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Metering of gas flows in power to gas plants

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Current natural gas infrastructures transmit and distribute mainly fossil and partly regenerative gases. In Germany the injection of regenerative gases in gas pipelines is regulated and supported by the law on the energy industry (EnWG). In particular, fermentative biogases and hydrogen generated by power to gas plants are highlighted. Moreover, synthetic natural gas (SNG) as a reaction product of hydrogen and carbon dioxide is enclosed. In contrast to SNG, hydrogen as admixture to natural gases can significantly modify gas qualities. In particular, the calorific value and density is lowered. There is a set of pilot plants in Germany used for operation of almost carbon free gas generation technologies and injection stations. Regenerative gases are distributed and traded in the exact same manner as fossil gases. Since all gases are commodities, the related energy needs to be metered. In Germany metering of commodities is covered by the weights and measure act. Therefore, devices used for metering need approval and calibration at registered test rigs. In this presentation the metering technology of regenerative gases and carbon dioxide used in power to gas facilities is presented. Metering stations and metering sections in injection stations described. Moreover, metering results and meter accuracy curves of calibrations are shown. It is concluded that generally accepted gas meters of the gas industry can also be deployed for fiscal and custody transfer metering of regenerative hydrogen, carbon dioxide, SNG, biogas and hydrogen enriched natural gases.

Introduction

On the whole the composition of natural gases has not changed much since the very beginning of the industry. Already in 1817 Johann Joseph Prechtl lists in addition to methane and higher hydrocarbons hydrogen, carbon monoxide and dioxide [1]. Current fossil fuel gases consist of these gases in different combinations and concentrations [2].

Quite recently the natural gas industry explores regenerative gases as a new business opportunity. Renewable gases as admixture to fossil natural gas are transmitted and distributed in the currently operated networks. The gaseous renewables are traded as new energy products using already existing sales channels. Beyond biogas, hydrogen and synthetic natural gas (SNG) generated in power to gas plants are considered [3]. Power to gas technology converts wind or photovoltaic power into “green” hydrogen or in a second step into SNG. In Germany already 16 pilot power to gas plants are in operation [4,5]. Many of them generate pure hydrogen and feed it directly into the natural gas networks to store electrical power in the existing gas infrastructure. Beyond energy industry the automotive industry takes an interest in “green” hydrogen to meet future low carbon emission limits within the European Union [6].

Whether fossil, regenerative or mixed gases are transmitted, distributed and traded, the related flows have to be metered. In case of billing services the metering might be covered by weights and measure acts. Beyond billing meter data are used to control and monitor gas infrastructure. Moreover, transmission services request custody transfer metering. In all cases the generation of “green” gases and the admixture to natural gases leads to the request to meter pure hydrogen, hydrogen enriched natural gases, SNG and CO_2 for SNG production with the existing metering infrastructure and technology. Therefore E.ON launched a measurement program to verify the capability of generally accepted metering technologies in the natural gas industry to meet this particular request. Test program and results are described below.

Metering of gas flows in meshed infrastructures

The meshed European gas network transmits and distributes predominantly methane-rich natural gases [2]. It is expected that the importance of natural gas continues to increase worldwide and that natural gas will be sufficiently available in the next few decades [7]. Although currently insignificant compared with the volume of fossil gases, regenerative gases achieve increasing attention in the energy industry. Hydrogen and SNG from power to gas plants have the potential to store significant amount of “green” electrical power in the gas infrastructure. Moreover, “green” gases provide new products at an expected premium price. The feed into the natural gas networks, however, increases the variety of gas qualities. The following gas qualities are expected.

1. natural gases of different nature
2. regasified LNG from various countries of origin

3. biogas from fermentation processes
4. "green" synthetic natural gas (SNG)
5. renewable hydrogen (H_2)
6. hydrogen enriched natural gases
7. carbon dioxide (CO_2) as the input material for the methanation of hydrogen and
8. various mixtures, with qualities depending on gas composition, flows at entry and exit points.

