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Particle Emissions & Toxicity of 2-S scooters; General Issues of small engines

5th Final Information Report for IEA Implementing Agreement AMF, Annex XXXIII, international activities 2009/2010

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Report :

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*) Abbreviations see at the end of report

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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 in the last period 2009/2010.

This report is a final report of Annex XXXIII, which focused on the emissions of 2-S scooters [1, 2, 3, 4]. Some information about other applications of small engines is given.

Most interesting are the experiences concerning toxical influences of the exhaust aerosol on cell cultures, PhD thesis University of Bern, [5]. In this work cell cultures of human lung were exposured to the exhaust gas in an appropriate exposure system and comparisons of different conditions of exposure, incubation times and different emission levels of vehicles were performed.

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. The engines for handhold machines 2-S & 4-S represent challenges of emission reduction both: from the point of view of cost and technology.
In the Eastern Asia markets several innovative and low cost solutions for 2-wheelers are offered: thermic engines with CNC or LPG, hybrid-electric and electric propulsion systems. The key information about these products is included in this report.

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 developing 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 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 autumn 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 5th report gives further overview of international activities on research of 2-S scooters and other small engines in scope to promote further technical collaborations, exchange with authorities and general improvement of the critical air pollution.

A very important step of the networking process was the organisation of an International Conference on (Particle) Emissions of 2-S Scooters together with EC JRC Ispra, Monza (Milano), June 11-12, 2009, [4].

Another important activity triggered by Annex XXXIII was the intensification of networking collaboration about toxicity of Diesel exhaust aerosol, since 37th ExCoMeeting, Helsinki, May 2009. The Swiss and French delegates together with observers from Netherlands organized several meetings and prepared a proposal of an EU-project (per August 2010). As results of these coordinating activities and of the contacts with oversee partners the worldwide activities on toxicity of exhaust gases from engines can be summarized with a flow-chart Annex 1. Some years before the Duch Ministry of Environment (VROM) charged the National Institute of Public Health (RIVM) to define legal procedures of possibly quick and simple validation of toxicity. During the common works it became clear, that this task has to be divided in several steps.
The activities on the political-administrative level were called “SET POINT” and the research projects at technical-scientific level were called EngToxNet (Engine Toxicity Network).

3. ACTIVITIES OF THE SWISS NETWORK

The activities of the Swiss Scooter Network are described in the previous reports [1, 2, 3, 4]. The joint project of University of Bern, Institute for Anatomy and Laboratory for IC-Engines & Exhaust Emission Control, Bern University of Applied Sciences (AFHB) about toxicity of scooter exhaust gases finished with the PhD. Thesis of Mrs. Dr. Loretta Müller, Aug. 17th, 2010.
Additionally to these activities AFHB performed some research projects on 2-wheelers in charge of the Swiss Federal Office of Environment.

3.1. TOXICITY UNI BERN - AFHB

A special cell-exposition chamber was prepared at AFHB and expositions of lung cells cultures were performed with different exhaust gas quality of a 2-S scooters, [5], annex A2.

For comparison simple tests with 4-S scooter and with Diesel passenger car with / without DPF were performed.

As conclusions can be remarked, that:
- there is a clear influence of exhaust gas quality on the cytotoxicity, oxidative stress and inflammatory reactions of cells,
- the exposure of cells to the combined aerosol (with gaseous and particulate toxic components) is a very useful method of research of toxicity; it is proposed to apply this method for all kind of pollution sources.

The PhD. Thesis [5] will be available on the AFHB homepage since Dec. 2010 at: www.afhb.bfh.ch → official reports → Dissertation L. Müller.

3.2. OTHER ACTIVITIES IN THE SWISS NETWORK

Tests with ethanol blend fuels were performed at AFHB in collaboration with TU Delft, NL and with support of FOEN, [6, 7].

There was 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. Special attention is paid in this research to the hydrous ethanol, since the production costs of hydrous ethanol are much less than those for (dry) ethanol.

The most important results are:

- there are no significant differences of results between the blends with pure ethanol (E), or hydrous ethanol (EH), except of some cases, where EH improves slightly the emissions (CO, HC, PM, NP) and reduces the fuel consumption,
- addition of ethanol to the gasoline provokes a leaner tuning of the engine operation,
- for the investigated newer 2-S scooter with leaner tuning the irregularities of combustion and increased emissions of PM & NP were remarkable with higher ethanol content, there was a poor driveability,
- the older 2-S scooter showed good performances and reduction of CO and of fuel consumption up to E15; no impact on or reduction of (nano-) particles and reduction of particle mass emissions with growing ethanol content,
- 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,
- with catalyst there is an efficient reduction of CO, HC, PM and NP, the higher share of ethanol can lower the exhaust temperature and due to that lower the catalytic converter efficiency.

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

Further research works about the use of different filtration materials for the 2-S exhaust aerosol were performed at AFHB. It was found, that the oxidation intensity of the used aftertreatment device is more important than the filtration quality. A paper informing about these results was submitted to the SAE World Congress Detroit 2011.

