Emissions of a 4-Stroke Scooter 50cc with Ethanol Blends

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Sept. 2008
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1. SUMMARY

Exhaust emissions measurements of 4-Stroke scooter with gasoline-ethanol blend fuels have been performed in the present work according to the measuring procedures, which were established in the previous research in the Swiss 2-wheelers programs.

The investigated fuels contained ethanol (E), or hydrous ethanol (EH) in the portion of 10, 15 and 20% by volume.

The investigated scooter represented a 4-stroke technology with carburettor and without catalyst.

Since there is a special concern about the particle emissions of the small engines, the particle mass and nanoparticle measurements were systematically performed.

The nanoparticulate emissions were measured by means of SMPS (CPC) and NanoMet *).

The most important results are:

- addition of ethanol to the gasoline provokes a leaner tuning of the engine operation,
- influence of the leaning effect by means of ethanol depends very much on the basic original tuning,
- the operation of 4-S scooter was without problems, the leaning by ethanol caused: lowering of CO, HC & fuel consumption, increase of NOx, no effect on PM and reduction of nanoparticles count concentrations especially at transient operation,
- there are no significant differences of results between the blends with pure ethanol (E), or hydrous ethanol (EH).

The present investigations did not concern the durability of parts exposed to the chemical influences of ethanol. Also the cold startability, particularly in extreme conditions and the lube oil dilution were not addressed.

2. INTRODUCTION AND OBJECTIVES

Laboratories for IC-Engines and Exhaust Emission Control (AFHB) of the University of Applied Sciences, Biel, Switzerland are involved since 2000 in several research projects about emission factors and possibilities of reduction of (nano)particle emissions of 2-wheelers. A special attention was paid to the 2-stroke scooters, which have much higher particulate emission, than the 4-strokers.

In an international network project several topics were investigated, [1, 2, 3, 4, 5, 6] and the combinations of technical measures to lower the particle emissions of scooters confirmed the expected effects and showed considerable reduction potentials.

These technical measures were:
- Higher tier lube oils
- Lower oil dosing
- Active oxidation catalyst
- Supplementary filtration & oxidation devise (WFC).
- Special fuel.

*) Nanoparticulates measurement methods see Annex, chap. 10, abbreviations see chap. 11
The special fuel used in those tests was Alkylat Aspen gasoline with a uniform HC-matrix (mostly isooctane) and no aromats.

The idea of using ethanol blends was known, but not applied before in the research of scooters.

Ethanol is used for passenger cars since a long date (Brazil). In the last years, due to the increasing prices of crude oil, there is a growing interest for ethanol. Several countries have objectives to substitute a part of the energy of traffic by the renewable energy. On the other hand there are interferences with the prices of food in certain regions.

Some manufacturers offer FFV (flex fuel vehicles), which is particularly challenging for high ethanol content (E85) in countries, like Sweden with colder climatic conditions.

There are several technical problems to resolve to guarantee the long live operation of the engine with E85, [7, 8, 9, 10, 11]:
- adaptation of engine construction in regard to a changed thermal stress of combustion chamber parts,
- adaptation of spark plugs and injectors,
- fuel injection system,
- wear of valves, pistons, rings and liners,
- polymer materials and sealings,
- crankcase ventilation and oil dilution,
- software of engine ECU, new or flexible parameter settings.

Small portions of ethanol E5 are generally accepted for the vehicle fleets without any adaptations.

Very useful information about handling of gasoline-ethanol blends up to 10% v/v is given in the CONCAWE report No. 3/08, see annex A1, [12].

The objectives of the present work are to investigate the limited and the unregulated emissions of a typical 4-stroke scooter with different ethanol blend fuels. There will be also comparison of two different ethanol fuels: pure ethanol (E) and hydrous ethanol (EH) which contains 3.9% water and is denatured with 1.5% gasoline. The vehicle will be with carburetor and without catalyst, which represents the most frequent technology in Eastern Asia and offers the information of engine-out emissions.

During the test a systematical analysis of particle mass (PM) and nanoparticles counts (NP) will be performed.

