Emissions of 2-Stroke Small Motorbike
Kreidler 50cc with Ethanol Blends

Ordered by:
Technical University of Delft, Faculty Applied Sciences,
Julianalaan 136, NL-2628 BL Delft, Netherlands

HE Blends B.V., Catharinastraat 21 F, NL-4811 XD Breda, Netherlands

Report:
J. Czerwinski, Dipl. Ing. Dr. techn.
P. Comte, Dipl. Ing. ETS
P. Wili
UNIVERSITY OF APPLIED SCIENCES
LAB. FOR IC-ENGINES & EXHAUST EMISSION CONTROL, AFHB
Gwerdtstrasse 5, CH-2560 Nidau / Switzerland

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1. SUMMARY

Exhaust emissions measurements of a small motorbike Kreidler 2-S, 50cc 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 Scooter Network.

The investigated fuels contained ethanol (E), or hydrous ethanol (EH) in the portion of 5, 10 and 15% by volume.

The investigated motorbike represented an older (1976) 2-stroke technology with carburettor, without catalyst and with blending the lube oil to the fuel.

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,
- for the investigated older 2-S motorbike the rich basic tuning enabled a satisfactory driveability with E15 and EH15,
- the leaning effect of ethanol blend fuels enabled reduction of CO, HC, particle mass and nanoparticles,
- there are little differences of results between the blends with pure ethanol (E), or hydrous ethanol (EH), nevertheless in some cases the hydrous ethanol shows further advantages concerning emissions and fuels consumption.

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.

*) Nanoparticulates measurement methods see Annex, chap. 10, abbreviations see chap. 11
2. INTRODUCTION

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, 14] 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.

The special fuel used in those tests was Alkylate 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 4-S car 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 older type 2-stroke motorbike 50 cc 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 denaturised with 1.5% gasoline. The vehicle is with carburator and without catalyst, which represents the most frequent technology in Eastern Asia and offers the information of engine-out emissions. The lubrication is performed by blending the lube oil (2%) to the fuel.

During the test a systematical analysis of particle mass (PM) and nanoparticles counts (NP) will be performed.
This work is an extention of the investigations from [13], where the hydrous ethanol was investigated only on a newer type 2-S scooter with leaner tuning and with lube oil injection in the engine intake air.

3. INVESTIGATED 2-WHEELER

The research of emissions was performed with an older type 2-stroke motorbike Kreidler Florett RS (lube oil directly mixed with the fuel).

Fig. 1 shows the vehicle and Table 1 represents the most important data.

![Fig. 1: Investigated small motorbike Kreidler Florett 2-S 50cc](image)

<table>
<thead>
<tr>
<th></th>
<th>Kreidler</th>
</tr>
</thead>
<tbody>
<tr>
<td>vehicle identification</td>
<td>K54/511 Florett RS</td>
</tr>
<tr>
<td>model year</td>
<td>1976</td>
</tr>
<tr>
<td>transmission no. of gears</td>
<td>m5</td>
</tr>
<tr>
<td>km at beginning</td>
<td>8316</td>
</tr>
<tr>
<td>engine:</td>
<td></td>
</tr>
<tr>
<td>type</td>
<td>2 stroke</td>
</tr>
<tr>
<td>displacement cm³</td>
<td>50</td>
</tr>
<tr>
<td>number of cylinders</td>
<td>1</td>
</tr>
<tr>
<td>cooling</td>
<td>Air cooled</td>
</tr>
<tr>
<td>rated power</td>
<td>kW 3.93</td>
</tr>
<tr>
<td>rated speed</td>
<td>rpm 7000</td>
</tr>
<tr>
<td>idling speed</td>
<td>rpm 1800</td>
</tr>
<tr>
<td>max vehicle speed</td>
<td>km/h 70</td>
</tr>
<tr>
<td>weight empty</td>
<td>kg 93</td>
</tr>
<tr>
<td>mixture preparation</td>
<td>carburettor blend 2% lube oil in gasoline</td>
</tr>
<tr>
<td>SAS (secondary air system)</td>
<td>No</td>
</tr>
<tr>
<td>catalyst</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Table 1: Data of the investigated motorbike

The vehicle uses simple conventional carburettor with a cable-controlled throttle body and needle.
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).