4. EC JRC RESEARCH ON SCOOTER EMISSIONS

The Institute for Environment and Sustainability, Transport and Air Quality Unit of the EC JRC Ispra performed an extended chemical characterization of emissions from 2-stroke mopeds with consideration of non-legislated compounds, ozone formation potential and toxicity equivalents; [8], see annex A3.
Recommendations for a revised future test protocol are demonstrated and discussed.

5. AECC – INFORMATION SERVICE

Important information about international emission topics is to be found in the periodic newsletters of AECC (www.aecc.be), some text pages see annex A4:

In the newsletter January-February 2010, p.2 the report of EC about emissions of motorcycles is explained. Without further legal measures the portion of pollution from 2-wheelers will very much increase in the next years.

In the newsletter March-April 2010, p.8, new proposals of reduction of evaporation emissions from off-highway recreational vehicles in California are described.

In the newsletter July-August 2010, there is interesting information about:

- US EPA's withdrawal of emissions approval for small off-road vehicles of some Chinese manufacturers, p.5,
- measures of improving the technical state and lowering the emissions of the motorbikes fleet in Vietnam, p.9.

6. CNR Naples, It.

Instituto Motori, Consiglio Nazionale delle Richerche performed an extensive research of regulated and unregulated emissions of nine mopeds 2-S & 4-S of different technical state of the art, [9], annex A5. Particle mass and nanoparticles as well as PAH are analyzed. With technical measures like direct injection or oxidation catalyst some remarkable emission reductions are possible.

7. CAMBUSTION Cambridge, UK

CAMBUSTION Ltd., a renowned manufacturer of measuring equipment, presents examples of application of the fast particulate spectrometer DMS 500 for 2-S exhaust gas aerosol, [10], annex A6.

The instantaneous measurement of nanoparticles size distribution spectra and of the changes during the transients offers an important tool for research of the aerosol. This research will be very important, if the nanoparticles will be introduced as validation parameter in the future legistlation.

8. TU Graz, A

Institute for Internal Combustion Engines and Thermodynamics, Graz University of Technology has a long tradition of research and development of small 2-S & 4-S engines for different applications.

At the International Vienna Engine Symposium 2009 TUG presented a development of a crankcase-supercharged small 4-S engine for scooters, [11], annex A7.

Comparing to the naturaly aspirated version the output parameters of the engine can be increased by approx. 20%. The crank mechanism is mixture-lubricated, similarly like for 2-S, but there are no scavenging losses. To minimize the emission of lube oil an oil separator is used in the transfer channel between crankcase and cylinder.

At the International Vienna Engine Symposium 2010 TUG presented a development of a loop-scavenged 2-S engine with a new low pressure direct injection strategy, [12], annexe A8. This development opens further potentials of emission reduction.

9. OTHERS

STIHL a German manufacturer of handheld machinery presented at SETC 2009 en electronic management system for small engines, which enables an easier starting, operation and lower emissions, [13]. In another paper “Spectroscopic Measurements in Small Two-Stroke SI Engines”, [14], STIHL together with the Institute for IC-Engines, University Karlsruhe gives an insight in the highly sophisticated method of basic investigation of combustion in a small 2-S engine. This method focuses on the cycle-by-cycle spectroscopic examination of the combustion radiation and gives a valuable information about the physico-chemical processes running in the combustion chamber.

Further information about the emission-related research of small engines is given in some papers of SETC 2010 (www.sae.org/setc):

- Michigan Technological University & AVL North America:
  “Measurement of Dry Soot and Particulate Matter From Two-Stroke and Four-Stroke Snowmobiles”. Scoot A. Miers, Michigan Technological Univ.; Christopher A. Green, Jay S. Meldrum, Michigan Technological Univ; Christine Lundberg, Michigan Technological University; Wiliam Silvis, Harry Pankratz, AVL North America Inc., SAE Nr. 2010-32-0042.

- Porsche Engineering Services:
  “Potential of Expansion Chamber Exhaust Pipes for Two-Stroke Powered Tools”. Gerhard Zsiga, Robert Kerres, Matthias Bach, Klaus Fuoss, Porsche Engineering Services, SAE Nr. 2010-32-0011.

- Scion-Sprays Ltd:
  “Fuel Injection for Low Emission 50cc 2-Stroke Scooter”. Paul Ravenhill, Jeffrey Allen, Benjamin Smither, Gavin Farmer, Scion-Sprays Ltd., SAE Nr. 2010-32-0020.

Next SETC 2011 (SAE Small Engine Technology Conference) is scheduled for November 8th-10th, 2011, Sapporo, Japan, (www.setc-jsae.com)

China: there is an explosive development of market of all kind 2-wheel & 3-wheel vehicles with propulsion: electric, hybrid, CNG, LPC, 2-S, 4-S. Annexes A9 & A10 give further information and links.

