Publishable Summary for 20IND13 SAFEST
Sustainable advanced flow meter calibration for the transport sector

Overview

Greenhouse gas emissions produced by the road and maritime transport sector significantly contribute to climate change, therefore these emissions need to be reduced and a decarbonisation of these sectors is being pursued. Recent measures to achieve this have focused on alternative and synthetic fuels, improvements in engine testing and setting up tightened emission standards. However, advances also need to be made in flow metrology as these new measures directly depend on the quality of flow measurements for determining engine efficiency through fuel consumption and emissions measurements. The purpose of this project is to provide the foundation for advanced flow metrology in this sector, leading to reliable fuel consumption measurements. The characterisation of flow meters, at close to operational conditions, and an improved understanding of how the fuel's properties effect flow measurements will foster innovation in the transport sector. It will increase the deployment of sustainable alternative and synthetic transport fuels. Moreover, the results will contribute to appropriate emissions calculations.

Need

Tightened emission requirements and stricter fuel consumption limits (e.g. Regulations (EU) 2015/757, (EU) 2019/631, FuelEU Maritime Initiative adopted Oct. 2022) have resulted in reliable fuel consumption measurements being a hot topic for vehicles and ships. The recent decision to include the shipping sector in the Emissions Trading Scheme (ETS) from January 2024 onwards and a separate ETS that will govern emissions from land transport have exacerbated the situation. What is of importance here is that the quality of the fuel consumption measurement, based on which emissions are also often determined, is directly linked to the quality of the fuel flow measurement, and in turn, to the measurement performance of the flow meter.

Metrological engagement in the transport sector is needed in a number of ways. So far, there are no reliable quantitative insights into how flow meters perform under real-world fuel flow changes because they are calibrated at steady flow rates. Therefore, a metrological infrastructure, suitable for testing flow meters under variable flow conditions needs to be developed. [Objective 1] There is also a lack of sufficient quantitative information on the effect of operating conditions, such as ambient and fuel temperatures, on the performance of flow meters. [Objective 2] This information will be important as the calibration and operating conditions of the flow meters are significantly different. In addition, this information will be of relevance when looking at in-use fuel consumption measurements for vehicles. [Objective 1] Fuel properties have a direct impact on engine performance. Thus, the adoption of new fuels and efficient engine development will only happen if the fuel's properties are well known. Therefore, there is, a need for sufficient information on the viscosity and density of alternative and synthetic fuels. [Objective 3]. The effects of changes in the fluid properties (viscosity and density) and their influence on the performance of the flow meter must also be assessed. This is particularly relevant for the maritime sector as quite a diverse range of fuels are used. [Objective 2] As knowledge of the density and viscosity of a fuel are crucial for both flow measurement and efficient engine operation, there is a clear need for the advanced inline measurement of these parameters. [Objective 3] Furthermore, there is a need to have this metrological information available in a concise and easily accessible way for stakeholders. It will be used for state-of-the-art recommendations for advancements in fuel consumption measurements and as input for the regulations that are needed to reliably monitor and determine fuel consumption and emissions in the transport sector at a European level. [Objective 4]

Objectives

The overall objective of this project is to develop a metrological infrastructure for use in performing advanced flow measurements in the transport sector.

The specific objectives of the project are:

1. To develop the infrastructure required for evaluating the accuracy of the flow meters and other systems (e.g. flow meters integrated in conditioning systems), which are used in cars and trucks to measure the consumption of fuel, under the New European Driving Cycle, the Worldwide harmonised Light vehicles Test Cycle, or the World Harmonised Transient Cycle. Test liquids should include e.g. water and hydrocarbons, with densities > 400 kg/m³, viscosities > 0.01 mPa·s, pressures ≤ 300 bar, and flow rates 0.0001 m³/h – 8 m³/h.
2. To develop the infrastructure and procedures required for evaluating the accuracy of flow meters, which have potential for measuring the consumption of alternative fuels in the maritime sector, under close to real world conditions. The selected alternative fuels should have the same range of densities, viscosities, pressures and flow rates as specified in objective 1. This objective should address measurements of dynamic flow and en route fuel consumption, with uncertainties.
3. To prepare a fuel property matrix of the transport properties of alternative fuels e.g. bio-diesel (FAME), bio-alcohol and synthetic fuels. This should enable the transfer of calibrations between fuels and extrapolation to higher temperatures and pressures. The selected fuels should have densities > 400 kg/m³, viscosities > 0.01 mPa·s, temperatures ≤ 620 K, pressures ≤ 300 bar and flow rates ≤ 2 m³/h. Sensors should also be developed for traceably measuring density and viscosity in situ.
4. To provide metrological input, and pre-normative research, for the further development of international standards with a focus on close to real-world flow calibrations in the transport sector. In addition, to contribute to the development of a pan-European harmonised framework, which will enable the emission targets set by the International Maritime Organization, the European Conference of Ministers of Transport and the Fédération Internationale de l'Automobile to be met and controlled.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories, instrumentation manufacturers), standards developing organisations (IMO, ISO) and end users (transport sector).

