A CONTINUOUS CALORIFIC VALUE MEASURING SYSTEM BASED ON A CORRELATIVE METHOD

Virginie van Ranterghem, Gaz de France, Alfortville, France
Stéphane Loubat, Gaz de France, Saint-Denis, France

1. Introduction

In the context of the gas market opening up to competition, the number of participants in the gas chain is increasing, exchanges are intensifying and the gas supply sources are multiplying for some parts of the world, notably in Europe where the networks are more and more interconnected.
Therefore, it is crucial to be able to better determine the quantities of energy exchanged and the variations in the gas quality, with the view to having more accurate and more equitable billing. The variation over time in the calorific value at a given point in the grid can be as high as a few percent and can have important economic effects. Information on the Wobbe index or the density of the gas is also very useful for some industrial process controls: the Wobbe index variation may have strong effects on the products quality for industries like glassmakers. So important customers are more and more interested in a device able to continuously monitor gas quality variations, as well as the calorific value and the Wobbe index.

For all these reasons, more and more developments are taking place all around the world: the aim consists in conceiving and building devices able to follow the values of the calorific value, the density and/or the Wobbe index with more and more accuracy and quickness.

Up to now, the energy measuring systems used on the gas networks are based on the gas chromatography technology. In France, the gas chromatographs are the only devices certified for custody transfer by the *Laboratoire National d'Essais*, the French laboratory approving devices to be used on the French network for billing purposes. Since a few years, new cost-effective devices based on new technologies have appeared on the market. These energy metering systems are integrated systems able to measure or calculate the calorific value, the density, the Wobbe index and so on, and from these values and from information of volume metering, the integrated system is also able to calculate the energy delivered.

With this in mind, Gaz de France decided to find a partner to develop a new kind of energy measuring system, that is, to develop a device able to calculate quantities of energy exchanged with a better accuracy. In 1999, cooperation between the Research and Development Division of Gaz de France and METRA began. METRA is the French distributor of the German company RMG Messtechnik products. A new device based on a new calorific value measurement concept has been developed: the EMC 500 consists of the WOM 02, which continuously calculates the calorific value, the density and the Wobbe index of the gas from a correlation between some properties of the gas analysed and the calorific value and the density and, of the ERZ 9104 T that is a flow computer calculating the energy exchanged.
This cooperation has lead to laboratory and field tests of the new energy metering system in France.

The aim of this paper is to describe this new system developed by RMG and METRA. This paper describes the method of calorific value determination. It also presents the results of various tests, which have been performed by Gaz de France in its laboratories and on its gas network all around the country. Finally this paper presents the future improvements that will be made to the WOM 02 in 2003.

2. Device description

The WOM 02 [1] is a calorific value and density measuring system associated to a flow computer. Both are developments of RMG group.

2.1. WOM 02 – Calorific value measuring system

The measuring device – the WOM 02 – is an improved version of the WOM 2000.
Photos of the WOM 02 are shown below.

Figure 1: WOM 02 Photo

Figure 2: View of the WOM 02 installed on site in France

The dimensions of the blue box are 475x720x340 mm (LxHxD). It contains the measuring element that is the heart of the WOM 02: the "sensor block". Its dimensions are 200x100x150 mm (LxHxD). This element allows the calculation of the calorific value, the density, the relative density and the Wobbe index.
This part of the WOM 02 is maintained at a constant temperature level of 65 °C ± 0.2 °C (149 °F ± 0.5 °F) with a regulation system, whereas temperature inside the blue box is within a temperature range of 18°C (64°F) to 50 °C (122 °F), depending on the climate conditions. This is not regulated but controlled: a warming resistance is functioning when it is under 18 °C (64°F).
Two versions of the WOM 02 are available. One is explosion-proof and can be installed in hazardous areas. On Figure 2 the WOM 02 is installed on site to check its performance in operating conditions. The second version is not explosion-proof and has to be installed in a safe area.

2.2. ERZ 9104 T – The energy flow computer

The flow computer associated with the WOM 02 is the ERZ 9104 T. This model is an energy flow computer: the ERZ 9104 T is able to calculate the base volume and the energy exchanged from the volume measured in operating conditions and from the calorific value.
Moreover the ERZ 9104 T has storage and averaging functions, so it offers monthly, daily or hourly average values of calorific value, volume or energy.