These gas flows are metered primarily for two reasons: They are part of the process variables to control and monitor flows, processes and infrastructure. Therefore, the specification of the measuring instruments used follow the requirements of the process they support. Furthermore, meters quantify energy and gas flows for billing purposes. Instruments deployed might therefore be subject to the requirements of legal metrology, described by weights and measure acts and European Measuring Instrument Directive (MID) [8].

The determination of energy flows of fossil natural gases and their mixtures is described in [9], and the biogas produced by fermentation processes in [10]. Methanated hydrogen as SNG consists largely of methane and can therefore be treated as methan rich natural gas. Subsequently, the focus in this article is on hydrogen (H_2), hydrogen-enriched natural gases and carbon dioxide (CO_2).

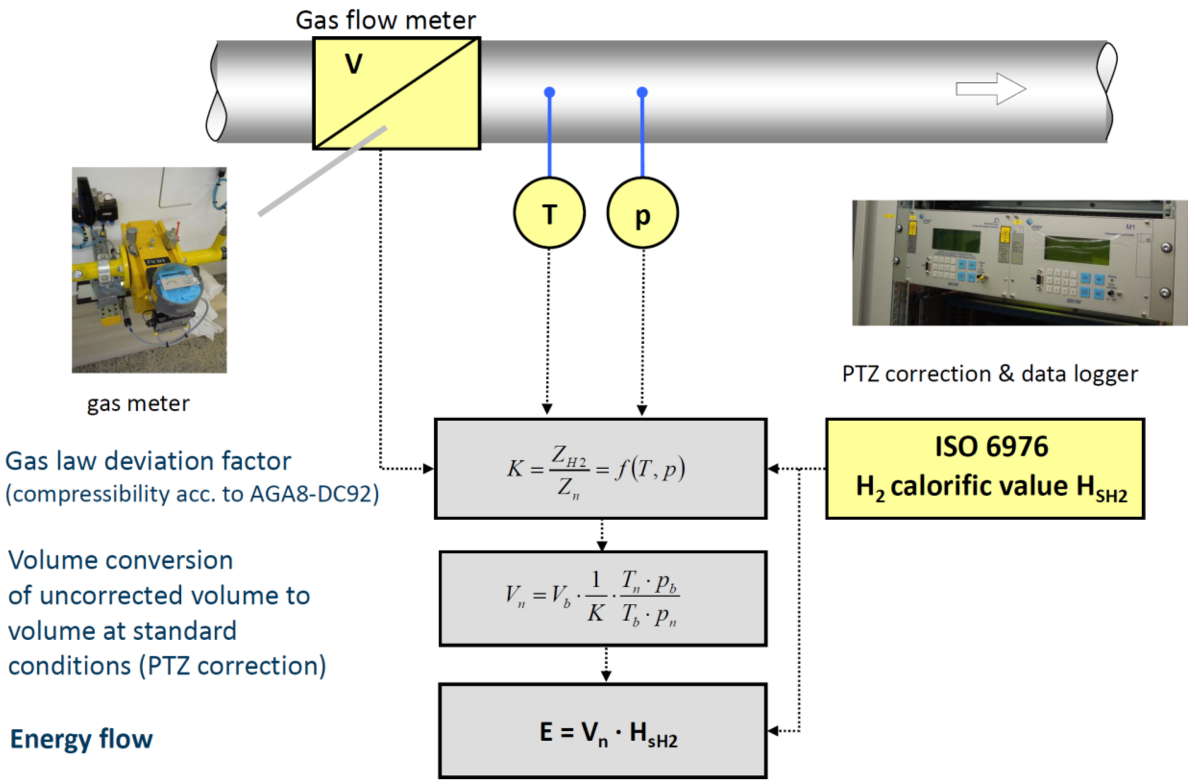


Figure 1: Fiscal metering and valuation of injected H_2 energy flows at E.ON´s power to gas plants; standard conditions: T_n = 0°C; p_n = 1,01325 bar.

