Week 10

Gas Power Cycles
Today’s Outline

• Gas power cycles
• Internal combustion engines
• Four-stroke cycle
• Thermodynamic cycles
• Ideal cycle
Gas Power Cycles

- Working fluid (WF) is in gas phase most of cycle
- Examples include **internal combustion (IC) engines** such as spark-ignition, diesel, and gas turbine engines
- Heat engine burning fuel in confined space e.g. combustion chamber
- Hence, composition of working fluid changes – we will **assume WF is air** – AF is typically high
- Produces high T and P gases which are allowed to **expand directly** causing movement and hence work
- Operate on **open cycle** – we will model as closed
- Compare to external combustion engine e.g. steam engine
Air Standard Assumptions (ASA) for Ideal Cycle

- **WF is air**, continuously circulating in a closed loop and behaves as **ideal gas**
- All processes in cycle are **internally reversible**
- Combustion process replaced by **heat addition** from external source (see next slide)
- Intake/exhaust replaced by **heat rejection** which restores WF to initial state
- For qualitative results, **cold air standard assumptions (CASA)** assume **constant specific heats** using room temperature (25°C) values
Modeling Combustion Process as Heat Addition

(a) Actual

(b) Ideal
How about air standard Carnot cycle as ideal cycle?

- Carnot yields maximum efficiency
  \[ \eta_{\text{Carnot}} = 1 - \frac{T_L}{T_H} \]
- Executed in closed system or open steady-flow device (see next slide)
- Efficiency increases with increasing/decreasing high/low temperature
- Reversible isothermal heat transfer – not practical
Carnot Cycle in Open Steady-Flow Devices

![Diagram of Carnot Cycle in Open Steady-Flow Devices]

- Isothermal compressor
- Isentropic compressor
- Isothermal turbine
- Isentropic turbine

1. Isothermal compression
2. Isentropic compression
3. Isothermal expansion
4. Isentropic expansion

$q_{in}$: Heat input
$q_{out}$: Heat output
$w_{net}$: Net work output
Reciprocating Engines

Intake valve  Exhaust valve

Bore  Stroke  TDC

(a) Displacement volume  (b) Clearance volume

ME 300 Thermodynamics II
Mean Effective Pressure (MEP)

- Imaginary pressure which if acted on the piston during the power stroke (outward stroke) would produce same amount of net work as during actual cycle.
Classes of Reciprocating Engines

• “Come on baby, light my fire . . . Try to set the *fuel* on fire!” Doors (1970)

• Gasoline engine is a homogeneous charge spark-ignition engine

• Diesel engine is a stratified charge compression ignition engine

• Homogeneous charge compression ignition

http://www.me.berkeley.edu/cal/HCCI/ ME 300 Thermodynamics II
Engine Comparison

REducing SOot and NOx Emissions

In HCCI and petrol engines, the fuel and air are mixed before combustion, preventing the soot emissions of diesel engines. Only HCCI engines have multiple ignition points throughout the chamber. This plus their lean burn keeps temperatures low, preventing formation of nitrogen oxides (NOx).

http://www.me.berkeley.edu/cal/HCCI/
Computational Fluid Dynamics (CFD) as analysis/design tool

Fuel spray in SI engine

Swirl effects diesel fuel spray

Diesel combustion

NO formation in Diesel engine
Four-stroke cycle

- Most commonly used IC engine e.g. cars, trucks, generators
- Four strokes of piston inside cylinder
  - Intake stroke
  - Compression stroke
  - Power stroke
  - Exhaust stroke
- Spark-ignition (SI) or compression-ignition (CI) versions

http://en.wikipedia.org/wiki/Four-stroke_cycle
Four-stroke cycle – first half

Top dead center (TDC)

Starting position  Intake stroke  Compression stroke
Four-stroke cycle – second half

Ignition of fuel

Power stroke

Exhaust stroke
Ideal Otto Cycle - pictures

Do you like my cycle?
Ideal Otto cycle - details

- 4 internally **reversible** processes
  - 1-2 isentropic compression
  - 2-3 \( v = \text{constant} \) heat addition
  - 3-4 isentropic expansion
  - 4-1 \( v = \text{constant} \) heat rejection
Ideal Otto Cycle - Analysis

• Conservation of energy
Ideal Otto Cycle - Analysis
Ideal Otto Cycle - Performance

\[ \eta_{th, Otto} \]

Compression ratio, \( r \)

\[ k = 1.667 \]
\[ k = 1.4 \]
\[ k = 1.3 \]

Compression ratio, \( r \)

Typical compression ratios for gasoline engines
Ideal Otto Cycle – Variable Specific Heats
Example

- An ideal Otto cycle has a compression ratio of 8. Pre-compression air conditions are 100kPa, 17°C and 800 kJ/kg heat transferred to air during \(v=\text{constant} \) heat-addition process. Accounting for variable specific heats determine: (a) maximum \(T\), \(P\), (b) net work output, (c) thermal efficiency, (d) MEP.
Example
Example
Summary

- *Air standard assumptions* turn IC engines into EC engines for modeling.
- Reciprocating engines make *piston-cylinder device* a reality! Learn the lingo!
- *Spark-ignition engine* modeled as *ideal Otto cycle*.
- Combustion modeled as constant volume, e.g. *instantaneous*, heat addition.
- “Who’s that *knocking* at my door?”
Today’s Outline

• Diesel cycle
• Diesel cycle analysis
• Diesel cycle example
Diesel Cycle – Ideal Cycle for CI Engines

My cycle is better than Otto’s!

Rudolf Diesel (1890s)
Penetration of diesel sprays into different ambient pressures. The top spray is into 1 atm N2 gas, the middle spray is into 2 atm N2 gas, and the bottom spray is into 5 atm N2 gas. The fuel-injection pressures (500 bar) and the time elapsed for each injection event (110 microseconds) is identical for each image.
Diesel Flame (Dec, SAE970873)

Out with the Old and in with the New!
Diesel Cycle - Details

- 4 reversible processes
  - 1-2 isentropic compression
  - 2-3 constant pressure heat addition
  - 3-4 isentropic expansion
  - 4-1 constant volume heat rejection
Diesel Cycle - Analysis
Diesel Cycle - Analysis
Diesel Cycle - Performance

Typical compression ratios for diesel engines:

- $r_c = 1$ (Otto)
- $r_c = 2$
- $r_c = 3$
- $r_c = 4$

Graph showing efficiency ($\eta_{th,\text{Diesel}}$) vs. compression ratio ($r$).
Dual Cycle

The diagram illustrates a dual cycle process in a $P-v$ diagram. The cycle consists of two isentropic processes (labeled as 'Isentropic') and two heat transfer processes (labeled as $q_{in}$ and $q_{out}$). The points on the diagram are labeled as 1, 2, 3, and 4, indicating the sequence of states in the cycle.
Example

- An ideal Diesel cycle with air as working fluid has a compression ratio of 18 and a cutoff ratio of 2. At the beginning of compression process, working fluid is at 14.7 psia and 80°F, and 117 in³. Utilizing the CASA, determine (a) T, P at end of each process, (b) net work output and thermal efficiency, and (c) MEP.
Example
Example
Example
Summary

• *Diesel cycle* is ideal cycle for *CI engine*

• Combustion process modeled as *constant pressure heat addition*

• For same r, Otto is more efficiency than Diesel

• But, Diesel can reach higher r’s since no knock – but mixing/pollutants challenge

• Active research area – HCCI, hybrids, fuel-cells, etc.