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How a National Standards liquid flow facility was successfully moved by using the uncertainty budget as a guide.

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1 INTRODUCTION

Over the past few decades, liquid flow meters have successfully been developed to measure mass or volume passing through a pipeline with impressive accuracy, achieving flow measurement specifications as low as ±0.05 %. To prove these specifications, manufacturers and metrology institutes have developed calibration and test facilities capable of achieving even more impressive measurement uncertainties.

In 2004, VSL took this significant step by designing and constructing a liquid flow meter calibration facility to achieve a Calibration and Measurement Capability (CMC) of 0.02 %. With this facility, VSL as National Metrology Institute (NMI) of the Netherlands, was supporting industry calibration laboratories and service providers to measure with great precision for liquid flow around the world. However, the building housing this facility was constructed in the 1960s and required increasing attention and maintenance to maintain the low CMCs of the calibration facilities and its measurement standards.

Therefore, in 2021 work began to relocate the facility to a new location and upgrade it to handle higher flow rates, ensuring continued support for future developments, particularly in the context of the ongoing energy transition. With the increased demand for high accuracies, it was crucial to ensure that the CMCs would remain unchanged during the move and anchored in place between the old and new locations.

The relocation of the facility from the city of Dordrecht to the port of Rotterdam was successful, with the CMCs remaining equal. This paper outlies a few important steps taken during design, construction and the commissioning phase. With the successful move, industry and other stakeholders now have access to liquid flow facilities that meet the high accuracy demands of today's world.

Picture 1 – VSL's European Center for Flow Measurement in the Port of Rotterdam (NL)

How a National Standards liquid flow facility was successfully moved by using the uncertainty budget as a guide.

2 THE NATIONAL STANDARDS BEFORE THE MOVE

Prior to 2004, VSL recognized that the CMCs of its existing liquid flow facilities had not kept pace with industry, and it was only a matter of time before flow meter manufacturers would claim new, improved accuracies up to two times or more better than VSL's facilities. To meet industry's needs, The Netherlands new national standards for liquid flow was built in 2004 in the city of Dordrecht and opened for business after commissioning in 2005. This was a third-generation facility and the first of its kind regarding very low CMCs for liquid flow. Throughout its lifetime, the facility underwent upgrades to adopt new technologies. The CMCs were proven several times through comparisons with other National Metrology Institutes, with one result detailed in sub-paragraph 2.1. The CMCs as used in this facility are presented in sub-paragraph 2.2.

2.1 VSL Results from Key-comparison CCM.FF-K1.2015

In 2016, VSL participated in the Key-comparison CCM.FF-K1.2015 organised for the Working Group for Fluid Flow (WGFF) from the International Bureau of Weights and Measures (BIPM). From this comparison, VSL calculated its measurement uncertainty for mass flow rate to be 0.015 % (*k=2*) for most of the evaluated flow rates. However, at the lowest flow rate, the measurement uncertainty increased to 0.030 % (*k=2*) due to the artifact used. VSL's results passed the Normalized degree of equivalence ($E_N < 1$) check, as shown in Figure 1. All detailed results are in the final report [2], published and available on the BIPM website (https://www.bipm.org/).

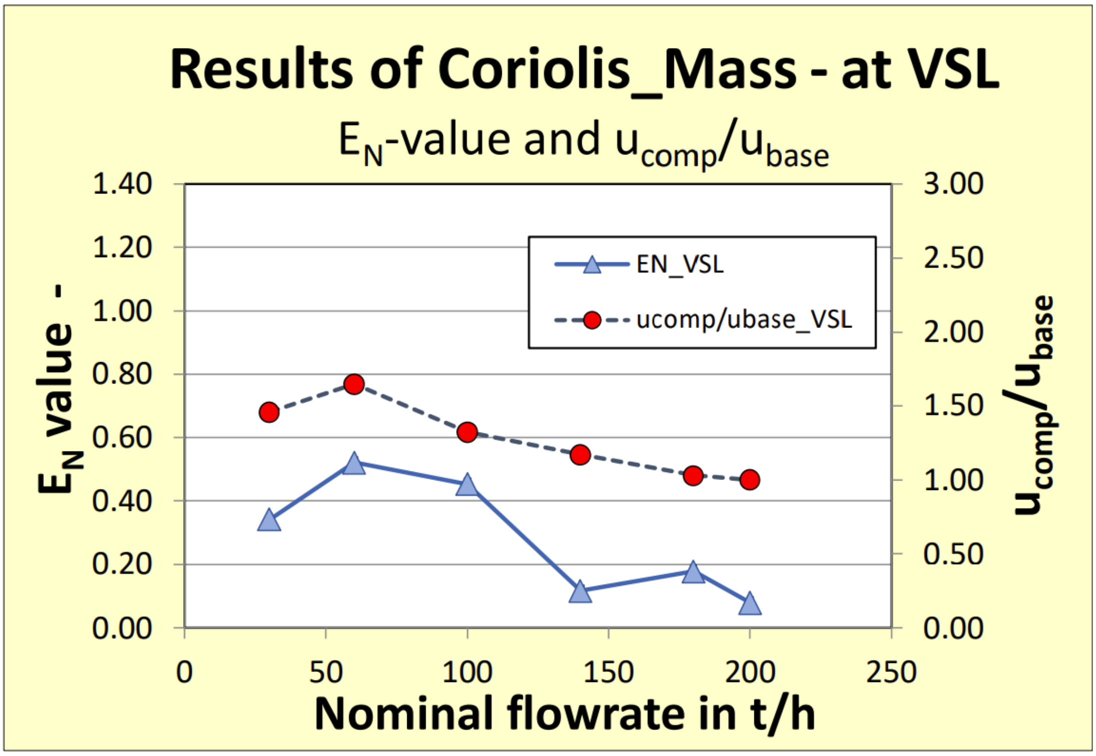


Fig. 1 – E_N value results of VSL in Key-comparison CCM.FF-K1.2015 from final report [2]