Progress beyond the state of the art

The project aims at establishing a metrological infrastructure and to provide recommendations for an integral characterisation of flow meters ensuring reliable fuel consumption measurements in road and maritime transport.

Currently, exhaust emissions and the fuel consumption of motor vehicles are determined based on the Worldwide harmonized Light vehicles Test Procedure (WLTP) or the New European Driving Cycle. For the evaluation of fuel consumption, the regulation UN ECE.R49 only recommends the performance specification for the measurement instruments and not the complete measurement system. Further contributions to the measurement results, such as from the environment, are also not clearly required to be taken into consideration. Thus, the measurement errors caused by the dynamic execution of the test cycles are almost unknown.

In this project, test rigs, which are used for flow meter calibrations, will be realised that will be capable of generating and measuring dynamic flow changes based on test cycles. This novel metrological infrastructure will go beyond the current state of the art and will be evaluated in an inter-comparison; with the results used for setting up an appropriate uncertainty assessment. The consortium will also develop the protocols required for the new dynamic test regime and will closely work together with standards bodies to enable a timely transfer to practical application. By evaluating the impact that operating conditions, and the transport properties of the fuel, have on flow meter performance, an innovative integral uncertainty assessment of the flow measurement will be possible. In addition, a numerical tool will be provided that will enable the investigation of different operating conditions and parametric analyses to be performed, which are currently difficult to carry out experimentally. (Objective 1)

Recent changes in the regulations for the emission control of ships, and in order to support alternative fuels and endeavours in increasing engine efficiency, have resulted in a key role for fuel consumption measurements. As in the automotive sector, the characterisation of flow meters in the maritime sector has not developed further in recent years: flow meters are calibrated at test points with steady flows, with one test liquid and at standard conditions. The measurement uncertainty also applies to these conditions, which are far removed from actual operating conditions.

In this project, infrastructure and procedures will be developed, as required, for the evaluation of the accuracy of the flow meters deployed in fuel consumption measurements in the maritime sector. New insights will be provided into the impact of the operating conditions of the flow meters and on the transport properties of the fuels on flow meter performance. The focus will be on the properties of alternative liquid fuels which are considered promising for future uses such as biodiesel, methanol or synthetic fuels. Furthermore, flow meter performance under dynamic loads, as occurring e.g. in Emission Control Areas (ECA), will be addressed and the results will be summarised in a comprehensive uncertainty budget. For road transport, a validated numerical tool will be provided as support for experiments to address the impact of the operating conditions and the test liquid on flow meter performance. (Objective 2)

Fuel properties have a direct impact on engine performance and hence any negative impacts will affect the acceptance and adoption of new fuels. Furthermore, the measurement performance of a flow meter depends on the transport properties of the liquid and it therefore affects the correctness and reliability of the fuel consumption measurement. In all cases reliable liquid properties data is essential. As current operating conditions generally vary, the transport properties must be known in relation to pressure and temperature. This situation results in the need for up-to-date and accurate density and viscosity data and data on how these transport properties change under different operating conditions. In addition, sensors or sensor systems are required for traceably measuring both parameters in situ and this will contribute to an improved on-board fuel consumption measurement.

