

VSL Report to the CCM

April 2021

Main research and development activities in the fields of Fluid Flow and Pressure

1. Fluid Flow

European Metrology Network for Energy Gases: VSL is chair of the EMN for Energy gases which brings measurement science expertise to society and industry to support the implementation of the energy transition to renewable gaseous fuels. By bridging the gap between research and end-user communities and acting as a central nucleus for measurement science activities, the EMN for Energy Gases will facilitate a safe, reliable, and diverse energy network for the future.

LNG Flow (16ENG09, 2017 - 2020): From 2010 to 2020, VSL coordinated three EMRP/EMPIR projects on liquefied natural gas (LNG). The major accomplishment of these projects is a significant reduction in the measurement uncertainty of transferred LNG quantity for trading purposes. In the first project, ENG03 (2010-2013), VSL developed the world first primary standard for flow measurement at $-163\text{ }^{\circ}\text{C}$ - the temperature of LNG - with an uncertainty of 0.12 to 0.15% for LNG flow rates up to $25\text{ m}^3/\text{h}$. In the second project, ENG60 (2014-2017), VSL built a mid-scale LNG mass and volume flow facility, that is traceable to the previously developed primary flow standard. In the third EMPIR project (2017-2020) the mid-scale facility was metrologically validated and an extensive calibration campaign was performed on Coriolis and ultrasonic meters of which the results were publicized.

Infusion Uptake (15SIP03, 2016-2019): VSL coordinated "InfusionUptake", in which a publicly available course (<https://academy.esicm.org/course/view.php?id=210>) was developed. Further a good practice guide on the safe use of infusion technology led to the revision of IEC and ISO standards (ISO 7886-2 and IEC 60601-2-24) on best metrology practices related to calibration of infusion devices.

Metrology of multi-modality imaging of impaired tissue perfusion (15HLT05, 2016-2019): In EMPIR project Perfusimaging VSL contributed to the design of a flow standard for medical perfusion imaging. The main part of this standard consists of a 3D-printed part mimicking the myocardium of a human heart and consisting of more than 200 parallel channels with cross sections ranging from $1\text{ to }7\text{ mm}^2$.

Metrology for air pollutant emissions (16ENV08, 2017 - 2020): VSL led work package 3 of EMPIR project IMPRESS II dealing with emission flow measurements in narrow stacks. VSL developed a stack simulator to quantify uncertainties in emission measurements. From measurement results combined with CFD simulations from CMI it was found that errors due to misalignment of the flow with typical measuring probes (pitot tubes) are small compared to errors resulting from the positioning of these probes in the measurement plane. The data from this study can be used to inform revisions of the applicable standards (EN ISO 16911-1 and EN 15259).

Metrology for hydrogen vehicles (16ENG01, 2017-2020): Within EMPIR project MetroHyVe VSL developed a primary standard for flow calibration of hydrogen refuelling stations and validated it with nitrogen. It is able to calibrate HRSs within the challenging conditions (hydrogen is provided at nominal working pressures (NWP) as high as 700 bar and the temperature can fluctuate down to $-40\text{ }^{\circ}\text{C}$) and this will be part of future work.

Flow metering of renewable Gases (18NRM06, 2019-2022): Within EMPIR project NEWGASMET VSL is leading work package 2 which is on hydrogen and biogas durability tests of domestic gas meters, and on the evaluation of gas meters standards (within CEN/TC237 and OIML TC8/SC7) for use with renewable gases. VSL will perform a high pressure (at about 10 bar) calibration of a rotary meter with hydrogen enriched natural gas, and it will participate into an intercomparison for domestic gas meter calibration primary standards with hydrogen.

Support for a European Metrology Network for energy gases (18NET01, 2019-2023): VSL is coordinator of the EMPIR project Energy Gases. The project will support the EMN for Energy Gases in its initial tasks, thus providing the basis for a harmonised and sustainable European measurement infrastructure to catalyse the energy transition. VSL is leading the work package 3 on developing processes to enhance synergies between members of the EMN, stakeholders and other relevant parties so that complex or upcoming needs related to the energy gas transition can be easily addressed and prompt solutions can be found.