2.2 CMCs of the liquid flow meter calibration facility located in the city of Dordrecht

For the liquid flow meter calibration facilities VSL has the CMC values claimed and approved by two organisations. The first is at BIPM in the so-called KCDB database. The CMC values are reviewed by expert metrologist and scientist from NMI's around the world through the

How a National Standards liquid flow facility was successfully moved by using the uncertainty budget as a guide.

Regional Metrology Organisations (RMO's) like EURAMET in Europe. EURAMET also validates that VSL works according to the requirements for a calibration laboratory laid down in ISO/IEC17025:2017 General requirements for the competence of testing and calibration laboratories [1]. Unlike some NMI's that self-declare their quality system is in accordance with ISO/IEC17025:2017 (through peer reviews), VSL has an accreditation by the Dutch Council for Accreditation (RvA). Yearly audits take place with technical assessors from NMI's around the world. Therefore, on VSL calibration certificates for liquid flow meters, two additional logos can be found next to the VSL logo, providing customers verification that their calibration has been done according to the requirements of both BIPM and RvA. This ensures global acceptance of VSL's measurement traceability to the SI units of measurement for mass, mass flow, volume and volume flow. In Table 1 the CMCs up to 2023 are presented for the flow meter calibration facilities in the city of Dordrecht.

Table 1 – VSL CMCs liquid flow in ISO/IEC17025 RvA scope up to end of 2023

FL 10 Flow of liquids				
HCS Code	Quantity, Instrument, Measure	Measuring range	CMC	Remarks
FL 11	**Mass flow rate**			
	Flow meters, batch meters (Water)	0.001 t/h – 400 t/h	0.02 %	Gravimetric method
		0.8 t/h – 400 t/h	0.02 %	Pipe prover method
		0.001 t/h – 400 t/h	0.04 %	Master meter method
FL 12	**Volume flow rate**			
	Flow meters, batch meters (Water)	0.001 m³/h – 400 m³/h	0.02 %	Gravimetric method
		0.8 m³/h – 400 m³/h	0.02 %	Pipe prover method
		0.001 m³/h – 400 m³/h	0.04 %	Master meter method

3 A NEW LOCATION

VSL knew for a long time that at some moment the National Standards for liquid flow measurement would need to be moved to a new location. During these years a few options were investigated. One option included the construction of a building next to the headquarters of VSL in Delft. At the end of 2020, funding for the new facilities was granted and as VSL's LNG liquid flow meter calibration facility also needed to be moved, it was decided to put these two facilities together including the liquid volume laboratory. In January of 2021 a team was formed to work on finding a new location, construction of a building, move existing and design new measurement facilities. The most important parameters were identified, and work started.

VSL's LNG facility was in the Port of Rotterdam and the Port Authorities encouraged VSL to stay within the borders of the Port and identified five potential locations for the new site. Three of them were not suitable, leaving two sites to be investigated to make sure a liquid flow meter calibration facility with low measurement uncertainty would be suitable at that location. Vibrations from surrounding activities are always a concern when working with accurate weighing devices and Coriolis type reference meters. All the involved weighing scale and mass comparator manufacturers were asked about the level of vibrations allowed. None of them provided a suitable answer and simply informed VSL to make sure no vibrations were present. This recommendation is not realistically achievable for an industrial location. The existing weighing instruments were going to be moved from Dordrecht to the new location in Rotterdam, so an investigation took place to learn what the vibration levels were in Dordrecht to establish a baseline. If the vibration levels at the old and new locations are similar it would be possible to achieve the same measurement uncertainty for mass. A specialized company was hired to identify the baseline vibration levels in Dordrecht and compare them with the vibration measurement data for the two potential locations. From this data, it was clear that one location was not suitable due to the fact a low frequency vibration was generated by slow rolling trains not too far from the location. The final location had vibration levels very similar to the baseline measurements in Dordrecht, so this location at the Walrusweg, Maasvlakte was chosen. Additionally, the vibration measurement data was used to design a concrete floor that would minimize the vibrations that are present at the Maasvlakte. In Figure 2 below, one can see the observed vibration over a period of five days including a weekend period.