10. CONCLUSIONS

Two stroke (2-S) small engines with lost-oil lubrication have a clearly higher emissions and toxicity level; than the modern 4-S engines.

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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12. REFERENCES

[1] Czerwinski, J.; Schramm, J.: Particle Emissions of 2-S Scooters. 1st information report for IEA Implementing Agreement AMF, Annex XXXIII, international activities 2004/2005, AFHB B169, Oct. 2005, DTU, BfE, www.iea-amf.vtt.fi -> download -> Annex XXXIII.

[2] Czerwinski, J.; Schramm, J.: Particle Emissions of 2-S Scooters. 2nd information report for IEA Implementing Agreement AMF, Annex XXXIII, international activities 2005/2006 AFHB B189, Nov. 2006, DTU, BfE, www.iea-amf.vtt.fi -> download -> Annex XXXIII.

[3] Czerwinski, J.; Schramm, J.: Particle Emissions of 2-S Scooters. 3rd information report for IEA Implementing Agreement AMF, Annex XXXIII, international activities 2006/2007 AFHB B209, Dec. 2007, DTU, BfE, www.iea-amf.vtt.fi -> download -> Annex XXXIII.

[4] Czerwinski, J.; Schramm, J.: Particle Emissions of 2-S Scooters & General Emissions Issues of 2- and 3- Wheelers. 4th information report for IEA Implementing Agreement AMF, Annex XXXIII, international activities 2007/2009 AFHB B249, Jan. 2009, DTU, BfE, www.iea-amf.vtt.fi -> download -> Annex XXXIII.

[5] Müller, L. PhD thesis “Toxicity of Scooter Exhaust Emissions”, University of Bern, August 2010

[6] Czerwinski, J.; Comte, P.; Reutiman, F.; Makkee, M.: Emissions of 2-Stroke Scooters with Ethanol Blends. SAE Techn. Paper 2009-24-0143.

[7] Czerwinski, J.; Comte, P.; Reutiman, F.; Makkee, M.: (Particle) Emissions of Small 2-& 4-Stroke Scooters with (Hydrous) Ethanol Blends. SAE Techn. Paper 2010-01-0794.

[8] Adam, T.; Farvaletti, A.; Montero, L.; Martini, G.; Manfredi, U.; Larsen, B.; De Santi, G.; Krasenkbrink, A.; Astroga, C.: Chemical Characterization of Emissions from Modern Two-Stroke Mopeds Complying with Legislative Regulation in Europe (EURO-2). EC JRC, Ispra, Environmental Science & Technology, Vol. 44 No. 1, 2010.

[9] Prati, M. V.; Costagliola, M. A.: Emissions of Fine Particles and Organic Compounds from Mopeds. Environmental Engineering Sciences, Vol. 26, No. 1, 2009.

[10] Hands, T.; Nickolaus, Ch.; Symonds, J.; Finch, A.: Real-time Particle Emissions from 2-Stroke Motorbikes with and without PMP Sampling System. Tech. Paper No. 10 SETC-0107, SAE 2010-32-0047.

[11] Kirchberger, R. ; Eichlseder, H. : Entwicklung eines Viertakt Ottomotors mit Kurbelgehäuse-aufladung, TU Graz, 30. Internationales Wiener Motorensymposium 2009 .

[12] Kirchberger, R.; Winkler, F.; Eichlseder, H.: Are Loop Scavenged 2-Stroke Engines for Recreational Purposes Able to Fulfil Future Emission Limits? TU Graz, 31. Internationales Wiener Motorensymposium 2010.

[13] Hehnke, M.; Naegele, C. ; Leufen, H. ; Bähner, A.: Intelligent Engine Management System for Small Handheld Low Emission Engines. SAE Techn. Paper 2009-31-0019/20097019.

[14] Beck, K.W. ; Heidenreich, Th. ; Busch, S. ; Spicher, U. ; Gegg, T. ; Kölmel, A.: Spectroscopic Measurments in Small Two-Stroke SI Engines. SAE Techn. Paper 2009-32-0030/20097030

13. 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, (www.afhb.bfh.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
DPF	Diesel Particle Filter
DTU	Technical University of Denmark, Lyngby DK
ECU	electronic control unit
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 (www.swissoil.ch)
FL	full load
FOEN	Federal Office of Environment (BAFU)
G-DI	gasoline direct injection
GRPE	Groupe Rapporteur Pollution et Energie
HEV	hybrid electric vehicles
IA	Implementing Agreement
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

SI	spark ignition
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 (www.vss-lubes.ch)
VTT	Technical Research Center of Finland
WFC	wiremesh filter catalyst
WMTC	Worldwide Motorcycle Test Cycle

14. ANNEXES

A 1	Worldwide Activities on Toxicity of Exhaust Gases from Engines
A 2	Toxicity of Scooter Emissions, [5]
A 3	Title page paper JRC, [8]
A 4	Pages from AECC newsletters
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