Diesel Engine continued

Limitations of air standard cycle
Features of real engine:
- real gas properties
- combustion parameters modify rate of pressure change
- heat transfer occurs during process & cylinder cooling
- intake and exhaust processes modify parts of the p-v diagram
- valve losses
- friction between piston rings and cylinder walls => reduced power output
- turbocharging modifies some of process

Data for plot

\[ f_{tr} := 1 \quad f_{tr} = 1 \text{ for model} \]

\[ \text{Figure: dual cycle diagram} \]

- indicator diagram
- theoretical model for analysis

Supercharging or turbocharging

- inlet pressure increased + increased mass of air; need more fuel; power ~ mass
- pressure + => increased loads
- mass further increased by cooler
- normally driven by exhaust turbine

See Woud 7.6
Designation of diesels (somewhat arbitrary)

<table>
<thead>
<tr>
<th>RPM</th>
<th>slow speed</th>
<th>medium speed</th>
<th>high speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 -250 rpm</td>
<td>350-1200 rpm</td>
<td>&gt;1200 rpm A.D.C.</td>
<td></td>
</tr>
<tr>
<td>76-250 rpm (2 stroke)</td>
<td>400-1000 rpm</td>
<td>750-1000 rpm Manbw.com marine engine programmes</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RPM</th>
<th>slow speed</th>
<th>medium speed</th>
<th>high speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>piston ft/min</td>
<td>1200-1600</td>
<td>1200-1800</td>
<td>1600-2000</td>
</tr>
<tr>
<td>speed m/sec</td>
<td>1200-1800</td>
<td>1200-1800</td>
<td>1600-2000</td>
</tr>
<tr>
<td>bar</td>
<td>1200-1800</td>
<td>1200-1800</td>
<td>1600-2000</td>
</tr>
<tr>
<td>6.1 - 8.1</td>
<td>6.1 - 9.1</td>
<td>8.1 - 10.2</td>
<td></td>
</tr>
<tr>
<td>190-300</td>
<td>190-350</td>
<td>100-300</td>
<td></td>
</tr>
<tr>
<td>13-21</td>
<td>13-24</td>
<td>7 - 21</td>
<td></td>
</tr>
<tr>
<td>13-21</td>
<td>13-24</td>
<td>7 - 21</td>
<td></td>
</tr>
</tbody>
</table>

2 stroke; 4 stroke

turbocharged vs. normal aspiration

fuel grade

1.3.1 Slow-, Medium-, High-Speed Diesel Engines

*Slow-Speed Engines* means diesel engines having a rated speed of less than 400 rpm.

*Medium Speed Engines* diesel engines having a rated speed of 400 rpm or more; but, approximately less than 1200 rpm.

*High-Speed Engines* means diesel engines having a rated speed of approximately 1200 rpm or more.

**Operating Characteristics**

\[
\text{MCR} = \text{maximum\_continuous\_rating} \quad \text{continuous\_service\_rating} = \text{MCR} \times (1 - \text{engine\_margin\%})
\]

\[
\text{mean\_indicated\_pressure} \times \eta_{\text{mechanical}} = \text{mean\_effective\_pressure} \quad \text{MIP} \times \eta_{\text{mech}} = \text{MEP}
\]

\[
\text{MEP} \times \text{rpm} = \text{brake\_power\_output} \quad \text{rated\_MEP\_rated\_rpm} = \text{MCR} \quad \text{MEP limits engine power}
\]
Engine Layout (ship power with engine design limits, MCR minimum determined data sourced from text example 11.7 page 462. Ship has attached generator. Design condition (propulsion specified (and power) - plotted, plus generator - plotted) shown with two additional off design plots:
  light load (lower resistance with half load on generator)
  heavy - weather, heavily fouled etc

Engine margin (EM) = 0.85, engine is limited to 103% rpm at MCR and constant Bmep below MCR.

This is a busy curve and will be explained in lecture.
Improvements to Diesels

- fuel efficiency increased 15-25% over two decades
- use of lower quality fuel

waste heat recovery

energy balance typical large 2 stroke diesel

<table>
<thead>
<tr>
<th>Input:</th>
<th>100 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outputs:</td>
<td></td>
</tr>
<tr>
<td>$W_x$</td>
<td>45 %</td>
</tr>
<tr>
<td>exhaust @ 560 K cooled to 25 C</td>
<td>29 %</td>
</tr>
<tr>
<td>charge air cooler cooled to 450 -&gt; 30 C</td>
<td>14 %</td>
</tr>
<tr>
<td>cooling 360 K -&gt; 340 K</td>
<td>11 %</td>
</tr>
<tr>
<td>oil cooler</td>
<td>~ 1 %</td>
</tr>
</tbody>
</table>