Fiscal hydrogen metrology

Electrolytic hydrogen from power to gas plants has usually a purity of at least 99.9 % (mol/mol). Oxygen as primary minor constituent is process dependently traceable. Nitrogen is used as purge gas for inerting the entire system in case of events. Nitrogen traces in hydrogen can therefore also be detected. Furthermore, moisture occurs. However, in E.ON´s power to gas plant at Falkenhagen [11,12] the hydrogen is dried before the meter run below the allowed maximum limit of 50mg/Nm³ of the DVGW worksheet G260 [13]. Oxygen, nitrogen and humidity is automatically monitored. Any exceedance of the limits alerts dispatching and shuts down hydrogen generation. The exclusion of further gas impurities is frequently demonstrated by sampling and analysis. German metrological authorities therefore allow to consider electrolytic hydrogen to be dealed as pure hydrogen.

Commercially available calibrated natural gas meters are deployed for measuring the flow rate of the quasi pure hydrogen - see Figure 1. Since there are no authorised hydrogen test rigs available, legal metrology rules request MID conformity declaration and calibration at a generally accepted test rig for natural gas meters. Consequently, the fiscal meter deployed in E.ON´s power to gas plant at Falkenhagen was calibrated at high pressures. Furthermore, German metrological authorities requested accuracy tests with hydrogen rich gases according to DIN EN 437 [14]. Moreover, the meter supplier has been obliged to provide a qualification statement on the hydrogen metering capability. For safety reasons the entire meter equipment shall be suitable to be used in hydrogen explosive atmospheres.

Correction procedure based on state variables (PTZ correction) is applied to convert the measured volume into volume at standard conditions. Required chemical and physical parameters such as the calorific value of pure hydrogen are taken from the DIN EN ISO 6976 [15]. The gas law deviation factor is determined according to the AGA8 - DC92 equation [16]. German metrological authorities accepted usage of AGA8-DC92 equation after simulation of deviations from calculations with GERG-2004 equation of state [17]. Deviations are minimal in the usual pressure and temperature ranges of the natural gas industry and virtually negligible. However, it was assumed here that the GERG- 2004 equation of state accurately describes the "real" state of the hydrogen. The GasCalc computer program delivered simulation data and required gas quantities [18].

Beyond requirements set by the weights and measure act the injection station has to obey the gas network operator´s codes and standards. For instance, meter inspection and more frequent recalibration periods, remote reading access to the meter archives for billing purposes or network balancing and SCADA data to monitor hydrogen generation and injection might be requested.

All sections of E.ON´s power to gas plant in Falkenhagen are monitored. This includes the hydrogen pipeline which is supervised by a leakage detection and leak localisation system. Another leakage detection method is implemented to monitor the compression unit which raises the hydrogen pressure from electrolysis pressure level to the operating pressure of the natural gas network. Station programmable logic controller (PLC) automatically compares hydrogen flows at low pressure electrolysis exit with high pressure pipeline entry. Transmission network and power to gas plant operators agreed on this comparison with the fiscal meter as the reference.

