Exhaust emission testing methods – BOSMAL’s legislative and development emission testing laboratories

The latest legislation regarding the reduction of harmful exhaust emissions, greenhouse gases and fuel consumption determines not only maximum permissible emissions factors, but also emissions testing methods and laboratory design and additionally leads to the development of new research methods. BOSMAL has risen to meet these challenges by investing in an updated, state-of-the-art emissions testing laboratory, housed within a climate chamber and in parallel investing in a completely new laboratory designed with incoming and future legislative requirements in mind. This paper presents BOSMAL’s improved M1/N1 vehicular emissions and fuel consumption laboratory in a climate chamber and BOSMAL’s standard chamber for the testing of vehicles in accordance with European Union, US and Japanese standards. The specifications, capabilities and design features of the sampling, analysis and development research possibilities and climate simulation systems are presented and discussed in relation to the increasing drive for cleaner, light duty road vehicles (including hybrids and electric vehicles). The recently-renovated laboratory with extended standard temperature range and the laboratory with climatic chamber are described in the context of the newest European Union legislation on the emission in the range of Euro 6d testing requirements. The laboratories permit BOSMAL’s engineers to compete in the international automotive arena in the development of new, more ecologically friendly and increasingly fuel efficient vehicles.

Key words: emission testing, emission test methods, climatic simulation, Euro 6, WLTP

1. Introduction

Vehicular transport is one of the biggest sources of harmful emissions and major changes in engine and vehicle design have been observed in recent years in response to emissions reduction legislation [1, 2] (in the EU: the introduction of the Worldwide Harmonized Light Vehicles Test Procedures (WLTP) over the years 2018/2019, and the scheduled introduction of Euro 6d in 2020/2022). An additional factor is widespread pressure for the reduction of greenhouse gases, mostly by reduction of CO$_2$ emissions. One of the major challenges for humanity is to fight global warming by reducing greenhouse gas emission (particularly CO$_2$; but CH$_4$ and N$_2$O as well) to the atmosphere, by 45 per cent by 2020 and 60 per cent by 2050 [3]. As mentioned, road transport is currently one of the largest single sources of CO$_2$ emissions in the EU [4] and the group of 20 largest economies (G20) accounted for 81% of global CO$_2$ emissions overworld [5]. The introduced changes in the legislation regarding type approval of new vehicles and the first vehicles registered determine new requirements in the test methodology in the emissions laboratories based on the WLTC cycles as a part of the Worldwide harmonized Light vehicles Test Procedures (WLTP in ECE Global Technical Regulation No. 15) which will decrease the divergence between laboratory test and real world emissions [6]. The European Union has introduced the new WLTC cycle, which ensures development of vehicle testing based on real-world driving data.

The legislation of other countries (with the motivation of reduction global CO$_2$ emissions) leads them to use the World-Harmonized Light-Duty Vehicles Test Procedure as well. The China 6 Standard will be mandatory from 2023 and is generally based on the Euro 6 regulation. In Japan the WLTP has been established in law from 2018 as the official procedure of emission testing, while the Indian government introduced the FAME policy (Faster Adoption & Manufacturing of (Hybrid & Electric Vehicle) to boost and support hybrid and electrical vehicles’ position on the market [7].