3. INVESTIGATED SCOOTER

The research of emissions was performed on the 4-stroke scooter Honda Zoomer. The vehicle uses simple conventional carburettors with a cable-controlled throttle body and needle. Fig. 1 shows the vehicle and Table 1 represents the most important data.

3.1. Fuels

As a basic fuel a standard gasoline, lead-free, RON 95, Swiss market quality was used. At the beginning of network projects about the particle emissions of 2-S scooters a big charge of this gasoline was purchased to perform all research with the same fuel. The sulphur content of this gasoline was analysed and no sulphur was found (detection limit < 2 ppm).
Table 1: Data of the investigated scooter.

The investigated fuel blends contained ethanol (E), or hydrous ethanol (EH) in the portions of 10, 15 and 20% by volume.

Pure ethanol is C₂H₅OH and the hydrous ethanol contains: 94.56% vol ethanol, 3.94% vol water and 1.5% gasoline.

The most important parameters of the used fuels are summarized in the Table 2.

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Ethanol C₂H₅OH</th>
<th>E10</th>
<th>E15</th>
<th>E20</th>
<th>EH10</th>
<th>EH15</th>
<th>EH20</th>
</tr>
</thead>
<tbody>
<tr>
<td>density [g/cm³]</td>
<td>0.737</td>
<td>0.789</td>
<td>0.742</td>
<td>0.745</td>
<td>0.747</td>
<td>0.743</td>
<td>0.746</td>
<td>0.749</td>
</tr>
<tr>
<td>stoichiometric air / fuel ratio [-]</td>
<td>14.6</td>
<td>9.0</td>
<td>14.00</td>
<td>13.71</td>
<td>13.42</td>
<td>13.96</td>
<td>13.64</td>
<td>13.33</td>
</tr>
<tr>
<td>lower calorific value [MJ/kg]</td>
<td>43.0</td>
<td>26.8</td>
<td>41.3</td>
<td>40.4</td>
<td>39.6</td>
<td>41.1</td>
<td>40.2</td>
<td>39.3</td>
</tr>
<tr>
<td>* boiling point [°C]</td>
<td>30 - 200</td>
<td>78.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* Research Octane Nbr. [-]</td>
<td>95</td>
<td>111</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* latent heat of evaporation [kJ/kg]</td>
<td>420</td>
<td>845</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Parameters of used fuels.

*) according to [9]

It can be seen, that with increasing the ethanol ratio the stoichiometric air requirement of the blendfuel decreases. That means by an approximately equal air flow rate the air-fuel-mixture will be leaner. Furthermore there is less heat value in ethanol. The fix boiling point and the high latent heat of evaporation of ethanol may cause serious problems of cold starting.
3.2. Lube oils

The used lube oils were according to the requirements of vehicle manufacturers:
- for Honda Zoomer – Motorex oil 10W-40, API SG.

4. MEASURING APPARATUS

4.1. Chassis dynamometer

- roller dynamometer: Schenk 500 G5 60
- driver conductor system: Zöllner FLG 2 Typ. RP 0927-3d, Progr. Version 1.4
- CVS dilution system: Horiba CVS-9500T with Roots blower
- air conditioning in the hall (intake- and dilution air) automatic
  temperature: 20 – 30 °C
  humidity: 5.5 – 12.2 g/kg

The measuring set-up on a chassis dynamometer is represented in Fig. 2.

Fig. 2: Sampling and measuring set-up for emission measurements.
4.2. Test equipment for regulated exhaust gas emissions

This equipment fulfills the requirements of the Swiss and European exhaust gas legislation – 70/220/EWG; 98/69/EG; 2003/76; 97/24 - chap.5/2002/51.

- gaseous components:
  - exhaust gas measuring system Horiba MEXA-9400H
  - CO, CO₂ ... infrared analysers (IR)
  - HC(IR)... only for idling
  - HC(FID)... flame ionisation detector for total hydrocarbons
  - NO/NOₓ... chemoluminescence analyser (CLA)
  - O₂... Magnos
  - The dilution ratio DF in the CVS-dilution tunnel is variable and can be controlled by means of the CO₂-analysis.