This project will provide a fuel property matrix of the transport properties of current and up-coming alternative and synthetic fuels for the temperature and pressure range relevant to road transport and the maritime sector. This will improve the transfer of flow meter calibrations between different fuels and it will enable an appropriate determination of the measurement uncertainty of flow meters especially under actual operating conditions. Thermophysical property models for alternative fuels will also be made available which can then be used to extrapolate the fuel properties to operating conditions, (i.e. conditions which cannot be easily realised in labs). The thermophysical property models will represent a useful ready-to-use tool for manufacturers and end users. Further progress will be achieved by the project by addressing the in-line measurement of density and viscosity, which are important for both an improved en-route fuel consumption determination and to ensure engine performance and efficiency. In addition, sensor systems based on commercially available components will be addressed and a prototype ultrasonic densimeter will be developed. (Objective 3)

Currently only standards and recommendations exist for the evaluation of flow meters at single test points with steady flows and for meter stress tests based on switch-on/switch-off procedures which are independent of the specific application area. This means that, it is difficult to quantify the uncertainty associated with transferring the calibration for one liquid to another because the measurements required for this are not sufficiently available. If taxation and emission determination are based on fuel consumption measurements and the amount of fuel consumption is a major selling point, the quality of the fuel consumption measurement becomes much more important and with it the associated measurement uncertainty. The problem has been partly recognised e.g. the new ISO development of an evaluation method for transient flow rates, but progress is currently very slow.

This project will develop guidelines for the evaluation of the flow meters deployed in the transport sector, with a view to real-world operating conditions, including recommendations for the determination of uncertainty budgets. Further input will be provided by the project to metrological technical committees such as EURAMET TC Flow (TC-F) or BIPM CCM WG Fluid Flow (WGFF) and relevant national committees as they also provide guidelines on flow measurements which are used by end users. At present there are no specific stakeholder bodies in the transport sector with clear links to flow metrology. However, various competence centres, clusters and alliances of interest exist at the national or European level and relevant conferences will be targeted for dissemination of the project's results. (Objective 4, 5)

Results

To develop the infrastructure required for evaluating the accuracy of the flow meters and other systems (e.g. the conditioning system around the flow meter), which are used in cars and trucks to measure the consumption of fuel, under the New European Driving Cycle, the Worldwide harmonised Light vehicles Test Cycle (WLTC), or the World Harmonised Transient Cycle (WHTC). Test liquids should include e.g. water and hydrocarbons, with densities > 400 kg/m³, viscosities > 0.01 mPa·s, pressures ≤ 300 bar, and flow rates 0.0001 m³/h – 8 m³/h. (Objective 1)

From the WLTC for passenger car engines and the WHTC for truck engines the equivalent turndown ratios were derived. Based on real test executions, the fuel demands from the engine control units (ECUs) were determined and correlated to the dynamic response of the test equipment applied. Based on the information test profiles for passenger cars and trucks were derived which take up characteristic sequences of the harmonised test cycles. In particular, fuel consumption at idle and zero consumption phases were included. These are critical in consumption measurements as the flow meters deployed are not calibrated in this range. Different engine sizes can be addressed by simply scaling the profiles. The test profiles serve as the basis for the development of test rigs, at the partners facilities, which are capable of realising dynamic flow changes with these characteristics. Attention was paid to the fact that the profiles are suitable for practicable implementation at the stakeholders, for eventual dynamic calibrations of flow meters.

One approach for a technical realisation of the vehicle-related profiles on a test rig consists of a combination of cavitation nozzles, other ones rely on on/off valves, proportional valves and fuel injectors. It is essential that the measurement is against a sufficiently accurate reference that is traceable. However, this alone is not sufficient to assess the quality of a profile implementation on the test rig as e.g. the realisation of the individual flow rate changes is also of importance. Further evaluation criteria are therefore needed based on the consideration of the residuals, time until a stable flow rate is achieved, repeatability etc. The feasibility of these criteria was demonstrated in the EMPIR project 17IND13 “Metrowamet” [1][2]. Concerning the evaluation of flow meter performance with regard to dynamic flow changes, a recommendation was drafted for a procedure, protocol and evaluation. Concerning the test rig developments the focus was on finalising the infrastructure and individually evaluating the performance of the rigs to optimise hardware and the measurement regime.