The fleet target for CO$_2$ emission in Europe in 2020 of 95 g/km and 68–78 g/km in 2025 (proposition) [8] leads to the inevitability of implementation of new technologies and high accuracy of measurements and vehicle testing. In order to meet the new requirements of legislation and changes in the methodology of emissions testing on the chassis dynamometers at BOSMAL AR&DI Ltd. [9], the company’s emissions laboratories are constantly improved and updated to meet the requirements of current and incoming regulations. Based on the demanding requirements of the test procedures (WLTP) and the limits enforced over the new driving cycle (WLTC), vehicle manufacturers should introduce many new solutions and new systems for management of aftertreatment systems. This forces the acquisition of as many data as possible and the use advanced measurement techniques during vehicle testing in the emission laboratory. Modern emissions testing laboratories like BOSMAL’s should be ready for incoming new measurement requirements – and must, in parallel, educate personnel, young engineers to be ready to fulfill the special customer requirements via high quality services and extensive knowledge. In 2017, the Emissions Laboratory No. 1 was equipped with a modern AVL emission system and together with the existing Emissions Laboratory No. 2 equipped with the Horiba emission system and the climate chamber, fully meets the current challenges posed by legislative requirements and development testing. Both BOSMAL’s laboratories have an Accreditation for homologation testing and meets requirements of the PN-EN ISO/IEC 17025:2005 standard (No. AB 128 – full scope of accreditation of the testing laboratory is available to download [9]). The laboratories provide
the opportunity to meet future requirements for low-emission testing of vehicles fuelled with conventional fuels, alternative fuels [10] and testing hybrid and electric vehicles.

This paper presents the research possibilities of BOSMAL’s emission laboratories in the scope of tests compliant with corresponding regulations and procedures as well as in developmental testing of vehicles of categories M and N.

2. Characteristics of the emissions laboratories

BOSMAL’s emissions testing laboratories are advanced, ambient (Emission Laboratory No. 1) and climate-controlled (Emission Laboratory No. 2) facilities for performing emissions, fuel consumption and performance tests over a range of driving cycles and a broad range of ambient conditions. Exhaust emissions testing itself is carried out with the aid of sampling bags (legislative tests), diluted and raw modal analysis (development tests) for use with CI, SI and hybrid vehicles. These facilities permit the execution of a wide range of legislative and development emissions tests, including:

- CVS bag diluted emissions testing to international standards [11, 12],
- \(\text{CO}_2\) emissions and fuel consumption measurement according to EU standards [13, 14],
- gravimetric and numerical quantification of particulate matter emission according to [15, 16],
- measurement of battery current balance according to [11],
- measurement of compounds which are unregulated in the EU, such as \(\text{N}_2\text{O}, \text{NH}_3\), using additional analyzers,
- measurement of soot and particulate matter from raw exhaust gases using additional devices,
- checks of vehicles according to Conformity of Production (COP) requirements [11, 12],
- maximum power measurement on the wheels of vehicle [14],
- electric consumption energy and electric vehicles range [11, 12].

A schematic diagram of both laboratories and vehicle soak areas are presented in Fig. 1. In the next part of this paper, the wide range of possibilities of emission tests in BOSMAL’s laboratories in the range of legislated and un-legislated emission tests are presented.

2.1. Legislative emissions measurement

As mentioned previously, BOSMAL’s laboratories permit the execution of legislative emissions tests according to existing international and global regulations such as [2, 17, 18]. These types of emission tests should fulfill restrictive requirements which are described in the regulations and therefore demand that the laboratories are equipped with suitable measurement devices of high accuracy.

Ambient conditions for exhaust emissions tests

The base or heart of the laboratories are their ambient and climatic chambers within which emissions, fuel consumption and performance measurements are performed. In the Emission laboratory No. 1 activities can be carried out in the temperature range +14°C to +28°C (Fig. 2). The chambers are equipped with temperature and humidity control systems, which facilitate the maintenance of the desired temperature and humidity levels. The software in Laboratory No. 1 (ambient chamber) (Fig. 3) permits the following during emission tests:

- temperature control within the range +14°C to +28°C,
- control accuracy (temperature tolerance): ±2.0°C,
- control over the humidity value during emissions tests: from 5.5 to 12.2 grams of water per kilogram of dry air for temperatures within the range +14°C to +28°C,
- variation in humidity level: ≤ 5%.

In Emission Laboratory No. 2 (Fig. 4), all activities can be performed at temperatures ranging from –35°C to +60°C. Such a temperature range far exceeds current legislative requirements; the 95°C temperature range capability is a response to the current and future requirements of engine and vehicle development projects, cold start ability at low temperatures, etc., and oil, fuel and catalyst manufacturers’ testing demands.