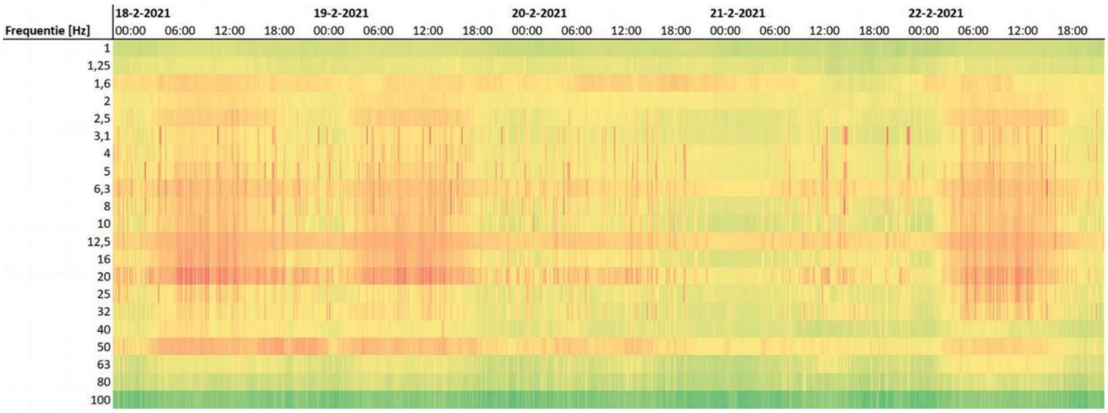
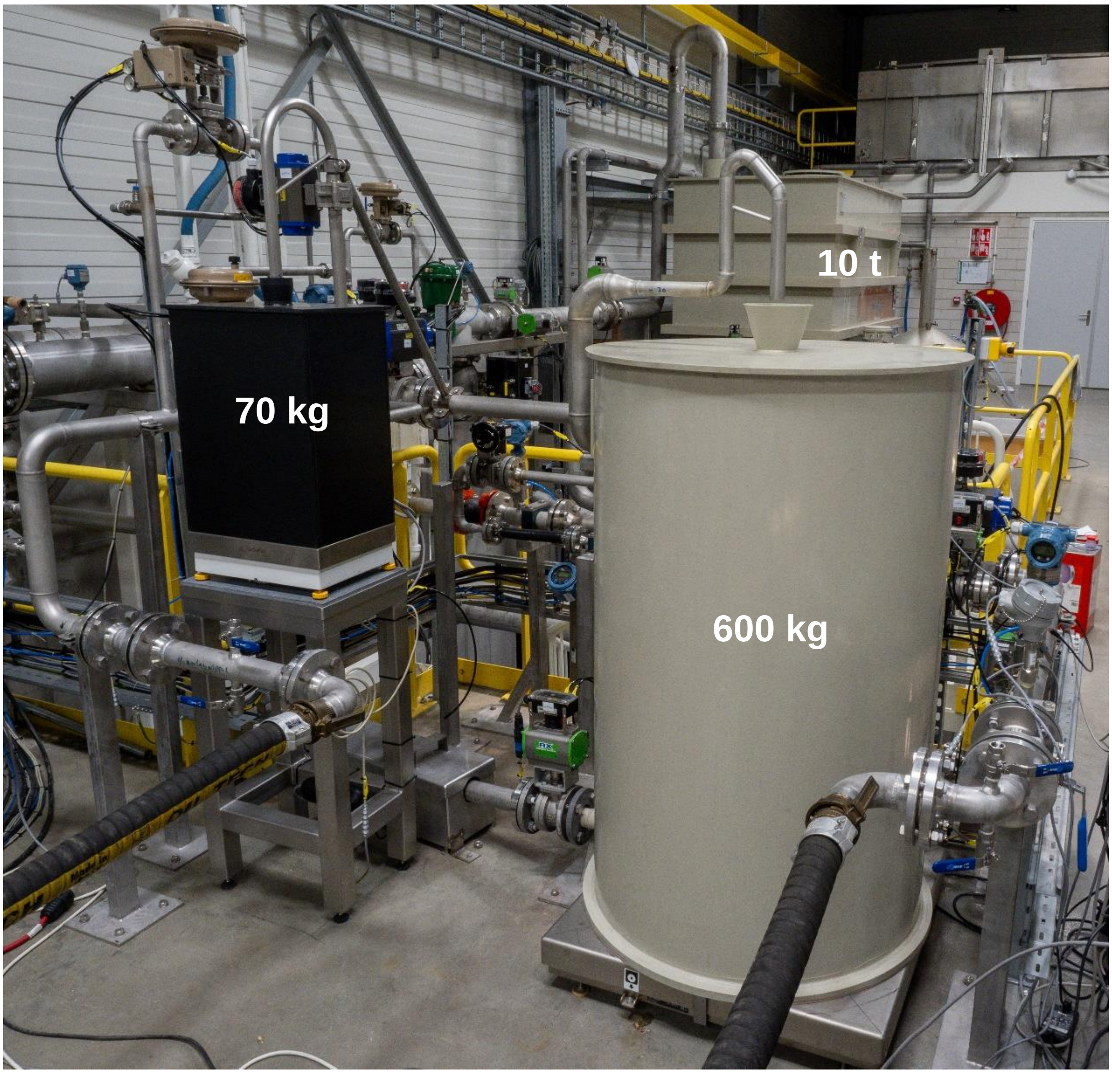


Fig. 2 – Observed vibration over a period of five days at Walrusweg, Maasvlakte Rotterdam

