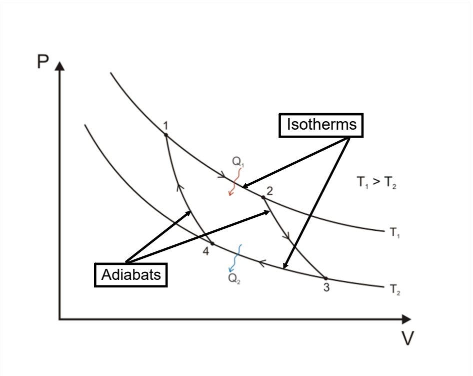
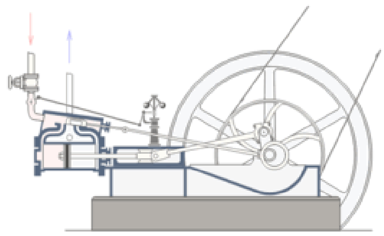
2.C.4 Heat Engines and Efficiency



Start Steam Engine Demo

Check this out!

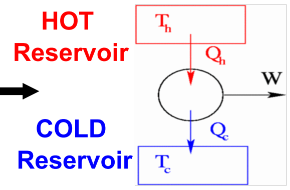


Heat Engines

A device that converts heat energy to work - gas/ diesel engines, steam engines, Stirling engines, etc.

Some heat from a high temperature source is converted to useful work, and the rest is expelled.

Power plants convert coal, gas, liquid fuel, nuclear, or geothermal sources of heat to electricity.

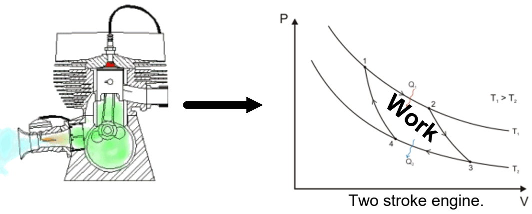


Thermal Cycle

Processes bringing a system to its original state.

At each step, W, Q, and ΔU can be calculated using the 1st Law of Thermo.

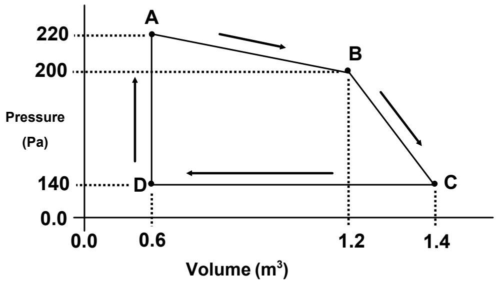
Overall work is the sum of work done during each step of the process, and in a P-V diagram, work equals the area surrounded by process lines.



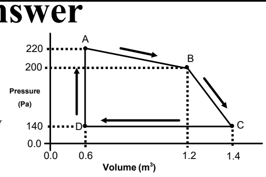
Work Example

In the following P-V graph, a very simplified thermal cycle is shown.

1. What work is done during each step in the process?
2. What is the overall work done?



Work Answer



Steps:

A - B $W = -\bar{P}\Delta V = -\frac{P_2 + P_1}{2} \bullet \Delta V$

$= -\frac{220\,Pa + 200\,Pa}{2} \bullet (1.2\,m^3 - 0.6\,m^3) = -126\,J$

B - C $W = -\bar{P}\Delta V = -\frac{P_2 + P_1}{2} \bullet \Delta V$

$= -\frac{200\,Pa + 140\,Pa}{2} \bullet (1.4\,m^3 - 1.2\,m^3) = -34\,J$

C - D $W = -P\Delta V = -140\,Pa\,(0.6\,m^3 - 1.4\,m^3) = 112\,J$

D - A $W = 0\,J$

Total: W = -126 J + -34 J + 112 J = - 48 J.

The Four-Stroke Otto Cycle P-V Diagram:

1: Intake stroke: isobaric expansion.

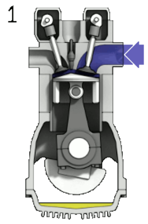
2: Compression stroke: adiabatic compression.