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**Fig. 1.** Technical drawing of BOSMAL’s Emission Testing Laboratories No. 1 (green description) and No. 2 (blue description) and heat soak areas.
During operation of the climatic chamber, (including during the execution of emission and vehicle performance tests), the chamber permits:

- temperature control over the range –35°C to +60°C,
- control accuracy (temperature tolerance): ±1.0°C (under static conditions, with zero heat load); ±1.2°C (during emissions tests); ±2°C (during performance tests),
- variation in humidity level: ≤5%,
- temperature gradient (with the chamber empty): 0.5°C per minute during warm-up and cool-down phases,
- control over the humidity value during emissions tests: from 5.5 to 15.0 grams of water per kilogram of dry air at temperatures ranging from +20°C to +35°C.

The climatic chamber’s control software permits the execution of user-defined automated programs, so that stabilization of the temperature in the chamber can be achieved well before any testing begins (Fig. 5).

The climatic chamber’s roof features standard lamps to provide even illumination throughout the chamber, but may be upgraded to include high-power solar lamps in the future, as required for the EPA’s supplemental air conditioning test cycle (‘SFTP-SC03’), performed at a temperature of +35°C with a solar flux of 850 ±45 W/m² [19, 20].

Aside from the possibility of thermal conditioning (‘soaking’) of vehicles inside the climatic chamber of Emission Laboratory No. 2, in the direct vicinity of both laboratories are located two soak areas and a soak container with key parameters as described in Table 2.

### Table 1. Specification of the ambient conditions regulation inside the BOSMAL’s Emission Laboratories

| Parameter                          | Unit | EmiLab.1 | EmiLab.2 |
|------------------------------------|------|----------|----------|
| Temp. control range                | °C   | 14/+28   | 35/+60   |
| Control accuracy during emission test (tolerance) | °C   | ±0.2     | ±1.2     |
| Humidity during emission test      | gH₂O/kg dry air | 5.5–12.2 | 5.5–15.0 |
| Variation in humidity level        | %    | ≤5       | ≤5       |

### Table 2. Specification of BOSMAL’s soak areas

| Parameter                  | Soak Area 1 | Soak Area 2 | Soaking Container | EmiLab.2 |
|----------------------------|-------------|-------------|-------------------|----------|
| Vehicle capacity – large car/small van | 6 pcs. | 14 pcs. | 2 pcs. | 7–8 pcs. |
| Temperature range          | +20°C,+30°C | +20°C,+28°C | +20°C,+40°C | −35°C,+60°C |
| Battery charging           | Yes         | Yes         | No                | Yes      |
Chassis dynamometers

The laboratory chassis dynamometers (AVL Zoellner 48” compact) are mounted in the ambient and climatic chamber floors (see Fig. 2 and Fig. 4). Fully integrated in the laboratory management system (AVL iGEM and HORIBA VETS), they are controlled by software which includes functions not only for emissions testing according to international test cycles (EU cycles: WLTC, RTS95 (used for RDE development work), NEDC, WMTC; US cycles: FTP-75, HWFET, US06; Japanese cycles: JC08), but also for obtaining engine power measurements under both static and dynamic conditions and can be capable of simulating various non-legislative driving cycles used for R&D purposes. In order to carry out cycle-based emissions tests, the laboratories feature a single roller chassis dynamometer in Emission Laboratory No. 1 (2WD) and a twin axle single roller chassis dynamometer in Emission Laboratory No. 2 (4WD), both made by AVL of Austria, with the specification presented in Table 3.