- measurement of the particulate mass (PM):
  - sampling from the full-flow dilution tunnel CVS
  - filter temperature ≤ 52 °C
  - conditioning of filter: 8 ÷ 24 h (20°C, rel. humidity 50%)
  - scale: Mettler, accuracy ± 1 μg

4.3. Particle size analysis

In addition to the gravimetric measurement of particulate mass, the particle size and counts distributions were analysed with following apparatus:

- SMPS – Scanning Mobility Particle Sizer, TSI (DMA TSI 3071, CPC TSI 3025 A)
- NanoMet – System consisting of:
  - PAS – Photoelectric Aerosol Sensor (Eco Chem PAS 2000)
  - DC – Diffusion Charging Sensor (Matter Eng. LQ1-DC)
  - MD19 tunable minidiluter (Matter Eng. MD19-2E)

A detailed description of those systems is given in annex A2. The sampling and measuring set-up during the tests shows Fig. 2.

The nanoparticulates measurements were performed at stationary and at transient engine operation.

5. RESEARCH PROCEDURES

The investigations with each variant of fuel were performed according to the same procedure:

- 5 min conditioning at full load
- legal test cycle - for Honda Zoomer unlimited speed ECE 40,
- constant speed 40 km/h
  - first 5 min conditioning
  - further 10 min measurements of PSD’s with SMPS
  - last 3 min → last scan SMPS.

The driving resistances of the test bench were set according to the Swiss exhaust gas legislation, see annex A3.
The driving cycles are represented in Fig. 3.

![Driving cycle ECE 40](image)

**Fig. 3:** Driving cycle used for the investigated vehicle.

The driving cycle, which was really performed on the chassis dynamometer was measured and the characteristic parameters \( v_m, a_m, \) etc.) of this cycle were evaluated. This allows to consider the differences between the desired (conducting) and the realised (real) driving cycle. These differences can be particularly significant for the low-power vehicles (here with fuel with lower heat values), which may not always follow the conducting (desired) driving cycle.

The characteristic parameters of the realised driving cycle of all measuring series are given in annexes A4 – Honda Zoomer (ECE 40).

### 6. RESULTS

The results are represented graphically in the figures, see chap. 9 and are tabulated in annexes A5 & A6.

In following the results are shortly discussed according to the performed tests-blocs and in each bloc in the sequence of testing (i.e. first driving cycles and after constant speed).

#### 6.1. Honda Zoomer 4-S, Figures 4-11

Before and after tests the mixture tuning was controlled at idling (with SAS). There were following values:

<table>
<thead>
<tr>
<th></th>
<th>CO idl.</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>before tests</td>
<td>2.5 %</td>
<td>2020 rpm</td>
</tr>
<tr>
<td>after tests</td>
<td>3.1 %</td>
<td>1950 rpm</td>
</tr>
</tbody>
</table>

**Fig. 4** shows the plots of exhaust gas temperature – measured 30 cm after tailpipe – in the driving cycles with all fuels. There is a general tendency of cooling down after previous conditioning (5 min full load) and there are principally no differences between the fuels, except of starting with gasoline (BF) at a slightly higher temperature (higher temperatures after conditioning).

**Fig. 5** shows the time-plots of CPC summary particle counts (10-400 nm) in the driving cycles with all fuels. The numeric average values of last 4 cycles are given. With hydrous ethanol there are slightly lower NP count concentrations, than with pure ethanol. All blended
fuels yield lower emissions, as gasoline. It has to be remarked, that E10 has at the beginning of the measuring period exceptionally high emissions (discussion later).

Fig. 6 confirms the findings of the previous Fig. 5 with NanoMet signals: there is a lower emission level with blends, than with gasoline, but E10 shows also too high emission values at the beginning of measurements. The solid particles are visible as PAS-signal.

Fig. 7 represents the SMPS PSD-spectra and integral NP-emissions with all fuels at constant speed v = 40 km/h. The measurements with SMPS were started after the driving cycles and after 5 min conditioning at the same constant speed (see Procedures, chap. 5).