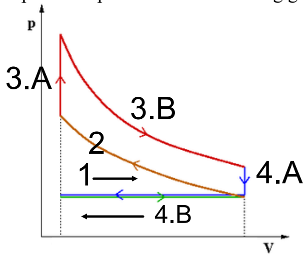
3.A: Combustion of fuel: isochoric (isometric) process.

3.B: Power Stroke: adiabatic expansion.

4.A: Exhaust Start: isochoric process: valve lets pressurized gases out.

4.B: Exhaust End: isobaric compression: piston forces remaining gases out.





Thermal Efficiency

Comparison of output work (W_{net}) to energy input (Q_h) is efficiency:

$\varepsilon = \frac{W_{net}}{Q_h} \bullet 100\%$	ε = Efficiency (%) W_{net} = Joules (J) Q_h = Energy In (J)

Work is computed by direct calculation, or a 1st Law of Thermo. analysis.

3. Efficiency Example

A steam engine burns 150 Joules worth of fuel, and lifts 1.0 kg 2.5 meters vertically as a result. How efficient is the steam engine?

Hint: Find the work done to lift the mass first.

$$W = Fd = m \bullet g \bullet h$$

$$= 1.0\,kg \bullet 9.81\,m/s^2 \bullet 2.5\,m = 24.5\,J$$

$$\varepsilon = \frac{W_{net}}{Q_h} \bullet 100\% = \frac{24.5\,J}{150\,J} \bullet 100\% = 16.3\%$$

Maximum Efficiency

By Second Law, it's impossible to have a 100% efficient engine.

What is the maximum limit to engine efficiency?

Sadi Carnot (1796 – 1832) investigated this question.

Determined that an *Ideal* engine absorbs heat from a constant high temperature reservoir (T_h), and exhausts it into a constant low temperature reservoir (T_c).

Can you guess how he died?

Carnot Rabbit Hole!

Carnot's Death

Carnot died in a cholera epidemic in 1832 when he was only 36.

Cholera is characterized by extreme diarrhea (10 - 20 L/day! (3 - 5 gal)) and vomiting. Death results from dehydration.

Because of the concern of cholera, many of his belongings and writings were buried together with him after his death.

Thus, only a handful of his scientific writings survived besides his book.

Carnot Cycle Equations

Carnot cycle efficiency (ε_c) math primarily focuses on input and output temperature differences:

$\varepsilon_C = 1 - \frac{T_c}{T_h} \bullet 100\%$	T_h = Temperature of hot reservoir (K) T_c = Temperature of cold reservoir (K)

It also looks at input vs. output heat:

$\varepsilon_C = 1 - \frac{Q_c}{Q_h} \bullet 100\%$	Q_h = Heat from hot reservoir (J) Q_c = Heat expelled into environment (J)

4. Carnot Cycle Example

What is the efficiency of a Carnot engine operating at 560 K, and expelling exhaust at 380 K?

$$\varepsilon_C = 1 - \frac{T_c}{T_h} \bullet 100\%$$
$$= 1 - \frac{380K}{560K} \bullet 100\%$$
$$= 0.321 = 32.1\%$$

Carnot Cycle

A true Carnot engine can't be built because the reversible processes can only be approximated.

All that aside, it illustrates the general idea that the greater the difference in the temperatures of the heat reservoirs, the greater the Carnot efficiency.

Does that mean that our cars will be more efficient at 40 below?

NO! Trick question: if the exhaust coming out of the car were -40, then that would be pretty efficient (high energy recovery).

Third Law of Thermodynamics

If the cold reservoir were at absolute zero, by the Carnot efficiency equation you'd have a 100% efficient engine.

So far, scientists have come close, but not quite exactly at absolute zero (4.5 E -10 K). (How do you suppose they measure that?)

This gives rise to the Third Law: "It is impossible to reach absolute zero in a finite number of thermal processes."

Homework

2.C.4 Booklet Problems
Due: Next Class

Review Problems: Scanned 10/30, Tuesday