Table 3. Specification of the chassis dynamometers

| Parameter                  | Unit | EmiLab.1 | EmiLab.2 |
|----------------------------|------|----------|----------|
| Number of axles            | pcs. | 1        | 2        |
| Number of rollers          | pcs. | 2        | 4        |
| Roller diameter            | mm   | 1219.2   | 1219.2   |
| Distance between inner roller edges | mm   | 914      | 914      |
| Axle base                  | mm   | 2 000–4 600 | 2 000–4 600 |
| Nominal power              | kW   | 153      | 153      |
| Peak power                 | kW   | 258      | 258      |
| Maximum velocity           | km/h | 200      | 250      |
| Simulated mass 2WD         | kg   | 454–5448 | 454–5448 |
| Simulated mass 4WD         | kg   | –        | 800–5448 |
| Motorcycle sim. mass       | kg   | –        | 150–454  |

The AVL-Zoellner 48” compact chassis dynamometer systems in BOSMAL’s laboratories for exhaust emissions analysis is designed for testing 2 axled motor vehicles with either front, rear and all-wheel drive and with axle loads of up to 2000 kg. The design of these chassis dynamometers are based on the US EPA C100001T1 specification and the AAIM/EPA/CARB acceptance procedure, Regulation GTR 15, Regulations EC (No. 715/2007, 692/2008 and 595/2009), EPA 40 CFR 1066, TRIAS 31-J042(3)-01 and TRIAS 99-006-01. These test systems are designed with the AC power engines positioned between the rollers. The wind-speed fans are positioned in front on the chassis dynamometer to simulate speed-proportional air flow at speeds 0–150 km/h (Fig. 2 and Fig. 4). The chassis dynamometer in the Emission Laboratory No. 2 includes the functional extension to test motorcycles (Fig. 6), mopeds and scooters with the inertia simulation range from 150 kg to 454 kg.

Emissions testing systems

The laboratories feature emissions analysis suites from the Austrian firm AVL in Emission Laboratory No. 1 and the Japanese firm Horiba in Emission Laboratory No. 2. The AVL emissions system in Laboratory No. 1 consists of a CVS i60 sampling system, together with a dilution tunnel (Fig. 7), a set of AMA i60 SII D1 LE exhaust analyzers and an AVL iGEM management system (Fig. 8).

The Horiba emissions system in Laboratory No. 2 consists of a CVS-CFV sampling system, together with a dilution tunnel (Fig. 9), a set of MEXA 7400 HRTLE exhaust analyzers and a VETS7000NT management system (Fig. 10).
Sample bags of both emissions systems for the sampling of ambient and exhaust gases are housed in a heated, insulated units maintained at 35°C to prevent condensation. The dilution tunnels are connected to installations for filtering diluted exhaust gas through particulate matter filters, which are weighed before and after testing to quantify emission of PM from any vehicle type. The AVL iGEM control software and the Horiba VETS7000NT control software maintain the analyzers and their various activities during testing and analysis of bag emissions, such as calibration, purging, etc. Both systems automate the signals sent to the driver’s aids, and include options for testing over all the test cycles previously mentioned, as well as any other cycle added to the system via the implementation of new programs. Additionally, the software monitors the laboratories’ environmental parameters (temperature, pressure, humidity) as well as ambient concentrations of HC, CH₄, CO, and O₂ within the chamber to ensure that each test is safe, reliable, repeatable and thoroughly documented.

The climatic chamber for PM stabilization and weighting

European emission legislation (and others) also require increased accuracy of particulate sample filter weighing, as well as specially equipped climatic rooms in which to install the microbalance for filter weighing. The climatic chamber for stabilization and weighing of PM membrane filters for use in emission tests has been described previously [19], and is shown in Fig. 11. The temperature inside the chamber is maintained within the range +20°C to +30°C (with a tolerance of ±2°C), and the humidity is maintained within the range 35%–55% (with a tolerance ±6%), throughout the prescribed stabilization and weighing periods for the PM membrane filter.