4 PLAN TO MOVE THE CALIBRATION FACILITY

From the moment it was known that the calibration facility was going to move, a plan was made to ensure the current CMCs would be maintained at the new location. The foundation for the existing and new CMCs are the gravimetric measurements using the weighing scales in the calibration facility. Therefore, the first focus was on how to move the small (0.1 kg to 600 kg) and large (100 kg to 10 t) weighing instruments. The two larger instruments, with a maximum capacity of 3.5 t and 10 t were identified to be the most challenging to move. Contact was made with the manufacturer as breaking down and building up these instruments needed to be performed by them due to the special skills and knowledge required for this sophisticated job. Together with the manufacturer, a plan was made to make sure no changes to the performance would occur. There was a complicating factor as the internal measurement units of the weighing instruments had almost become obsolete. Therefore, VSL with the knowledge in mind that a move would happen soon changed the electronics of the 3.5 t in Dordrecht in advance (about two years prior to the move being announced). The new electronics (load cell based) after a few improvements made by the manufacturer worked identically to the old electronics (gyroscope based). Due to the time it took to make the improvements the 10t weighing instrument could not be converted to the new electronics in Dordrecht in time to prove the same performance. So, the plan was to move the 10t weighing instrument with the old electronics and back up electronics to the new location. At the new location, we had to make sure that with the old electronics the move was successful, and it showed good short-term stability. When acceptable short-term stability was established, the new electronics would be installed and then the new electronics verification process could start. Everyone was informed about how important the gravimetric foundation for traceability is in every meeting VSL had with the contractors for the construction of the building and other organisations working in the project. The other two weighing instruments would go through the same procedures except that VSL would transport them according to the instructions of the manufacturers. Validation would be performed to show equal performance at the new location.



Picture 2 – The weighing instruments with holding tanks (70 kg, 600 kg and 10 t)

With the plans made for moving the weighing instruments, VSL moved to the second most important step in the plan. Afterall, the flow CMCs are not guaranteed to 0.02% ($k=2$) with just good working weighing instruments. While the facility move plan was being made, it was getting clearer that there would be a chance the Dordrecht facility would be shut down before any comparison measurements could be performed at the Maasvlakte. Therefore, a good plan was needed to ensure a flow meter calibration would be the same at both locations and well within the CMCs. Nine new reference flow meters would be installed at the new location and these meters would play a vital role in securing the new CMCs. The manufacturer of these reference flow meters, who also has the same mass flow CMCs as VSL, was asked to apply their internal reference meter selection criteria for these meters. In doing so, the manufacturer performed extra diagnostic measurements to identify the best possible reference meters for VSL. The initial manufacturer ISO/IEC17025 reference meter calibration would then be the first reference point covering most of the flow rate range of the new VSL facility. All nine new reference meters and three existing reference meters from the Dordrecht facility were identified as standards to prove consistency in the CMCs using the gravimetric method of calibration. The three reference meters from Dordrecht had a history of many calibrations performed, showing no trends and random results over the course of years indicating they have good long-term stability. However,

these were all relatively small flow meters up to 50 mm in diameter. Therefore, the plan for lower flow rates was easier than for the larger flow rates. The nine new flow meters ranging from 25 mm to 200 mm would be ordered early in the project allowing for at least two calibrations to be performed in Dordrecht for comparison with the manufacturer's calibration and giving an indication of short-term stability (±1 year).
Another concern identified was if a difference was found at the new location and Dordrecht was already shut down. To address this concern, it was decided to perform additional tests at another facility for comparison in addition to the manufacturer of the reference flow meters. The decision for where to test was guided by the need for a facility with similarly low CMCs for flow measurements and that their CMCs were well recognized. To meet these needs, VSL contacted colleagues from PTB in Germany and they agreed to help. VSL required another reference meter that would not be permanently installed in the facilities but would act as a transfer between facilities of VSL and others. Another flow meter would be prepared by the reference flow meter manufacturer for this purpose. The meter was ordered in time to get at least one calibration at the facility in Dordrecht. This new reference meter would later be installed in the Unit Under Test (UUT) section at the new location to be calibrated with the gravimetric method and with the new reference meters (master meter method) for comparison.

Picture 3 – reference flow meter used for comparisons

The last important step to consider for moving locations was moving the compact prover of the Dordrecht facility. It was known the compact prover would need some maintenance after being taken out of service from the Dordrecht facility. A plan was made with the compact prover manufacturer and a service company to do this job. From previous experience, it was known that with this maintenance there would be a chance that parts would need to be replaced that could influence the distance between the detectors of the measurement tube. VSL had done this before and if the change in distance between the detectors was not measurable, only small changes to the CMCs could be expected.

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5 THE NEW LIQUID FLOW CALIBRATION FACILITIES

In 2022 the construction of the new building and the calibration facilities started. At the end of the year the larger part of the facility was ready to start commissioning. The new facility has three locations where flow meters from customers and other equipment can be installed. In fact, there are two connected facilities that can run independently from each other. The facilities have been given the identifiers WF650 and WF2500. The WF650 includes parts that moved from Dordrecht to Maasvlakte such as the gravimetric references (weighing instruments), compact prover and some of the reference meters from Dordrecht. Additionally, the WF650 was upgraded with three new reference meters. The WF2500 is new and has six reference meters and a connection to the WF650 to calibrate the reference meters with the gravimetric system.

