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Particle Emissions of 2-S scooters
&
General Emissions Issues of 2- and 3-Wheelers

**3rd Information Report for IEA Implementing Agreement AMF,
Annex XXXIII, international activities 2006/2007**

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Report :

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*) Abbreviations see at the end of report

1. ABSTRACT

The serious health effects of particle emissions from traffic are known from the discussions about diesel engines technology and legislation. In this context the particle emissions of small 2-S engines with lost oils lubrication cannot be neglected any more.
A particular concern is about the 2-S scooters, small motorcycles and 2-S 3-wheelers, which in several countries are used very much in congested city centers.

To promote the exchange of information and mutual collaborations and progress in this domain, the present report summarizes shortly the international technical activities and activities in the reporting institutes.

There are several possibilities to reduce emissions from 2-S engines by means of technical measures and application of the best available technology (BAT*). Nevertheless the technical efforts alone cannot solve the pollution problem in several countries. The information and involvement of the political, economical and legal authorities, as well as the awareness and education of the population (users) are very important factors.

Small 4-S engines, which are going to replace more and more the 2-S engines in several new fleets, also have large potentials of emission improvements. In the present report, information about activities on 4-S engines is included.

2. INTRODUCTION

At present there is a demand for improved knowledge about particulate emissions from 2-S Scooters. Since emissions from other type of vehicles have been dramatically decreased as a result of more stringent emission regulations in many countries, the focus on 2-S Scooter emissions is becoming more obvious. Furthermore, some Third World countries suffer from extreme emissions from 2-S vehicles, due to the large number of those vehicles.

Therefore projects on measuring and evaluation of the impact of emissions have been started up in many countries. The influence of factors like: fuel, lubricant, engine and aftertreatment technology is being investigated in the different projects. These are the main factors that can be adjusted in order to develop cleaner vehicles.

In order to obtain an overview of the investigations the IEA *) AMF Annex XXXIII with following objectives was started in automn 2004 :

- an overview of the content of ongoing projects
- establishment of an information network between project leaders
- establishment of links between projects, where mutual progress can be obtained
- a summary report, describing the results from the projects

The present 3rd report gives futher overview of international activities on research of 2-S scooters in scope to promote further technical collaborations, exchange with authorities and general improvement of the critical air pollution.

3. ACTIVITIES OF THE SWISS NETWORK

Due to the large interest from different parties and also different possibilities of performing the project work it was appropriate to see different project modules, which are represented in annex A1. This network, which works on “task-sharing” basis, is still open for new interested parties to join it.

Following interconnections between Swiss working group (project A) and other working parties are to mention at present:

- exchange of samples and analytical work at EU-JRC Ispra, Italy (project B)
- exchange of information VTT Finland (project C)
- exchange of information and collaboration with the Toxicity Network France (project D)
- focusing on older engine technology and specific situation in Asian Countries (project F)
- leading of an annex of IEA AMF together with Techn. University Lyngby, DK (project G, present report).

3.1. AFHB

The extensive research activities at AFHB are reported in references of [1] & [2]. An executive summary report of Project A is given in [3].
Annex A2 represents a poster from SAE Paper, which is scheduled for publication at the Detroit SAE World Congress, Apr. 2008 and Annex A3 represents a topic, which will be presented in a specific paper during 2008.

Following main conclusions can be pointed out:

Catalysts screening

- Dummy – a substrate without washcoat and without catalytic coating – shows generally no catalytic conversion with the highest values of CO, HC, PM & DC. The emitted particles are in a bigger size spectrum.
- Thermally aged catalyst (1000°C, 24h, air) shows generally lower conversions with higher CO, HC, PM & DC –values. For some applications (Carburettor with highest $t_{exhaust}$) there are no differences between thermally aged and mass production catalyst.
- The “other catalysts”, which were supplied specifically for each vehicle show generally similar results like the mass production catalysts.
- There is a good repeatability of emission results with the catalysts.
- No conversion (dummy), or weak conversion (thermally aged) are indicated by lower $t_{exhaust}$ after cat.

Combinations of technical measures

- The combinations of technical measures to lower the particle emissions of scooters confirmed the expected effects and showed considerable reduction potentials.
- These technical measures are:
    - Higher tier lube oils
    - Lower oil dosing
    - Active oxidation catalyst
    - Supplementary filtration & oxidation devise (WFC).

- In scope of minimizing the particle emissions the general oil dosing in the fleet should be as much as possible reduced. To better attain this goal a stricter standardization and a very narrow variance of the oil quality parameters on the market will be necessary.
- To guarantee the satisfactory efficiency of oxidation catalysts in the 2-wheeler application the introduction of production conformity control and periodical emission check is urgently necessary.
- There are several materials, which can help to better filtrate and oxidize the exhaust gas components. Promoting of further R&D, as well as introduction to the market through the appropriate regulations or incentives are necessary.

