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2009-08-06

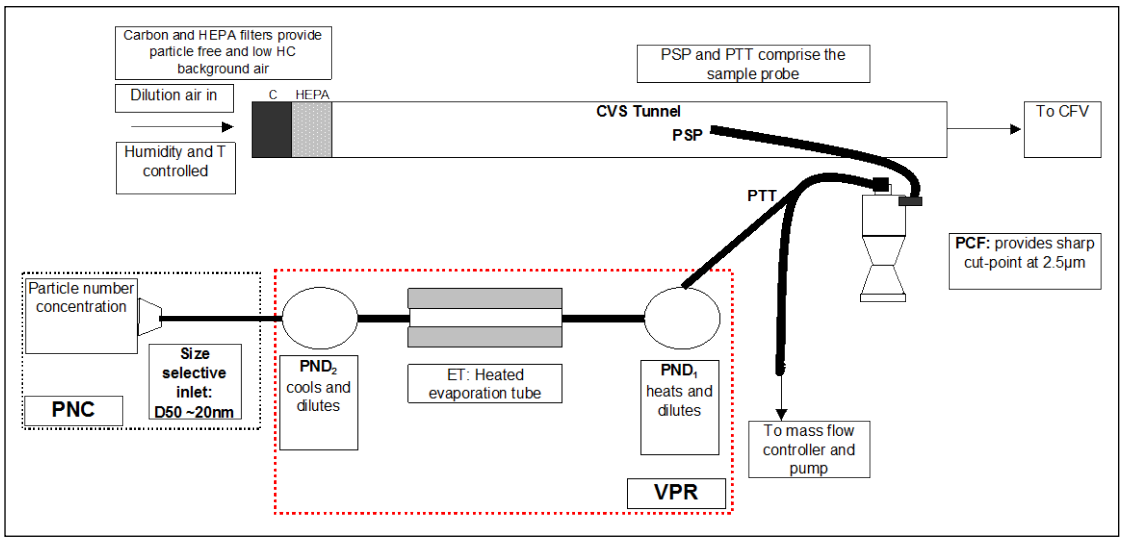
PMP measurement systems from ExIS

Background - The PMP programme

Concern for adverse health effects from vehicle particle emissions has become a great concern in the scientific community. Not only particle mass but rather the smallest particles, i.e. ultrafine particles (diameter <100 nm) and nanoparticles (diameter <50 nm) are suspected to cause both short-term (daily mortality and morbidity) and long-term health effects (e.g. cancer and cardiovascular diseases). Current emission norms for engines and vehicles only regulate the mass while particle number is dominated by small particles, with little contribution to the total mass. The issues above were the main drivers behind the Particle Measurement Programme (PMP), which was initiated by a Working Group of the UN-ECE.

The objective of the PMP programme was to develop new particle measurement technologies to complement or replace the existing particulate mass measurement, with special consideration to measuring particle emissions at very low levels. In the PMP programme, it was concluded to measure only solid particles, since these are anticipated to have the most adverse health effects. As the PMP measurement protocol now is being finalised (ECE Regulation R83), new measurement systems have been developed fulfil the criteria set in this regulation.

In brief, the PMP measurement system may be described as: a sampling probe inside the CVS-tunnel; a unit to remove coarse particles; a dilution unit to provide a dilution factors (DF) in the range of 1:1 to 1:1 000; an evaporation tube (ET) to heat the aerosol for volatile material removal; a second dilution stage to provide DF 1:1 to 1:30 and an instrument to measure the particle number concentration. A schematic picture of the PMP setup is shown in the figure below.



The measurement system comprises, among other things, a volatile particle remover (VPR) as one of the most important sub-systems. The VPR has a first hot stage of dilution (PND1) and a second cold stage (PND2) with an evaporation tube (ET) in

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between these stages. The ET, which must operate at a fixed temperature level between 300ºC and 400ºC, evaporates the potentially remaining volatiles from the hot stage of dilution. For particle counting, an instrument of the condensation particle counter (CPC) type is foreseen, i.e. the ECE Regulation R83 is written for this type of instrument. It should be noted that other types of instruments also can count the total number of particles but these can so far not be used for legislative purposes (e.g. certification, in-use compliance, and so on...). The specification for the CPC is thoroughly set, which has necessitated the development of adapted CPC instruments. Among other things, the lower cut-off diameter is limited to 23 nm, implying that the counting efficiency should be 50 % at this diameter and particles smaller than that are practically not counted. An optional cyclone can be used to remove the largest particles from the exhaust dilution tunnel.

