A Modern Diesel Engine Operated with Pure Rapeseed Oil; Effects on the Emissions

Annett Wollmann#
Bernd Benker#
Stephan Rudolph*

#CUTEC Institut GmbH Clausthal-Zellerfeld
*eoil automotive & technologies GmbH, Alfeld Germany
Motivation and scope of examination
Technical equipment and fuel properties
Results
  Gaseous and particulate emissions
  PAH sampling
summary
motivation

- Due to present oil prices and tax policy the use of rapeseed oil as a fuel is very interesting, e.g. for agriculture.

- Can the engines fulfil existing emission limits with rapeseed oil?

- What happens to the unlimited emissions?
scope of the examination

- The data were obtained as part of a preliminary examination of a pre-treatment system.
- The data indicate how a highly developed diesel engine reacts to a rather different fuel.
- It is not intended to show compliance with legal limits.
Technical equipment and fuel properties
VW TDI-PUI 4 cylinder 1.9 L, 85 kW, 285 Nm@1900 rpm

Engine
Physical properties of diesel fuel and pure rapeseed oil

<table>
<thead>
<tr>
<th>parameter</th>
<th>diesel fuel (DIN EN 590)</th>
<th>rapeseed oil ((^(*)))</th>
</tr>
</thead>
<tbody>
<tr>
<td>calorific value [MJ/kg]</td>
<td>46</td>
<td>39</td>
</tr>
<tr>
<td>Cetane number</td>
<td>51</td>
<td>39</td>
</tr>
<tr>
<td>Density (15°C) [kg/m(^3)]</td>
<td>0.83</td>
<td>0.92</td>
</tr>
<tr>
<td>Viscosity (40°C) [mm(^2)/s]</td>
<td>4</td>
<td>75</td>
</tr>
</tbody>
</table>

used rapeseed oil according to the Weihenstephan standard and DIN 5160, resp.

*source: Birkner, M, Diss. Kaiserslautern 1995
Scheme of the fuel switching

Diesel fuel

Inlet valve

Engine

physical pre-treatment

rapeseed oil

T_{oil} = 70°C - 110 °C

reflow valve
Gaseous and particulate emissions
Stationary engine settings and characteristic parameters

<table>
<thead>
<tr>
<th>speed [rpm]</th>
<th>torque [Nm]</th>
<th>power [kW]</th>
<th>BMEP [bar]</th>
<th>$T_{\text{diesel}}$ [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1400</td>
<td>25</td>
<td>3.7</td>
<td>1.6</td>
<td>200</td>
</tr>
<tr>
<td>1600</td>
<td>50</td>
<td>8.4</td>
<td>3.2</td>
<td>270</td>
</tr>
<tr>
<td>1800</td>
<td>80</td>
<td>15</td>
<td>5</td>
<td>330</td>
</tr>
<tr>
<td>2000</td>
<td>186</td>
<td>39</td>
<td>12</td>
<td>420</td>
</tr>
</tbody>
</table>
measured gas concentration with rapeseed oil: diesel as reference

**1400/25**

\[ T_{\text{exhaust}} = 200^\circ C \]

**1600/50**

\[ T_{\text{exhaust}} = 270^\circ C \]

**1800/80**

\[ T_{\text{exhaust}} = 325^\circ C \]

**2000/186**

\[ T_{\text{exhaust}} = 415^\circ C \]
Total soot mass flow
diesel and rapeseed oil

soot mass flow [mg/m³]

standard deviation of 4 measurements

- rapeseed oil
- diesel

<table>
<thead>
<tr>
<th>Nm</th>
<th>rpm</th>
<th>soot mass flow [mg/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>1400</td>
<td>35</td>
</tr>
<tr>
<td>50</td>
<td>1600</td>
<td>15</td>
</tr>
<tr>
<td>80</td>
<td>1800</td>
<td>10</td>
</tr>
<tr>
<td>186</td>
<td>2000</td>
<td>5</td>
</tr>
</tbody>
</table>
Carbon mass flow classified in SOF and EC

stdv.: standard deviation

mass flow [mg/m^3]