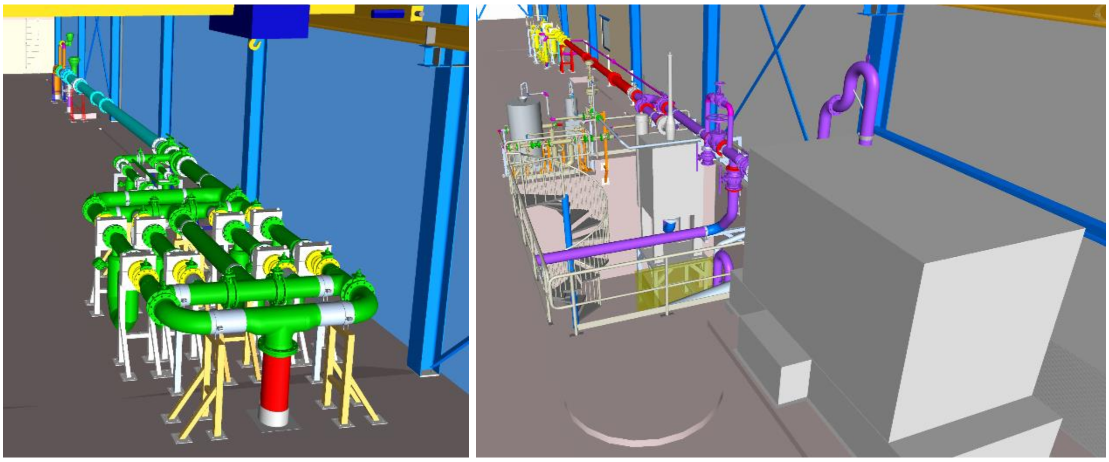

Fig. 3 – On the left side the WF2500 facility and on the right side the WF650 facility

Picture 4 – WF2500 master meter sections

6 MASS BALANCE

In Dordrecht the calibration models (equations) to evaluate the performance of a UUT were mostly volumetric orientated using the mass balance theory. At the Maasvlakte for the new facility this was converted to fully mass orientated and only when needed converted to volume or volume flow rate. This improved calculation model led to a simplification for most of the possibilities available for calibrating flow meters. It also improved CMCs for these possibilities as a few small sources of measurement uncertainty fell out of the equations. In the future when more stability values are known for the new reference meters this could potentially lead to improved CMCs for the master meter method.

How a National Standards liquid flow facility was successfully moved by using the uncertainty budget as a guide.

7 EVALUATION AND VALIDATION FOR CMCS

As soon as the first water was flowing, the evaluation and validation of the reference standards started next to operating the system. At that time the weighing instruments had not moved yet, and VSL needed a way to check the correctness of the reference meters. VSL uses Coriolis mass flow meters, so Coriolis diagnostics were utilized to help with this. In the WF2500 system for flow rates up to 2500 t/h or m³/h, four reference meters are installed in parallel with an additional pipe in-between them. This additional pipe makes it possible to also put meters in series and even combine two parallel meters to validate one reference meter against another reference meter. Many reference meter combinations can be made when a larger reference meter is installed in the UUT section. Each of the four parallel reference meters can measure the error of the UUT flow meter at the same flow rate individually and in combinations. Experimenting with the different combinations gave a lot of insight into the new facility and the capabilities of the new reference meters working alone or in parallel combinations. The calibration procedures for customers will use a defined combination of reference meters for a specific flow rate to maintain consistency between calibrations. Using the parallel meters, it is also possible to do a so-called bootstrapping method to increase to higher flow rates. This bootstrapping method is currently needed for flow rates above 2000 t/h.

After a few months the largest weighing instruments were installed, and the first calibrations could be performed utilizing the gravimetric method. After a period where the stability of the weighing instruments was evaluated, all reference meters were calibrated for the first time at the new location in Maasvlakte. The results lined up very well with the results found in Dordrecht and other facilities. The plan utilized for the move had worked. In Figure 4, the results of most measurements for one of the larger reference meters with an internal diameter of 200 mm and TAG number 2500 RM-202 are shown. The measurement uncertainty, or CMC, from Dordrecht was the basis used to evaluate these results as the CMC from Dordrecht was proven in the key-comparison CCM.FF-K1.2015 [2] to match with NMI's around the world.