PMP measurement systems offered by ExIS

ExIS is proud to offer the most comprehensive collection of instrumentation for PMP measurement among any distributor of such equipment. ExIS co-operate with the leading instrument manufacturers in this field, such as: Dekati (FIN), Grimm Aerosol Technik (DE), Matter Engineering (CH) and Ecomesure (F).

PMP CPC by Grimm

The PMP protocol sets a couple of requirements for the particle counter. Grimm has developed a special CPC to fulfil these requirements. The Grimm PMP CPC, model 5.412, is based on the well-proven 5.400 series. It includes many specific features first introduced by Grimm, such as, e.g., butanol safety measures (anti-spill and odour removal) that have later been copied by other manufacturers.

The CPC from Grimm can be used as a stand-alone instrument in combination with a dilution system, or as part of an integrated measurement system (see description of the RS-PMP instrument below). In the latter case, a specially developed CPC instrument is provided by Grimm.

The rotating disk diluter from Matter Engineering

The rotating disk diluter provided by Matter Engineering of Switzerland was the first commercial measurement system developed for PMP measurements. It was used as the “golden” measurement system in the PMP programme for light-duty vehicles. Thus, it is probably one of the best characterised measurement systems, which has manifested itself in numerous publications.

The rotating disk diluter provides a very wide range of dilution ratios ranging from 1:15 to 1:3 000, where the dilution ratio is infinitely variable. The latest version of the rotating disk diluter,

MD19-3E, was introduced in the spring 2009. The target for the new MD19-3E diluter was to achieve a lifetime of 1 000 hours for the diluter head. After testing a broad variety of materials and designs, the new MD19-3E fulfils this target. In addition to the above mentioned modifications, the peristaltic pump was replaced with a rotating pump, which dramatically reduces the maintenance, as there is no more need to change the peristaltic pump tube. The new cyclone is much smaller and does not need an extra pump. The lightweight cyclone also contributes to the reduction of the general size of the diluter head, improving handling, flexibility and ultimately save installation and maintenance costs.

The dilution principle of the full PMP-compliant system, meViPR, is based on the MD19-3E rotating disk diluter described above. The dilution system is a “plug-and-play” system that can be combined with a CPC for an integrated complete PMP measurement system. In the version of the meViPR system provided by ExIS, a CPC from Grimm is used. Remote operation of the meViPR via the AK protocol can be obtained on request.

Dekati DEED

The modifications in the PMP protocol in spring 2007 enabled significant simplifications of the PMP dilution system. The Dekati Engine Exhaust Diluter (DEED) has been designed with this objective in mind. No special user training is required; just switch on, warm up and go! The dilution ratio can be varied in two stages; i.e. high (for high emissions) and low (for low emissions). DEED is based on the ejector diluter principle, which has no moving parts and has a long record of reliable operation. Very low losses minimize the instrument downtime. Pressure balancing of the diluters eliminates influence of varying CVS pressure. DEED can be combined with any type of particle instrument. It is mounted in a single rack cabinet and can be controlled remotely via the AK protocol.

New developments for the DEED dilution system in 2008/2009 are a stainless steel sampling line and a “mini-CVS” device with an additional dilution stage for measuring upstream of a DPF. An optional “by-pass” of one of the ejector diluters that provides an additional outlet of sample gas for a low dilution ratio of 1:10 will follow in the autumn 2009.

RS-PMP from Ecomesure

The RS-PMP measurement system is produced by Ecomesure; a distributor of Dekati and Grimm products in France. The RS-PMP system was developed in co-operation between Ecomesure, Dekati and ExIS, with support from Grimm regarding CPC development.

The RS-PMP comprises a DEED dilution system (described above) and a Grimm CPC integrated in a measurement rack with a touch-screen PC-based control system. Instead of the limitation to high/low DR selection for the DEED, a mass flow controller provides a wider range of dilution ratios and an extension of the dilution ratio to 1:6 000, according to the requirements of the German automotive industry. All the requirements of a fully-integrated PMP measurement system for automatic checks (e.g. zero, leakage, etc.) are fulfilled by the RS-PMP.

