Article citation info:
BIELACZYC, P., KLIMKIEWICZ, D., WOODBURN, J., SZCZOTKA, A. Exhaust emission testing methods – BOSMAL's legislative and development emission testing laboratories. *Combustion Engines*. 2019, **178**(3), 88-98. DOI: 10.19206/CE-2019-316

Piotr BIELACZYC
Dariusz KLIMKIEWICZ
Joseph WOODBURN
Andrzej SZCZOTKA

CE-2019-316

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 climatic 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_2O 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 (proposal) [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 fulfil 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],
- 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 N_2O, 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 unlegislated 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.

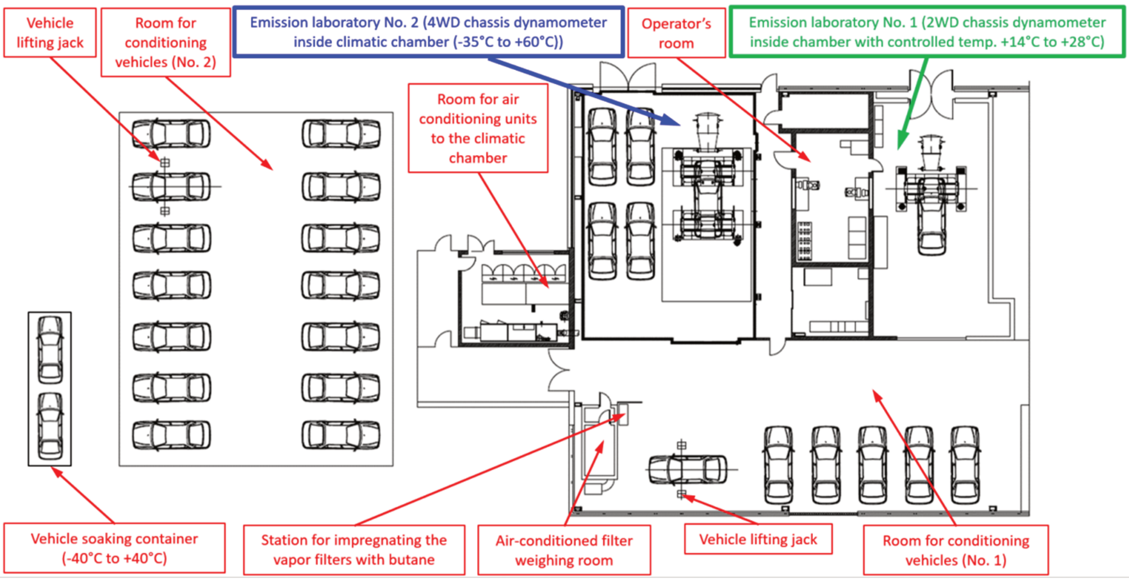

Fig. 1. Technical drawing of BOSMAL's Emission Testing Laboratories No. 1 (green description) and No. 2 (blue description) and heat soak areas

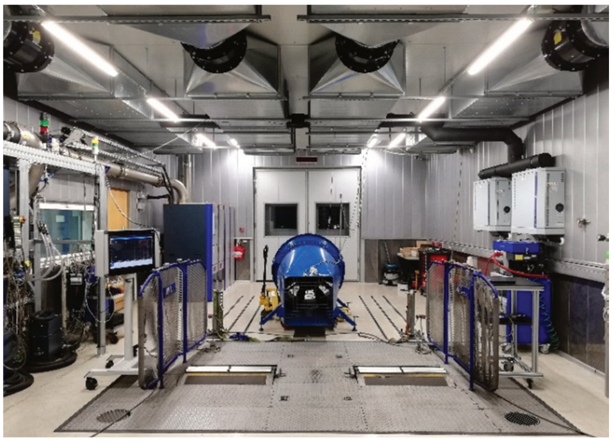

Fig. 2. Internal view of the ambient chamber of Emission Laboratory No. 1, showing the single roller chassis dynamometer and the windspeed fan in front

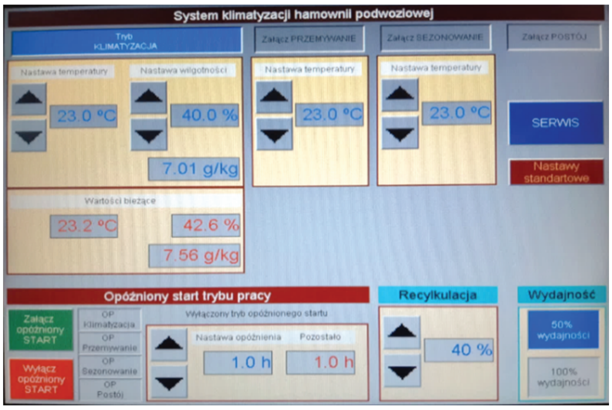

Fig. 3. Air conditioning control system in Laboratory No. 1

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/m^2 [19, 20].