The investigated fuel blends contained ethanol (E), or hydrous ethanol (EH) in the portions of 5, 10 and 15% by volume. Pure ethanol is \( \text{C}_2\text{H}_5\text{OH} \) 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 C(_2\text{H}_5\text{OH})</th>
<th>E5</th>
<th>E10</th>
<th>E15</th>
<th>EH5</th>
<th>EH10</th>
<th>EH15</th>
</tr>
</thead>
<tbody>
<tr>
<td>density [g/cm(^3)]</td>
<td>0.737</td>
<td>0.789</td>
<td>0.740</td>
<td>0.742</td>
<td>0.745</td>
<td>0.740</td>
<td>0.743</td>
<td>0.746</td>
</tr>
<tr>
<td>stoichiometric air / fuel ratio [-]</td>
<td>14.6</td>
<td>9.0</td>
<td>14.30</td>
<td>14.00</td>
<td>13.71</td>
<td>14.28</td>
<td>13.96</td>
<td>13.64</td>
</tr>
<tr>
<td>lower calorific value [MJ/kg]</td>
<td>43.0</td>
<td>26.8</td>
<td>42.1</td>
<td>41.3</td>
<td>40.4</td>
<td>42.1</td>
<td>41.1</td>
<td>40.2</td>
</tr>
<tr>
<td>(^\dagger) 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>(^\dagger) 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>(^\dagger) 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>

It can be seen, that with increasing the ethanol ratio the stoichiometric air requirement of the blend-fuel 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 oil

The used lube oil was according to the requirements of vehicle manufacturer: fully synthetic oil Motorex Nbr. 4, [14], 2% blend.
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 \(\pm\) 30 \(^{\circ}\)C
humidity: 5.5 – 12.2. g/kg

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

![Diagram of measuring set-up](image)

\[ e) L=0.22 \text{ m} / \varnothing: 6\text{ mm}; \quad f) L=0.95 \text{ m} / \varnothing: 6\text{ mm}; \]
\[ ^{c)} \text{ from the sampling position of MD19 to the edge of the CVS-tunnel} \]

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)
  - HCR... only for idling
  - HCFID... 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 \( \leq 52 \, ^{\circ}\text{C} \)
  - conditioning of filter: 8 ÷ 24 h (20°C, rel. humidity 50%)
  - scale: Mettler, accuracy \( \pm 1 \, \mu\text{g} \)

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 sampling was at tail pipe, without thermoconditioner.

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 Kreidler with unlimited speed ECE 40,
- constant speed 40 km/h
  - first 5 min conditioning at full load
  - second 5 min conditioning at 40km/h
  - 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 cycle is represented in Fig. 3.

![Driving cycle ECE 40, warm](image)

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

The driving cycles, which were really performed on the chassis dynamometer were measured and the characteristic parameters ($v_m$, $a_m$, etc.) of those cycles 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 cannot always follow the conducting (desired) driving cycle.

The characteristic parameters of the realised driving cycles for the investigated vehicle and all measuring series are given in annex A4. The vehicle has enough power and can follow without problem the conducting cycle.

There are experiences from previous research that in the first period of work with ethanol blend there are “washing out” effects of residues from engine and exhaust system, which have impact on the measured (nano) particle emissions. Therefore the sequence of measuring series was set as follows:

Base fuel BF, after: approx. 45 min mixte operation with E25 without measurements, after: E15, E10, E5, EH15, EH10, EH5 and repetition of BF.

### 6. RESULTS

The results are represented graphically in the figures, see chap. 9 and are tabulated in annexes A5, A6 & A7.

In following the results are shortly discussed according to the performed tests and in the sequence of testing.
Before, during and after tests the mixture tuning was controlled at idling, (annex A7). 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>4.36</td>
<td>1630 rpm</td>
</tr>
<tr>
<td>after tests</td>
<td>5.97</td>
<td>1750 rpm</td>
</tr>
</tbody>
</table>

The tuning of engine mixture is very rich and there is almost no possibility to change it.

**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.

**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. Comparing these values between gasoline and ethanol, or between E and EH no tendencies can be remarked.

