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**NON-EXHAUST PARTICLE EMISSIONS FROM VEHICLES**

**BACKGROUND**

Following the submission of informal documents by the Russian Federation, UNECE WP.29 agreed with the GRPE decision to assign the follow-up of the issues concerning the emissions of particles from tyre and brake wear to the PMP informal working group.

In the 68th GRPE session of January 2014, the topic of traffic related non-exhaust particle emissions was further discussed. GRPE acknowledged the information provided by the PMP informal working group and the Russian Federation and requested the PMP group to propose in the June 2014 session of GRPE a possible roadmap on how to proceed further with the issue of particles from tyre and brake wear.

**INTRODUCTION**

Several aspects should be considered when assessing the relevance of non-exhaust traffic related particle emissions, and particularly those generated as a result of brake and tyre and road wear, in human health.

For some of these aspects available literature data is sufficient to draw conclusions since there is a general consensus among the scientific community. More specifically available data provides a quite clear picture, even if with some uncertainties, of the contribution of brake and tyre and road wear particles to traffic related particulate matter (PM) emissions as well as of the typical PM10 emission factors, mass and number size distribution and chemical composition of these particles.

On the other hand, there are many other aspects for which the current knowledge is not sufficient to reach sound conclusions. This is due in some cases to the scarcity of data, while in other cases the results reported in the publicly available studies are not consistent or even are contrasting as a consequence of the use of different measurement techniques and sampling procedures. How non-exhaust wear particles are dispersed in the air and what is the fate of bigger wear particles, the exposure of the population to those particles, the impact of wear particles on human health, how influencing factors affect wear particle emissions, the effectiveness of technological and non-technological mitigation measures, are among the issues that should be further investigated.

A summary of the level of knowledge and the still existing gaps is provided in the Annex I.

Addressing these many open issues related to non-exhaust particle emissions would require large projects with a multidisciplinary approach. These projects should involve experts from many different specialized fields (i.e. braking systems, tyres, air quality, modeling, transport infrastructures, mobility planners, health science, impact assessment) as well as field and laboratory experimental activities. Important financial resources would be also needed.

The PMP group activities since its inception, focused on development of an alternative metric with increased sensitivity compared to the existing particulate matter mass measurement system for heavy duty and light duty engines / vehicles (M and N category vehicles). For that reason the PMP group comprises mainly experts from the field of exhaust emissions, as well as experts on techniques and sampling systems to characterize particles emitted by engines.

Due to the complexity of the matter, and considering the existing mandate, the expertise and the limited resources available within the PMP group, it is the view of the group that a valuable contribution can be provided only on specific but still important issues. More specifically, the PMP group believes that the experience acquired over more than 10 years of research on particle emissions can be an important forum where valuable help on the **development of a set of recommended measurement techniques and sampling procedures**, the **investigation of typical driving patterns**, the **compilation and monitoring of on-going research projects**, as well as the **networking and exchange of information with experts in the field of non-exhaust traffic related particle emissions** could be provided.

**PROPOSED APPROACH**

***STRUCTURE OF THE GROUP***

It is proposed that the PMP group will address the issues related to non-exhaust traffic related particle emissions listed in the next section without creating a new informal group.

Experts in other fields relevant to the addressed topics will be invited to attend the informal meetings of the PMP group that will be split into two sessions, one dedicated to exhaust emissions and the other to non-exhaust traffic related particle emissions.

***SCOPE AND WORK ITEMS***

The scope of the activities to be carried out within the PMP group related to non-exhaust traffic related particle emissions will focus on the following sources: brake wear, tyre and road wear, clutch wear.

As far as clutch wear is concerned, due to the enclosed nature of the clutch mechanism it is likely that most of the wear material is retained inside the housing. However, existing literature data do not provide much information and therefore further investigation is necessary first of all to understand the relevance of these emissions.

Road dust resuspension was decided not to be examined - at least within the PMP group - due to the fact that resuspended dust derives from multiple sources, some of which are not traffic related (i.e. industry, natural sources). Additionally, dust resuspension is not a direct source of particles in the environment like all other non-exhaust traffic related sources, and it can also be a result of other factors than traffic (i.e. wind).