In the course of the investigations, it was also studied how different flow meters perform if they encounter a steplike flow drop to zero. It was found that turbine meters systematically underestimate the total volume. For one step an effect of 1 % to 1.5 % occurred, for two steps the measurement deviation amounted to 6 % to 7 %. Coriolis flow meters typically measured too much volume compared to the reference, about 0.7 % for one step and 2 % for two steps. Generally, the deviations decreased somewhat if auto zero effects were considered. It was also visible how the flow meters followed the flow rate changes.

A prerequisite for any development towards future dynamic calibrations of flow meters is that the quality with which the test profiles are realised on a test rig can be verified and quantified. On the one hand, the aforementioned evaluation criteria come into play, and on the other hand, the quality and comparability of the technical implementations will be determined by means of an inter-comparison employing well-characterised transfer standards. Two transfer setups were developed and characterised for this purpose. Each setup consists of a Coriolis flow meter, a temperature and pressure sensor upstream and downstream of the meter and a data acquisition system. Both flow meters were extensively tested at the beginning if they are fit for purpose. Furthermore, the technical protocol was prepared and agreed upon. Two types of test liquids will be used to accommodate all parties intending to participate in the inter-comparison: Calibration oil ISO 4113 and water. Apart from PTB, INRIM and UNIPG, three external parties plan to join the inter-comparison, METAS, CETIAT and NMIJ. By this it will become possible to compare different technologies of dynamic flow generations.

Furthermore, measurements of different types of flow meters at room temperature using different test liquids and liquid temperatures were carried out. Depending on the meter type viscosity-related effects occurred ranging from negligible up to significant. The results obtained however also demonstrate the suitability of the Reynolds number approach to transfer the calibration from one liquid to another as long as the optimum measuring range of the meter is exclusively being considered.

Moreover, additional effects due to temperature or pressure fluctuations causing small changes in meter geometry or in parts of it and by this opening miniscule gaps in this measuring range were not found so far.

Two routes are being followed for the development of a numerical tool with which the interaction between test liquid and flow meter can be investigated beyond the Reynolds number approach. On the one hand, a CFD model was set up. Based on a 3D transient simulation using OpenFOAM a sensitivity simulation was carried out. The performance of different turbulence models was investigated by comparing the numerical results with those theoretically obtained by applying the Standard ISO5167-2. The liquid behaviour (= velocity field) was first analysed as a function of different temperatures. Flow rate boundary conditions were applied to the inlet section of an orifice plate. On the other hand, using Flow Structure Iteration (FSI) the interaction of a Coriolis flow meter with the test fluid is being investigated. In a first step a well-known test case was considered to demonstrate that FSI works with Open FOAM because both fluid and solid components need to be modelled. The domain and mesh for the Coriolis flow meter have been set up. After considering an unsteady flow field moving through the meter, a model analysis of the test case was carried out for a stationary fluid. More advanced modelling based on the partners' test rigs and flow meters is currently being pursued. Here in particular the prototype flow meter investigated in the context of Objective 2 is addressed.

To develop the infrastructure and procedures required for evaluating the accuracy of flow meters, which have potential for measuring the consumption of alternative fuels in the maritime sector, under close to real world conditions. The selected alternative fuels should have the same range of densities, viscosities, pressures and flow rates as specified in objective 1. This objective should address measurements of dynamic flow and en route fuel consumption, with uncertainties. (*Objective 2)*

Measurements were performed for different test liquids such as Exxsol D40, Exxsol D60, Exxsol D120 and Mobiltherm 605 at different temperatures. In this way a kinematic viscosity range of 1.3 mm²/s to 82.3 mm²/s was covered. The selected flow meter types comprise among others Coriolis flow meters, pd sensors and piston meters. Concerning the development of a test cycle for the maritime sector the fuel consumption of a ferry navigating in a harbour was selected. As for vehicles it could be shown that the fuel consumption can be scaled to different ship engine sizes. Based on measurements a test profile was derived. Tests were carried out regarding the technical realisation of the flow changes on a test rig. By use of a needle valve in combination with a pulse-driven control via a Coriolis flow meter very good realisation results could be obtained. It was shown that neither the distance between the meter under test and the gravimetric reference nor the distance between the dynamic flow realisation, the meter under test or the reference play a relevant role on the realisation. Various methods were used to verify the realisation, such as reading out the scale values dynamically. The noise level can be reduced when e.g. the weighing vessel is already partly filled. It is important to account for a delay time for the reference to ensure that the meter under test and the reference capture the same amount of liquid. The most straightforward way to determine the delay time is to use a step flow change and observe the response.