REESS charge balance measurement

The measurement of RCB in all phases of WLTC is required for all batteries installed on the vehicles (all low voltage and high voltage batteries) [11, 15]. The electricity balance (ΔREESS) is equivalent to the value of current at the end of the cycle compared to the beginning of the cycle, multiplied by the nominal battery voltage (e.g. 12 V) to give a final value for the change in electrical power. The REESS charge balance measurement for WLTP testing can have an influence on the final fuel consumption results and a legislative exhaust emissions laboratory must be equipped with measurement devices capable of providing this functionality. The current measurement on the electrical and hybrid vehicles during all type of emission test and preconditioning cycles as well. In BOSMAL’s emissions systems, those requirements are fulfilled by using a Hioki Power PW3390 Analyzer and suitable current measurement probes (Fig. 12) in the Horiba VETS emission system and standalone current probes directly connected to the AVL iGEM system (Fig. 12, Table 4). The current measurement is integrated over time at minimum frequency of 20 Hz yielding the measured value of current, expressed in ampere-hours Ah [21]. The Hioki Power Analyzer PW 3390 has four current channels and four voltage channels, which provide possibilities to measure all four current and voltage signals at the same time.

2.2. Emissions measurement for development purposes (non-legislative measurements)

BOSMAL has over 45 years’ experience and wide possibilities of development emission measurement with diluted and undiluted modal analysis of exhaust gas. BOSMAL’s laboratories have the possibilities to carried the engine
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('Pre-Cat') and tailpipe ('Post-Cat') development undiluted measurement and diluted modal analysis from the dilution tunnel on a second-by-second basis (for use with CI, SI and Hybrid vehicles). These facilities permit the execution of a wide range of development emissions tests, including:

- modal analysis of diluted and raw exhaust gases,
- modal analysis of raw exhaust sampled from two locations (nominally pre-cat & post-cat, but the sampling locations are flexible),
- measurement and archival of temperatures from up to eight thermocouples mounted at different locations on the vehicle and on the exhaust line at 10 Hz,
- measurement of the air-fuel ratio and calculation of λ and the EGR percentage,
- catalytic converter efficiency testing (and determination of light-off time) for elimination of THC, CH₄, NMHC, CO, NO, NO₂ and NOₓ,
- measurement of unregulated compounds such as N₂O, NH₃ using additional analyzers,
- measurement of modal (raw, undiluted exhaust gas) PN using an additional particulate counter with advanced, optional hardware for sampling under high temperature and pressure conditions,
- unregulated soot measurement of undiluted exhaust gas,
- opacity N [%] or absorption coefficient k [m⁻¹] measurement of undiluted exhaust gas.

The mentioned measurements are described below, with the examples of devices used in BOSMAL’s laboratories.

Views of the prefilters of the raw exhaust gas sampling lines for emissions measurements using the AVL emission system and Horiba OVNs (raw exhaust gas sampling lines of Horiba emission systems) are presented below (Fig. 13 and Fig. 14). The analyzers used in both emission system with the ranges of gases are presented in Table 5 and Table 6.

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Table 4. Specification of the Hioki 3390 Power Analyzer and the current probes CT6843 and CT6844

| Parameter           | Unit     | Hioki 3390       | Current probes CT6843 |
|---------------------|----------|------------------|-----------------------|
| Voltage range       | V        | 15–1500          | 500                   |
| Current range       | A        | 0.1–20 kA        | 200                   |
| Frequency range     | Hz       | 0.5–20           | 500                   |
| Current channels    | –        | 4                | 500                   |
| Voltage channels    | –        | 4                | 200                   |

Table 5. Component detection ranges of the Horiba MEXA exhaust gas analysis system