The software has been developed for intuitive and simple operation and uses AK protocol for host computer communication. Convenient operation of the unit in test cell environment is enabled via the built-in touch-screen PC.

RS-PMP has been tested by the French official emission laboratory at UTAC with very good results and since then, at several automotive companies and automotive suppliers. Delivery of the RS-PMP system started in autumn 2008.

Further developments of the RS-PMP instrument since the introduction, besides the accessories already mentioned for the DEED above, are the adaptation to a smaller rack of only 140 cm (excl. rollers) in height and some internal hardware modifications. A further reduction to 120 cm is also an option if a somewhat smaller PC is mounted. Improvements of the RS-PMP software have also been dome subsequently. Future developments scheduled for introduction in late 2009 will provide real-time mass emission data in addition to particle number emissions.

Other particle instruments

As mentioned above, the CPC type of instrument is foreseen in the emission regulations. However, this instrument type has one crucial drawback, i.e. it counts all particles regardless of the particle size (within the lower and upper limitations of the instrument). Another feature of interest for research and development would be to also measure particle mass in real time. Both these shortcomings can be overcome by the alternative instruments discussed below.

This overview is limited to real-time instruments, since the requirements from the motor industry is usually that such instruments should be able to measure under transient conditions.

ELPI from Dekati

The principle of the Electrical Low Pressure Impactor (ELPI) was first conceived by Keskinen et al. at the

Tampere University of Technology (TUT) in Finland. ELPI was introduced on the market by Dekati in the mid 1990's as the first instrument that could measure a wide size range of particles in real time conditions. Since then, the ELPI instrument has been continuously developed further.

The ELPI operating principle is based on particle charging and classification in a cascade in a 13-stage impactor. The currents from each stage are measured with sensitive electrometers. With the optional absolute filter stage, ELPI can measure particle sizes between 7 nm and 10 μm with a time resolution of 1 Hz. The lowest impactor stage in ELPI is at 30 nm. Thus, an approximate total number of particles similar to PMP measurement can be obtained by just excluding the lowest filter stage from the summary of particles. In the open literature, there are numerous comparisons between ELPI and CPC instruments that show excellent correlations. Thus, ELPI can be used to provide more insight about e.g. the filtration efficiency of diesel particle filters (DPFs) as function of particle size.

The newest development of accessories for ELPI instrument includes a PCI board that provide 16 (used defined) analogue outputs for more convenient data transfer to the data logging system in the test cell. ELPI can also be remotely operated from a computer via, e.g., the Ethernet network. With the latest software, two single instruments can also be controlled by one computer.

DMM-230a from Dekati

The Dekati Mass Monitor (DMM) was developed to provide data on real-time particle mass emissions in the exhaust from diesel and petrol engines. The operating principle is similar to the well-proven ELPI instrument, with the addition of a mobility channel that provides data for calculation of the effective particle density that is used for determination of particle mass emissions.

Important factors such as, ease of use, robustness and reliability have been considered in the development of the DMM instrument. The latest version of the instrument, i.e. the DMM-230a, was introduced in the autumn 2008 (see description below).

Despite the discussed number-based measurement standards, the mass emission is still used in all regulatory measurements. Conventional PM measurements are based on gravimetric filter weighing, resulting only in a total, cumulative mass emission. Real-time data from DMM provides second-by-second information about particle total mass during accelerations, decelerations and different speed points immediately during the measurement. This is of particular interest in, e.g. determining DPF loading and development of regeneration strategies. DMM also provide information about the size distribution (mass median size and geometric standard deviation). With a detection limit below 1 μg/m^3, DMM provides about one order of magnitude better resolution than competing instruments in this field. Furthermore, DMM measures not only soot but all particles. Preferably, volatile particles can be removed in the dilution process to mimic the PMP sampling conditions for particle measurement, as described above.

The latest development of the DMM instrument hardware (DMM-230a) includes sheath air for the charger, which enables longer intervals of operating time between cleaning. The latest software also provides total particle number emissions similar to the PMP protocol. These features were introduced in the autumn 2008. Thus, DMM is now a "complete" instrument providing results on particle mass, total number and size distribution. New for 2009 is communication with the host computer in the test cell via the AK protocol. Upgrades of current units in operation to the DMM-230a hardware can be provided on request.