3.2. EMPA

Morphology

In August 2005 a measuring campaign concerning morphology was performed by EMPA laboratory for IC engines in cooperation with AFHB.

For this research the scooters Peugeot TSDI and Carb. were used and the emissions were analysed at stationary, warm operating conditions (v = 40 km/h).

General conclusions of this work (for TSDI) are:

- Particles investigated before catalyst consist mostly of soluble (liquid) materials, while the particles after catalyst show mostly a soot-like structure.
- Under electron beam the particles are instable – a stochastic partial evaporation reveals, that they are volatile materials.
- The treatment of sampled aerosol by hot thermodesorber shows similar effects, like treatment by the oxidation catalyst: elimination of liquid fraction, more dry carbonaceous structure.
- The SMPS results with TD thermal sample treatment confirm the results from [1] (chap. 8) and show much evaporation of the particles as seen from the present images of Transmission Electron Microscopy (TEM).

EMPA performed in 2006 further research on this subject using similar scooters: Peugeot TSDI (50cc, 2002) and Kymco Carb. (50cc, 2001) and reported about it in [4] with following conclusions:

- Particles emitted from 2-stroke scooters were highly volatile.
- The relative volume loss of the exhaust particles upstream of the catalyst is higher than their downstream counterparts. This is, most likely, due to the removal of highly volatile particles by the catalytic converter.
- No solid core was detected within the size range of the SMPS.
- No significant difference could be identified between particles sampled from the two different scooters (TSDI, carburettor).
- Volatile particles observed under cryo-electron microscopy are in agreement with the SMPS measurement.
- The microstructure of the soot like particles seems to be less graphitized than diesel engine soot particles.
- The presence of Ca and S in some particles gives clear indication on the contribution of lubrication oil.

It has been shown, that the particle emission level of Carb. scooter can vary considerably for different vehicle types according to their mixture tuning, oil dosing exhaust gas temperature and secondary air dosing – all conditions, which influence the intensity of particle postoxidation in the exhaust system.

3.3 OTHER ACTIVITIES IN THE SWISS NETWORK

According to annex A1 following activities can be mentioned:

Project A:	finished in Feb. 2007
Project B:	further analytics of PAH & TEQ at JRC Laboratories, Ispra, It
Project D:	start of the research of toxicity 2007 with INSERM, Univ. Rouen, F; Univ. of Berne, CH; BAFU & TTM (organization chart see annex A4)
Project G:	present report.

4. ENEA & MUNICIPALITY OF ROME, ITALY (www.enea.it)

Due to a high level particle pollution in the big italian cities the Italian National Agency for New Technologies, Energy and Environment together with the Municipality of Rome performed research focused on particle emissions of 2-wheelers mainly with 2-S engines.

It was reported about these works in [1] and [2]. Further works 2006/2007 concerned analysis of PAH emissions from the 4-S scooters without catalyst, [5].
The most important statement is, that both: particle mass emission (PM) and PAH emissions from 2-wheelers – even with 4-stroke engines – should not be neglected in urban emission inventories. These still unregulated emission components have to be taken into consideration to enable a reduction of air pollution in the urban centres, see annex A5.

The PAH-emissions of small 4-S engines without catalyst were comparable to the emissions of passenger cars. For a worn-out engine with high lube-oil consumption the emissions of PM and PAH are very high (4x to 8x).

5. TECHNICAL UNIVERSITY GRAZ, A (http://fvkma.tu-graz.ac.at)

The institute for IC-engine of TU Graz (TUG) has a long tradition and experience with small 2-S and 4-S engines. One of the recent projects, presented at the SETC 2007, Niigata JP, [6] compares the potentials of high technology 50 cc 2-S & 4-S engines, annex A6.
Regarding the production costs, the attainable emissions, power and torque characteristics, as well as the demand of different markets the authors come to following conclusions:

Applied with a suitable exhaust gas aftertreatment 2 stroke as well as 4 stroke engines have the possibilities to fulfil future emission legislations. For 4S engines a closed loop engine control solution with a 3-way catalyst is the choice to be made for future emission limits. By contrast in 2S application it is still an oxidation catalyst but it becomes evident, that external mixture preparation systems have problems to fulfil the enhanced emission targets in the 50 cm^3 segment. One possibility to achieve Euro III limits with a carburettor or the herein described 2S-PI system is to apply an additional secondary air valve to the aftertreatment system without improving fuel consumption and engine efficiency.
Depending on the unique demands of the different markets, the choice of the engine concept will be different.
For the European market no clear decision regarding 4S or 2S engine technology can be expected within the next years. Depending on the character of the planned vehicle type, the engine performance will have an influence on the decision whether a 4S or a 2S concept will be chosen. Driveability as well as noise- and torque characteristics put the 4S engine in advance, whereas the higher performance of the 2S engine is a major argument for its use in a vehicle with racing character. The higher production costs of the 4S-NA vehicles can be regained by the better fuel economy, whereas the lower sales price of the 2S engines due to the lower production costs offers a better starting position for the 2S vehicle class.