SOF
elemental carbon (EC)

rapeseed oil
diesel

stdv. SOF
stdv. EC

25 50 80 186

25 50 80 186

1400 1600 1800 2000

1400 1600 1800 2000

0 5 10 15 20 25 30 35 40

stdv.: standard deviation
Particle number distribution for different fuels and engine operation points

![Graphs showing particle number distribution for different fuels and engine operation points.](image-url)
PAH sampling and results
PAH sampling system

- Coil condensers
- PU-plugs
- Volatile fraction
- Filter
- Flow meter
- Condensed liquid fraction + soot particles
Procedure of PAH sampling and PAH analysing according to VDI Richtline 3872

- isokinetic sampling
- rinse the sampling system with Acetone
- evaporation of Acetone and change of solvent
- soxhlet extraction
- drying water residua with sodium sulphate
- filtration of the soot particles
- concentration and clean up of the samples
- measurement by HPLC
PAH species detected into the gas phase for different engine operating points (diesel fuel)
PAH species detected into the gas phase for different engine operating points (rapeseed oil)

![Bar chart showing PAH concentrations for different operating points and rapeseed oil as oil.]

- Naphtalene
- Acenaphthene
- Fluorene
- Phenanthrene
- Anthracene
- Fluoranthene
- Pyrene
- Benzo[a]anthracene
- Chrysene
- Benzo[b]fluoranthene
- Benzo[k]fluoranthene
- Benzo[a]pyrene
- Dibenz[a,h]anthracene
- Benzo[g,h,i]perylene
- Ibeno[1,2,3-c,d]perylene

Concentration in [µg/m³]:
- 1400/25
- 1600/50
- 1800/80
- 2000/186
Sum of detected PAH for different engine operating points

\[ \Sigma_{\text{Total}} = 526 \, \mu g/m^3 \]

rapeseed oil

\[ \Sigma_{\text{Total}} \Sigma = 515 \, \mu g/m^3 \]

diesel
detected PAH species and their ring numbers

<table>
<thead>
<tr>
<th>species</th>
<th>Number of rings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naphtalene</td>
<td>2</td>
</tr>
<tr>
<td>Acenaphthene, Fluorene, Phenanthrene, Anthracene</td>
<td>3</td>
</tr>
<tr>
<td>Fluoranthene, Pyrene, Benz[a]anthracene, Chrysene</td>
<td>4</td>
</tr>
<tr>
<td>Benzo[b]fluoranthene, Benzo[k]fluoranthene, Benzo[a]pyrene, Dibenz[a,h]anthracene</td>
<td>5</td>
</tr>
<tr>
<td>Benzo[g,h,i]perylene</td>
<td>6</td>
</tr>
<tr>
<td>Ideno[1,2,3-c,d]perylene</td>
<td>7</td>
</tr>
</tbody>
</table>
Sum of PAH divided into rings for both fuels

<table>
<thead>
<tr>
<th>PAH</th>
<th>Σ PAH diesel [µg/m³]</th>
<th>Σ PAH rapeseed oil [µg/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-ring*</td>
<td>456</td>
<td>384</td>
</tr>
<tr>
<td>3-ring+</td>
<td>54</td>
<td>113</td>
</tr>
<tr>
<td>4-ring+</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>5-ring+</td>
<td>0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>6-ring*</td>
<td>0.002</td>
<td>0.4</td>
</tr>
<tr>
<td>7-ring*</td>
<td>0.004</td>
<td>0.09</td>
</tr>
</tbody>
</table>

*one species  
+ four species

*not valid values*
Database only 4 stationary points

- **Expectation:**
  - Physical properties of rapeseed oil differ in most cases by 10 to 20 percent from diesel.
  - Viscosity is higher by a factor of 20.
    - different flow regime and spray formation
    - different combustion
Observed (with pre-treatment):
- Gaseous emissions in the range 0.25 up to 2.5 of diesel
- SOF lightly higher but lower amount of elemental carbon
- PAH average correspond with diesel

Further research
- NEUDC test cycle
- Effects on after-treatment system
Thank you for your attention!

Annett Wollmann#
Bernd Benker#
Stephan Rudolph*

#CUTEC Institut GmbH Clausthal-Zellerfeld
*eoil automotive & technologies GmbH, Alfeld Germany

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