| Component (detection principle) | Low Emission | Diluted | PreCat | PostCat | EGR | Tracer CO₂ |
|---------------------------------|--------------|---------|--------|---------|-----|------------|
| CO (L) (NDIR) ppm              | 0 – 500      | 0 – 1 000 | 0 – 5 000 | 0 – 5 000 | -   | -          |
| CO (H) (NDIR) %                | -            | 0 – 10   | 0 – 10  | 0 – 5 000 | -   | -          |
| CO₂ (NDIR) %                   | 0 – 20       | 0 – 20   | 0 – 20  | 0 – 20   | 0 – 20 | 0 – 20     |
| O₂ (MPA) %                     | -            | -        | 0 – 25  | -        | -   | -          |
| NO (CLD) ppm                   | 0 – 100      | 0 – 1 000 | 0 – 6 000 | 0 – 6 000 | -   | -          |
| NO (CLD) ppm                   | -            | -        | 0 – 6 000 | 0 – 6 000 | -   | -          |
| THC (FID) ppmC₁                 | 0 – 50       | 0 – 3 000 | 0 – 3 700 | 0 – 3 700 | -   | -          |
| THC (HFID) ppmC₁               | -            | 0 – 3 000 | -       | -        | -   | -          |
| CH₄ (GC-FID) ppmC₁             | 0 – 400      | -        | 0 – 20 000 | 0 – 20 000 | -   | -          |
| THC / CH₄ (HFID) ppmC₁         | -            | -        | 0 – 3 700 (THC) | 0 – 3 700 (THC) | -   | -          |
Table 6. Component detection ranges of the AVL AMA exhaust gas analysis system

| Component (detection principle) | Diluted | PreCat | PostCat | Tracer CO₂ |
|---------------------------------|---------|--------|---------|------------|
| Line                            | Range   | Range  | Range   | Range      |
| CO (L) (NDIR)                   | [ppm]   | 0 - 5 000 | 0 - 1 000 | 0 - 1 000 | -          |
| CO (H) (NDIR)                   | [%]     | 0 - 0.5 | 0 - 10  | 0 - 10    | -          |
| CO₂ (NDIR)                      | [%]     | 0 - 20  | 0 - 20  | 0 - 20    | 0 - 20     |
| O₂ (PMD)                        | [ppm]   | -      | 0 - 2 50 000 | 0 - 2 50 000 | -          |
| NOx / NO (CLD)                  | [ppm]   | 0 - 1 000 | 0 - 6 000 | 0 - 6 000 | -          |
| THC (FID)                       | [ppmC1] | 0 - 3 000 | 0 - 37 000 | 0 - 10 000 | -          |
| CH₃ (NMHC Cutter)               | [ppmC1] | 0 - 400 | 0 - 20 000 | 0 - 3 000 | -          |

The raw modal results calculation is based on the Tracer CO₂ method in the Horiba emission system as a stand-alone line. In the AVL emission systems, the Tracer CO₂ method is used, and the second possibility in AVL emission system is the measurement of highly dynamic gas flows. The AVL emission system was built to include the AVL FLOWSONIX™ Air measurement unit (Fig. 15). The ultrasonic transit time measurement principle combined with specifically developed AVL ultrasonic sensors is capable of measuring highly dynamic bidirectional air flows with a data rate of up to 1 kHz [22]. The working range of air flow measurement is 0–2600 kg/h. The ultrasonic sensor is more precise in comparison to the CO₂ Tracer method during the emission testing of vehicle with partially or fully hybridized powertrains (including mild hybrids and the simplest variants: micro hybrids with Stop & Start systems).

Fig. 15. The AVL FLOWSONIX™ unit mounted on the dilution tunnel in Emission Laboratory No. 1

Dedicated RNC measurement devices

Emissions of reactive nitrogen compounds (RNCs) such as nitric oxide (NO), nitrogen dioxide (NO₂), and ammonia (NH₃) have a real impact on air quality in city centres and urban agglomerations. Unregulated compound of exhaust emission gas like NH₃ contributes to the formation of secondary particulate aerosols, an important air pollutant of impacts on human health [24]. In BOSMAL’s laboratories online modal measurements are provided by two types of RNC/NH₃ analysers: MEXA 1400QL-NX (Fig. 16) measuring all RNCs, produced by the Japanese firm HORIBA and AMA i60 LDD measuring NH₃ only (Fig. 16) produced by the Austrian firm AVL. The specifications of both devices are presented in Table 7. The MEXA-1400QL-NX is an analyser for direct measurement of all four RNCs: NO, NO₂, N₂O, NH₃ simultaneously in exhaust gas in real-time, sampled at the tailpipe or closer to the vehicle’s aftertreatment or even in the CVS system as well. The measuring principle of MEXA-1400QL-NX is based on the IR spectroscopy method.