The supercharged 4S engine has the potential to compete with high end 2S vehicles in the upper price segment of the 50 cm³ market.
Focusing on Asian markets, e.g. the Indian market, the priority of the customer clearly lies on the fuel economy and not on the vehicle performance. In this case, the 4S engine will be favoured.

6. GEO_2 Particle Filtration

GEO_2 Technologies, Inc., MA USA created a new ceramic filtration material with particularly high thermal resistance and low backpressure aptitude, [7]. This material will be applied for Diesel gas filtration.

GEO_2 performs actually R&D to apply this material for a full filtration of exhaust gases from 2-S scooters, annex A7. This can be a revolutionary improvement of 2-S exhaust gas quality.

7. AECC & ICCT

Important information about international emission topics is to be found in the periodic newsletters of AECC (www.aecc.be).

In the newsletter Sept – Oct. '07 an ICCT Report on Emissions of Two- and Three Wheelers is mentioned, see annex A8.

This report is available on the homepage of ICCT (www.theicct.org) under the title: "Air Emissions Issues Related to Two- and Three- Wheeled Motorcycles". It gives an extensive worldwide overview about statistics of vehicles, emissions, technologies and cost-effectivness of emission control measures. It acknowledges the importance of:

- PM-emissions from 2- & 3-wheelers, vehicle control, analytics and emission limits,
- in-use control,
- inspection & maintenance (I/M),
- education & instruction, (see summary, annex A9).

Another useful information about emission standards, emission control policies, in-use control and I/M programs from several Eastern Asian Countries is given at the same ICCT homepage (www.theicct.org) under the Conference:

> Motorcycle Emission Control:
> Vietnamese and International Experience,
> Hanoi, Vietnam, March 6, 2007.

8. OTHERS

An in-cylinder combustion control of a small 2-S engine was investigated in [8]. By means of ceramic coating, or Copper coating on the piston crown significant reduction of CO and HC was possible.

Similar research with Copper – and Zirconia – coated engine cylinder head was performed in [9]. The potentials of reduction of CO, HC, reduction of cyclic variation and a slight increase of brake thermal efficiency were confirmed. A magnetic field, with an intensity far superior to that

generated by regular permanent magnets, was also applied on the fuel line. This showed nevertheless the lowest potentials.

A concept of bifuel 3-wheeler (gasoline + CNG) for Indian market is presented in [10] from the Austrian manufacturer MAGNA STEYR and TU Graz. This concept offers important advantages for the low-cost and low-emission necessities of highly congested asian traffic areas.

An advanced concept of 2/4 stroke switchable engine is presented by Ricardo Consultants Ltd. UK in [11]. Even if this complex and expensive engine (3 cyl., GDI, 2-stage boosting, electro- hydraulic valvetrain) is not applicable for 2-wheelers, it is worth to mention, that the 2-Stroke working principle is still taken into consideration for the advanced automotive solutions.

Piaggio, the Italian manufacturer of Vespa scooter, has introduced two plug-in hybrid prototypes based on the standard Vespa LX 50 and X8 125 models, [12].
The HyS (Hybrid Scooter) models are parallel hybrids, combining four-stroke combustion engines with electric motors. The electric motor provides power assist, supplying a 25% boost in power for acceleration over the first few meters (a good feature for lunging through urban traffic), while at the same time supporting a 20% decrease in fuel consumption.
The rider uses all the normal controls (accelerator, brakes and additional handlebar commands) as well as a specific switch to choose one of four operating modes:

- Standard hybrid
- High-charge hybrid
- Low-charge hybrid
- Electric-only

Regenerative braking recharges the batteries. Plug-in charging is possible.

In electric-only mode, the Piaggio HyS shuts down the combustion engine and turns into a silent, zero-emission electric vehicle – an important consideration for those European cities that are increasingly placing restrictions on emitting vehicles.

Since April 1st, 2006, Germany introduced a periodic exhaust gas control for motorbikes, [13]. This control concerns only the vehicles with displacement bigger than 50 cc and it limits CO at idling, or – for vehicles with catalysts – at higher idling.