There are again two types of representation: with average of 3 samples (Fig. 7-1) and with the last 3rd sample only (Fig. 7-2). Both of them show higher emission values for the first two samples: E10 & E15 → the sequence of representation of the measuring series (see bars at bottom of figures) responds to the sequence of performing the tests. It becomes clear, that the higher emissions and the higher NP count concentrations in nuclei mode with E10 and E15 is caused by other effects, than the fuels only.

Fig. 8 shows all PSD’s as average of 3 scans (Fig. 8-1), or the last scan only (Fig. 8-2). The consecutive increase of nuclei mode concentrations with E15 is particularly well visible. The tailpipe temperature during this v = const measurements increases from approx. 80-90°C at the end of driving cycles (Fig. 4) to approx. 132 – 138°C at the end of v = const period (Fig. 11).

Fig. 9 show the time plots of NanoMet signals in the measuring period of 10 min. For further comparisons these signals will be represented as integral averages in this time period.

Fig. 10 resumes the results. The gaseous components indicate the leaner tuning with increasing share of alcohol – reduction of CO & HC, increase of NOx.

The fuel consumption is reduced due to the leaning and increase of the effective engine efficiency.

Regarding the PM- and NP-emissions the cases E10 and E15 have to be excluded, since there are “washing effects” and artefacts responsible for the deviating results (repetitions and confirmation in following section).

Apart from this fact it can be stated, that:

- there is no influence of alcohol-fuels on PM,
- ethanol blend fuels help to reduce the NP-emissions especially at transient operation.

Fig. 11 there is a little impact of the used fuels with ethanol on the maximum speed. With hydrous ethanol there is almost no impact.

The application of fuels with a lower heat value and the shift to leaner air/fuel ratio do not reduce the maximum power very much, because there is an effect of improved engine efficiency.
**6.2. Repetitions Honda Zoomer 4-S, Figures 12-17**

To confirm the artefacts observed with E10 and E15 it was decided to repeat some of the measuring series, but in another sequence. The chosen series and sequence are: EH10, E10, E20 and BF.

Before the beginning of these tests with blend fuels the scooter was operated with gasoline (BF) after the end of previous series with ethanol.

Fig. 12 shows the CPC traces of the first 4 cycles and the average values of the last 4 cycles.

Fig. 13 shows the DC plots of all 6 cycles.
At the beginning with EH10 rep. there is an emission peak, which is a sign of memory effects from the previous operation with gasoline. Also the average values of the last 4 cycles are for EH10 rep. clearly higher, than for EH10 (original).

Fig. 14 shows the SMPS PSD’s and the integral average values of DC and SMPS NP count concentrations of the original and repeated series. It is confirmed, that the repetition results E10 rep. are in line with the other results and do not show the peak values, as at the beginning of tests (E10).

The different representations of PSD’s in logarithmic and in linear scale (Fig. 14-2 & Fig. 14-3) have to show the optical differences.

Regarding the comparison of all SMPS PSD-spectra in Fig. 15 the different scales of the ordinate in some cases have to be considered. The comparison of E10 and E10 rep. shows the maximal difference of NP count concentrations, but also all other repetitions yield lower values, than the original measurements.

Comparisons of DC-signals at constant speed, Fig. 16, show again the particular difference between E10 and E10 rep. (Fig. 16-3).

The summarizing results in Fig. 17 show repeatability of all parameters between the original test and the repetitions test. Looking back to the Fig. 10 which represents the comparison of all investigated fuels it can be stated, that for some parameters, like fuel consumption and particle mass PM the differences measured with different fuels are in the range of measuring dispersion.

**7. CONCLUSIONS**

After the research of emissions of a 4-S scooter (50 cc, carburettor, no catalyst) following conclusions can be pointed out:

**4-S (Honda Zoomer)**

There was a good drivability of the investigated scooter with all ethanol blends.

The limited gaseous components indicate the leaner tuning with increasing share of alcohol – reduction of CO & HC, increase of NOx.
The fuel consumption is reduced due to the leaning and increase of the effective engine efficiency. There is no remarkable reduction of maximum power in the investigated domain of equivalence ratio.