The meDisc from Matter Engineering

The meDisc is a new instrument from Matter Engineering. It is based on the same principle as a diffusion battery but with some additional innovations. The aerosol sample is charged and passes through 3 measurement stages. In the diffusion stage, the smaller particles are deposited at a series of stainless steel grids. After that, the aerosol passes through an induction stage and finally they are deposited on a filter. Sensitive current amplifiers measure the current from the mentioned stages. A calculation of particle number and size (20 to 200 nm interval) is made. Among the features of the meDisc instrument are that it is portable, robust and easy to use.

New on-going development for the meDisc includes the integration of a rotating disk dilution system to provide a portable measurement system (PEMS) for on-board measurement of particle number emissions. Although not compliant with the PMP protocol, this measurement system provides a very cost-effective and convenient solution for on-board measurements of particle number emissions.

Alternative dilution systems

Other dilution systems than those above, can be used for PMP sampling and dilution. The stand-alone versions of the rotating disk diluter and the DEED were already mentioned above but there are also other options.

FPS and double diluter

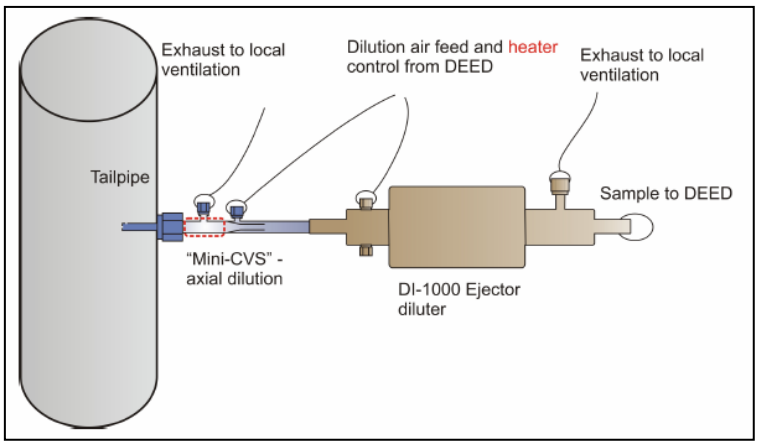
With an optional evaporation tube, the Dekati FPS dilution system can be used for PMP dilution. Also the Dekati double diluter system (DD) can be equipped with an evaporation tube for this purpose. For double diluters in use, the evaporation tube can be delivered as an accessory. As an alternative to the evaporation tube, a Thermodenuder can be used with either of these systems to remove volatiles.

Dilution for other instruments than a CPC

The PMP measurement protocol was intended to be used with a CPC. The CPC type of instrument has very high measurement resolution but cannot measure at high concentrations. Furthermore, it does not provide any information about particle size distribution. These shortcomings are obvious for research and development applications, where more information than just total particle number is of interest. At the same time, the PMP dilution is intended for high or very high dilution ratios, which implies that these dilution systems are not ideal for such applications.

For instruments that can characterize particle size or measure particle mass in real time, the dilution ratio should be kept relatively low compared to the dilution for a CPC (i.e. ultimately as low as 1:10 – or lower – when connected to a CVS tunnel), so that the concentrations can be maintained at a level suitable for such instruments. However, for these applications, a "PMP-like" dilution system is still desired, either for tailpipe sampling or for mounting directly on a CVS tunnel. With additional accessories, this can be accomplished with the FPS dilution system. Other customized solutions are based on the ejector diluters or axial diluter (DAD) from Dekati, both in combination with a heated sampling line for volatile particle removal.

In upstream DPF applications, a so-called "mini-CVS" axial dilution is used to avoid influence of pressure fluctuations. This option is already available for the DEED but can also be used in combination with ejector or axial diluters. This setup is shown in the figure here. A more detailed description is provided in the DEED accessory note (available through this link).



The alternative dilution systems described above can provide similar result as the PMP dilution regarding volatile particle removal of but with far less complexity and thus, they are much more cost-effective than fully PMP-compliant dilution systems. Contact us for more information about how to customize a solution for your particular measurement application.