The PMP has identified the following work items:

* **Investigation of typical driving patterns and in particular of typical accelerations/decelerations.**

Objective: Driving conditions have obviously a large influence on wear processes. The activity data collected in the framework of other projects (e.g. WLTP) will be reviewed in order to derive the typical acceleration / deceleration frequency distributions. The objective of this activity is to reach a shared definition of typical/normal driving conditions as well as of severe, extreme or infrequent conditions. The definition of typical or normal driving conditions will narrow down the range of driving conditions to be taken into consideration as far as non-exhaust particle emissions are concerned. This will be helpful both for the review of the existing data which was sometimes derived under extreme driving conditions, and for future studies.

* **Compilation and monitoring of the on-going research projects on non-exhaust traffic related particle emissions.**

Objective: There are several on-going research projects, some funded by the EU (e.g. REBRAKE) some by other organizations, that address different issues and very often are not known outside the involved groups or organizations. Information (objectives, timing, experimental approach, expected results) about these projects will be collected in a living document that would be regularly updated. Whenever possible, meetings between the PMP group and the main actors of the projects will be organized to promote the exchange of information and monitor the progress achieved. This will be mutually beneficial both for the PMP group and the groups involved in the projects (better focused research activities, extended expertise, more complete technical and instrumental support, avoid of duplications/overlapping).

* **Networking and exchange of information with experts in the field of non-exhaust traffic related particle emissions.**

Objective: Promoting the exchange of information among the PMP group and the renowned experts in the field of non-exhaust traffic related emissions. As an example, non-exhaust traffic related particle emissions, mainly due to the use of studded tyres and road salt over the winter season, are of high concern and interest in Nordic Countries and a lot of experience is available on the effectiveness of different mitigation measures.

* **Development of a set of recommended measurement techniques and sampling procedures.**

Objective: The lack of standardized approaches in investigating the different aspects of non-exhaust traffic related particles has often led to inconsistent or even contrasting results. A set of recommended measurement and sampling procedures will be developed as a guideline for future studies.

