Internal Combustion Engines

Two-stroke Engines

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Background

- Since the two stroke engine fires on every revolution of the crankshaft, a two stroke engine is usually more powerful than a four stroke engine of equivalent size. This, coupled with their lighter, simpler construction, makes two stroke engines popular in chainsaws, line trimmers, outboard motors, snowmobiles, jet-skis, light motorcycles, and model airplanes.

- Unfortunately most two stroke engines are inefficient and are terrible polluters due to the amount of unspent fuel that escapes through the exhaust port.
History

- The first two-stroke design was a diesel engine invented by Dugald Clark in 1878, and used a similar cylinder head to a four-stroke diesel engine, and a supercharger.

- The gasoline two stroke engine, and the cylinder ports on which it depends, were invented by Joseph Day in 1889. These cylinder ports were subsequently incorporated into diesel two-stroke engines, replacing either just the inlet valves or both inlet and exhaust valves.
Two-Cycle SI Engines

(A) INTAKE AND EXHAUST

(B) IGNITION AND POWER
Two-Cycle SI Engines

- Two-Cycle engines can be either SI or CI.
- Two-Cycle SI engines typically use crankcase for as an air pump.
- Check valve required to control flow of air/fuel mixture.
- High power/weight ratio – often used for chain saws, string trimmers and boat motors.
- Erratic idle.
- Poor fuel economy.
Two-Cycle CI Engines
Two-Cycle CI Engines

- Often use mechanical blowers.
- Compressed air helps to sweep residual exhaust gases from the cylinder.
- High power/weight ratios - often use to power busses.

Detroit Diesel with Blower
The composition of flows in and out of a two-stroke engine and the cylinder
Typical sequence of a two-stroke cycle events. The outer circle shows the processes occurring inside the cylinder as a function of crank angle, the inner circle shows those occurring in the crankcase.
Typical Timing of Two-Cycle CI Engine

EVO = EXHAUST VALVE OPENS
EVC = EXHAUST VALVE CLOSES
IPO = INTAKE PORT OPENS
IPC = INTAKE PORT CLOSES
Design issues

- A major problem with the two-stroke engine has been the short-circuiting of fresh charge from intake to exhaust which increases fuel consumption and emissions of unburned hydrocarbons.

- The cylinder ports and piston top are shaped to minimize this mixing of the intake and exhaust flows. Furthermore, a tuned pipe with an expansion chamber provides back pressure at just the right time to push fresh air-fuel mixture sneaking out the exhaust back in again.
Design issues

- The major components of two-stroke engines are tuned so that optimum airflow results. Intake and exhaust pipes are tuned so that resonances in airflow give better flow.

- Two-stroke engines mix lubricants with their fuel; this mixture lubricates the cylinder, crankshaft and connecting rod bearings. The lubricant is subsequently burned, resulting in undesirable emissions. An independent lubrication system from below, as is used in four-stroke designs, cannot be used in the above-described engine design, since the crankcase is being used to hold the air-fuel mixture.
Cycle Fundamentals

4-Stroke Cycle

2-Stroke Cycle

Naturally Aspirated

Turbocharged
Heat Balance

**Two-stroke engines**

- The thermal distribution of a two-stroke diesel engine is about $1/3^{rd}$ power, $1/3^{rd}$ cooling and $1/3^{rd}$ exhaust.
- When turbocharged and after-cooled it is about 38% power, 32% exhaust and 30% cooling.

**Four-stroke engines**

- A turbocharged and after-cooled four-stroke engine is more efficient than a two-stroke engine.
- The thermal distribution of a four stroke engine is 42 % power, 30% exhaust and 28% cooling.
Two-Stroke Engine In-Cylinder Flow

- **Loop-scavenged**
  This method of scavenging uses carefully aimed transfer ports to loop fresh mixture up one side of the cylinder and down the other pushing the burnt exhaust ahead of it and out the exhaust port. It features a flat or slightly domed piston crown for efficient combustion. Loop scavenging is by far the most used system of scavenging.
Two-Stroke Engine In-Cylinder Flow

- Cross flow-scavenged

  In a cross flow engine the transfer ports and exhaust ports are on opposite sides of the cylinder and a baffle shaped piston dome directs the fresh mixture up and over the dome pushing the exhaust down the other side of the baffle and out the exhaust port. Before loop scavenging was invented almost all two strokes were made this way. The heavy piston with its very high heat absorption along with its poor scavenging and combustion characteristics make it an antiquated design now except where there is no way to use loop scavenging.
Two-Stroke Engine In-Cylinder Flow

- Most common two-stroke engines are crankcase-scavenged.
- Another class of two-stroke engine uses a separate compressor to deliver air into the cylinder to scavenge the combustion products, fuel is injected directly into the cylinder.
Scavenging in Two-Stroke Engine

