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New tools for in-situ checking of gas flow meters

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Back ground

KEMA has developed a two valuable tools and instruments to obtain further confidence in the accuracy of flow meters for custody transfer as well as for process purposes. In this paper we will describe the use and the benefits of these tools and show some results in lab tests and in-situ application at metering stations.

What are benefits for the gas metering worlf? As flow meters in custody transfer applications are directly linked to the cash register of a gas client any measurement error directly results into a financial mistake. Therefore the companies involved in gas trading want to have proper means to check flow meters, as these meters have a large contribution to measurement uncertainty. Gas consumers or gas measurement responsible authorities can save a considerable amount of time and money when flow meters can be checked in-situ instead of in a calibration facility. Moreover an in-situ check has specific benefits besides cost as it takes into account all process and piping conditions influencing a proper flow measurement. The specific flow conditions or dynamically changing pressure or flow conditions (which can lead to measurement error of several percent) at a metering station can never be checked by performing a recalibration at a calibration facility. Hence these type of tools are a valuable addition to the overall spectrum of operational checks, controls and (re)calibrations.

KEMA has developed two check or verification options, which are available to the gas industry and its gas consuming clients

1. Tracer technique to check in-situ flow measurement equipment
2. Dynamic conditions toolkit to determine the flow metering errors of turbine meter in field conditions

1 INTRODUCTION

Natural gas serves as prime energy resource and in that sense it is a valuable asset and ought to be treated as such. Therefore good exact knowledge of the transported and/or traded quantities is of great economic importance. In the trading of quantities of gas the measurement of (volume) flow usually contributes to the highest measurement uncertainties and hence the largest financial risks.
In reality it just happens that the checking or calibration of flow meters directly is done with a quite low frequency as compared to other more secondary instruments. Calibration of a flow meter system usually means high costs and possible downtime of the metering system and therefore many flow metering systems operate unattended for many years thus contributing to large operational measurement risks.

Tracer:

One solution to overcome this issue has been developed by KEMA. It is a tracer technique to perform a flow system verification in situ with an accuracy targeted at a 2-σ uncertainty value of < 0.5%. The technique of this tracer method consists of injection of a Argon tracer to the main gas flow upstream from the flow meter to be checked, and to measure its concentration downstream close to the flow meter. The injected mass flow Argon and its concentration in the gas flow are measured accurately, which results in an accurate determination of the gas flow through the flow meter. In this paper we show the current status of this tool to serve the gas measurement community. It is a further development of earlier work done by Gasunie Engineering & Technology (ref. [1]) now KEMA Gas Consulting & Services.

Dynamic conditions toolkit

Nowadays more and more parties are involved in the trade and allocation of gas. Sometimes even on hourly basis the measurement values need to be registered and balanced in a gas transport system. This implies more and more dynamic time varying gas offsets and hence flow metering systems like turbine meter, which are sensitive to these dynamic effects tend to exhibit systematic (over)reading in these circumstances.
Turbine meters (TM) are considered still to be flow measurement devices showing a large accuracy and stability over a long period of time. Therefore it is not very surprising that very many of the natural gas custody transfer stations are equipped with turbine meters. KEMA developed a solution to determine the systematic error created by the dynamic conditions affecting turbine meter systems. It is most powerful once the dynamic conditions are measured at the HF signal of the flow meter along with a fast (acoustic) pressure measurement with a set of pulsation transducers. This paper describes the development and first results of this technique in a number of laboratory and field applications.

2 TRACER TECHNIQUE

The developed tracer method performs in-situ checks on all types of gas flow meters. The method has a broad application range as it is independent of meter type or pressure (up to over 100 bar). In this chapter we will discuss the working principle, its benefits and the current status and achievements.