**ANNEX I – Stat of the art of knowledge and open issues**

**Brake wear (BW) particles**

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|  | **State of the art of knowledge** | **Open issues / Research Needs** | **Involvement of PMP group** |
| **Contribution to PM10** | * 50% of brake debris becomes airborne. Among it 80% is PM10 and 60% PM2.5**1,2** * 16-55% of non-exhaust traffic related PM10 emissions is attributed to BW. Lower contributions at freeways (<3%)**3** | * Lack of reliable estimations regarding the contribution of BW to ambient PM10 and PM2.5 * Lack of estimations regarding actual ambient concentrations of BW |  |
| **Factors influencing brake wear content and generation rates** | * Driving behavior (i.e. frequency and severity of braking) * Conditions under which the braking event occurs (i.e. speed, ambient temperature) * Composition of pads and drums (NAO, low- or semi-metallic and metallic) * Light or heavy duty vehicles | * Lack of standardized sampling methods. * Differences in location and type of brake, sampling procedure (on-road/ lab), type of the sampling system (open /close) result in non-comparable results * No definition of “normal” or “typical” driving conditions (different speeds, accelerations and decelerations applied) | * Definition of “normal” or “typical” driving conditions |
| **Generation mechanisms** | * Abrasion mainly generates coarse particles * Thermochemical processes mainly generate fine particles | * Understanding and modelling the mechanisms | * Monitoring of on-going projects (i.e. REBRAKE) and activities (i.e. published studies, workshops) which may provide some relevant information |
| **Mass distribution** | * BW PM10 distributions are unimodal (peak between 2-6 μm)**1, 2, 4** | * How mass distribution is affected by the type of brake. More in depth comparison of different types of brakes * How mass distribution is affected by the type of vehicle | * Monitoring of on-going projects (i.e. REBRAKE) and activities (i.e. published studies, workshops) which may provide some relevant information |
| **Size distribution** | * At least one peak of BW PN distribution lies within fine size fraction**2, 4, 5** * Most of BW mass is distributed in particle sizes smaller than 2.5 μm | * Studies demonstrate bimodal PN distributions with a 2nd peak at PM2.5 * Studies report the 1st peak at the UF size, while others at ~0.3 μm * More in depth comparison how different types of brakes affect size distribution * How size distribution is affected by the type of vehicle | * Monitoring of on-going projects (i.e. REBRAKE) and activities (i.e. published studies, workshops) which may provide some relevant information |
| **Other physical properties** | * No information available | * Limited information about agglomeration state, surface area and surface charge of BW particles |  |
| **Chemical composition** | * Fine BW particles contain transition metals, elemental and organic carbon and other trace elements * Coarse BW particles contain mainly transition metals oxides and trace elements (i.e. Sn, Ba, Zr, Al) | * Limited information regarding specific organic constituents of BW PM10 * Outdated chemical profiles * Presence of Sb in modern BW PM10 * More in depth comparison of different types of brakes | * Monitoring of on-going projects (i.e. REBRAKE) and activities (i.e. published studies, workshops) which may provide some relevant information |
| **Emission factors** | * PM10 EFs of LDVs range between 2.0-8.8 mg km-1veh-1 with most studies finding values close to 7.0 mg km-1veh-1 * PM10 EFs of BW for LDVs are close to the Euro 4/5 standard**1, 3, 6, 7** * PM10 EFs of HDVs are one order of magnitude higher compared to LDVs * Most commonly used key tracer is Cu**7** | * How site specific these EFs are * No definition of “normal” or “typical” driving conditions * More in depth comparison of different types of brakes * Not very accurate PM2.5 EFs estimations * Cu has also other sources in ambient PM10 besides BW | * Monitoring of on-going projects (i.e. REBRAKE) and activities (i.e. published studies, workshops) which may provide some relevant information * Definition of “normal” or “typical” driving conditions |
| **Sampling procedures** | * SAE J2707 protocol for dyno testing - is not frequently used in published studies * A wide variety of speeds, accelerations and decelerations have been applied * On-road and laboratory studies as well as open and close sampling systems have been tested | * Lack of standardized sampling method * SAE J2707 protocol is not representative to real world conditions * No definition of “normal” or “typical” driving conditions (different speeds, accelerations and decelerations applied) | * Development of a set of recommended measurement and sampling procedures * Definition of “normal” or “typical” driving conditions |
| **Measurement techniques** | * Several different approaches of measuring BW particles * A wide variety of instrumentation has been used for PM distributions (i.e. MOUDI, APS, OPC) * A wide variety of instrumentation has been used for PN distributions (i.e. ELPI, SMPS, APS, TEM) | * Limitations in instrumentation capacity of measuring all particle sizes * Specific field tests combined with model evaluation | * Development of a set of recommended measurement and sampling procedures |
| **Impact on air quality** | * No information available | * It is unknown to what extend BW particles contribute to ambient PM10 and PM2.5 * Behavior of BW particles (dispersion, chemical availability, travelling distance, remaining time) * Differences between sites (busy junctions, traffic lights, corners) | * Monitoring of on-going projects (i.e. REBRAKE) and activities (i.e. published studies, workshops) which may provide some relevant information |
| **Soil and water contamination** | * 50% of BW debris is deposited on the road or nearby with its fate being unknown**1, 3, 4** | * Effects of brake wear particles in soil and water environments * Risk assessment * Questions about the adequacy of currently used markers (i.e. Cu) |  |
| **Health effects** | * BW contains particles from all fractions involved in the respiratory function * Some chemical constituents of BW have been recognized as dangerous or potentially dangerous for humans * In vitro and animal studies have shown adverse impacts of BW particles | * No comprehensive studies directly linking BW PM with adverse health effects on humans * Not all information needed is available (i.e. physical properties, chemical composition) * Difficulty in extrapolating in vitro and animal studies to humans * Personal exposure assessment | * Monitoring of on-going projects (i.e. REBRAKE) and activities (i.e. published studies, workshops) which may provide some relevant information * Organization of a session dedicated to the health effects of non-exhaust particles in a major conference on particles (e.g. ETH conference on particles) |
| **Mitigation measures** | Proposed measures are:   * Reduction of traffic emissions and exposure (i.e. improve traffic management, reduce traffic density, enforce traffic flow, make car free residential areas) * Changes in composition of pads * Shift to contact-free electrical brake systems * Mandatory regenerative braking * Build air-tight drum brakes for busses | * Cost of possible mitigation/reduction measures * Effectiveness of the different possible mitigation measures and impact on air quality | * Exchange of information with experts in the field |
| **Cost effectiveness** | * No information available | * Expected benefits from a possible reduction of BW EFs * Comparison of cost/effectiveness of possible abatement measures | * Exchange of information with experts in the field |