Cross  |  Loop  |  Uniflow

(a)    |  (b)   |  (c)
Cylinder Volume = Swept Volume = \( V_d \)

Cylinder Mass = \( \rho_a V_d = m_c \)

Mass of Fresh Charge Delivered / Ingested = \( m_i \)

Mass of Fresh Charge Retained / Trapped = \( m_t \)

Mass of Charge Lost (Short-circuiting) = \( m_i - m_t \)

Mass of Charge Trapped (including Exh. Residuals) = \( m_{tc} \)

**Delivery Ratio:**
\[
\lambda_{dr} = \frac{m_i}{m_c}
\]

**Charging Efficiency:**
\[
\lambda_{ce} = \frac{m_t}{m_c}
\]

**Trapping Efficiency:**
\[
\lambda_{te} = \frac{m_t}{m_i}
\]

**Scavenging Efficiency:**
\[
\lambda_{se} = \frac{m_t}{m_{tc}}
\]

**Relative Charge:**
\[
\lambda_{rc} = \frac{m_{tc}}{m_c} = \frac{\lambda_{ce}}{\lambda_{se}}
\]

\( \therefore \) \( \lambda_{dr} > \lambda_{ce} \)

**Charging Efficiency**

= Delivery Ratio \times Trapping Efficiency

**Charging Efficiency**

= Relative Charge \times Scavenging Efficiency
A. Perfect scavanging - no mixing, air displaces the products out the exhaust (if extra air is delivered i.e., when delivery ratio > \( \frac{r}{r-1} \), it is not retained).

B. Short circuiting - the air initially displaces all the products within the path of the short circuit and then flows into and out of the cylinder.

C. Perfect mixing - the first air to enter the cylinder mixes instantaneously with the products and the gas leaving is almost all residual (for larger delivery ratio most of gas leaving is air).
Two-stroke Engines

- Turbulence is detrimental in the scavenging process of two-stroke cycle engines. This is because, the incoming air mixes more with the exhaust gases, and a greater exhaust residual will remain within the cylinder.

- Another negative result occurs during combustion when high turbulence enhances the convective heat transfer to the walls in the combustion chamber. This higher heat loss lowers the thermal efficiency of the engine.
<table>
<thead>
<tr>
<th>Peculiarity</th>
<th>Advantage</th>
<th>Drawback</th>
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<tbody>
<tr>
<td>1. Products of combustion are scavenged by the fresh charge.</td>
<td>Exhaust and intake strokes are removed, thus doubling the number of power strokes per unit time.</td>
<td>Loss of fresh charge to exhaust results in fuel losses in pre-mixed (carbureted) engines; increases fuel consumption and HC emissions.</td>
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<tr>
<td></td>
<td>Mixing between the two gases results in inherent exhaust gas recycling (EGR), reducing NOX emissions.</td>
<td>Mixing between the two gases results in a low charging efficiency (low torque) and poor operation at idle. Scavenge pressure must be slightly above exhaust pressure.</td>
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<tr>
<td>2. Doubles number of power strokes per unit time.</td>
<td>Higher engine power/weight ratio and power/swept-volume ratio; smoother torque-versus-time profile; smaller flywheel (lower moment of inertia)</td>
<td>Higher thermal stresses and component temperatures (especially piston)</td>
</tr>
<tr>
<td>3. Intake pressure must be slightly above exhaust pressure.</td>
<td></td>
<td>Charge compression is needed prior to scavenging; there are difficulties in employing turbocharging system, catalytic converter, noise reduction and engine brake systems</td>
</tr>
<tr>
<td>4. Piston-controlled ports</td>
<td>Simple structure; low production cost; small bulk volume</td>
<td>Symmetrical timing around BC, which results in a loss of torque at low and high speeds; long-skirt piston, high piston inertia</td>
</tr>
<tr>
<td>5. Piston lubrication by oil-in-air mixture</td>
<td>Simple maintenance</td>
<td>Higher HC and smoke emissions</td>
</tr>
<tr>
<td>Method</td>
<td>Advantages</td>
<td>Drawbacks</td>
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<tr>
<td>--------------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
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<tr>
<td>Cross</td>
<td>Good scavenging at partial throttling and low speeds</td>
<td>High bsfc at high throttle opening and high speeds</td>
</tr>
<tr>
<td></td>
<td>Low engine volume for multicylinder arrangements</td>
<td>High tendency to knock limits compression ratio</td>
</tr>
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<td></td>
<td>Low manufacturing cost</td>
<td></td>
</tr>
<tr>
<td>Loop, MAN-type</td>
<td>Good scavenging at WOT</td>
<td>Poor scavenging at part-throttle operation</td>
</tr>
<tr>
<td></td>
<td>Low surface-to-volume ratio combustion chamber</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low manufacturing cost</td>
<td></td>
</tr>
<tr>
<td>Loop, Schnürle-type</td>
<td>Good scavenging at WOT and medium engine speed</td>
<td>High bsfc at part throttle operation</td>
</tr>
<tr>
<td></td>
<td>Fair scavenging at part throttle and other than medium engine speeds</td>
<td></td>
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<tr>
<td></td>
<td>Low manufacturing cost</td>
<td></td>
</tr>
<tr>
<td>Uniflow, exhaust valve</td>
<td>Very good scavenging at WOT for high stroke-to-bore ratio</td>
<td>Need for exhaust valves; thus more complex and higher manufacturing cost</td>
</tr>
<tr>
<td></td>
<td>Excellent bsfc</td>
<td></td>
</tr>
<tr>
<td>Uniflow, opposed piston</td>
<td>Very good scavenging at WOT for high stroke-to-bore ratio</td>
<td>Need for mechanical coupling between two crankshafts</td>
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</tbody>
</table>
Performance characteristics of a three-cylinder 450 cm³, two-stroke cycle spark ignition engine; Bore = 58 mm, Stroke = 56 mm.
Total friction mean effective pressure (tfmep) of a crankcase-scavenged two-stroke cycle engine versus engine speed for wide-open-throttle and idle operation.
Comparison of pumping mean effective pressure as a function of load (bmeP) for crankcase-scavenged two-stroke SI engine and four-stroke cycle engine.
Table 8-4 Oil consumption of small industrial four-stroke and two-stroke cycle engines