2.1 Principle of the tracer technique

The tracer technique to determine the flow in a medium has been applied for many decades and in many types of flow applications. The technique is widely known in closed piping, but also in open channel fluid measurements. There are basically two types of tracer methods:

1 method based on transit time measurement (time between upstream tracer injection and downstream tracer detection)

2 method based on dilution measurement

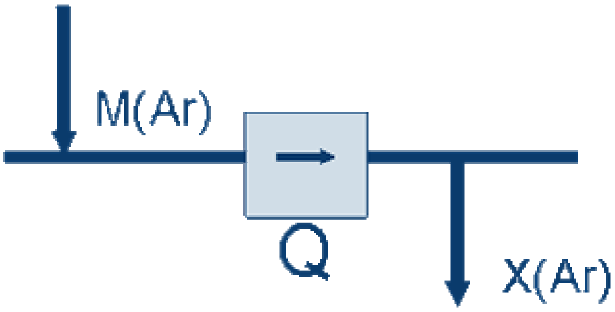

Figure 1 Tracer Principle

Consider a gas flow in a pipe with a flow quantity Q (e.g. in kg/sec) to be measured. As for the dilution method we inject in the pipe a known and controlled flow quantity M (also in kg/sec) of tracer material Ar in the flowing gas. Further downstream we make an accurate measurement of the concentration or dilution of the tracer material Ar in the gas medium x (in mol %). Through this concentration measurement we can directly verify a flow meter measuring Q_f and determine its deviation ε as:

$$\varepsilon = Q - Q_f = \frac{M}{x} - Q_f \qquad (1)$$

In this way an accurately injected flow along with an accurate measurement of concentration gives rise to an accurate estimate of the deviation of the flow meter in a real operational gas system.

2.2 Advantage of tracer field check vs. calibration

A field check or an in-situ method like Tracer can have large advantages as compared to the more traditional method of flow meter calibration. There can be several factors in field situation influencing a good flow metering performance and hence the accuracy of the flow readings:

- Operational conditions (e.g. temperature or pressure effects) in real application differ from the calibration conditions
- The piping geometry can differ between calibration and actual situation. We know that in particular for certain measurement principles like US this can make a significant contribution to the error
- Usually the calibration conditions are supposed to be quite stable non-varying, whereas in actual applications dynamic effects, like pulsations, quick process variations or instabilities in control systems can cause metering errors

Also other disadvantages of calibration of a flow meter can be present, e.g. the risk of damage/incidents during transport and the necessary downtime of a metering system during and in between built-out and built-in. It either requires spare meters or spare metering runs and in any case it means extra costs.

2.3 Tracer achievements over the last decades

Tracer methods have been applied for many decades in various applications to image flowing processes. The application scope is broad, ranging from human brain processes (e.g. PET scans), oil well imaging or river flow determination. For imaging flow processes one talks about flow tracers. In principle for a flow tracer one can use any specific fluid property to track the flowing medium. Most tracers particles are artificially introduced, like a kind of dye, and sometimes even accidentally. A funny example occurred in 1992, when about 30.000 toys in the shape of turtles, ducks, beavers and frogs packed in a cargo container splashed into the ocean, creating a real-life validation of the Pacific ocean surface currents.

We here discuss the tracer methods in high pressure natural gas applications. So far these methods have not yet received the full accuracy of a flow calibration, but some progress has been made. First attempt in high pressure natural gas was in the 80's performed by Gasunie

Research, reaching an uncertainty of 2% or higher. In the late 90’s Gastec performed test using ethane concentration as tracer gas and also here the uncertainty at best was 1%, with 1.5% a more typical value [ref.2]. In 2003 Advantica patented a tracer application using as tracer Helium gas, and heat conductivity as concentration measurement; claimed uncertainty U >~1% [ref 3].

Since 2006 the KEMA flow group under the flag of Gasunie Engineering & Technology [ref. 1] was concentrated on using speed-of-sound method to determine the tracer concentrations, but for reaching the final goal of about ~0.5% a switch to a more direct method with a micro GC was made, see section 3.

2.4 **Applications of an accurate tracer technique**

Such an accurate verification tool is of course very well suited to determine the accuracy of fiscal flow meters and especially to determine the specific field condition effects, which usually are not taken into account when a flow meter is calibrated at a calibration facility. So the tool is well suited for in situ check on gas measurement installations.
Particularly in cases of flow meter disputes such a tracer tool will directly deliver an independent verification, usually faster at no downtime and at lower costs as compared to calibration. One could really consider such a tracer check as a good alternative for a recalibration, especially when there is an indication of necessity or suspect of systematic flow error readings.
An other application field is a real verification of flow applications in pressures exceeding the usual upper end pressure of 60 bar at calibration facilities. The current tracer method described here is suitable up to pressures ~100 bar.

