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Particle Emissions of 2-S scooters

1st information report for IEA implementing Agreement AMF, Annex XXXIII, international activities 2004/2005

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Report :

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*) Abbreviations see at the end of report

Abstracts

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.

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 after treatment 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 report gives the first 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.

*) Abbreviations see at the end of report

Activities of the Swiss Network

Due to the large interest from different parties and also different possibilities of performing the project work it is appropriate to see different project modules, which are represented in annex A1. This network, which works on “task-sharing” basis, is always 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 research material and results with VTT Finland (project C)
- exchange of samples (or ev. research material) with the Toxicity Network France (project D)
- focusing on older engine technology and specific situation in India (project F)
- leading of an annex of IEA AMF together with Techn. University Lyngby, DK (project G, present report).

AFHB

The extensive research activities at AFHB are reported in detail in [1] and [2], more general overview offer the published papers [3], [4], [5], [6]. Annex A2 represents a poster from [6].

Following conclusions can be pointed out :

Engine technology, oils & fuels

- the composition of emitted aerosol depends on engine technology (DI-Carb.), exhaust gas after treatment (texh, SAS) and the used oil and fuel. The differences of the aerosol are visible by thermoconditioning of the sample,
- the influences of lube oils on the particle emissions from previous works could be confirmed on the scooter with DI and gasoline and they are slightly modified on the Carb. scooter,
- changing the fuel quality (Aspen) may increase the condensates with one oil and lower the condensates with another oil,
- due to an intense oxidation in the exhaust of the Carb. scooter the particle mass emission PM is very little and it is almost independent on lube oil quality,
- due to a high exhaust temperature of the Carb. scooter there are sulfates as condensates in the nuclei mode of the PSD-spectra,
- there is a clear evidence of coinfluences of oil & fuel on the spontaneous condensation and on the particle emission parameters,
- with direct injection (TSDI) the heterogeneous combustion of gasoline contributes to the formation of solids,

Sampling for particle analysis

- the sampling devices: thermoconditioner and thermodesorber influence clearly the aerosol in the sense of elimination of condensates by increasing the sampling temperature – these influences depend on the composition of aerosol,
- the sampling place: tailpipe, or CVS influences strongly the particle size distributions (PSD) due to condensation – and coagulation effects,

PAH

- the amount of total PAH, as well as the toxicity equivalence TEQ correlate roughly with the total particle mass PM,
- the Carburettor scooter “warm” has the lowest PM & PAH emissions due to the intense oxidation in the exhaust. With cold start, when the catalyst is not active at the beginning of the warm-up phase, the Carb. Scooter has, particularly with the standard gasoline, the highest emissions of PAH,
- the alkylat fuel Aspen is generally better from the point of view of total PAH. Nevertheless, due to different composition of PAH this tendency is not exactly the same for the toxicity equivalence,

EC/OC

- the results of coulometric EC/OC – analysis accord well with the particle mass (PM) measurement and tendentially also with the results of soxhlet extractions; nevertheless coulometry seems to indicate to high share of EC, which can be due to some artefacts and will be addressed in further research,
- at cold start there are the highest PM-values for Carb. with a lower INSOF-content; at warm operation, due to a strong oxidation in the exhaust system, the PM-emissions for Carb. becomes very little, but with a high share of INSOF,

VOC

the VOC analyses at stationary, warm operating conditions show, that :

- aspen fuel causes a higher ozone-forming potential (OP) with Carb. and lower OP with TSDI,
- with Carb. there is generally higher specific reacivity,
- investigated oil quality has a little influence on the NMOG, OP, toxics and carcenogenics,
- there is no combination of oil/fuel/vehicule, which would be the best one for all criteria (NP, PM, PAH, TEQ and VOC),

Catalyst ageing (1)

- the pollution of catalyst by oil overtreatment (4%) and 4h idling causes clearly lowering of the CO-conversion rate and – particularly in the first start after the pollution – roughly doubling of the light-off time. Further starts after the pollution show shorter light off times due to cleaning effect of the catalyst,
- the direct pollution of dismantled catalyst shows similar effects – lowering of the conversion rate and increasing of the light-off time,
- the direct pollution with old oil has similar effects as with new oil, the washing of catalyst shows no special influences on the conversion rate and light of time,

Oil screening (2)

- the biodegradable oils (2 & 4) produce higher (nano) particle emissions on TSDI and lower emissions on Carb., which is due to the oil composition and the specific conditions in the exhaust system of each type of vehicle,
- the metal-free oils don’t show any special effects on the particle emission components,
- the influence of oil quality on the (nano) particle emissions changes for different scooters,

Buck WFC

- the WFC inline with oxidation catalyst traps and oxidizes the volatile and particulate compounds more efficiently, than the WFC alone,
- the WFC provokes some store-release effects, which are dependent on exhaust gas temperature and due to the longer time scale of changes they can overlap and falsify the instantaneous emission results,

- conditioning at full load cleans the WFC, may provoke better oxidation ability, but also damaging of the catalytic coating (this second will be further investigated).