In addition to fulfilling US testing requirements, such an upgrade would also extend the laboratory's capabilities in terms of reproduction and simulation of real driving emissions tests, including worst-case scenarios.

A simple comparison of the ambient conditions in both BOSMAL's laboratories is presented in Table 1.

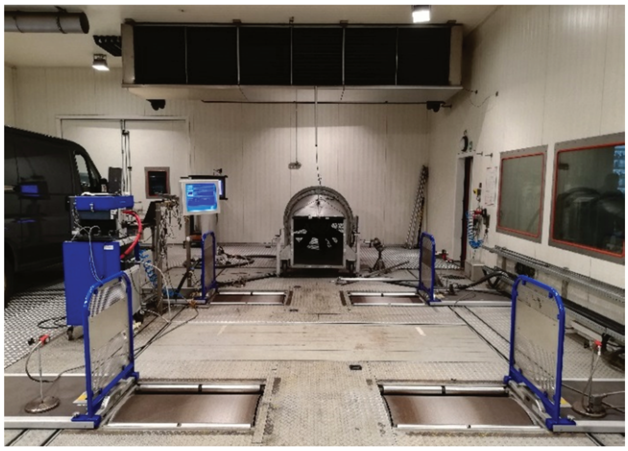

Fig. 4. Internal view of the climatic chamber of Emission Laboratory No. 2, showing the double rollers chassis dynamometer and the windspeed fan in front

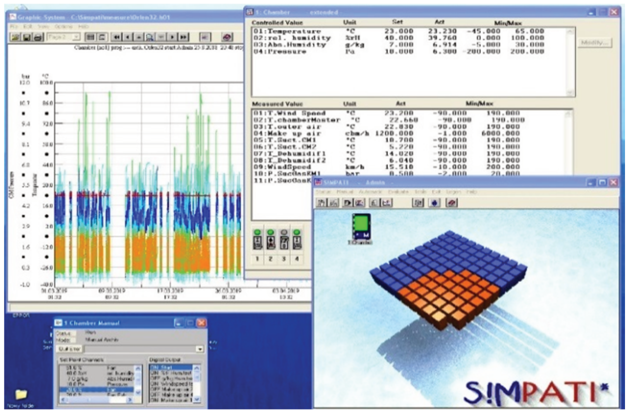

Fig. 5. Simpati climatic chamber control software in Laboratory No. 2

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	±2.0	±1.2
Humidity during emission test	gH_2O/kg dry air	5.5–12.2	5.5–15.0
Variation in humidity level	%	≤ 5	≤ 5

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 2. Specification of BOSMAL's soak areas

Parameter	Soak Area 1	Soak Area 2	Soaking Container	EmiLab2
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	–40°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
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 C100081T1 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).

Fig. 6. View of a motorcycle positioned on the chassis dynamometer in Emission Laboratory No. 2

Fig. 7. AVL's dilution tunnel in Emission Laboratory No. 1

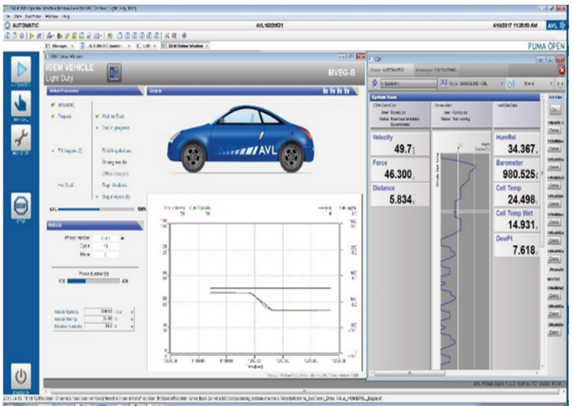

Fig. 8. AVL iGEM emission system management in Emission Laboratory No. 1

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).