9. CONCLUSIONS

A lot of work is done yearly in the R&D of gasoline 2-S and 4-S engines for 2- and 3- wheelers.

Several improvements of engine- and exhaust gas aftertreatment technology are possible.

To reduce sustainably the emissions of 2-wheeler fleet the technical improvements of new vehicles are not sufficient.

Further legal and political steps to increase the awareness of the users and to promote control and maintenance are necessary.

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"Exhaust Gas Control for Motorbikes" since 1. April 2006 (German)

12. ABBREVIATIONS

ACEM	Association des Constructeurs Européens de Motocycles (www.acem.eu)
ADEME	Agence de l'Environnement et de la Maîtrise de l'Energie, France
AECC	Association for Emission Control by Catalyst (www.aecc.be)
AFHB	Abgasprüfstelle der Fachhochschule, Biel CH, (Lab.For Exhaust Gas Control, Univ. of Appl. Sciences, Biel-Bienne, Switzerland)
AMF	Advanced Motor Fuels
ANCMA	Associazione Nazionale Ciclo Motociclo Accessori, Milano, It.
BfE	Bundesmat für Energie, CH (SFOE)
BAT	best available technology
BAFU	Bundesamt für Umwelt, (Swiss EPA, FOEN)
C	Carburetor
Carb	Carburetor
CARB	Californian Air Resources Board
CERTAM	Centre d'Etudes et de Recherche Technologique en Aérothermique et Moteur
CPC	condensation particle counter
CVS	constant volume sampling
DC	diffusion charging sensor
DI	direction injection
DMA	differential mobility analyser
DTU	Technical University of Denmark, Lyngby DK
EMPA	Eidgenössische Materialprüfungs- und Forschungsanstalt
ENEA	National Agency for New Technologies, Energy and Environment, Rome, Italy (Ente Nazionale per le Nuove Technologie, l'Energia e l'Ambiente)
EPA	Environmental Protection Agency
ETHZ	Eidgenössische Technische Hochschule Zürich
EV	Erdöl Vereinigung, CH
FL	full load
G-DI	gasoline direct injection
GRPE	Groupe Rapporteur Pollution et Energie
ICCT	International Council on Clean Transportation (www.theicct.org)
IEA	International Energy Agency

I/M	inspection / maintenance
INSERM	Institut National de la Santé et de la Recherche Médicale, F
INSOF	insoluble fraction
JRC	EU Joint Research Center, Ispra It.
JASO	Japanese Automobile Standard Organisation
JSAE	Japanese Society of Automotive Engineering (www.jsae.or.jp)
ME	Matter Engineering, CH
NanoMet	minidiluter + PAS + DC (ev. + TC, or TD)
NMOG	non methan organic gases
NP	nanoparticulates
OP	ozon potential
PAH	polycyclic aromatic hydrocarbons
PAS	photoelectric aerosol sensor
PC	particles counts
PM	particulate matter, particulate mass
PMP	Particle Measuring Program of the UNO ECE GRPE
PN	particles number
PSD	particles size distribution
PSI	Paul Scherrer Institut, Switzerland
SAE	Society of Automotive Engineering (www.sae.org)
SAG	Swiss Aerosol Group (medical)
SAI	secondary air injection
SAS	secondary air system
SETC	Small Engines Technology Conference (www.sae.org)
SFOE	Swiss Federal Office of Energy
SMPS	scanning mobility particles sizer
SOF	soluble organic fractions
SUVA	Schw. Unfall Versicherungs Anstalt, Swiss Occupational Insurance
SWRI	South West Research Institute
T	TSDI
TC	thermoconditioner, total carbon
TEF	Toxicity Equivalence Factor
TEQ	Toxicity Equivalence TEQ = sum (TEF_i x $concentration_i$)
TSDI	Two Stroke Direct Injection
TPN	total particle number
TTM	Technik Thermische Maschinen, Niederrohrdorf, CH
TUG	Technical University Graz, Austria
VSS	Verband der Schweizerischen Schmierstoffindustrie
VTT	Technical Research Center of Finland
WFC	wiremesh filter catalyst
WMTC	Worldwide Motorcycle Test Cycle

13. ANNEXES

A1	2-S Scooters Swiss Project Network
A2	Poster AFHB: Catalyst Ageing, Catalysts Screening
A3	Poster AFHB: Emission Reduction with Combinations of Technical Measures
A4	Project D: Toxicity, organisation chart
A5	ENEA & Municipality of Rome – investigations of PAH for 4-S scooters, [5]
A6	Low emission 50 cc engine concepts, TUG, [6]
A7	GEO_2 full filtration for 2-S scooters
A8	AECC newsletter Sept. – Oct. 2007
A9	ICCT 2- & 3-Wheelers Report – Summary