Of course the application field is much broader than custody transfer metering. For instance a simplified version of the Tracer tool can be used for determining gas leakage; flow in gas manifolds or pipes with process flow meters or even without flow meter can be checked.
Sometimes in troubleshooting cases it is very essential to know flows in an accumulation pipe leading to a flare or also there is a need to know for the performance of gas turbines .
Last but not least the method as it is now -based on direct concentration measurement- can also be applied beyond the field of natural gas in any gas system which does not contain Argon gas.

3 KEMA'S METHOD OF TRACER FLOW VERIFICATIONS

The technique of this tracer method consists of injection of a tracer gas (Argon) to the main gas flow upstream from the flow meter to be checked and to measure its concentration downstream close to the flow meter.

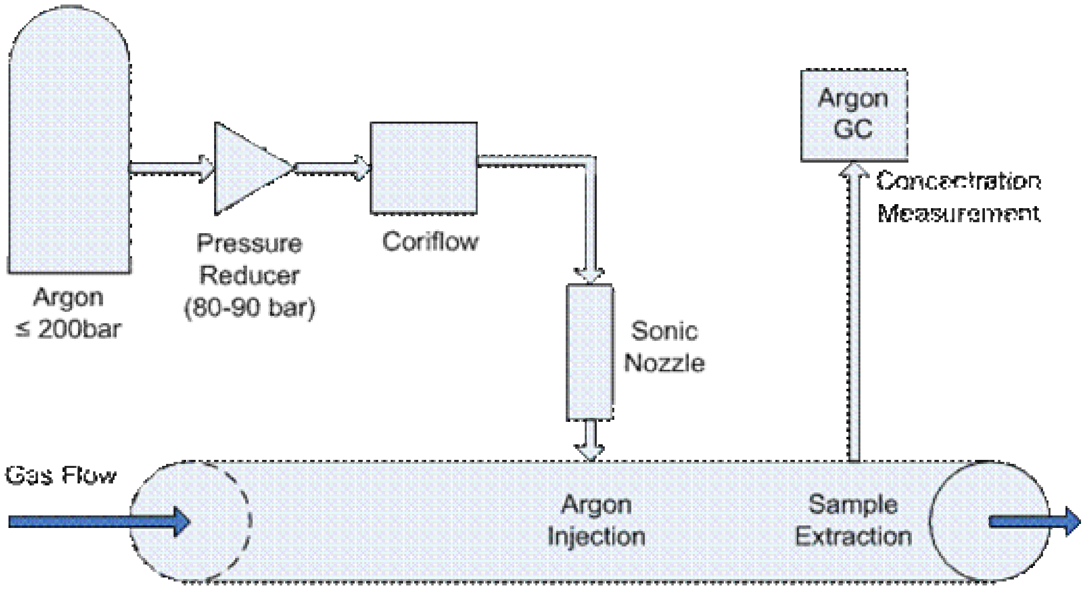

Figure 2 Scheme of KEMA tracer method

The current method chosen is the constant dilution method, suitable for many applications in gas measurement stations with measurement in combination with varying pipe diameters and usually pressure reducing elements.

The constant dilution method requires a constant accurate injection (M), good mixing of tracer (Argon) with the gas flow and accurate concentration measurement (X). Before zooming in on these issues first the targeted uncertainty and the choice of the tracer gas is rectified.