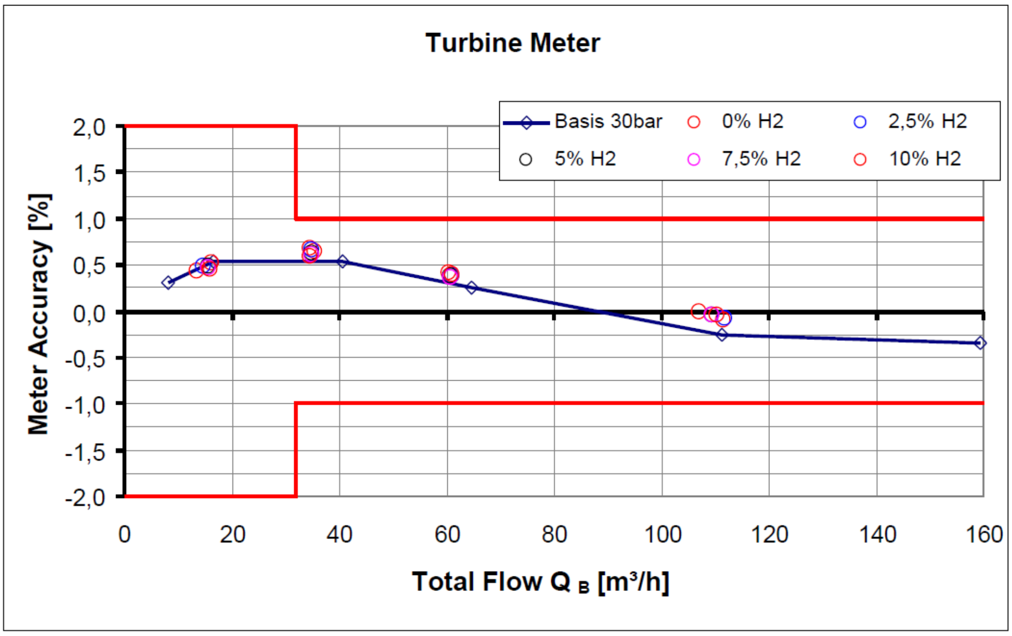
Fiscal metering of hydrogen enriched natural gases

Current natural gases do not contain hydrogen. Until the mid-eighties of the last century, however, hydrogen as a constituent of coal and town gas was added to natural gases. Since power to gas plants inject hydrogen into the natural gas infrastructure, a renaissance of hydrogen as constituent of natural gases is expected in the near future. Hydrogen admixtures will have an impact on the gas quality parameters and therefore on the combustion characteristics [19]. To what extent hydrogen admixtures have any impact on metering of natural gases, is not clear so far. Experience is limited to hydrogen rich town and coal gases. Therefore E.ON launched a test to clarify performance of commercially available turbine and ultrasonic gas meters measuring hydrogen enriched natural gases at pigsar™. pigsar™ is one of the worldwide leading high pressure test facilities for gas meters. It represents the German standard for the cubic meter of natural gas [20].

Hydrogen was gradually added to natural gas at high pressures in predetermined steps up to 10 % (mol/mol) content. Natural gas flows were controlled by standard procedures of the test facility. Mass flow meters controlled the hydrogen injection. A static mixer ensured sufficient gas blending. Hydrogen content of the gas mixture was automatically monitored by a process gas chromatograph. Results have been finally verified via analyzing gas samples in addition. Further details of the test setup and parameters are described in Ref. [21].

Accuracy results are shown in Figure 2. The solid line represents the original high pressure calibration curve of the meters under test. The dots show results of operating points at different flows and hydrogen contents. The final cycle was conducted without any hydrogen admixture. Under almost all operating conditions with and without hydrogen admixtures the accuracy deviation is close to the original calibration curve. The enrichment of natural gas with hydrogen up to 10% has not led to a quantifiable increase of uncertainties or to a systematic impact on accuracy. A gas quality dependent displacement at high pressures cannot be observed. There are no concerns based on the measurement range to use commercially available turbine and ultrasonic gas meters for fiscal metering of hydrogen enriched natural gases up to 10% volumetric hydrogen content. In this context it should be mentioned that such meters are also used to meter hydrogen rich town and coal gases. Current volumetric hydrogen shares in E.ON´s coal gases are well above 60%.

The determination of the energy content of hydrogen enriched natural gas flows assumes knowledge of the constituents and/or calorific values. Devices to measure chemical components or parameters and flow computers to calculate gas volume at standard conditions are commercially available. Authorization of proposed devices and equation of state used for correction should be clarified with the local metrological authorities or network operators. In Ref. [22] a German approach is described in detail.