Flow measurements using different types of flow meters (measuring principle (e.g. Coriolis, turbine, pd) / manufacturer) that are used in the maritime sector for different liquid temperatures and using different hydrocarbon liquids were carried out. The analysis of the data led to insights into influencing factors which might need to be taken into account when using these flow meters. The results show the principal suitability of the Reynolds number approach. It works well for a medium flow range and within a certain viscosity range. Limitations to the approach occur if additional effects, e.g. temperature-related, are present as could be illustrated by measurements. The adaption of the calibration curve based on the Reynolds number approach was associated with an error of 0.2 % to 0.4 % at optimum conditions. In the worst case the error amounts to several percent.

A pd-type flow meter prototype to be deployed in ships was extensively characterised. Here, both a viscosity-dependent influence and an upstream-pressure-related influence were evident in the measurement results. The fact that these are real effects caused by the measuring device could be proven by measuring with a scale as well as with a prover as a reference.

To prepare a fuel property matrix of the transport properties of alternative fuels e.g. bio-diesel (FAME), bio-alcohol and synthetic fuels. This should enable the transfer of calibrations between fuels and extrapolation to higher temperatures and pressures. The selected fuels should have densities > 400 kg/m³, viscosities > 0.01 mPa·s, temperatures ≤ 620 K, pressures ≤ 300 bar and flow rates ≤ 2 m³/h. Sensors should also be developed for traceably measuring density and viscosity in situ. (Objective 3)

Based on a comprehensive survey of alternative and synthetic fuels a number of relevant current and upcoming fuels were identified. Based on these four fuel classes were defined for which further studies and measurements were carried out: Biodiesel (FAME), Hydrotreated Vegetable Oil (HVO), Oxymethylether (OME), E10. Based on literature studies and stakeholder input it was decided to measure several diesel surrogates and one gasoline surrogate, among them ethyl tetradecanoate, methyl dodecanoate, OME3 and OME4 and a blend of them, SYN E10 blends. For OME3 and OME4, the investigated temperatures covered a range from 0 °C to 150 °C in 25 °C steps. Due to the melting temperature of ethyl tetradecanoate and methyl dodecanoate, the investigated temperatures covered a range from 25 °C to 150 °C, also with 25 °C steps. With the exception of ethyl tetradecanoate which might solidify at 25 °C and above 500 bar (and was thus only measured up to 400 bar), the pressure covered a range from 1 bar up to 1000 bar. Using this data, density (Tait equation) and viscosity (Tait-Andrade equation) correlations were developed. For quality assurance of the density and viscosity measurements it was decided to validate the devices using an N4 standard. Measurements of the N4 standard have shown that the results of all partners are in good agreement.

Materials and design details of a prototype ultrasonic densimeter to fit the required working conditions were evaluated. The new densimeter has been assembled and it is currently being tested. Furthermore, a new test rig for in-line density and viscosity measurements, also to be hosting the prototype ultrasonic densimeter and a viscometer was set up. Improvements of in line measurements of commercially available density and viscosity devices have been discussed and are currently being implemented and tested.

To provide metrological input, and pre-normative research, for the further development of international standards with a focus on close to real-world flow calibrations in the transport sector. In addition, to contribute to the development of a pan-European harmonised framework, which will enable the emission targets set by the International Maritime Organization, the European Conference of Ministers of Transport and the Fédération Internationale de l'Automobile to be met and controlled. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories, instrumentation manufacturers), standards developing organisations (IMO, ISO) and end users (transport sector). (Objectives 4, 5)

The outputs associated with objectives 1-3 will be used to prepare guidelines for the evaluation of the flow meters used in the transport sector, with a view to real world operating conditions, including recommendations for the determination of uncertainty budgets. This means this part of the project gains relevance towards the end of the project.