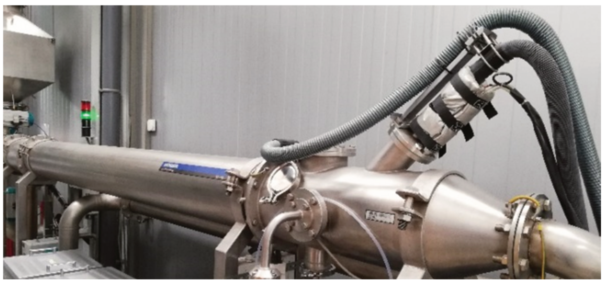

Fig. 9. HORIBA's dilution tunnel in Emission Laboratory No. 2

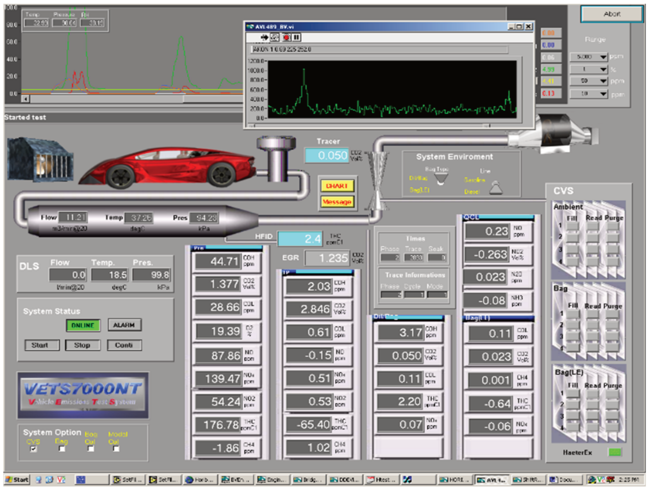

Fig. 10. HORIBA VETS emission system management in Emission Laboratory No. 2

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 HoribaVETS7000NT 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, CH_4, CO, and O_2 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 (ΔE_{REESS}) 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 to possibilities to measure all four current and voltage signals at the same time.

Fig. 11. The balance, filter conditioning racks and filter cartridges in the climate controlled weighing chamber

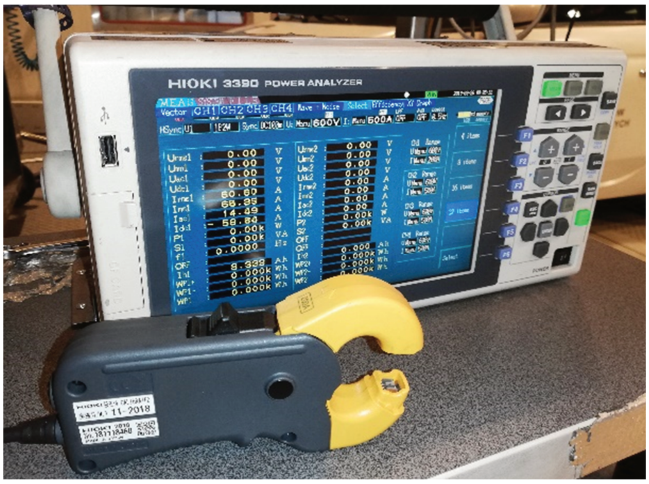

Fig. 12. Hioki Power Analyzer PW3390 with the current probe using as a set (Horiba system) or as a standalone device (AVL iGEM system)

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

('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:

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

Parameter	Unit	Hioki 3390
Voltage range (7 ranges)	V	15–1500
Current range	A	0.1–20 kA
Frequency range	Hz	0.5–20
Current channels	–	4
Voltage channels	–	4
Parameter	**Unit**	**Current probe CT6843**
Rated current	A	200
Operating temperature	°C	–40 to +85
Maximum frequency	kHz	500
Parameter	**Unit**	**Current probe CT6844**
Rated current	A	500
Operating temperature	°C	–40 to +85
Maximum frequency	kHz	200

- 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, CH_4, NMHC, CO, NO, NO_2 and NO_x,
- measurement of unregulated compounds such as N_2O, NH_3 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.