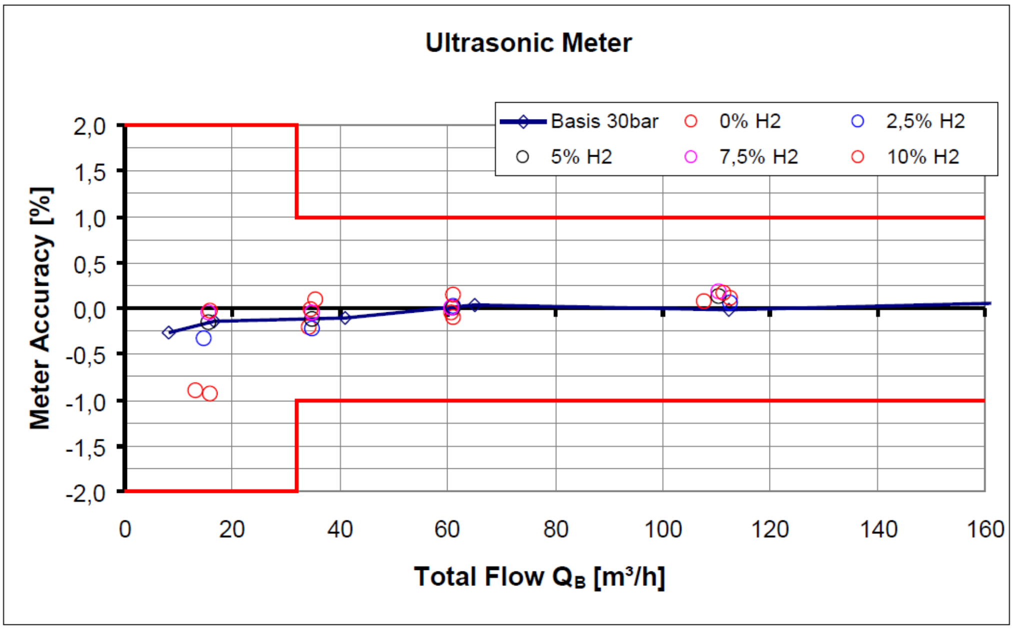


Figure 2: Point of contact metering of H_2 enriched natural gases; there are only 2 accuracy figures having a certain, but insignificant impact on meter accuracy up to 10% H_2 content.

Any volumetric metering of hydrogen enriched natural gases requests sufficient blending of hydrogen with the natural gas. The hydrogen injection station of E.ON´s power to gas plant in Falkenhagen uses a T piece to mix the gas flows. Simulations of the mixing process have been done at 3 and 0.3 m/s transmission speed of the natural gas. Almost 20m after the injection point hydrogen is sufficiently merged with the natural gas at 3m/s. However, 2.5km are needed for sufficiently blended gases at 0.3m/s. For any metering downstream the injection point this result might be important to recognize in case of requested high metering accuracy.