3.1.1 Uncertainty budget of the method

In this section the uncertainty of the tracer verification method is described. Uncertainties here are expressed in type 2 (95% confidence level). Making calculations according to the GUM (ISO/IEC Guide 98-3:2008 Uncertainty of measurement -- Part 3: Guide to the expression of uncertainty in measurement) we can derive for the uncertainty of the verified flow value simply given by $Q = M / X$

- Q = flow through gas meter (kg/h)
- M = injected Ar (kg/h)

- X = Ar % (gas mixture)

Therefore we have split the target uncertainty budget U_Q with target ≤ 0,5% in the following sub budgets:

Uncertainty injection system	U_M	≤ 0,3%
Uncertainty concentration method	U_X (GC)	≤ 0,3%
Uncertainty by mixing:		≤ 0,1%
Other effects, influence		≤ 0,25%

3.1.2 **Choice of tracer gas**

The choice of Argon as tracer gas for these type of applications is based on the following arguments:

- Argon is a safe noble gas. It is not controversial and does not affect surroundings and environment like other types e.g. radioactive tracers. Moreover it has quite suitable gas properties as it is virtually non-reactive, non-polarizing and non-adsorbing.
- For natural gas applications it has also significantly different physical properties making it suitable for the non-direct gas composition determination methods of physical properties (e.g. molar mass, density or speed-of-sound).

Figure 3 Ar-bottle stack used for the tracer tests

- In contrast to light element of tracer gases made up of hydrogen or helium it does not diffuse through pipe elements or small cavities in gaskets. Also it is virtually never present in common natural gas sources and as such its concentration when measured can all be contributed to the injected tracer gas.
- Argon as a gas is easily obtainable, in abundant supplies and in rather pure form (e.g. 5.0 or higher) and as such it has also an economic advantage as compared to other types of gases.
- Because Argon is quite a heavy molecule as compared to natural gas (M=40) it is possible to create accurate reference standards necessary for a proper calibration of the Gas

Chromatographs (GC). These gas calibration standards can accurately be made in gravimetric methods assuring the traceability to international standards .

3.1.3 **Injection system of Ar tracer gas**

Crucial elements of the injection system is the mass flow controller. We have made a small survey and choose a mass flow controller Coriflow in combination with a sonic nozzle to control the injected Ar flow. In the various lab tests (both at KEMA Flow laboratory in Groningen as well as NMi/ VSL lab in Dordrecht) we had to make sure that the system could be accurate (uncertainty <0.3% on mass flow) under various rapidly changing conditions of pressure and temperature.

First test in 2006-2008 revealed that a few improvements were needed to make the uncertainty meet the budget. Essential in the setup process was to position of the mass flow meter, protect it from the dynamics in the system (vibrations) and shield it from environment and changing expanded gas temperatures. Remember the gas in the gas bottles is initially at 200 bar pressure, but during a measurement this initial pressure will be decreasing and thus the expanded gas temperature at the controlled pressure of e.g. 80 bar will -due to Joule-Thomson effects- rather be increasing in time.

Therefore the following measures were taken to improve the injection system.

1 The Coriflow was mounted in a stable position not connected to the system either through acoustic, structural vibrations or by environmental temperature effects. To get this done the mass flow meter was mounted on a steady surface and connected with a flexible hose to the sonic nozzle. Through the use of the sonic nozzle the injection system is also acoustically ‘closed’ i.e. not connected to any flow disturbances in the main flow system.

2 The Coriflow was placed inside an isolated cabinet, which is heated to obtain an environmental temperature of the coriflow system close to the gas temperature (e.g. 25^0C)

3 The whole injection system is heated by ‘tracer-cord’ (from Argon bottle to sonic nozzle) to maintain the injection gas temperature and the gas temperature on the same level

Figure 4 the sonic nozzle of the injection system

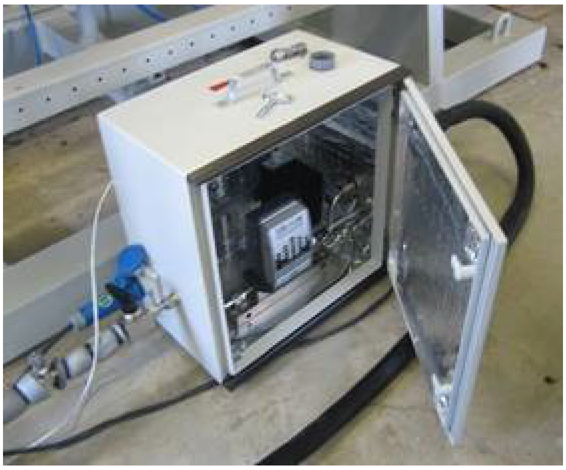

Figure 5 Coriflow in isolated (heated) cabinet with flexible hose

Figure 6 tracer-cord at sonic nozzle to inject the Argon with a constant temperature