Impact

A stakeholder advisory board was set up comprised of representatives of manufacturers of flow meters and test rig technologies for the transport sector, a maritime association, a national metrological institute and standardisation bodies. It has the responsibility for keeping the project aligned with industry's needs and for informing end users about project findings as they emerge. NMIJ, the University of Torino and AVL GmbH joined the project as collaborators and will provide insights based on their long-term and diverse experience. To foster impact the project has a dedicated website. Presentations were given by project partners at several workshops and meetings hosted by industry. Furthermore, the partners participated in various international conferences related to dedicated project-relevant topics giving presentations and providing proceedings papers about project results. Several papers were published, some more are currently undergoing a review process. A webinar on the first project results was held for the stakeholder community in February 2023. There are plans to host a second webinar. Plans for the dissemination workshop at the end of the project are in progress, as is the planning of the contributions at the 20th International Flow Measurement Conference. Moreover, project results are also to be disseminated to aviation.

Impact on industrial and other user communities

The outputs of this project will create impact by enabling stakeholders who depend on fuel consumption measurements in the road transport and maritime sectors, such as vehicle manufacturers, freight forwarders, ship owners, and regulatory authorities, to have access to reliable fuel consumption data.

One key project output will be advanced calibration capabilities. These will generate impact by enabling flow meter performance to be assessed under the dynamic flows that are associated with test cycles such as the World Harmonized Stationary Cycle (WHSC) or the World Harmonized Transient Cycle (WHTC). The project's associated technical guide and the design for a secondary test rig, which will be capable of generating dynamic loads, will help to facilitate practical take-up. In addition, efforts towards downsizing vehicle engines will be supported by the project's improved fuel consumption measurements.

By providing a fuel property matrix of alternative and synthetic fuels, companies will be supported in their endeavours to develop engines which work efficiently with alternative or synthetic fuels. The provision of a validated numerical tool for investigating the interaction between test liquid and flow meter performance will enable companies to replace experimental setups with simulations with known uncertainties, in particular in the case where experimental conditions are costly or dangerous to realise. Likewise, the provision of two well-characterised synthetic test liquids for use as substitute fuels for flow meter characterisations will support the work of companies that are active in the development of drive systems and testing technology.

The project's technical guides for the comprehensive uncertainty assessment of the flow meters that are used for the fuel consumption measurement of cars and trucks and in the maritime sector will create impact by helping manufacturers of these devices to supply their customers with more reliable information about the performance quality of their products. The project's outputs will also help to create impact by paving the way towards a realistic uncertainty determination for fuel consumption measurements.

The project will contribute to improving the measurement capabilities of the fuel transport properties under operating conditions through its advancement of in-line measurements of the density and viscosity of alternative and synthetic fuels, by developing a sophisticated system combining standardised calibration procedures. This will in turn support an improved fuel consumption determination as the flow meter performance for the real-time transport properties will be taken into consideration in the flow measurement.

To foster the take up of the project's findings by a wider community in flow metrology from NMIs/DIs, industry and academia, all outputs with direct links to flow measurements and measurement quality will be compiled in a PTB-Report, which will be made freely available to end users via the project's website.

Impact on the metrology and scientific communities

Based on the outputs of this project, such as the assessment of the measurement performance of flow meters under dynamic loads, the project partners will develop novel measurement capabilities and procedures which will allow them to perform a more detailed and profound characterisation of the devices than was previously possible. The technical guides, for the comprehensive uncertainty assessment of flow meters, as well as the PTB-Report, are especially relevant to flow metrology and they are intended to serve as a basis for broader knowledge dissemination to the scientific community.

The technical guide for the assessment of flow meter performance under dynamic load changes will contribute towards future dynamic calibrations by providing, (i) guidance on requirements for the realisation of a test rig that is able to generate and measure dynamic loads, and (ii) recommendations for a measurement procedure and for the analysis of the results.

Stakeholders in the metrology and scientific communities will be further supported by establishing new capabilities at project partners to measure the transport properties of liquids at significantly higher pressure ranges than available at present. For density, the range covered will be up to 170 °C and 1000 bar. For viscosity, the ranges covered will be up to 350 °C and 40 bar, as well as up to 150 °C and 700 bar. The knowledge, primarily residing at universities in this area, will be transferred to NMIs/DIs via this project.

