}$<br>$\eta_P = \frac{\text{Propulsive power}}{\text{Energy input rate}} = \frac{\dot{W}_P}{\dot{Q}_{in}}$ | |  |
| Rankine Cycle | Ideal Cycle for Vapor Power Cycles | Steam (alternately vaporized and condensed) | 1-2 Isentropic compression in a pump<br>2-3 Constant pressure heat addition in a boiler<br>3-4 Isentropic expansion in a turbine<br>4-1 Constant pressure heat rejection in a condenser | Vapor Power Engines | Carnot vapor cycle is not suitable for vapor power cycle, but the Rankine Cycle can. | | $w_{pump,in} = h_2 - h_1$<br>or $w_{pump,in} = v(P_2 - P_1)$<br>$q_{in} = h_3 - h_2$<br>$w_{turb,out} = h_3 - h_4$<br>$q_{out} = h_4 - h_1$<br>$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$ | |  |
| Ideal Vapor-Compression Refrigeration Cycle | Ideal Vapor-Compression Refrigeration Cycle | vapor<br>(not using gas because the vapor has phase change which is better for refrigeration) | 1-2 Isentropic compression in a compressor<br>2-3 Constant-pressure heat rejection in a condenser<br>3-4 Throttling in an expansion device<br>4-1 Constant-pressure heat absorption in an evaporator | Heat pumps and refrigerators | The reversed Carnot cycle cannot be approximated in actual devices and is not a realistic model for refrigeration cycles, but the Ideal Vapor-Compression Refrigeration Cycle can. | | Second-Law Analysis of Vapor-Compression Refrigeration Cycle<br>$\eta_{II,cycle} = \frac{\dot{X}_{\dot{Q}_L}}{\dot{W}_{in}} = \frac{\dot{W}_{min,in}}{\dot{W}_{in}} = 1 - \frac{\dot{X}_{dest,total}}{\dot{W}_{in}}$<br>$= \frac{\dot{Q}_L(T_0 - T_L)/T_L}{\dot{Q}_L/COP_R} = \frac{COP_R}{T_L/(T_H - T_L)} = \frac{COP_R}{COP_{R,rev}}$<br>$COP_R = \frac{q_L}{w_{net,in}} = \frac{h_1 - h_4}{h_2 - h_1}$<br>Note that state 1 is saturated vapor<br>and state 3 is saturated liquid) | |  |