Fig. 13. The prefilters of tailpipe modal measurement of AVL iGEM emission system

Fig. 14. The Horiba OVNs of tailpipe modal measurement of Horiba emission system

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

MEXA 7400 HTRLE + MEXA 7500 DEGR Modal Emission Analysis System								
Line			Low Emission	Diluted	PreCat	PostCat	EGR	Tracer CO_2
Component (detection principle)			Range	Range	Range	Range	Range	Range
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	-	-
CO_2	(NDIR)	[%]	0 - 20	0 - 20	0 - 20	0 - 20	0 - 20	0 - 20
O_2	(MPA)	[%]	-	-	0 - 25	-	-	-
NO_x	(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 - 37 000	0 - 37 000	-	-
THC	(HFID)	[ppmC1]	-	0 - 3 000	-	-	-	-
CH_4	(GC-FID)	[ppmC1]	0 - 400	-	0 - 20 000	0 - 20 000	-	-
THC / CH_4	(HFID)	[ppmC1]	-	-	0 - 37 000 (THC) 0 - 20 000 (CH_4)	0 - 37 000 (THC) 0 - 20 000 (CH_4)	-	-

Table 6. Component detection ranges of the AVL AMA exhaust gas analysis system

AVL AMA i60 Modal Emission Analysis System						
Line			Diluted	PreCat	PostCat	Tracer CO_2
Component (detection principle)			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	-
CO_2	(NDIR)	[%]	0 - 20	0 - 20	0 - 20	0 - 20
O_2	(PMD)	[ppm]	-	0 - 250 000	0 - 250 000	-
NO_x / NO	(CLD)	[ppm]	0 - 1 000	0 - 6 000	0 - 6 000	-
THC	(FID)	[ppmC1]	0 - 3 000	0 - 37 000	0 - 10 000	-
CH_4	(FID) (NMHC Cutter)	[ppmC1]	0 - 400	0 - 20 000	0 - 3 000	-

The raw modal results calculation is based on the Tracer CO_2 method in the Horiba emission system as a stand-alone line. In the AVL emission systems, the Tracer CO_2 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 CO_2 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).

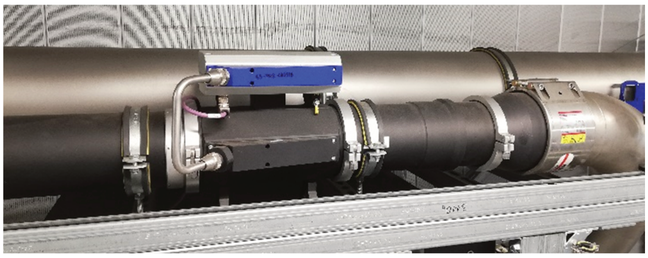

Fig. 15. The AVL FLOWSONIX™ unit mounted on the dilution tunnel in Emission Laboratory No. 1

Dedicated RNC measurement devices

Emissions of reactive nitrogen compounds (RNCs) such as nitric oxide (NO), nitrogen dioxide (NO_2), and ammonia (NH_3) have a real impact on air quality in city centres and urban agglomerations. Unregulated compound of exhaust emission gas like NH_3 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/NH_3 analysers: MEXA 1400QL-NX (Fig. 16) measuring all RNCs, produced by the Japanese firm HORIBA and AMA i60 LDD measuring NH_3 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, NO_2, N_2O, NH_3 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 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. NH_3 range	0–50 ppm	0–100 ppm
Max. NH_3 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 $T_{10\text{-}90}$ for NH_3	Within 2.5 s (by switching N_2 to NH_3, at 50 ppm range)	≤ 1.5 sec (depending on the flow)

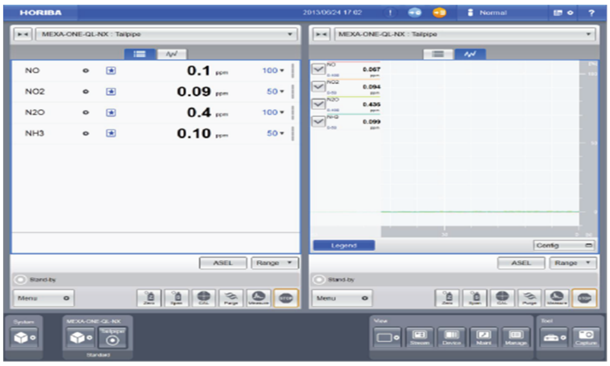

Fig. 16. View of software of HORIBA MEXA-1400QL-NX stand-alone analyzer of NH_3 in the emission laboratory