<table>
<thead>
<tr>
<th></th>
<th>Four-stroke cycle engine, 7.5 kW</th>
<th>Two-stroke cycle engine, 7.5 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption (g/h)</td>
<td>2200</td>
<td>3500</td>
</tr>
<tr>
<td>Oil consumption (g/h)</td>
<td>10</td>
<td>35</td>
</tr>
<tr>
<td>Fuel/oil ratio</td>
<td>220:1</td>
<td>100:1</td>
</tr>
<tr>
<td>Specific fuel consumption (g/kW-h)</td>
<td>290</td>
<td>460</td>
</tr>
<tr>
<td>Specific oil consumption (g/kW-h)</td>
<td>1.3</td>
<td>4.6</td>
</tr>
</tbody>
</table>
Table 8-5  Important physical and chemical properties of a lubricant for two-stroke cycle engines (based on SAE\textsuperscript{21})

<table>
<thead>
<tr>
<th>Property</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscibility and fluidity</td>
<td>Lubricants must have the ability to mix into gasoline and/or to flow at the prevailing ambient temperature</td>
</tr>
<tr>
<td>Rust</td>
<td>To prevent internal engine corrosion during shutdown</td>
</tr>
<tr>
<td>Stability and compatibility</td>
<td>To ensure oil homogeneity over a broad range of ambient temperatures for extended periods of time</td>
</tr>
<tr>
<td>Pour point</td>
<td>To ensure adequate dispensability at lower ambient temperatures</td>
</tr>
<tr>
<td>Solvent content</td>
<td>To ensure oil homogeneity in terms of liquid and highly volatile components</td>
</tr>
<tr>
<td>Ash content</td>
<td>Ash-forming lubricants are important for some air-cooled engines, where high temperatures are essentially involved</td>
</tr>
<tr>
<td>Flash point</td>
<td>A safety measure that determines the flash point of solvent-diluted lubricants</td>
</tr>
<tr>
<td>Biodegradability</td>
<td>To enhance environmentally friendly oils</td>
</tr>
<tr>
<td>Color</td>
<td>To distinguish the specific oil from other different-purpose oils; blue and green are common</td>
</tr>
</tbody>
</table>
Each downward stroke of the piston is a power stroke.

Each upward stroke of the piston is a compression stroke.

The intake and exhaust cycle may be considered a part of the power and compression stroke and begins after completion of the power stroke as the exhaust valves open.

The intake and exhaust cycle ends after the piston closes off the intake ports of the cylinder liner on the compression stroke.
Advantages of the two-stroke engine:

• Power to weight ratio is higher than the four stroke engine since there is one power stroke per crank shaft revolution.
• No valves or camshaft, just ports

Most often used for low cost, small engine applications such as lawn mowers, marine outboard engines, motorcycles….

Disadvantages of the two-stroke engine:

• Incomplete scavenging or too much scavenging
• Burns oil mixed in with the fuel
References

Web Resources

1. http://www.mne.psu.edu/simpson/courses
2. http://me.queensu.ca/courses
11. http://www.tpub.com/content/engine/14081/css
21. http://www.me.udel.edu
22. http://online.physics.uiuc.edu/courses/phys140