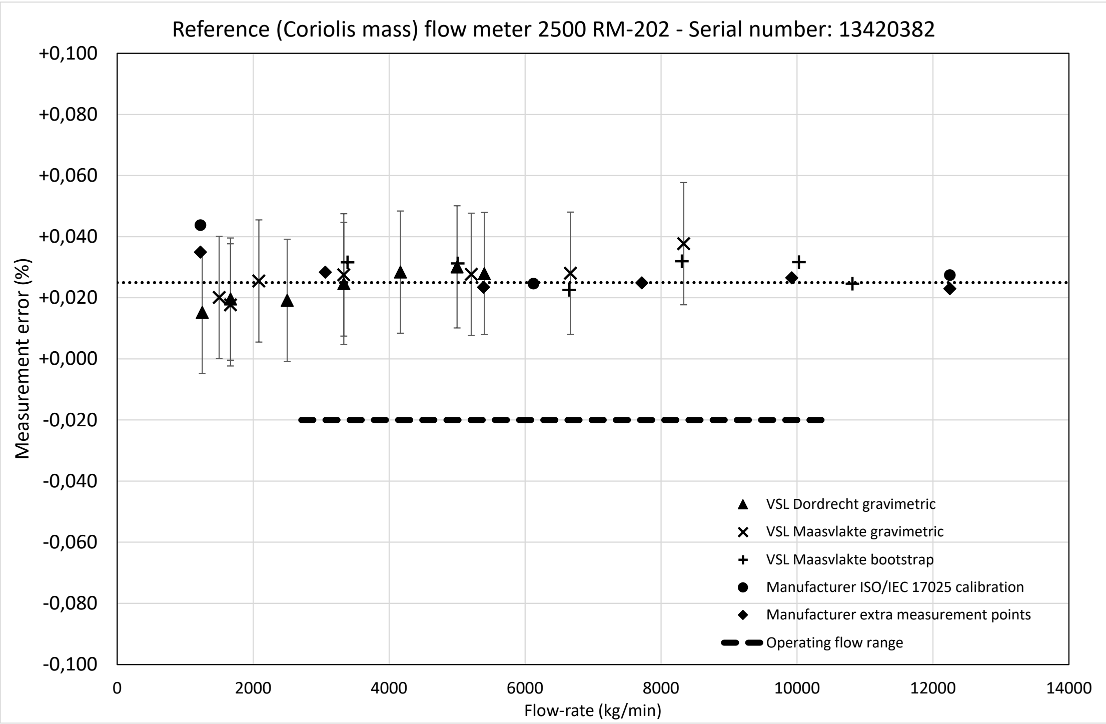

Fig. 4 – Calibration data reference meter with TAG number 2500 RM-202

Figure 4 shows that at lower flow rates the reference meter is affected by the zero stability. To make sure the zero of the reference flow meters is stable, strong supports were constructed and so-called bellows were installed to isolate the reference meters from vibrations in the facility, for example caused by the pumps. Small changes in zero can still be expected but they need to be small enough to not affect the result of the calibrations as seen in Figure 4. On a regular basis the zero (drift) was observed first thing in the morning and after using the reference meters to identify if an extra measurement uncertainty needed to be introduced. Observing the zero (drift) is done by setting the electronics to measure bi-directional flow and setting the low flow cutoff to zero. Once this is done, the mass is measured during a minimum period of five minutes to make sure the total mass stays within the specification given by the manufacturer. In Figure 5, results can be seen for all four larger 200 mm reference meters during the minimum five-minute observation. The red line is half of the specification of the manufacturer. It was noticed during the first observations that the reference meters did not meet the manufacturer's specification. After some consulting with the manufacturer, the clamps (see picture 4) holding the meters were adjusted and re-tightened leading to the results as shown in Figure 5. In addition to performing zero (drift) measurements, the metrologists and scientists working on the location can monitor the live zero on the display of the electronics to see if the reference meters still meet the required specification. Since the readjustment of the clamps no changes were observed.

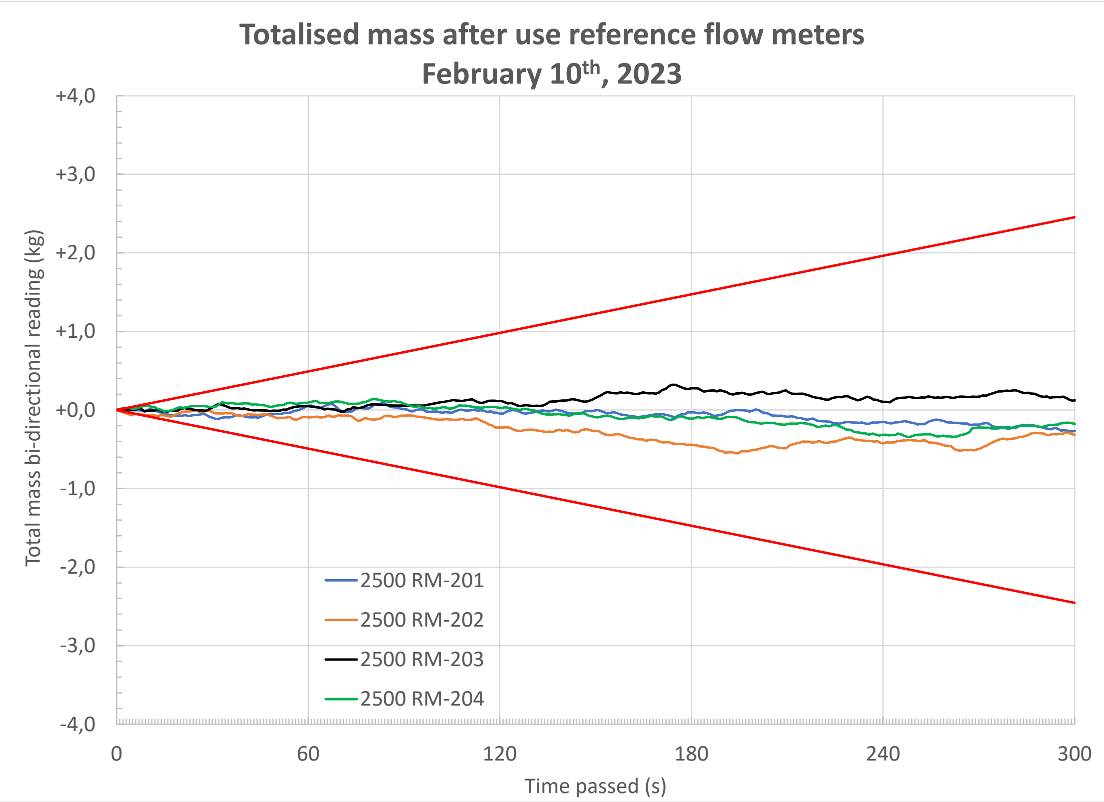

Fig. 5 – Zero stability observation TAG number 2500 RM-201 through 204 after measurements