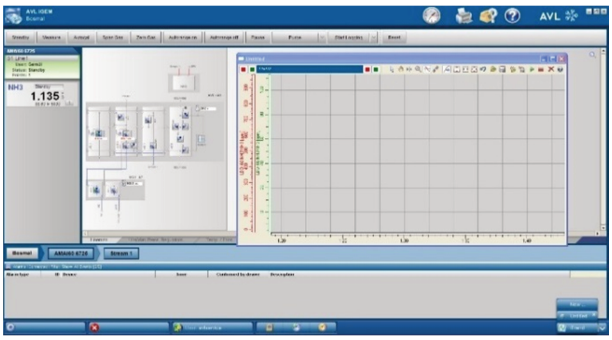

Fig. 17. View of software of AVL AMA i60 LDD stand-alone analyzer of NH_3 in the emission laboratory

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.

Fig. 18. AVL439 Opacimeter with high pressure optional unit (below)

Fig. 19. View of AVL483 Micro Soot Sensor unit

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/cm^3) 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.

Fig.20. Advance high pressure and temperature option for undiluted emissions measurement of APC AVL device

Table 8. Comparison of diluted and undiluted PN measurement

Parameter	Diluted (CERTIFICATION)	Undiluted option (ADVANCE)
Measuring range	0 … 30,000 p/cm³	0 … 30,000 p/cm³ up to 50,000 p/cm³
Field of application	Diluted measurement (CVS), partial flow dilution (PFDS)	Diluted measurement (CVS), partial flow dilution (PFDS), raw exhaust measurement
Total Dilution	100–3 000	2 000–20 000
Exhaust temperature	≤ 200°C	≤ 600°C Up to 1000°C
Exhaust pressure	± 200 mbar	± 200 mbar Up to 2000 mbar

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 an 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.

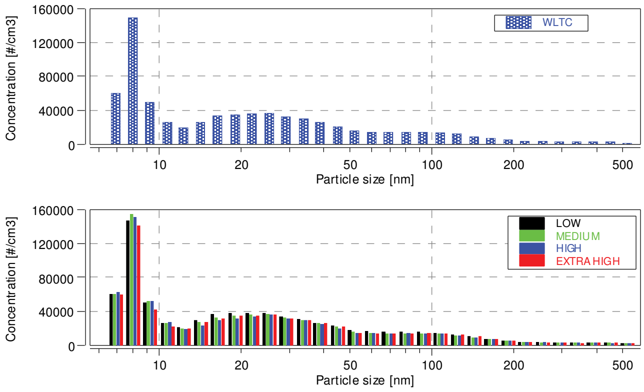

Fig. 21. An example of the particle size distribution over the WLTC

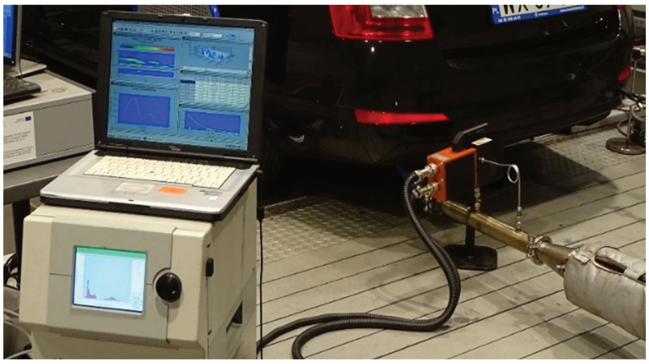

Fig. 22. The EEPS spectrometer and the Rotating Disk Thermodiluter with the heated sampling line mounted on the tailpipe during an emission test

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.

Fig. 23. M.O.V. E. GAS PEMS and M.O.V.E. PN PEMS mounted on a passenger car for an RDE test