Regarding the PM- and NP-emissions it can be stated, that:

- there is no influence of alcohol fuels on PM,
- the NP-emissions at transient operation are much higher, as at steady state operation,
- ethanol blend fuels help to reduce the NP-emissions especially at transient operation. That means, that alcohol helps to better oxidize the particles originating from the lube oil.

At the beginning of working period with ethanol fuels there is a release (“washing out”) of residues from the previous operation with gasoline. These residues containing sulfates (from lube oil) offer precursors for the spontaneous condensates in the nuclei mode (nano range), which is sensitively indicated by the NP measuring methods and is also visible in the PM emissions.

From the present results it can be concluded, that the basic tuning of the engine – not too lean – decides about the influence of leaning by means of ethanol blends. The 4-stroker can be deteriorated by the irregularities of combustion, if the basic tuning would be too lean (this can be the case of a modern 4-stokers).

Summarizing: the success of ethanol blend fuels in a 4-S engine depends on the basic tuning of the engine (air-fuel-ratio) and the ethanol content.

There are no significant differences of results between the blends with pure ethanol (E), or hydrous ethanol (EH).

The present investigations did not concern the durability of parts exposed to the chemical influences of ethanol. Also the cold startability, particularly in extreme conditions and the lube oil dilution were not addressed.

8. REFERENCES


9. LIST OF FIGURES

Fig. 1 Investigated scooters (in text)
Fig. 2 Sampling and measuring set-up (in text)
Fig. 3 Driving cycles used for the investigated vehicles (in text)

Honds Zoomer 4-S

Fig. 4 Tailpipe temperature during the driving cycles
Fig. 5 CPC particle counts during the driving cycles
Fig. 6 NanoMet-signals during the driving cycles
Fig. 7 SMPS PSD-spectra & integral NP-emissions with all fuels
Fig. 8 Comparison of all SMPS PSD-spectra
Fig. 9 NanoMet -signals at constant speed v = 40 km/h
Fig. 10 Limited and unlimited emissions with all fuels
Fig. 11 Max. tailpipe temperatures at 40 km/h and max. speeds

Repetitions Honda Zoomer 4-S

Fig. 12 CPC particle counts during the driving cycles
Fig. 13 NanoMet-signals during the driving cycles
Fig. 14 SMPS PSD-spectra & integral NP-emissions with EH10, E10, E20 & BF
Fig. 15 Comparison of all SMPS PSD-spectra
Fig. 16 NanoMet -signals at constant speed v = 40 km/h
Fig. 17 Limited and unlimited emissions with all fuels
10. ANNEXE

A1 Guidelines for blending and handling motor gasoline containing ethanol, CONCAWE report no 3/08.
A2 Particle size analysis (detailed description)
A3 Road resistance for investigated scooters
A4 Characteristic parameters of the ECE 40 driving cycles for Honda Zoomer
A5 Emission factors, Honda Zoomer
A6 Emission factors, repetitions, Honda Zoomer

11. ABBREVIATIONS

AFHB Abgasprüfstelle der Fachhochschule, Biel CH
(Lab. For Exhaust Gas Control, Univ. of Appl. Sciences, Biel-Bienne, CH)
BAFU Bundesamt für Umwelt (Swiss EPA)
BF gasoline lead-free, RON 95
C Carburetor
Carb Carburetor
CMD count median diameter
cond conducting driving cycle
CPC condensation particle counter
CVS constant volume sampling
DC diffusion charging sensor
DF dilution factor
DI direction injection
DMA differential mobility analyser
E pure ethanol
EC elemental carbon
EH hydrous ethanol
FHB Fachhochschule Biel
ME Matter Engineering, CH
NanoMet minidiluter + PAS + DC
NP nanoparticulates
OC organic carbon
PAH polycyclic aromatic hydrocarbons
PAS photoelectric aerosol sensor
PM particulate matter, particulate mass
PSD particles size distribution
real realized driving cycle
SAS secondary air system
SMPS scanning mobility particles sizer
SOF soluble organic fraction
TC thermoconditioner, total carbon
TP tailpipe
TPN total particle number
WFC wiremesh filter catalyst
WMTC Worldwide Motorcycle Test Cycle