3.1.4 **Mixing of tracer in the natural gas**

In our previous paper (ref. [1]) already the effects and uncertainties in mixing the tracer gas with the flowing natural gas was discussed and presented. In summary a uncertainty < 0.1% can be realized in natural gas as

- Usually the flows are quite turbulent (Re >> 4000)
- All pressure reducing elements are 'Mixing elements' in a gas installation. For instance pressure reducers, flow conditioners, shut-off valves, orifice plates, etc. mean good mixing elements
- Usually one can choose at a measurement station large upstream piping and sufficient distance and mixing elements between injection point and downstream gas sampling point.

- Finally further measures are to use an injection probe system that ensures homogeneous Argon mixing, see figure 7:

Figure 7 injection probe(L) and sampling probe(R) with multiple extraction points

3.1.5 **Concentration measurement of Ar in natural gas**

The previously (ref, [1]) presented indirect method of measuring speed-of-sound values as a way to determine the Ar tracer concentrations was a fast and potentially accurate method. However, for various reasons, e.g. the difficulty of getting an accurate non-linear calibration curve, its limited applicability as it was only suited for non-treated natural gases, but also the lack of support and spare parts were reasons to look for other methods in the tracer-constant dilution type of applications[1].

Therefore a direct method was developed, taking samples in the gas –Argon mixture in a ½ liter gas bottle with a flow controller in order to fill the gas bottle at mass wise equal fractions during the sampling time period. The sampling time is usually taken to be 5 minutes, but it can be changed. At any condition a number of gas samples are taken. When a flow indication is present we target the Ar flow such that a concentration of about 0.3% is to be expected. Subsequently a lab–GC (Agilent) was adapted to make it fit-for-purpose for accurate Ar concentration measurements in the range of 0.3% - 1 % with an uncertainty of < 0.3%. The adaptations on the were such, that the uncertainties (quality of the reference standards and reproducibility of the sampling & analysis process) could be maintained within the 2σ-value 0.3%

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[1] For time-of-flight tracer method the fast Speed-of-sound concentration method is still to be preferred.

Figure 8 KEMA adapted laboratory GC (Agilent 6890 with TCD detector) for accurate Ar concentration measurements

3.2 Current status - Results of lab tests

The instruments used for this tracer method have been (further) developed and tested in the Flow Lab Groningen during 2010. The results are in line with expectations. In a series of 4 tests the tracer method showed the following performance relative to the accurate flow standards (u < 0.2%):