Improved vehicle exhaust quantification by portable emission measurement systems (19ENV09, 2020 - 2023): Within EMPIR project MetroPEMS VSL is leading the work package 3 on flow metrology of exhaust flow meters (EFM), which are embedded in portable emission measurement systems (PEMS). PEMS are used in on-road type approval tests as prescribed in real driving emission (RDE) legislation. VSL will perform calibrations of EFMs in varied circumstances applicable to on-road testing to investigate uncertainty sources and develop PEMS EFM calibration procedures.

Metrology infrastructure for high-pressure gas and liquified hydrogen flows (20IND11 MetHyInfra, 2021 - 2024): Within EMPIR project MetHyInfra VSL is leading work package 4 in which primary standards will be developed for critical nozzle calibration at high pressures (pressures up to $p_{max} = 3$ MPa) and the establishment of SI-traceable measurement uncertainty of liquefied hydrogen gas flow measurement. VSL will perform calibrations of liquified hydrogen (LH2) flow meters (1000 kg/h to 5000 kg/h, $p_{max} = 3$ MPa) with alternative (cryogenic) fluids and perform LH2 measurements with the same flow meters.

Metrology for Decarbonising the Gas Grid (20IND13, 2021 – 2024): VSL participates in the flow work package of the EMPIR project Decarb which aims to (I) develop new primary standards and traceable flow calibration facilities for metering of hydrogen (mixtures) and carbon dioxide, and (II) assess the performance of various flow measurement technologies with hydrogen (mixtures) and carbon dioxide. VSL will participate into an intercomparison for hydrogen gas flow using its mercury sealed piston prover and VSL will perform tests of flow meters with hydrogen enriched natural gas and carbon dioxide.

2. Pressure

Dynamic pressure standard (17IND07, 2018-2021): Within EMPIR project DynPT, VSL developed a primary dynamic pressure standard for pressures up to 400 MPa with a pulse time-scale of milliseconds. The standard is based on the drop-weight principle and on the measurement of the refractive index of the hydraulic liquid by optical interferometry. VSL is leading work package 3 which is on development of dynamic pressure and temperature standards in harsh conditions and their validation in field tests (internal combustion engines and ammunition testing).

3. Participation in relevant comparisons

Comparison ID	Subfield	Number of participants	Pilot laboratory	Status	Years
CCM.V-K4	Kinematic viscosity	12	CENAM	In progress	2018-
CCM.D-K5	Density of liquids	15	BEV	In progress	2017-
EURAMET.M.P-S13	Liquid pressure 10 MPa to 100 MPa	14	UME	Completed	2013-2020
EURAMET.M.P-K1.c	Pressure 0.7 MPa to 7 MPa	20	FORCE	Completed	2011-2020
EURAMET n. 1479	1000 L volume	18	MIRS	In progress	2019-
EURAMET n. 1476	Air flow low pressure up to 400 m ³ /h	4	VSL	In progress	2019-
EURAMET n. 1452	Volume 20, 50 and 250 L	8	VSL	In progress	2018-
EURAMET n. 1325	Gas flow range 5 ml/min to 30 l/min	11	MIKES	Completed	2014-2019
EURAMET n. 1301	EUREGA-1 Harmonized reference values for volume and volume flow rate of high-pressure natural gas	4	PTB	Continuous	2014-
CCM-FF-K5C	Harmonized reference values for volume and volume flow rate of high-pressure natural gas	4	PTB	In progress	2015 - 2023
CCM-FF-K2.1.2011	Fluid flow of water and hydrocarbons	9	VSL	In progress	2013-
CCM-FF-K1.2015	Fluid flow of water	11	PTB	In progress	2015-
EURAMET n. 1517	High-pressure natural gas flow up to 200 m ³ /h	3	VSL	In progress	2020-
Euramet/APMP	Water flow up to 227 kg/min	2	NMC	In progress	2018