**Tyre and road wear (TRW) particles**

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|  | **State of the art of knowledge** | **Open issues / Research Needs** | **To be addressed within PMP** |
| **Contribution to PM10** | * 0.1-10% of tyre debris becomes airborne. The rest is deposited on the road or nearby **6, 8, 9** * 5-30% of non-exhaust traffic related PM10 emissions is attributed to TRWP**2** * TRWP particles are estimated to be 0.8-7% by mass of ambient PM10. In terms of ambient concentrations this corresponds to values ranging from 0.05 to 11 μg m-3 **9, 10, 11, 15** * Higher contributions have been reported with studded tyres | * Big differences among studies on the estimation of TRWP contribution to ambient PM10 * Factors affecting the estimation of TRW contribution to ambient PM10 and PM2.5 (i.e. distance from the road, type of sampling site) * Still some uncertainties on actual ambient concentrations of TRWP due to different methodologies (i.e. markers) used | * Monitoring of on-going projects (i.e. TIP project) and activities (i.e. published studies, workshops) which may provide some relevant information |
| **Factors influencing tyre wear content and generation rates** | * Driving behavior * Road surface characteristics such as material, texture pattern, porosity, wetness, silt loading, etc. * Tyre characteristics (type, size, tread depth, composition, mileage, set-up) * Vehicle characteristics (i.e. weight, load distribution, location of driving wheels, engine power) * Type of vehicle (LDV or HDV) | * Lack of standardized sampling methods. * Differences in location of tyre (front or rear), in type of tyre and in sampling procedure (on-road/ lab) often result in non-comparable results * No definition of “normal” or “typical” driving conditions * Tyres and pavement interaction alters the characteristics of wear particles compared to the original tyre tread | * Definition of “normal” or “typical” driving conditions |
| **Generation mechanisms** | * Abrasion processes which mainly generate coarse particles | * Mechanisms which create fine and possibly ultrafine particles * Understanding and modelling the mechanisms * Do pure tyre particle exist in the environment or they are always linked with pavement material | * Monitoring of on-going projects (i.e. TIP project) and activities (i.e. published studies, workshops) which may provide some relevant information |
| **Mass distribution** | * PM10 mass distribution is shifted towards larger sizes when studded tyres are tested compared to friction and summer tyres **11, 12, 13** * Tyre debris mass distribution has a clear mode at 50-80 μm **10** | * Bimodal and unimodal distributions have been reported for TRWP PM10 * More in depth study of how different types of tyres affect mass distribution * How mass distribution is affected by the type of vehicle (LDVs, HDVs) | * Monitoring of on-going projects (i.e. TIP project) and activities (i.e. published studies, workshops) which may provide some relevant information |
| **Size distribution** | * PN distribution of TRWP particles (<10 μm) is unimodal **10, 12, 13** * Regular tyres did not show ultrafine particles under “normal” driving/ cornering**16** * Studded tyres exhibit a noticeable peak in PN distribution within the ultrafine size fraction **12** | * Some studies report thepeak of the distribution at the UF size * UF particles generated only under extreme driving/cornering conditions? * How size distribution is affected by the road surface characteristics * How size distribution is affected by the type of vehicle | * Monitoring of on-going projects (i.e. TIP project) and activities (i.e. published studies, workshops) which may provide some relevant information |
| **Other physical properties** | * Quantitative analysis of particle morphology indicates the circularity value of 0.83 and the aspect ratio is 0.64 | * Limited information about the agglomeration state, the surface area and surface charge of TRWP particles |  |
| **Chemical composition** | * Fine TRWP particles contain transition metals, organic and inorganic Zn, elemental and organic carbon, S and Si * Coarse TRWP particles contain mainly transition metals oxides and trace elements (i.e. Cu, Si, Mn) * Thermogravimetric analysis of TRWP indicates that the particles are on average approximately 61% minerals, 13% carbon black, 16% polymers, and 10% plasticizers and oils | * Limited information regarding specific organic constituents of TRWP PM10 * Presence of PAHs in modern tyre’s wear PM10 * More in depth comparison between studded and friction tyres | * Monitoring of on-going projects (i.e. TIP project) and activities (i.e. published studies, workshops) which may provide some relevant information |