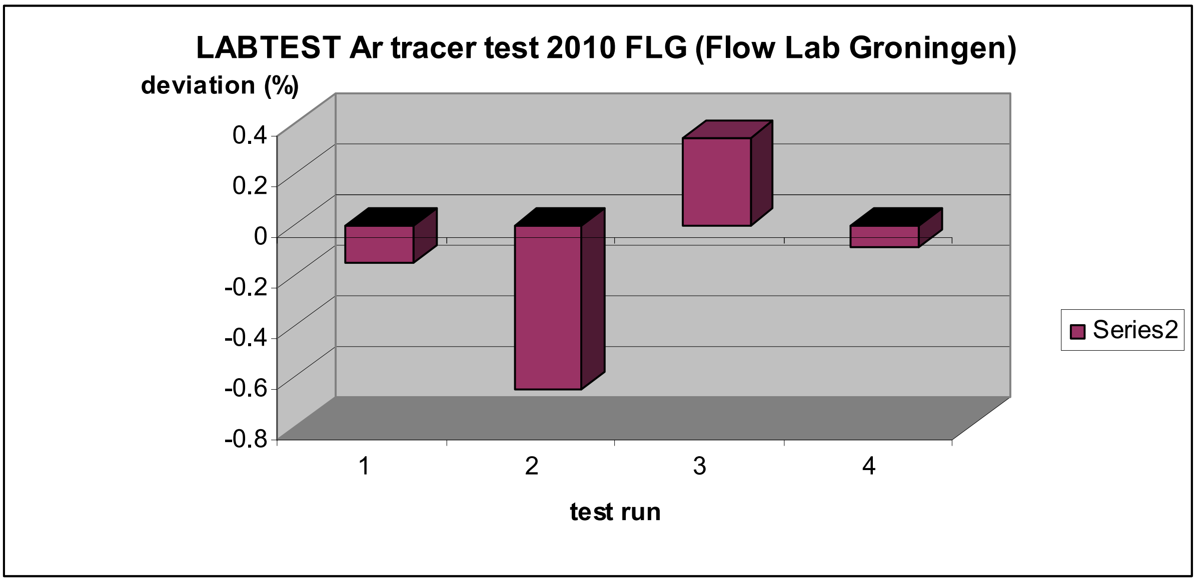

Figure 9 tracer test results in 2010 at FLG

3.3 Current status – Results of Field tests

Last April 2011 field tests have been carried out at a few out of the several Gas Measurement Stations (GMS) in the Netherlands where custody transfer of natural gas is taking place.

As in many of these stations there is only one flow meter system installed and there no other means to check the meter then taking it out of the system and sent it to a calibration facility to have it recalibrated. We can therefore compare the findings of the Tracer tool with the calibration results.

Concerning the field test results. We report here about two tests performed at GMS in April 2011:

At one location a rather stable flow condition was present and measurements were performed taking 5 samples at flow of 30% Qmax and at 60% Qmax. The results are:

- At the 30% Qmax it was accidentally thought that the flow readings were smaller (10% Qmax). Later on it turned out to be a miscommunication. Therefore the injection flow was tuned to the anticipated flow settings and the samples taken contained only about 0.1% of Ar instead of the targeted 0.3%. Although the overall average results were only < 0.2% deviating from calibration results, the results for the 5 samples showed a standard deviation of ~ 0.7% which could be attributed mainly to the low Ar concentration of the samples.
- At the 60% Qmax the 5 samples showed a consistent result with a standard deviation < 0.2%. The overall results was deviating from the calibration results with about 0.7%.

At a second location the conditions were in certain periods of time not very stable, see e.g. the following flow graph:

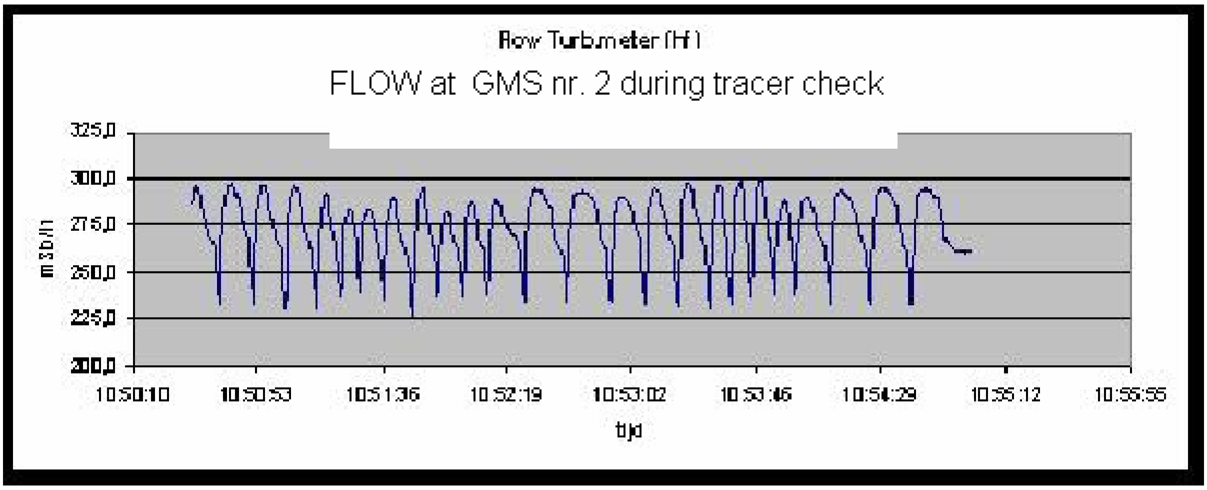

Figure 10 Rapid flow variations during tracer test at GMS nr. 2

The results of these tracer test revealed the already expected flow reading error due to the dynamic flow conditions.