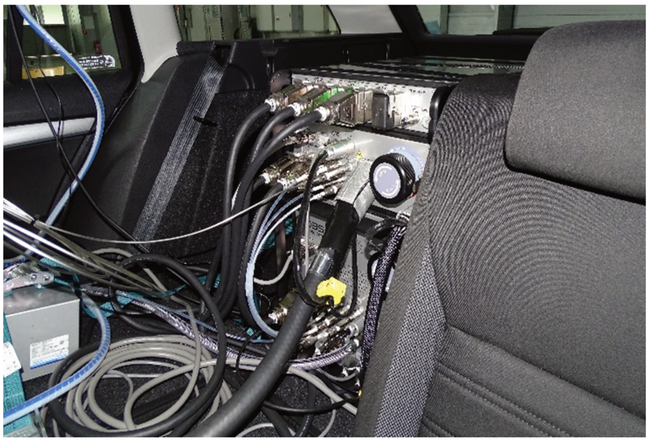

Fig. 24. OBS-ONE HORIBA mounted inside a passenger car for an RDE test

BOSMAL Automotive R&D Institute (Bielsko-Biala, Poland) is one of the largest research centers in Europe specializing in research on engines and automotive components as well as complete cars. BOSMAL cooperates with many leading vehicle and engine manufacturers to explore and launch new models of vehicles (gasoline, Diesel, CNG, LNG, hybrid – and increasingly electric) that meet increasingly stringent emission standards and assists in the development of new engine designs, reducing vehicular fuel consumption and the introduction of alternative powertrains and fuels. The two state-of-the-art laboratories described in this paper permit BOSMAL to compete in the international 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, aftertreatment 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&DI Ltd. is a private and independent company which are offering wide range of accredited testing, service, design and production for all Customers which want to perform specialized works witch high professional quality.

Fig. 25. BOSMAL's accreditation certificate for testing laboratory AB 128 with confirmation of the PN-EN ISO/IEC 17025:2005 standard

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
PM	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

Bibliography

[1] BIELACZYC, P. Global development of emissions reduction strategies from light duty vehicles, 2nd International Conference on the Sustainable Energy and Environmental Development, *IOP Conf. Series: Earth and Environmental Science*. 2019, **214**, 012139. DOI: 10.1088/1755-1315/214/1/012139.

[2] BIELACZYC, P., WOODBURN, J. Trends in Automotive Emission Legislation: *Impact on LD Engine Development, Fuels, Lubricants and Test Methods: a Global View, with a Focus on WLTP and RDE Regulations, Emission Control Science and Technology*. 2019, **5**, 86-98. DOI: 10.1007/s40825-019-0112-3.

[3] European Commission, Communication from the Commission to the European Parlament, the Council, the European Parliament and Social Committee and the Committee of the Regions, Commission Work Programme 2019, Strasbourg, 23.10.2018, COM(2018) 800 final.

[4] Transport & Environment (T&E), CO_2 Emissions from cars: the facts, April 2018.

[5] OLIVIER, J.G.J., SCHURE, K.M., PETERS, J.A.H.W. Trends in global CO_2 and total greenhouse gas emissions: 2017 Report, Netherlands Environmental Assessment Agency. *The Hague*, 2017, PBL publication number: 2674.

[6] European Environment Agency (EEA), Average CO2 emissions from newly registered motor vehicles. 11 Jun 2018.

[7] Continental, Worldwide Emission Standards and Related Regulations, Passenger Cars / Light and Medium Duty Vehicles, September 2017.

[8] International Council on Clean Transportation Europe (ICCT), European Vehicle Market Statistics, Pocketbook 2017/18.

[9] https://www.bosmal.eu/676-scope_of_accreditation_of_the_testing_laboratory_no._ab_128_02.08.2018_en

[10] BIELACZYC, P., SZCZOTKA, A., WOODBURN, J. Carbon dioxide emissions and fuel consumption from passenger cars tested over the NEDC and WLTC – an overview and experimental results from market representative vehicles, 2nd International Conference on the Sustainable Energy and Environmental Development. *IOP Conf. Series: Earth and Environmental Science*. 2019, **214**, 012136. DOI: 10.1088/1755-1315/214/1/012136.

[11] Commission Regulation (EU) 2017/1151 of 1 June 2017 supplementing Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to

vehicle repair and maintenance information, amending Directive 2007/46/EC of the European Parliament and of the Council, Commission Regulation (EC) No 692/2008 and Commission Regulation (EU) No 1230/2012 and repealing Commission Regulation (EC) No 692/2008. Official Journal of the European Union, L 175, 1-643, 7.7.2017.

[12] Commission Regulation (EC) No 692/2008 of 18 July 2008 implementing and amending Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information. Official Journal of the European Union, L199, 1-136, 28.7.2008.

[13] Regulation No 101 of the Economic Commission for Europe of the United Nations (UN/ECE)—Uniform provisions concerning the approval of passenger cars powered by an internal combustion engine only, or powered by a hybrid electric power train with regard to the measurement of the emission of carbon dioxide and fuel consumption and/or the measurement of electric energy consumption and electric range, and of categories M1and N1vehicles powered by an electric power train only with regard to the measurement of electric energy consumption and electric range. Supplement 7 to the original version of the Regulation—Date of entry into force: 18 June 2007.