8 COMPARISON WITH A THIRD PARTY

Once commissioned, VSL set-up a EURAMET project with number 1616 [6] for a bilateral comparison with PTB of Germany and the new WF2500 facility. The goal of the bilateral comparison was to provide conclusive comparison results supporting the CMCs of the WF2500 facility. In this bilateral comparison project, the error of the travelling standard was determined from the mass flow rate of water passing through the travelling standard at flow rates of 150

How a National Standards liquid flow facility was successfully moved by using the uncertainty budget as a guide.

t/h, 300 t/h, 400 t/h, 625 t/h, 800 t/h and 1200 t/h. The errors at the given flow rates at both laboratories are presented in figure 6. Before and after results obtained by VSL were used to determine the stability of the travelling standard. The stability of the transfer standard is included with the errors from the transfer standard found at each laboratory to determine the degree of equivalence between the two facilities (En value) and conclusiveness of the En value according to recommendations by the WGFF found in papers, [3], [4], [5]. Figure 7 shows that for all flow rates compared with PTB, the En value is less than 1.

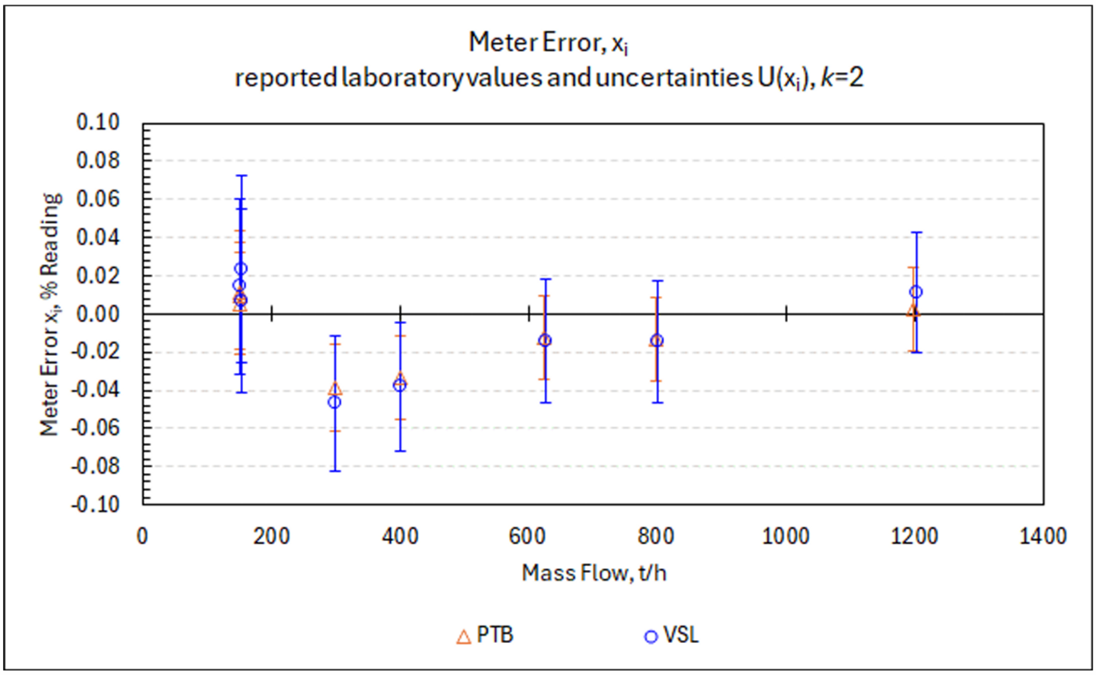

Fig. 6 – EURAMET Bilateral Comparison P1616, measurement results of PTB and VSL

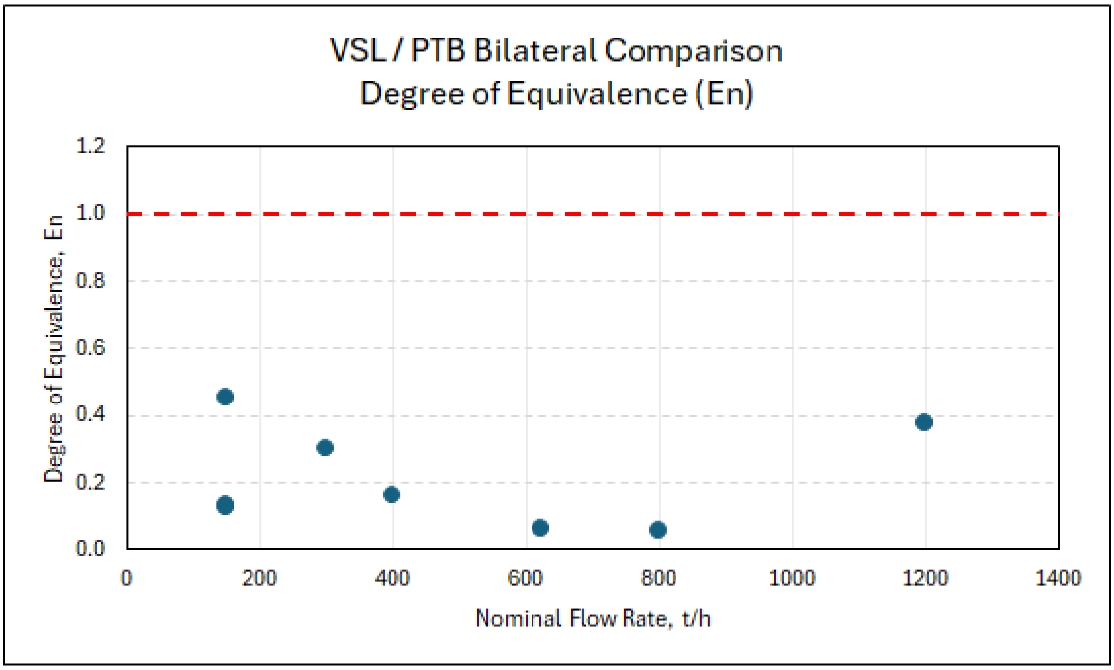

Fig. 7 – EURAMET Bilateral Comparison P1616, Degree of Equivalence Results

Table 2 – EURAMET Bilateral Comparison P1616, Conclusiveness of the Results

Criterion D						
No.	Rdgs	Flow nominal (t/h)	Probability Distribution (0.975)	(0.025)	Δ	≥ 0.95
1	3	150	1.000	0.002	1.00	PASS
2	5	300	0.990	0.000	0.99	PASS
3	10	400	0.996	0.000	1.00	PASS
4	5	625	0.997	0.001	1.00	PASS
5	3	150	1.000	0.014	0.99	PASS
6	5	800	0.997	0.001	1.00	PASS
7	10	1200	1.000	0.020	0.98	PASS
8	3	150	0.995	0.001	0.99	PASS

9 CONCLUSION AND FUTURE DEVELOPMENT

Moving National Measurement Standards and its facilities is far from easy. Every detail of the facility and its measurements needs to be investigated to make sure measurement uncertainties sources at least remain the same or that they can be improved. Specific data collections needs to start ahead of time to prove nothing changed after the move.

Based on the results from the EURAMET Bilateral Comparison P1616, the CMC of VSL's new water flow facility WF2500 is valid, and customers can be assured of the results provided to them are accurate, resulting in the CMC's that can be found in table 3.