The project will also support research linked to alternative and synthetic fuels as a more comprehensive data base on the density and viscosity of these liquids will be available in the fuel property matrix. The provision of two extensively characterised synthetic test liquids, which will be useable as fuel substitutes, will further support the use of alternative and synthetic fuels.

Furthermore, the project's results, obtained with different fuels, will improve the scientific community's understanding of the influence of the liquid on the flow meter itself as well as the effects that are due to changes in the flow profile. This deeper understanding will help with the quality assessments that are undertaken when different liquids are used for calibration and under operating conditions.

Impact on relevant standards

This project provides input to a number of national and international committees dealing with flow measurements. Among others, input is being provided to EURAMET TC-F and to the BIPM CCM WGFF. The technical guides on the assessment of the measurement uncertainty of flow meters, prepared in this project, as well as the PTB-Report on the advancements in flow metrology, will be used as inputs for new guides and for revisions to existing guides. The project also supports the work of EURAMET TC Mass and Related Quantities (TC- M) and the BIPM CCM WG on Density and Viscosity (WGDV) in their aim to provide guidance on density and viscosity determinations. At a national level, calibration service providers are being informed on a regular basis about the project's activities and results so that these can be taken into account in the revision of standards, recommendations and guidelines. Among these are the DIN NA152-04-02AA "Flow rate and Amount" and the DKD TC "Flow Measurands".

Longer-term economic, social and environmental impacts

The transport sector has been identified as one of the main sources of greenhouse gas emissions. This has led to major efforts to shift towards a climate-neutral mobility. Advanced flow metrology is a key factor in this move towards low-emission mobility, as increasing engine innovation, or validated emission determinations for ships and vehicles, rely on appropriate fuel consumption measurements. Reliable data and measurements of the transport properties of these fuels are also required and both will be fostered by the outcomes of this project.

CO_2 standards for heavy duty vehicles and ECA in the maritime sector are further means towards a low and zero emission mobility. The capabilities and knowhow developed in the project will help determine the relevant parameters with sufficient accuracy.

Standards and frameworks in liquid flow metrology will be advanced by the project's results which is a precondition to realising the long-lasting goal of a European harmonised approach for the evaluation of fuel flow measurements which are closer to real-world conditions. In the longer-term the project will also support stakeholders in their endeavours to comply with Europe's shift towards low-emission mobility whilst maintaining competitiveness.

List of publications

O. Büker, K. Stolt, C. Kroner, H. Warnecke, L. Postrioti, A. Piano, G. Hagemann, M. Werner, 2023. Characterisation of a Coriolis flow meter for fuel consumption measurements in realistic drive cycle tests. Flow. Meas. Instr., vol. 93, https://doi.org/10.1016/j.flowmeasinst.2023.102424

C. Wedler, J.P.M. Trusler, 2023. Review of density and viscosity data of pure fatty acid methyl ester, ethyl ester and butyl ester. Fuel, vol. 339, art. 127466. https://doi.org/10.1016/j.fuel.2023.127466

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:	01 September 2021, 36 months	
Coordinator: Corinna Kroner, PTB Tel: 0049 5315921500 E-mail: corinna.kroner@ptb.de Project website address: https://www.ptb.de/empir2021/safest/the-project/		
Internal Funded Partners: 1. PTB, Germany 2. INRIM, Italy 3. RISE, Sweden 4. TUBITAK, Türkiye 5. VTT, Finland	External Funded Partners: 6. IB-HAWE, Germany 7. IC, United Kingdom 8. TU-Ch, Germany 9. UNICAS, Italy 10. UNIPG, Italy	Unfunded Partners: -
RMG: -		

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[1] 17IND13 Metrowamet – Metrology for real-world domestic water metering; https://www.ptb.de/empir2018/metrowamet/the-project/

[2] Warnecke, H., Kroner, C., Ogheard, F., Kondrup, J.B., Christoffersen, N., Benková, M., Büker, O., Haack, S., Huovinen, M., Unsal, B, 2022. New metrological capabilities for measurements of dynamic liquid flows. Metrologia, https://doi.org/10.1088/1681-7575/ac566e