**Fig. 6** shows the time-plots of NanoMet signals in the driving cycle ECE40. The NanoMet signals of PAS and DC are converted to the values responding to the undiluted volume concentrations in the exhaust gas.

PAS (photoelectric aerosol sensor) is sensitive to the surface of particulates and to the chemical properties of the surface. It indicates the solid carbonaceous particles.

DC (diffusion charging sensor) measures the total particle surface independent of the chemical properties. It indicates the solids and the condensates.

Very often by the 2-S exhaust aerosol the solids are enveloped by the condensates (SOF) and are not detected by PAS. In this case of a very rich tuning PAS values are present. The total aerosol surface DC indicates all particles and correlates usually very well with the particle mass PM.

Regarding the integral average values from the last 4 cycles it can be remarked, that the DC-values for all E/EH-blends are slightly lower, than for BF, but there is no clear influence of blend-ratio, or hydrous ethanol (EH).

The PAS-values are slightly lower with EH, than with E and get the lowest values with the highest blend ratio E15 and EH15.

In the present case of rich tuning ethanol helps to lower the production of solid carbonaceous nanoparticles in the combustion chamber. Hydrous has in this regard a little bit stronger effect thanks to the presence of water.

The DC-values, which represent the total condensates, increase during the ECE40-cycle. This is caused by the decreasing exhaust temperature (**Fig. 4**).

**Fig. 7** shows the decreasing exhaust temperatures in the measuring period at constant speed 40km/h. The conditioning 5 min 40km/h after the full load was not long enough to cool down the exhaust system to the thermal level of the constant speed. This has some advantage to see the SMPS PSD spectra at different exhaust temperatures (see **Fig. 10**).

**Fig. 8** shows the NanoMet results during the measuring period at \( v = \text{const} \). There are similar tendencies, like in the driving cycles ECE40 (**Fig. 6**):

- there are no differences of DC last minute integral values with all E/EH blends,
- with hydrous ethanol (EH) there are clearly lower PAS-values.

**Fig. 9** represents the SMPS PSD-spectra and integral NP-emissions with all fuels at constant speed \( v = 40 \text{ km/h} \).
The measurements with SMPS were started after the driving cycles and after 5 min conditioning at the same constant speed (see Procedures, chap. 5). Nevertheless the indicated PSD-spectra were not well repetitive mostly due to the changing exhaust temperature. It was decided to perform two types of representation: with average of 3 samples (Fig. 9.1) and with the last 3rd sample only (Fig. 9.2). This second variant, which represents the last 2.5 minutes of the \( v = \text{constant} \) period can be assumed, as minimizing the differences of thermal state of engine and exhaust system.

The interpretation of different PSD-spectra is possible, but it leads often to open questions, which could be addressed with further research. Much more useful and practical is the look on integrated values. In the bottom of the figures there are integrated DC-signals over the last 10 min of constant speed and integrated NP-count concentrations over the particle sizes in the SMPS measuring range \([10 - 400 \text{ nm}]\).

It can be stated, that with increasing share of ethanol the summary surface of NP's (DC) decreases. DC decreases also with addition of water. The same is valid for the PM (total particle mass) and for integrated NP-counts.

It can be said, that for the rich tuning ethanol helps to oxidize the particles (according to the increased blend ratio). The application of hydrous ethanol (EH) increases slightly this tendency.

Fig. 9-3 represents the PSD's for 3rd sample in logarithmic scale and a comparison between the two types of evaluation: average of 3 scans or 3rd scan only. The principal influences and indicated relationships with both methods are the same. The 3rd scan only represents higher NP-values due to the lower exhaust gas temperature.

Fig. 10 gives an overview of all PSD's as 3 scans (Fig. 10.1), or the last scan only (Fig. 10.2). It is visible, that with the falling exhaust gas temperature the PSD moves to bigger sizes and higher count concentrations.

Fig. 11 gives an overview of all limited and unlimited emission components at constant speed and in the driving cycles.

Regarding CO, HC and NO\(_x\), following effects are visible:
- leaning of mixture by increasing ethanol portion,
- increasing the combustion peak temperatures and NO\(_x\) formation with increasing ethanol portion and strengthening of these effects with hydrous ethanol, (moving from low Lambda, very rich towards Lambda 1, less rich).

According to the driver there was no problem of driveability with the highest ethanol share E15, or EH15.