[14] Regulation No 115 of the Economic Commission for Europe of the United Nations (UN/ECE) Uniform provisions concerning the approval of: I. specific LPG (liquefied petroleum gases) retrofit systems to be installed in motor vehicles for the use of LPG in their propulsion system; II. specific CNG (compressed natural gas) retrofit systems to be installed in motor vehicles for the use of CNG in their propulsion system, Supplement 6 to the original version of the Regulation – Date of entry into force: 10 June 2014.

[15] Global technical regulation No. 15, Global technical regulation on Worldwide harmonized Light vehicles Test Procedures (WLTP), Amendment 3, Established in the Global Registry on 15 November 2017.

[16] GIECHASKIEL, B., LAHDE, T., SUAREZ-BERTOA, R. et al. Particle number measurements in the European legislation and future JRC activities. *Combustion Engines*. 2018, **174**(3), 3-16. DOI: 10.19206/CE-2018-301.

[17] BIELACZYC, P., WOODBURN, J., GANDYK, M. Trends in automotive emissions, fuels, lubricants, legislation and test methods – a global view, with a focus on the EU & US – Summary of the 5th International Exhaust Emissions Symposium (IEES). *Combustion Engines*. 2016, **166**(3), 76-82. DOI: 10.19206/CE-2016-342.

[18] United States Electronic Code of Federal Regulations, Title 40, Part 86.161, 86.161-00. Air conditioning environmental test facility ambient requirements. www.law.cornell.edu/cfr/text/40/86.161-00.

[19] BIELACZYC, P., SZCZOTKA, A., PAJDOWSKI, P., WOODBURN, J. Development of vehicle exhaust emission testing methods – BOSMAL's new emission testing laboratory. *Combustion Engines*. 2011, **144**(1), 3-12.

[20] United States Electronic Code of Federal Regulations, Title 40, Part 1066, 1066.835. Exhaust emission test procedure for SC03 emissions: www.law.cornell.edu/cfr/text/40/1066.835.

[21] www.hioki.com/en/products/detail/?product_key=6413

[22] www.avl.com/-/avl-flowsonix-air

[23] JAWORSKI, P. et al. SCR systems for NO_x reduction in heavy and light duty vehicles. *Combustion Engines*. 2016, **164**(1), 32-36.

[24] GIECHASKIEL, B., SCHIEFER, E., SCHINDLER, W. et al. Overview of soot emission measurements instrumentation: from smoke and filter mass to particle number European Commission. 2013-01-0138, TSAE-13AP-0138. DOI: 10.4271/2013-01-0138.

[25] GIECHASKIEL, B., LAHDE, T., CLAIROTTE, M. et al. Post Euro 6/VI activities focusing on particle number, Expert Panel Discussion EU/China Emissions Regulations, SAE WCX, 2019. DOI: 10.13140/RG.2.2.26039.37286.

[26] Delphi Technologies launches 26th worldwide emissions standards book. 2018/2019, Apr 26, 2018, www.delphi.com/newsroom/press-release/delphi-technologies-launches-26th-worldwide-emissions-standards-book.

[27] BIELACZYC, P. Particulate number (PN) & gaseous emissions in the EU automotive emissions context. Expert Panel Discussion EU/China Emissions Regulations. SAE WCX, 2019.

Piotr Bielaczyc, DEng. – Engine Research Department, BOSMAL Automotive Research and Development Institute Ltd in Bielsko-Biała.
e-mail: *piotr.bielaczyc@bosmal.com.pl*

Dariusz Klimkiewicz, DEng. – Exhaust Emission Laboratory, BOSMAL Automotive Research and Development Institute Ltd in Bielsko-Biała.
e-mail: *dariusz.klimkiewicz@bosmal.com.pl*

Joseph Woodburn, MSci – Exhaust Emission Laboratory, BOSMAL Automotive Research and Development Institute Ltd in Bielsko-Biała.
e-mail: *joseph.woodburn@bosmal.com.pl*

Andrzej Szczotka, DEng. – Exhaust Emission Laboratory, BOSMAL Automotive Research and Development Institute Ltd in Bielsko-Biała.
e-mail: *andrzej.szczotka@bosmal.com.pl*