$\text{mf}_{\text{dot}} \cdot \text{LHV}$

$0.45 \cdot \text{mf}_{\text{dot}} \cdot \text{LHV}$

$m_{\text{prod\_dot}} c_{\text{prod}} (560 - 298.15)$

$m_{\text{a\_dot}} c_{\text{air}} (450 - 303.15)$

$m_{\text{water\_dot}} c_{\text{water}} (360 - 340)$
Diesel Engine Pollution Control


Typical engine:

<table>
<thead>
<tr>
<th>Volume</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>air (7.5 kg/kW*hr)</td>
<td>71 % N</td>
</tr>
<tr>
<td></td>
<td>19 % O2</td>
</tr>
<tr>
<td>fuel (180 gm/kW*hr)</td>
<td>97 % H</td>
</tr>
<tr>
<td></td>
<td>3 %</td>
</tr>
<tr>
<td>lube oil (0.8 gm/kW*hr)</td>
<td>97.5 %</td>
</tr>
<tr>
<td></td>
<td>Ca=calcium 1.5 % Ca 1 % S</td>
</tr>
</tbody>
</table>

18 cyl 4 stroke 26,000 hp @ 500 rpm

=> 82 tonnes (1000 kg) fuel per day
=> 3400 tonnes induced air
=> 1/2 tonne lube oil

=> ~ 3500 tonnes combustion prod

![Combustion gases and induced air diagram](image)

Fig. 3 Specific mass flow rates of a large medium-speed diesel engine

Combustion products

99.7 % N₂, O₂, CO₂, H₂O typical:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂</td>
<td>74.3 %</td>
</tr>
<tr>
<td>O₂</td>
<td>11.3 %</td>
</tr>
<tr>
<td>CO₂</td>
<td>6 %</td>
</tr>
<tr>
<td>H₂O</td>
<td>8.1 %</td>
</tr>
</tbody>
</table>

0.3 % pollutants: NOₓ, SOₓ, HC, CO, particles

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NOₓ</td>
<td>17</td>
</tr>
<tr>
<td>SOₓ</td>
<td>10</td>
</tr>
<tr>
<td>HC</td>
<td>1</td>
</tr>
<tr>
<td>CO</td>
<td>0.8</td>
</tr>
<tr>
<td>particles</td>
<td>0.25</td>
</tr>
</tbody>
</table>

CO₂ => greenhouse effect, coastal areas may require low sulphur fuel
most serious NOₓ
**NO\textsubscript{x} Control**

- strongly dependent on peak temperature during burning

Control

1) reduce amounts formed
   a. reduce maximum pressure by delaying injection
   b. recirculating part of exhaust
   c. reduce amount of scavenging air
   d. spray water during combustion
   e. use emulsion of oil and water - reduces NO\textsubscript{x} by \sim 25\%

2) remove from exhaust
   - catalytic converters not practical - too much air
     a. Selective Catalytic Reduction (SCTR)
        mix exhaust gases (300-400°C) with correct amount of amonia - pass through catalyst

\[
\begin{align*}
4 \cdot \text{NO} + 4 \cdot \text{NH}_3 + \text{O}_2 & = 4 \text{N}_2 + 6 \text{H}_2\text{O} \\
6 \cdot \text{NO}_2 + 8 \cdot \text{NH}_3 & = 7 \text{N}_2 + 12 \text{H}_2\text{O}
\end{align*}
\]

urea - organic compoound of Carbon, N\textsubscript{2}, O\textsubscript{2}, & H\textsubscript{2} used more widely

90 % reduction can be achieved

In use today - typically during entry to port

see ASNE [presentation re: emissions](http://www.asne.org/)

and ... **New rules to reduce emissions from ships enter into force**


The Annex VI regulations set limits on sulphur oxide (SO\textsubscript{X}) and nitrogen oxide (NO\textsubscript{X}) emissions from ship exhausts and prohibit deliberate emissions of ozone-depleting substances

and ... **Shipping Emissions Abatement and Training (SEAaT) paper**

[http://www.seaat.org/media/EmissionControlv052.doc](http://www.seaat.org/media/EmissionControlv052.doc) on emissions

This international legislation covering all shipping activity establishes Sulphur Emissions Control Areas (SECAs) which are geographically defined areas where ships must limit their SO\textsubscript{x} emissions

The first of these, the Baltic Sea, will come into effect on May 20, 2006, with the North Sea and English Channel becoming SECAs in 2007

Shipping Emissions Abatement and Training (SEAaT)

SEAaT is a cross-industry, unique, pro-active and self funding group, whose mission is to encourage and facilitate efficient reduction of harmful emissions to air from shipping

N.B. these links do not work in the pdf format. It is necessary that the linked files be located and connected - they can be made to work but it take some time. the ASNE presentation, PA6B chart and Marine Technology paper (documents) are on the web. The other links are on the web