| **Emission factors** | * PM10 EFs of LDVs range between 3.5-9.0 mg km-1veh-1 for friction tyres with most studies giving 6.0 mg km-1veh-1 **9, 14** * Much higher EFs have been reported for studded tyres **12** * PM10 EFs of TRWP for LDVs are close to the Euro 4/5 standard * PM10 EFs of HDVs are one order of magnitude higher compared to LDVs * Most commonly used inorganic key tracer is Zn and organic SBR | * No definition of “normal” or “typical” driving conditions * Are EFs affected by the type of pavement and if yes in what extend * More in depth comparison of different types of tyres * Not very accurate PM2.5 EFs estimations * The use of Zn as a tracer since it has also other sources in ambient PM10 besides TRWP | * Monitoring of on-going projects (i.e. TIP project) and activities (i.e. published studies, workshops) which may provide some relevant information * Definition of “normal” or “typical” driving conditions |
| **Sampling procedures** | * There is not a standardized sampling procedure for TRWP particles * A wide variety of testing parameters have been applied * Both on-road and laboratory studies have been applied | * Lack of standardized sampling method * Not representative of real world conditions sampling methods * Lack of definition of “normal” or “typical” driving conditions (different speeds, cornering and accelerations applied) | * Development of a set of recommended measurement and sampling procedures * Definition of “normal” or “typical” driving conditions |
| **Measurement techniques** | * Several different approaches of measuring TRWP particles * A wide variety of instrumentation has been used for PM distributions (i.e. MOUDI, APS, cascade impactor) * A wide variety of instrumentation has been used for PN distributions (i.e. ELPI, SMPS, GRIMM, TOM) | * Limitations in instrumentation capacity of measuring all particle sizes * Specific field tests combined with model evaluation | * Development of a set of recommended measurement and sampling procedures |
| **Impact on air quality** | * No information available | * Reliable information to the extend that TRWP particles contribute to ambient PM10 and PM2.5 * Behavior of TRWP particles (dispersion, chemical availability, travelling distance, remaining time) * Differences between sites (busy junctions, traffic lights, corners, highways) | * Monitoring of on-going projects (i.e. TIP project) and activities (i.e. published studies, workshops) which may provide some relevant information |
| **Soil and water contamination** | * More than 90% of TRWP debris is deposited on the road or nearby with its fate being unknown * Maximum Predicted Environmental Concentrations of TRWP particles in surface waters and sediments have been estimated * Studies have shown that TRWP particles present potential risks for aquatic organisms | * Effects of tyre wear particles in soil and water environments should be evaluated * Risk assessment | * Monitoring of on-going projects (i.e. TIP project) and activities (i.e. published studies, workshops) which may provide some relevant information |
| **Health effects** | * TRWP contains particles from coarse and fine fraction * Some chemical constituents of TRWP have been recognized as dangerous or potentially dangerous for humans | * No comprehensive studies directly linking TRWP PM with adverse health effects on humans * Most studies examine TRWP related health effects in relation to the pavement wear, so the responses are not directly connected to tyres * In vitro and animal studies have reached contradictory conclusions * Not all necessary information is available (i.e. physical properties, chemical composition) * Difficulty in extrapolating in vitro and animal studies on humans * Personal exposure assessment | * Monitoring of on-going projects (i.e. TIP project) and activities (i.e. published studies, workshops) which may provide some relevant information * Organization of a session dedicated to the health effects of non-exhaust particles in one of the most important conferences on particles (e.g. ETH conference on particles) |
| **Mitigation measures** | Proposed measures are   * Reduction of traffic emissions and exposure (i.e. improve traffic management, reduce traffic density in city centres, enforce traffic flow, make car free residential areas) * Alternative pavements or adjusted pavement properties * Regulation of winter studded tyres | * Cost of possible mitigation/reduction measures * Effectiveness of the different possible mitigation measures and impact on air quality | * Exchange of information with experts in the field |
| **Cost effectiveness** | * No information available | * Expected benefits from a possible reduction of TRW EFs * Comparison of cost/effectiveness of different possible abatement measures | * Exchange of information with experts in the field |

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