It should be noted that the base volume determination is based on a PTZ correction: pressure and temperature information are obtained via pressure and temperature sensors and the compressibility factor is determined with the S-GERG 88 equation given in the international standard ISO12213 [2].

The following figure shows a view of the ERZ 9104 T that is not explosion-proof and has to be installed in a safe area.

Figure 3: Energy flow computer ERZ 9104 T

3. Measurement method

3.1. New concept of calorific value measurement

The WOM 02 system is based on the concept of a correlation between some physical characteristics of the gas measured, its calorific value and its density. Relative density and Wobbe index are then calculated from the values of calorific value and density.

Experience demonstrated that the calorific value and the density of the gas are dependent on three physical properties, which are the specific heat, the thermal conductivity and the viscosity of the gas analysed.

RMG built a sensor box made up of a flow resistance and two measuring elements. These two sensors deliver electrical signals, which are sensitive to the specific heat, the thermal conductivity and the viscosity of the gas.
An empirical relationship between the measured signals of the two sensors, the calorific value and the density at base conditions was established from a range of tests with reference gases whose physical properties as calorific value, density and viscosity were accurately known.

3.2. Measurement method

A sample of gas is taken continuously from the gas network and is lead to the WOM 02. If it is necessary, the pressure is reduced between 0.3 and 2.5 bar (g). A by-pass pipe is available to optimise the gas flow in the sensor box.
The gas to measure is selected by a system of three-way solenoid valves: either the gas from the network or a calibration gas can be measured. An associated control card operates the valves.

Then the selected gas crosses a filter and a first pressure regulator, which regulates the pressure at 160 mbar (g).

From here onwards the gas enters the sensor box. This box is maintained at a constant temperature level. This temperature is measured by a platinum sensor and regulated accurately by the associated control card. A second pressure regulator works on the pressure drop between the output of the sensors and the regulator itself: this pressure drop is maintained at a constant level of 50 mbar.
The gas runs through a warming room whose function is to bring the gas to the right temperature level.

Then the warmed gas passes through a first capillary and the two sensors. The capillary is a flow resistance, which generates a pressure loss, measured and compensated by the action of the pressure regulator and the control card. The two sensors are thermal flow sensors. Their electrical signals – sensitive to the physical properties of the gas – are repatriated to the control card and used to calculate the superior and inferior calorific values, the density and the Wobbe index of the gas.

Finally the gas passes through a second flow resistance before it is released to the atmosphere. This second flow resistance's function is to absorb the quick variations of vent atmospheric pressure.

The following figure shows the gas circulation within the sensor box above mentioned.