Catalyst ageing (2)

- the chosen ageing procedure (8h idling + 3 x 10 min FL) had no impact on the catalyst behaviour (conversion rate, light off),
- the chemical poisoning, which is very dangerous for some catalytic metals didn't appear due to very low sulfur content and no phosphorus of the used fully synthetic oils,

EMPA

In contrast to passenger cars which have to fulfil the emission legislation for a mileage of 80'000 km, two-wheelers have no such durability requirements. So, production cost minimization may shorten the life span of the after treatment systems used.
To monitor the real emissions and emission deterioration of such vehicles, six 50 cm^3 two stroke scooters were tested during their first 1000 km at EMPA Laboratories for IC-Engines, [7].
Annex A3 represents a poster from [7]. The conclusions confirm the present opinions about the modest efficiency of oxidation catalysts on 2-S 2-wheelers :

- Four of six scooters failed the legislative test as they came from the seller.
- The HC conversion rates of the catalysts range from 80 to 10 %. But the absolute values of the emissions do not correlate to the catalyst efficiencies.
- For some driving conditions and vehicles, the post catalyst CO and NO_x concentrations are higher than before the catalyst.
- The performance of the catalysts did not deteriorate during the first 1000 km, starting with 3-7 km mileage. It can not be excluded that some catalyst broke already before delivery.

Other activities in the Swiss network

According to annex A1 following activities can be mentioned :

Project B : analytics of PAH & TEQ at JRC Laboratories, Ispra, It
Project E : analytics of VOC & OP at EMPA Laboratories, CH
Project D : preparations for the research of toxicity 2006 with INSERM, Univ. Rouen, F; Univ. of Berne, CH; SAEFL & TTM
Project C & F : further search of funds
Project G : present report.

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.

In the first work, [8], which was performed on two 2-S scooters (50cc Euro1), both with carburettor, one with and another without oxidation catalyst an evidence was found, that particulate matter emissions from non-catalyzed moped are strongly related to lubricant consumption. In the case of catalyzed moped lubricant in the exhaust gases is oxidized according to catalyst temperature, the higher the catalyst temperature is, the more the lubricant is oxidized, and as a consequence, particulate matter emissions decline as catalyst temperature raises. Another result is that during ECE-47 cycle, particulate matter emissions from catalyzed moped are about 75% lower than emissions from non-catalyzed moped.

In the further work the particle emissions of several 2-S mopeds and 4-S scooters were investigated, [9], see annex A4. The most important conclusions are :

2-S mopeds
- PM emissions are linked to lube oil consumption;
- Pre Euro 1 have hot emissions of about 180 mg/km;
- Euro 1 have hot emissions of about 30 mg/km;
- Experimental data show no clear evidences that Euro 2 mopeds have PM hot emissions lower than Euro 1;
- Cold emissions are higher than hot ones. Only CM8 moped (with DI) shows cold emissions lower than hot;
- Over 98 % of the total collected mass shows an aerodynamic diameter less than 1μm for nearly all mopeds.

4-S scooters
- The scooter particulate mass emissions were, as expected, very low.
- No significant differences exist between whole cycle emissions and hot phase emissions.
- About 94% of the total collected mass has an aerodynamic diameter less than 1 μm.

Ricardo ,UK (www.ricardo.com)

As part of a UK Government programme to determine emissions factors for a variety of vehicles, further study was undertaken at Ricardo Consulting Engineers to measure individual chemical species of current and possible future concern, [10]. The aim of the study reported in [10] was to investigate the unregulated emissions from a range of twelve 2- and 4-stroke motorcycles with respect to various drive cycles, engine and after treatment technologies.

Annex A5 shows the data of tested bikes, procedures and examples of results. There were 2 bikes with 2-S engines - BK8 with DI and BK11 with carburettor. As most interesting it can be mentioned:

- Nitrogen dioxide emissions were highest from the direct injection two-stroke motorcycle, BK08, which operated as lean as 70:1 AFR during some transient excursions. The only other motorcycles which produced appreciable levels were the carburetted motorcycles with SAI but no three way catalysts.

- Particulate mass emissions from motorcycles were generally low; with the exception of the carburetted two-stroke (0.63 g/km) these did not exceed 0.02g/km – inside the Euro 4 emissions levels (0.025g/km) for a diesel vehicle irrespective of drive cycle.