Results of Tracer-test GMS nr.2				
Reference meter TM: 6" G650, Qmax = 1000 m3/h				
Targeted percentage Ar 0,4% Ar				
FLOW	**Deviat. TM @calibration (KEMA FLG)**	**Deviat. TM vs. (Tracer)**	**Diff. (Tracer-FLG)**	Remark
2 measurements at 275 m3/h (stable flow conditions)				
275 m3/h (28% Qmax)	0,1%	***0,25%*** *(2σ=1,4%)*	0,15%	Average of two measurements
4 measurements at 275 m3/h with unstable flow show a large TM error				
275 m3/h	(28% Qmax)	5,7%		N up-down =15 in 5 min.
		9,2%		N up-down =25 in 5 min.
		14,9%		N up-down =40 in 5 min.
		5,2%		N up-down =14 in 5 min.

The error of the turbine meter (TM) as determined by the tracer system is quite large (5%-15%) and could really be attributed to the dynamic field conditions. As such these type of effects could never be checked at the calibration facility where under the stable conditions the error is only about 0.1%. It should be noted that the errors are roughly proportional to the number of up-down movements $N_{up\text{-}down}$ in flow (the instability being caused by the pressure control system). This error reading in the dynamic field conditions could quantitatively be verified with another KEMA tool the dynamic toolkit (see below), difference all only within 1%!

4 FLOW DYNAMIC TOOLKIT (FDT)

Dynamic gas conditions are present in many gas stations and in many cases not expected nor predicted in the design stage. In many such cases the negative effects can be large. Whereas in gas stations the dynamic conditions (flow pulsation) can affect the mechanical integrity of the station in GMS they can significantly affect the accurate reading of metering systems.

Over the years KEMA's Flow acoustics team has developed special tools to investigate the origin and effects of dynamic flow conditions. One important engineering tool is a toolkit to predict (and prevent) Flow Induced Pulsations. These type of flow pulsations can occur in many gas stations [see ref. 4, 5]. and also in gas measurement stations (GMS).

Not only in the engineering phase calculation tools are available. In many of troubleshooting questions over the last years our expertise has been called to perform acoustic measurements, determine the cause of flow dynamic effects.

The last part of the spectrum is a toolkit called FDT (Flow Dynamic Toolkit) able to check the dynamic conditions available in the metering station and the corresponding error effects they exhibit on the readings of turbine meters.

4.1 **Working Principle**

It has been known since many decades that dynamic conditions like pulsations can influence the accuracy of turbine meters. Turbine meters are still being used in many custody transfer applications as they have over the years shown the best accuracy and reproducibility. They are also very common as working references at many flow calibration installations. However, as they operate and run, they exhibit the tendency (on the basis of their mass moments-of-inertia) to relative quickly speed up when the flow increases and relative slowly spin down when the flow decreases. This gives rise to an over reading when the conditions in the installations change rapidly. This effect has been referred to in literature as the "rotor-slip-error". An example is shown in an extreme dynamic flow created at Kema Flow Lab in Groningen.