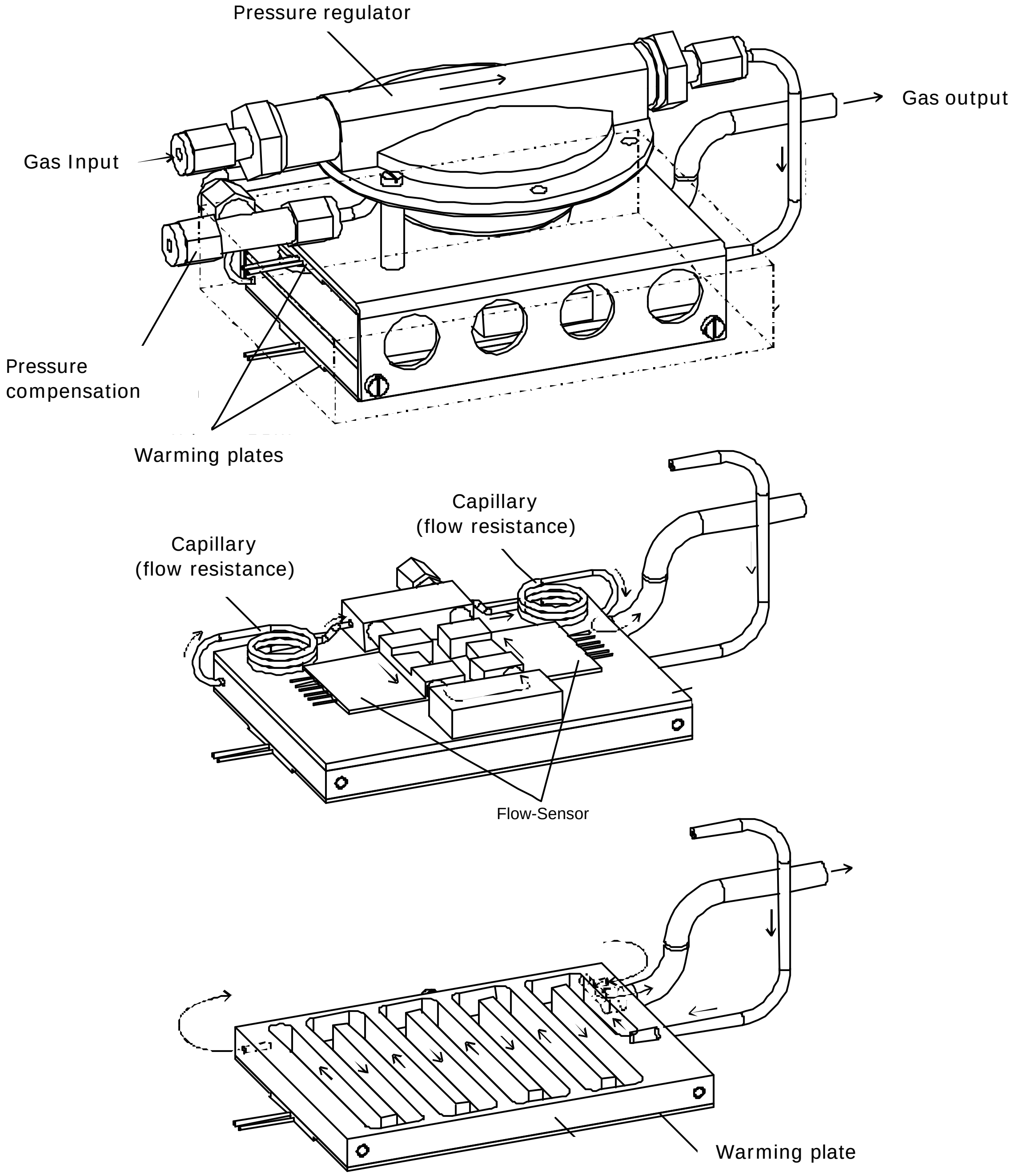

Figure 4: Sensor box

3.3. Calculation method

The two thermal flow sensors deliver two electrical signals directly correlated to the calorific value, the density and the Wobbe index of the gas.
The correlation method was developed in the form of an algorithm with several coefficients, which are determined during factory calibration. This calibration uses four calibration gas mixtures, which are representative of the gases delivered in Europe and whose physical and thermal properties are determined accurately.
Moreover the WOM 02 carries out a temperature and pressure correction whose correction factors are also determined during factory calibration.

Nevertheless some coefficients of the calculation algorithm have to be adjusted periodically by a control system. This adjustment is performed by the flow computer either manually or automatically and consists in a calibration gas injection and analysis. The use of pure methane (99.95 %) is recommended. Using methane as calibration gas offers many advantages: with a pure gas, condensation or stratification problems are never encountered and the cost of such a bottle is far cheaper than a certified gas mixture bottle.
The calibration frequency recommended from the following tests is once a week and is 7 minutes long.

4. Technical data

The major technical data of the WOM 02 given by RMG are as follows.

Operational range:	Superior Calorific Value	7 to 14 kWh/m^3
		25.2 to 50.4 MJ/m^3
	Density	0.65 to 1.3 kg/m^3
	Wobbe index	8 to 16 kWh/m^3
		28.8 to 57.6 MJ/m^3
	Ambient temperature	-20 to +55 °C
		-4 to 131 °F
	Inlet gauge pressure	0.3 to 2.5 bar
	Power requirements	24 VDC or 230 VAC
Performance:	Accuracy	
	Calorific Value	< 0.5%
	Density	< 0.5%
	CO_2	< 0.5 mol. %
	Response time	T_{90} = 60 s
	Gas consumption	15 (n)L/h max.

Note: The superior calorific value and the Wobbe index are expressed with the French reference conditions described in the international standard ISO 13443 [3].

5. Laboratory tests results

5.1. Nature of the tests carried out

The evaluation of the WOM 02 required the use of a panel of gas mixtures that are representative of those that pass through the country. To overcome purging problems associated with changes of gas, a gas selection device was used.
The evaluation of the WOM 02 concerned the study of influence of the variation of the gas composition on the response of the instrument. The following parameters were determined:

- ✓ Trueness and repeatability of experimental measurements on SCV and density at base conditions (standard density),
- ✓ Response time,
- ✓ Stability.