The volumetric fuel consumption is reduced due to the leaning of mixture and increased efficiency with the ethanol blend fuels. There is in particular an advantage of EH15, over E15.

Particle mass PM and particle counts generally decrease with the ethanol fuels, with some tendencies of more decrease for hydrous ethanol.

Figures 12 & 13 summarize the average values and the differences of tailpipe temperatures between beginning and end of measurements at ECE 40 (Fig. 12) and \( v = 40 \text{ km/h} \) (Fig. 13).

There is a general tendency of higher \( \Delta t \) with E & EH blend fuels. This is caused by the fact, that due to a slightly retarded combustion the E/EH fuels attain higher \( t_{\text{exh}} \) during the conditioning at full load and after that a higher temperature drop during cool down phase.

The maximum speeds, Fig. 14, show very little differences, but some advantages of hydrous ethanol.
7. CONCLUSIONS

After the research of emissions of a 2-S small motorbike Kreidler 50 cc, carburettor, no catalyst, following conclusions can be pointed out:

The original tuning of the mixture preparation and dosing is influenced by the ethanol containing fuels in the sense of leaner operation. This caused by this quite rich tuned motorbike advantages in regard of emissions and fuel consumption.

Regarding the legally limited components CO, HC and NOx following effects are visible:

- leaning of mixture by increasing ethanol portion,
- increasing the combustion peak temperatures and NOx formation with increasing ethanol portion and strengthening of these effects with hydrous ethanol,

The volumetric fuel consumption is reduced due to the leaning of mixture and increased efficiency with the ethanol blend fuels.

Particle mass PM and particle counts generally decrease with the ethanol fuels, with some tendencies of more decrease for hydrous ethanol.

Comparing these results with the previous results from [13] with a relatively lean tuned modern scooter (with lube oil injection in the intake air) it can be stated that:

The basic tuning of the engine is a very important factor, which decided if and how big ethanol shares are advantageous. By the rich tuning the emissions and fuel consumption are generally improved due to the leaning effects of ethanol. By the lean basic tuning the further leaning by means of ethanol can cause disadvantages due to the increased irregularities of engine operation approaching the lean limit.

At rich operation, when ethanol brings advantages the hydrous ethanol is also advantageous, it increases the effects of ethanol and yields in some cases further improvements of emissions and fuel consumption.

8. REFERENCES


9. LIST OF FIGURES

Fig. 1 Investigated scooter (in text)
Fig. 2 Sampling and measuring set-up (in text)
Fig. 3 Driving cycle used for the investigated vehicle (in text)

Kreidler Florett

Fig. 4 Tailpipe temperature during the ECE 40 driving cycles
Fig. 5 CPC particle counts during the ECE 40 driving cycles
Fig. 6 NanoMet-signals during the ECE 40 driving cycles
Fig. 7 Tailpipe temperature at constant speed v = 40 km/h
Fig. 8 NanoMet-signals at constant speed v = 40 km/h
Fig. 9 SMPS PSD-spectra & integral NP-emissions with all fuels
Fig. 10 Comparison of all SMPS PSD-spectra
Fig. 11 Limited and unlimited emissions with all fuels
Fig. 12 Average and difference of tailpipe temperatures between beginning and end of the ECE 40 driving cycles
Fig. 13 Average and difference of tailpipe temperatures between beginning and end of the constant speed v=40 km/h
Fig. 14 Comparison of the maximal reached speeds with all fuels

10. ANNEX

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 scooter
A4 Characteristic parameters of the ECE 40 driving cycles for Kreidler Florett
A5 Table of limited and unlimited emissions with all fuels, V=40 km/h & ECE 40
A6 Tables of the exhaust gas temperature at beginning of the driving cycles & maximal exhaust gas temperature during the driving cycles, with all fuels
A7 Comparison of emissions at idle speed with different fuels

11. ABBREVIATIONS

AFHB Abgasprüfstelle der Fachhochschule, Biel CH
(Blab. For Exhaust Gas Control, Univ. of Appl. Sciences, Biel-Bienne, CH)
BAFU Bundesamt für Umwelt (Swiss EPA)
BF gasoline lead-free, RON 95, base fuel
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
r rich basic tuning
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