Table 7. Specification of the HORIBA MEXA-1400QL-NX and AVL AMA i60 LDD

| Parameter                      | HORIBA MEXA-1400QL-NX | AVL AMA i60 LDD |
|-------------------------------|-----------------------|-----------------|
| Measuring principle           | Quantum Cascade Laser infrared spectroscopy | Fourier-Transform InfraRed (Laser Diode Detector) |
| Min. NH₃ range                | 0–50 ppm              | 0–100 ppm       |
| Max. NH₃ range                | 0–2 000 ppm           | 0–5 000 ppm     |
| Sample gas condition          | 113°C                 | 190°C           |
| Permissible Ambient Temperature | Stable within the range of 5°C to 35°C | +5°C up to +40°C, optional air condition on request |
| Response time T₁₀⁻₅₀ for NH₃  | Within 2.5 s (by switching N₂ to NH₃ at 50 ppm range) | ≤ 1.5 sec (depending on the flow) |

Fig. 16. View of software of HORIBA MEXA-1400QL-NX stand-alone analyzer of NH₃ in the emission laboratory

Fig. 17. View of software of AVL AMA i60 LDD stand-alone analyzer of NH₃ in the emission laboratory
Soot measurement

All combustion engines, but especially compression ignition and spark ignition engines with direct injection (DISI) produce unhealthy particles (soot) which are one of dangerous pollutants emitted by combustion engines and which have been regulated in various ways since the 1980s [25, 26]. In development testing on the chassis dyno, BOSMAL can carry out undiluted soot measurements performed using AVL Opacimeter AVL439 (Fig. 18) and Micro Soot Sensor AVL483 (Fig. 19) devices as tailpipe and engine out measurements. In the case of engine out measurements a special conditioning unit controlled by AVL483 (high pressure optional unit) is required, which provide the possibility to perform development testing of engines in the range of pressure relative to ambient pressure from 0 mbar to +3000 mbar. The exhaust gas temperature could increase up to 800°C in comparison to tailpipe measurement, where the temperature is normally limited to 600°C.

Particle number counter

Measurement of particle number (PN) in the range of direct undiluted exhaust was introduced in BOSMAL’s laboratories in 2010. The AVL APC features a wide measuring range (CPC count ≤ 10 000 particles/cm³) for various engine-aftertreatment combinations, so that repeatable results can be obtained for CI and DISI vehicles with engine out sampling and tailpipe sampling by using a high pressure and temperature solution (Fig. 21). This specification provides to use concentration reduction (known as ‘PCRF’ in this context) in the range of 2 000–20 000 compared to 100–3 000 for tunnel measurement (the legislative method). The main difference of the principle of both options’ functionality is the possibility to increase the PND1 dilution level and updated software is required for this purpose. While the main purpose of these systems is legislative measurements, the systems also archive second-by-second data of raw PN emissions from undiluted exhaust gases, so that comparisons with the second-by-second data of PN emissions from the legislative tunnel measurement could be presented. Such a comparison between diluted and undiluted measurement possibilities is presented in Table 8.

TSI EEPS size distribution spectrometer

The current debate in the EU on the application of the particle measurement size below 23 nm (down to 10 nm) [16, 24] creates the requirement to measure and test the emission of particle number in the range below the current lower limit. This can be achieved via the Engine Exhaust Particle Sizer (EEPS™) 3090 spectrometer device, which measures the size distribution of engine exhaust particle emissions from 5.6 to 560 nm with the fastest time resolution available (10 Hz). Users can visualize and study the dynamic behaviour of particle emissions that occur during
transient test cycles, during the first few seconds following a cold start, or during regeneration of a particle trap or diesel particulate filter (DPF). For development purposes, it is possible to analyse the particle size distribution as a function of particle size (Fig. 21). The sampling line is heated up to 80°C, 120°C or 150°C and the gases are diluted in the Rotating Disk Thermodiluter which is especially suited for sampling, diluting, and conditioning exhaust particles in based on two nominal dilution ranges: 1st range from 15:1 to 300:1 and 2nd range from 150:1 to 3 000:1. A view of the thermodiluter mounted at the tailpipe sampling point is presented in Fig. 22.