Table 3 – VSL CMCs liquid flow in ISO/IEC17025 RvA scope from 2024 [7]

FL 10 Flow of liquids				
HCS Code	Quantity, Instrument, Measure	Measuring range	CMC	Remarks
FL 11	**Mass flow rate**			
	Flow meters, batch meters (Water)	0.03 t/h – 500 t/h	0.02 %	Gravimetric method
		0.8 t/h – 600 t/h	0.02 %	Pipe prover method
		0.03 t/h – 600 t/h	0.04 %	Master meter method
		10 t/h – 2500 t/h	0.04 %	Master meter method
FL 12	**Volume flow rate**			
	Flow meters, batch meters (Water)	0.03 m³/h – 500 m³/h	0.02 %	Gravimetric method
		0.8 m³/h – 600 m³/h	0.02 %	Pipe prover method
		0.03 m³/h – 600 m³/h	0.04 %	Master meter method
		10 m³/h – 2500 m³/h	0.04 %	Master meter method

How a National Standards liquid flow facility was successfully moved by using the uncertainty budget as a guide.

With the results obtained in EURAMET project 1616 [6] the CMCs listed in table 2 can be improved for the master meter method. Claiming the improved CMC will happen in due time when VSL is convinced the master meters are stable at least over a period of minimal two years.

10 REFERENCES

[1] ISO/IEC17025 General requirements for the competence of testing and calibration laboratories.

[2] Dr. Enrico Frahm. Final report Key-Comparison CCM.FF-K1.2015, Comparison between eleven National Metrology Institutes for water flow between 30 and 200 m³/h.

[3] BIPM CCM-WGFF Guidelines for CMC Uncertainty and Calibration Report Uncertainty, October 21, 2013, http://www.bipm.org/utils/en/pdf/ccm-wgffguidelines.pdf.

[4] Wright, J., Mickan, B., Benkova, M., Chun-Lin, Ch. (2022): Laboratory Comparison Calculations Spreadsheet Template Following Cox 2002 Method, BIPM WGFF, unpublished working paper.

[5] Wright, J, Toman, B., Mickan, B., Wübbeler, G., Bodnar, O., Elster, C. (2016): Transfer standard uncertainty can cause inconclusive inter-laboratory comparisons, Metrologia 53, 243–1258, https://doi.org/10.1088/0026-1394/53/6/1243.

[6] EURAMET project 1616 Bilateral hybrid comparison: High flow rate water - 150 t/h to 1200 t/h. https://www.euramet.org/technical-committees/tc-projects/details/project/bilateral-hybrid-comparison-high-flow-rate-water-150-t-h-to-1200-t-h

[7] Dutch Council for Accreditation (RvA). Annex to ISO/IEC 17025:2017 declaration of accreditation for registration number: K 999 for VSL.