- Total particle number emissions from the 97/24/EC, 98/69/EC and WMTC cycles ranged from below 10^{12}/km to greater than 10^{14}/km – levels that are in line with the magnitude of emissions observed from light duty MPI and G-DI passenger cars over a range of operating conditions.

- Though almost entirely dominated by oil volatility hydrocarbons, the chemical composition of motorcycle particulate matter appears to be related to both cycle demand and to calibration.

- A visual analysis of filter papers was undertaken which revealed most papers showed a yellowish discoloration; this was investigated by chemical analysis and was found generally to be related to hydrocarbons within the lubricant fraction of particulate. Very few samples showed any visual evidence of soot.

- Chemical analysis of particulate composition showed that most samples were dominated by oil hydrocarbons, irrespective of drive cycle. Carbon was produced in response to rich operation, particularly over the WMTC#2 and WMTC#3 cycles; from the DI scooter at all conditions, which operated stratified lean combustion and from several bikes upon cold starting.

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 little 2-S engines. One of the recent projects, presented in [11], is a scooter with hybrid concept (HYC).
On a 50cc 2-S scooter several technical developments were performed, which allowed to reduce the emissions (first of all the particle mass emissions) and to improve the performances, like fuel consumption, idling quality, acceleration aptitude and maximum speed.

The technical developments were (examples see annex A6):

- mechanical (clutch, CVT)
- HYC battery management
- thermodynamic development of : piston, cylinder, intake silencer & exhaust system
- electrically heated catalyst (EHC)
- electric & electronic system
- engine idling.

EU Joint Research Center, Ispra, Italy (http:/www.jrc.cec.eu.int) (http:/ies.jrc.cec.eu.int/units/eh)

The Vehicle Emission Laboratory (VELA) of the Institute for Environment and Sustainability (IES) of JRC performed different research activities about the limited and nonlimited emissions of 2-wheelers. The effects of lubricant and fuel on the particulate emissions from 2-S mopeds (50cc, Euro1) were investigated, [12].

This study showed that the engine technology has a huge effect on particulate emissions from mopeds. Particulate emissions of the pre-Euro1 moped were very high while the Euro 1 mopeds tested at the JRC showed particulate emission values (g/km) close to those of Euro 3 diesel vehicles

Furthermore, it was observed that the lubricant quality has a significant impact on particulate mass, particle number and size but the effect strongly depends on the engine technology.

The moped equipped with the direct injection engine exhibited a different behaviour compared to conventional two stroke engines with carburettor.

The LPG conversion kit tested proved to be en effective way to reduce particulate emissions from mopeds.

Further information about the effects of motorcycle engine technology upon physical properties of nanoparticles see annex A7.

The differential analytics of the particle mass, performed at the JRC Analytical Laboratories showed a particularly high toxicity equivalence (TEQ) of the 2-S vehicles, [13], annex 8.

Technical University of Danmark (DTU)

DTU has been investigating the influence of mopeds on the total emissions of CO, HC, NOx and particulate matter in Denmark. Furthermore the influence of mixing gasoline with ethanol on emissions has been investigated on a single moped with carbureted 2-stroke engine and oxidation catalyst, [14].

The following conclusions were drawn:

- 2-wheelers contributes considerably to the emissions of CO, HC and particulate matter in Denmark, compared with the contribution from gasoline cars
- emission factors from a new technology "moped 30" 2-wheeler where found to be in the range of previously estimated emission factors, used for the calculation of the emission contribution in Denmark with respect to HC and particulate matter, however, the CO emission factor was found to be 100 % higher with the new technology vehicle
- addition of ethanol to the gasoline reduced the emissions of HC and CO moderately, however, the smoke emissions were reduced dramatically with an increased ethanol content up to 10% ethanol - further increase in ethanol content did not reduce smoke emissions further
- the fuel economy was improved with addition of ethanol to the gasoline
- the catalytic converter had moderate effect on the emissions of HC and CO, but did seem to be efficient to the reduction of the soluble organic fraction of the particulate emissions

The most important results of this investigation are given in Annex 9.

Others

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

In the newsletter July-August ’05 there are suggested Euro 3 motorcycle emission limits, where still no evidence of mentioning the particle emissions can be found.