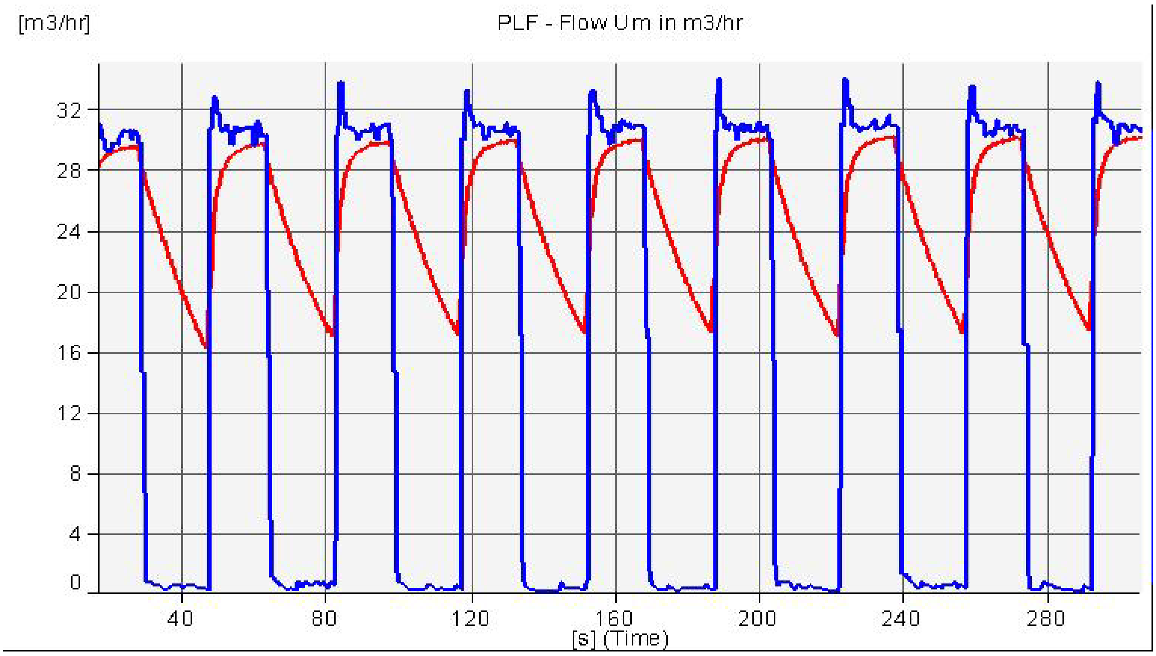

Figure 11 behavior of turbine meter (red curve) in rapid changing flow conditions (blue = real flow)

KEMA has developed the FDT and has applied it in several field applications. Combining the expertise of measuring and controlling flow induced pulsations and dynamic conditions with a solid background of theory and practices of turbine meter operation we perform an analysis of the actual dynamic conditions.

The adapted method is to perform direct analysis of the HF signal of the turbine meter along with direct measurements with pulsation transducers of the flow dynamics. All information is recorded with a high-frequency (up to 20 kHz). With this fast measurement information along with the geometric layout of the station and the essential physical parameters of the turbine meter (e.g. moments-of-inertia) a model based estimate can be made of the measurement error of the turbine meter during the measurement period.

4.2 **Examples of application**

In the period 2009-2011 KEMA helped to clarify an issue in custody transfer of natural gas regarding measurement errors due to dynamic field conditions. KEMA helped to prove and quantify the consequences of the dynamic effects by means of field measurements of pulsations in combination with the HF signal of the flow meter. In this way the dispute was solved and the gas user could rely on full payback of the systematically error volume over the last three years amounting more than 300.000 euros.

Further investigations for the gas supplier at other gas stations in Europe is currently ongoing.

4.3 **Model uncertainty and validation.**

The FDT model is about to be validated in the FLG lab along with the tracer technique (planning end of 2011).

5 CONCLUSIONS

The tracer method and dynamic toolkit have been tested in the high pressure natural gas grid applications and are now available for the market.

The tracer method and the dynamic toolkit are commercially available to perform in-situ flow checks at costs lower than needed for flow calibrations and without the need for built-in and built-out of flow meters and risk on transport error and/or measurement or plant downtime.

The uncertainty in field conditions of the tracer method ranges from 1% (at the low Ar concentration) to < 0.5% at Ar concentrations above 0.3%. The dynamic toolkit is targeted to predict dynamic flow errors of turbine meters within 0.5% in total or 10% of the registered error, whichever one is largest.

Efforts in the coming period are focused on creating a more automated and robust toolkit, start to develop an on-line field GC to do the job more quickly (for tracer) and prepare a validation test programme for both tools witnessed and certified by independent authority.

Both tools give very valuable insight in the overall flow measurement processes to account for all kind of effects in installations and operational conditions.

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