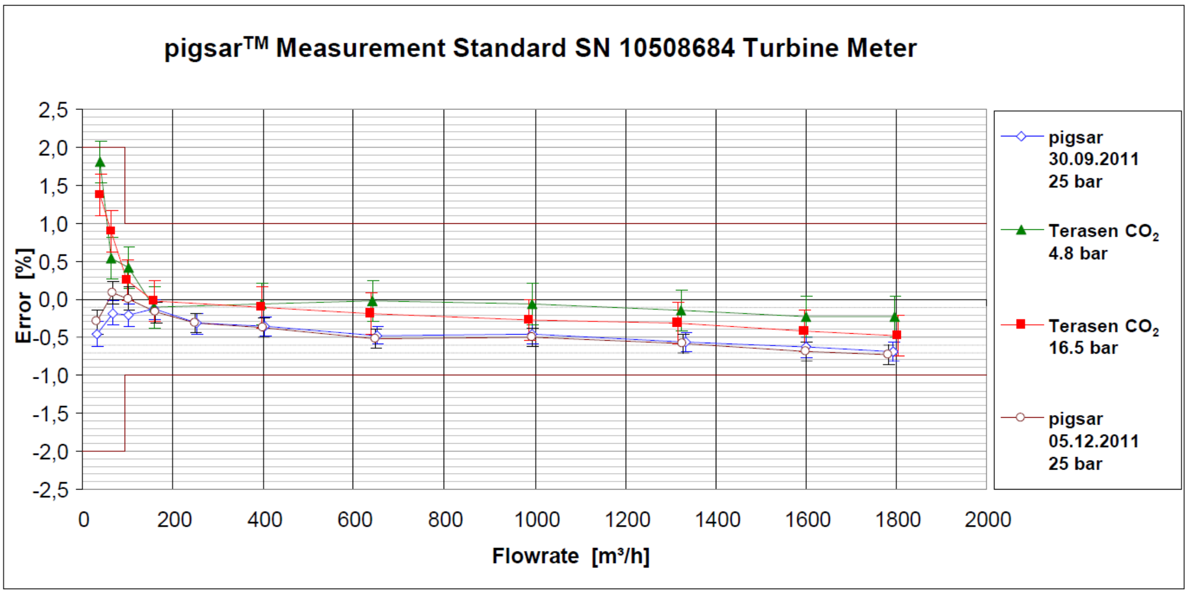
Furthermore, the gas flow direction of the natural gas at the injection point needs to be taken into account. Since reverse flows can occur, reverse and forward flows alternate. Consequently, any gas volume close to the hydrogen injection point oscillates. In such cases continuous hydrogen injection finally leads to an hydrogen content accumulation in the natural gas with the potential to exceed any allowed or agreed limits. Hydrogen injection needs to be controlled and limited to secure accurate metering downstream the injection point.

Gaseous carbon dioxide

Carbon dioxide (CO_2) comes with a bad image in the public debate. It is considered as a gas being harmful to the climate and should be limited in the atmosphere. Quite recently the energy industry, however, considers carbon dioxide as promising resource for chemical energy storage. Hydrogen and carbon dioxide may be converted into synthetic methane (SNG) by power to gas technologies [3-5]. Since SNG and natural gas exhibit almost similar gas quality and combustion properties, impact of SNG injection into natural gas is very much limited. Major investments to adapt the natural gas infrastructure to distribute and transmit regenerative gases may therefore be avoided.

Carbon dioxide used as means of gas production is to be treated as a commodity. Related values need to be determined. In particular in Germany, instruments used for this purpose are subject of the weights and measure act. Meters need MID approval and calibration. Since there are no authorized carbon dioxide test rigs available for calibration, E.ON launched a test program to verify deployment of commercially available natural gas meters for metering gaseous carbon dioxide. A meter used as measurement standard for natural gas and owned by pigsar™ was selected as device under test. Accuracy curves have been taken with air, natural gas and gaseous carbon dioxide under various pressure and flow conditions at different test rigs. Measured accuracy curves over the flow rate and the Reynolds number are shown in Figure 3. The illustrated metering points are average values out of 5 measurements with a test period of 60 seconds each. Uncertainties in measurements are marked by vertical bars. Metering has been done with natural gas at pigsar™, with air at the supplier´s and PTB´s test rig [23], finally, with carbon dioxide at Terasen [24]. Further details of the test program are described in Ref. [25].The main results of the test program may be summarized as follows.

The basic accuracy curve at the beginning of the tests and the final curve are almost identical. Meter performance has not changed during the test period. The meter performs long term stability of the accuracy. Deviations between the natural gas and carbon dioxide accuracy is below 0.3% above 10 % of the maximum specified flow Q_{max}. The deviation of meter accuracy is almost independent of the Reynolds number. High pressure calibration test rigs are therefore qualified to calibrate CO_2 meters with natural gas.