A french Agency for Environment and Energy Management (ADEME) found in a study, that 2-wheelers are responsible for more, than 10% of French urban air pollution, despite accounting for less than 1% of fuel use. ADEME suggests the necessity of replacement of the older vehicle fleet.

b) First mobike with H_2-propulsion was developed by the UK company Intelligent Energy (www.intelligent-energy.com)
More information in German can be found at www.pte.at/pte.mc? pte=050318044.
This product, although far from the reality of the worldwide market, indicates a will to introduce the newer and also newest technologies for 2-wheelers.

c) Various projects to look at Auto-Rickshaw Emissions and potential technologies to lessen the emission rates.
(Contact person: Greg Rideout, Environment Canada, email: greg.rideout@ec.gc.ca)
A collection of projects that undertook chassis dynamometer and full CVS sampling testing to evaluate fuels and emission control system effects on emissions from the Three-Wheelers. Particulate matter emissions were, however, not investigated.

d) In-Use Auto-Rickshaw Emissions.
(Contact person: Greg Rideout, Environment Canada, email: greg.rideout@ec.gc.ca)
Field testing of used three-wheelers in Dhaka Bangladesh. Testing was conducted on a very simple chassis dynamometer that was designed for steady state testing of the 3-wheelers. Tests consisted of idle and then wide open throttle under moderate road load simulation. Emission measurements were taken using a portable continuous emissions monitor (not particulate emissions). The objective was to document raw exhaust concentrations when retrofitting used rickshaws to operate with a CNG conversion system developed in Canada for this application. Also documented any power changes at wide open throttle when switching between fuels.

e) New-Engine Emissions Regulatory Program.
(Contact person: Peter Barton, Environment Canada, email: peter.barton@ec.gc.ca)
Under the Canadian Environmental Protection Act the emissions from new vehicles and engines are limited. Our facility conducts the emissions testing element of the program which is undertaken to confirm the manufacturer data for emissions and fuel consumption (not particulate emissions). Testing is conducted on engine dynamometer using full flow CVS dilution and sampling systems. Includes hand held engines, mounted/wheeled engines such as lawnmowers, and also outboard marine.

Conclusions

The importance of 2-S 2-wheelers emissions and their contribution to the air pollution in the cities is recognized and investigated in several countries.

The primary source of particle emissions is lubricating oil, which consumption has to be minimized.

Several improvements of particle emissions can be achieved by right choice of oil quality, by increasing the catalytic postoxidation, by using more efficient particle trap systems and eventually using of alternative fuels.

Very sophisticated technical solutions, like hybrid scooter, or H_2-mobike are possible, but difficult from the point of view of costs.

There is an interest of the EU-authority to further lower the emission levels and the toxic effects of 2-S 2-wheelers. Nevertheless the legal limits for particle mass, or counts are still not taken into consideration, for this sensible market sector.

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  Swiss Association of Lubricants Industry (VSS)
  Swiss Federal Office of Energy (BfE)

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  for promoting the activities of Annex XXXIII and for his constant engagement for energy, environment and economic development.

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Abbreviations

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
BUWAL	Bundesamt für Umwelt, Wald und Landschaft (Swiss EPA, SAEFL)
C	Carburetor
Carb	Carburetor
CPC	condensation particle counter
CVS	constant volume sampling
DC	diffusion charging sensor
DF	dilution factor
DI	direction injection
DMA	differential mobility analyser
DPF	Diesel Particle Filter
DTU	Technical University of Denmark, Lyngby DK
EC	elemental carbon

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
HYC	Hybrid Concept Scooter from TUG
IEA	International Energy Agency
INSERM	Institut National de la Santé et de la Recherche Médicale, F
INSOF	insoluble fraction
JRC	EU Joint Research Center, Ispra It.
ME	Matter Engineering, CH
MPI	multipoint port injection
NanoMet	minidiluter + PAS + DC (ev. + TC, or TD)
NMOG	non methan organic gases
NP	nanoparticulates
OC	organic carbon
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
SAEFL	Swiss Agency for Environment, Forests and Landscape (Swiss EPA, BUWAL)
SAI	secondary air injection
SAS	secondary air system
SFOE	Swiss Federal Office of Energy
SMPS	scanning mobility particles sizer
SOF	soluble organic fractions
SUVA	Schw. Unfall Versicherungs Anstalt, Swiss Occupational Insurance
T	TSDI
TC	thermoconditioner, total carbon
TD	thermodesorber
TEF	Toxicity Equivalence Factor
TEQ	Toxicity Equivalence TEQ = sum (TEF_i x $concentration_i$)
TSDI	Two Stroke Direct Injection
TP	tailpipe
TPN	total particle number
TTM	Technik Thermische Maschinen, Niederrohrdorf, CH
TUG	Technical University Graz, Austria
TWC	Three Way Cat
VOC	volatile organic compounds
VOF	volatile organic fraction
VSS	Verband der Schweizerischen Schmierstoffindustrie
VTT	Technical Research Center of Finland
WFC	wiremesh filter catalyst
WMTC	Worldwide Motorcycle Test Cycle

Annexes

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