4. List of relevant publications (2019 to 2021)

ISO/TC 28/WG 20, ISO/DIS 21903:2018(E), *Refrigerated Hydrocarbon Fluids — Dynamic Measurement — Requirements and guidelines for the calibration and installation of flowmeters used for LNG and other refrigerated hydrocarbon fluids.*

EURAMET Calibration Guide No. 21, Version 2.0 (05/2020), *Guidelines on the Calibration of Standard Capacity Measures Using the Volumetric Method.*

Kok, G., Pelevic, N., Chiribiri, A., Milidonis, X., Nazir, M., Capstick, M., Drost, S., Poelma, C., Schaeffter, T., *A calibrated physical flow standard for medical perfusion imaging*, Flomeko 2019 18th International Flow Measurement Conference.

Kok, G., van Putten, D., Zakharov, L., 2019, *Results from an intercomparison between multiphase flow test facilities*, Flomeko 2019 18th International Flow Measurement Conference.

Schakel, M., Kerkhof, O., van der Beek, M.P., van den Herik, P., van Hof, R., Lucas, P., Wulffers, S., *LNG Mid-Scale Loop flow metering; preliminary test results*, Flomeko 2019 18th International Flow Measurement Conference.

Schakel, M. (author), Standiford, D. (reviewer), Smits, E. (reviewer), *Liquid nitrogen calibrations of industry standard LNG flow meters used in LNG custody transfer*, <https://lngmetrology.info/vsl-releases-first-results-of-flow-meters-calibrated-in-cryogenic-conditions-at-its-lng-test-facility/>, publication date: 20 December 2019.

Schakel, M., van der Beek, M.P., Rahneberg, I., Schleichert, J., Einenkel, T., Rogge, N., Fröhlich, T., *Improvements to the primary LNG mass flow standard*, Flomeko 2019 18th International Flow Measurement Conference.

Schakel, M., Workamp, M., Gersl, J., *Cyclonic stack flow measurement uncertainties and impact on annualised mass emission measurements*, Flomeko 2019 18th International Flow Measurement Conference.

de Huu, M., Tschannen, M., Bissig, H., Stadelmann, P., Büker, O., MacDonald, M., Maury, R., Neuvonen, P.T., Petter H.T., Rasmussen, K., *Design of gravimetric primary standards for field-testing of hydrogen refuelling stations*, Flow Measurement and Instrumentation 73 (2020), 101747, <https://doi.org/10.1016/j.flowmeasinst.2020.101747>.

Milidonis, X., Nazir, M.S., Schneider, T., Capstick, M., Drost, S., Kok, G., Pelevic, N., Poelma, C., Schaeffter, T., Chiribiri, A., *Pixel-wise assessment of cardiovascular magnetic resonance first-pass perfusion using a cardiac phantom mimicking transmural myocardial perfusion gradients*. Magn. Reson. Med. 84: 2871– 2884 (2020) <https://doi.org/10.1002/mrm.28296>

Hunt, A., Rusli, I., Schakel, M., Kenbar, A., *High-speed density measurement for LNG and other cryogenic fluids using electrical capacitance tomography*, Cryogenics 113 103207 (2021) <https://doi.org/10.1016/j.cryogenics.2020.103207>

Kenbar, A., Schakel, M., *Influence of flow disturbances on the performance of industry-standard LNG flow meters*, Flow Measurement and Instrumentation, 77 101871 (2021) <https://doi.org/10.1016/j.flowmeasinst.2020.101871>

Knotek, S., Workamp, M., Geršl, J., Schakel, M.D., *Narrow stack emissions: errors in flow rate measurement due to disturbances and swirl*, Journal of the Air & Waste Management Association 71 No. 1 46-59 (2021) <https://doi.org/10.1080/10962247.2020.1832621>

Kok, G., Pelevic, N., Chiribiri, A., Milidonis, X., Nazir, M., Capstick, M., Drost, S., Poelma, C., Schaeffter, T., *A calibrated physical flow standard for medical perfusion imaging*, Flow Measurement and Instrumentation, 78 101907 (2021) <https://doi.org/10.1016/j.flowmeasinst.2021.101907>