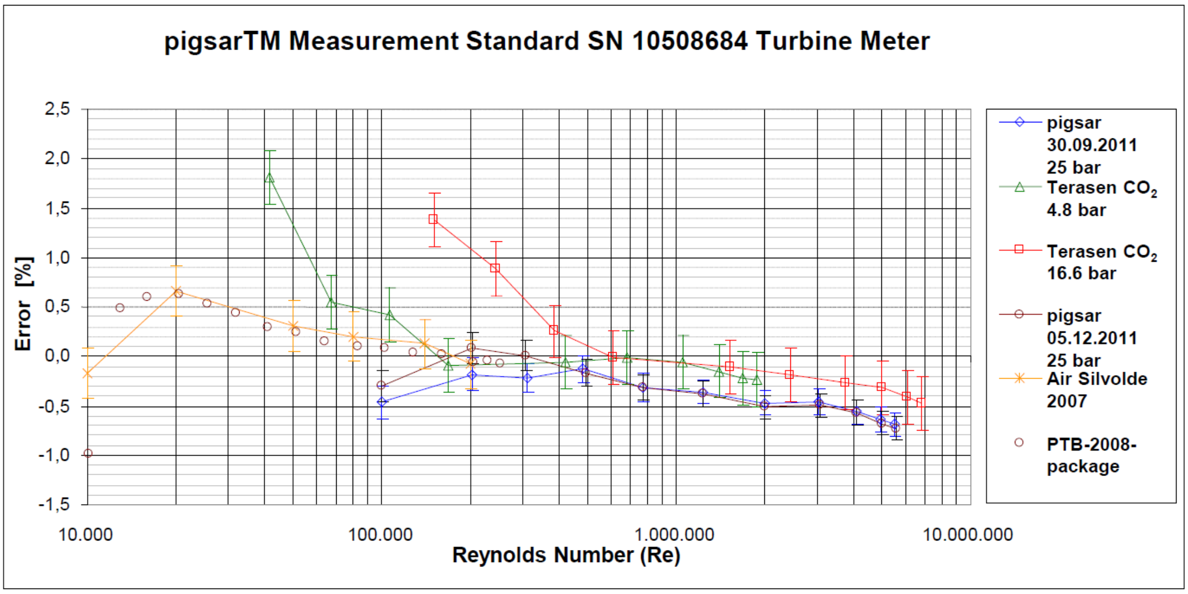


Figure 3 Errors of a turbine meter plotted against flowrate and Reynolds number; comparison of meter performance measured with natural gas, air and gaseous CO_2 at different pressures.

Conclusion

Future natural gas infrastructure distributes and transmits fossil and renewable gases. The energy industry currently highlights “green” hydrogen and synthetic natural gas (SNG) generated by power to gas technologies. Beyond new “green” products, the energy industry uses power to gas technology to store renewable power in the natural gas infrastructure. Regenerative gases are transmitted, distributed and traded in the same manner as natural gases thereby using the same sales channels and trading platforms. The injection of renewable gases, however, leads to a wider variety of gas qualities in the markets. Beyond biogas, hydrogen enriched natural gas, pure hydrogen, SNG and CO_2 for SNG synthesis occur. Whether fossil, regenerative or mixed gases are transmitted, distributed and traded the related value has to be determined by fiscal metering or custody transfer metering of the gas flow. Since new gases, admixtures to natural gas, mixtures and CO_2 as means of production and a related wider gas quality range provides a new challenge to the gas industry, E.ON launched a test program to verify the ability of currently deployed gas meters for future gas infrastructures. It was shown that commercially available gas meters can also be deployed for fiscal and custody transfer metering of regenerative hydrogen, carbon dioxide and hydrogen enriched natural gases. Moreover, correction can be done with procedures already used in the industry.

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