3. RDE testing

New requirements for type approval testing [11, 15] include real driving emissions (RDE) tests as well. RDE tests require the measurement of exhaust emissions outside the laboratory using portable emissions measurement systems (PEMS), but for R&D purposes, such devices can also be used in the laboratory on a chassis dynamometer instead of on the road. As such, PEMS systems can be understood to be components of a modern exhaust emissions laboratory. BOSMAL’s laboratories are equipped with an AVL M.O.V.E. GAS PEMS and PN PEMS system and a HORIBA OBS-ONE PEMS system. Both systems and their use for legislative and development testing will be presented during the 8th International Congress on Combustion Engines in Cracow, Poland, on 17–18 June, 2019 and a description and detailed technical discussion will be published in this journal with the title Development of RDE test methodology in light of Euro 6d emissions requirements (Author: Dr Piotr Pajdowski, Co-authors: Joseph Woodburn, Piotr Bielaczyc, Bartosz Puchałka). Overall views of both PEMS systems are presented in Fig. 23 and Fig. 24.

4. Summary

The introduction of new, ever more stringent emissions standards, such as Euro 6d [11, 15, 17, 26], the planned Euro 7 standard, globally-harmonized test procedures (the WLTP) and even local emissions limits (city/local authority vehicle circulation restrictions) [27] necessitate continuous financial and intellectual investment in emissions testing systems, technical know-how and thorough knowledge of test procedures and the interpretation of results.
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automotive arena in the testing and fulfilling of new requirements, more complex measurement techniques used in automotive emissions research. The laboratories have already been put to use in a range of projects representing the cutting-edge tests required by the industry, including a wide range of exhaust emissions analysis, performance tests, fuel consumption tests, engine oils and fuel assessments, after-treatment systems research and cold start drivability/emissions testing at various test cell temperatures. The performance of the new facilities have been highly satisfactory for BOSMAL and its customers alike. In addition to changes to testing hardware and its control software, test methods must be continually evaluated and developed, in concert with the demands of relevant legislation and private customers’ expectations and test specifications. Possession of an accreditation No. AB 128 (Fig. 25) for type approval in the range of exhaust emissions and fuel consumption testing mean BOSMAL has a place among the most professional and advanced laboratories of this type in Europe. The BOSMAL AR&DILtd. is a private and independent company which are offering wide range of accredited testing, service, design and production for all Customers who want to perform specialized works with high professional quality.

Nomenclature

| CARB | California Air Resources Board |
| CI | Compression ignition |
| CNG | Compressed natural gas |
| CVS | Constant volume sampling |
| DISI | Direct injection spark ignition |
| DPF | Diesel particulate filter |
| EPA | Environmental Protection Agency |
| EU | European Union |
| FTIR | Fourier-transform infrared spectroscopy |
| GHG | Greenhouse gas emissions |
| IR | Infrared spectroscopy |
| nm | nanometer |
| PEMS | Portable Emission Measurement System |
| FM | Particulate mass |
| PN | Particle number |
| PNC | Particle number counter |
| ppm | Parts per million |
| RCB | REESS charge balance |
| RDE | Real Driving Emissions |
| REESS | Rechargeable electric energy storage system |
| RNC | Reactive Nitrogen Compound |
| SCR | Selective Catalytic Reduction |
| SFTP | Supplemental Federal Test Procedure |
| SI | Spark ignition |
| VETS | Vehicle Emissions Testing System (Horiba trademark) |
| WLTC | Worldwide harmonized light-duty cycle |
| WLTP | Worldwide harmonized light-duty test procedures |

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