All these tests were performed within the R&D Division of Gaz de France, in a laboratory whose room temperature was between 20 and 22 °C with variations of less than 0.5°C per hour.

5.2. Nature of the gases used

5.2.1 Sample Gases

Six synthetic gas mixtures and two natural gas samples from the transmission network were used during this study.
Synthetic gas mixtures were prepared by gravimetric method in accordance with the international standard ISO 6142 [4]. Their superior calorific value was determined in accordance with the international standard ISO 6976 [5] from molar concentrations of the different components.
The gas composition covers, in terms of calorific value, a large scale from 37.03 to 44.87 $MJ.m^{-3}$ (0/0 °C).

Two of them are certified reference gas mixtures (CRM), prepared gravimetrically.
These six synthetic mixtures do not contain hydrocarbons higher than normal hexane ($n\text{-}C_6$) and may be classified in three groups:

- ✓ A low SCV gas (mixture n° 1), similar to Groningen gas from the Netherlands,
- ✓ A medium SCV gas close to methane (mixture n° 2 similar to Russian gas),
- ✓ Four high SCV gases (mixture n°3 similar to liquid natural gas (LNG) supplied to Montoir-de-Bretagne terminal, and mixtures n°4, n°5 and n°6 similar to North Sea gas with a high ethane content).

The two natural gases were withdrawn from the French-Belgian border station for the first one and on the French network for the second one. These two gases look alike in their molar composition natural gases coming from North Sea.

5.2.2 Reference gas

The reference gas recommended by RMG for calibration is only pure methane (at least 99.95%).

5.3. Experimental results

5.3.1 Trueness and repeatability on reference gas mixtures

Trueness and repeatability of the instrument were investigated on six reference gas mixtures and two natural gases. Trueness and repeatability results on SCV and on standard density were calculated on the last 40 consecutive measurements (one measure every 20 seconds) for each gas.

Table 1 shows results obtained in terms of trueness and repeatability on SCV and standard density. For the gas mixtures used in the study, the trueness was within –0.43 % and 0.21 % on the whole calorific values range.
The repeatability of measurement is better than 0.032 %.
Be that as it may, errors of trueness obtained on the superior calorific value are in accordance with characteristics announced by RMG (better than 0.5 %).

Density measurements were compared with the density calculated from molar composition in accordance with the international standard ISO 6976 (1995). The trueness was between - 0.73 % and + 0.79 % on the whole of density measured.
The repeatability of density measurement is better than 0.08 %.

It turned out that density measurements were overestimated by the RMG device for gas with high ethane content (gas mixtures n°5 and n°6 for which ethane content is respectively 15.3 and 12.4 % molar). On the other hand, SCV measurements were underestimated for these two mixtures made up of only 6 components instead of 11 as the other gas mixtures.

Reference gas mixtures	Reference SCV	Reference density	Trueness on **SCV**	Repeatability on **SCV**	Trueness on **density**	Repeatability on **density**
	$MJ.m^{-3}(n)$[1]	$kg.m^{-3}(n)$	%	(2s) %	%	(2s) %
N°1	37.03	0.8238	0.15	**0.032**	-0.09	0.047
N°2	39.89	0.7332	0.03	0.026	-0.50	**0.072**
N°3*	42.32	0.8198	0.20	0.026	-0.56	0.065
N°4	42.78	0.8255	0.21	0.027	-0.58	0.060
N°5*	43.32	0.8672	**-0.43**	0.031	**0.79**	0.054
N°6	44.87	0.8525	-0.15	0.029	0.40	0.061
Natural gas 1	41.58	0.7924	0.18	0.027	-0.73	0.067
Natural gas 2	43.69	0.8428	0.13	0.025	-0.50	0.062

Table 1: Trueness and repeatability results on reference gas mixtures and natural gases

* Only mixtures n°3 and 5 are CRMs.

5.3.2 Repeatability

The repeatability on SCV and standard density was checked with pure methane (99.95 %) over a period of 12 hours. The values measured were recorded every 10 seconds. Before starting the test, the device was calibrated with pure methane.
Figure 5 presents the SCV measurements and Figure 6 shows the standard density measurements. Repeatability of the SCV measurements is 2s = 0.085 % expressed by two times the standard deviation and repeatability of the density measurement is 2s = 0.18 %.

[1] The reference "(n)" symbolizes the French reference conditions for combustion (t_1) and metering (t_2) temperature, both reduced to 0/0 °C at a pressure of 101.325 kPa.

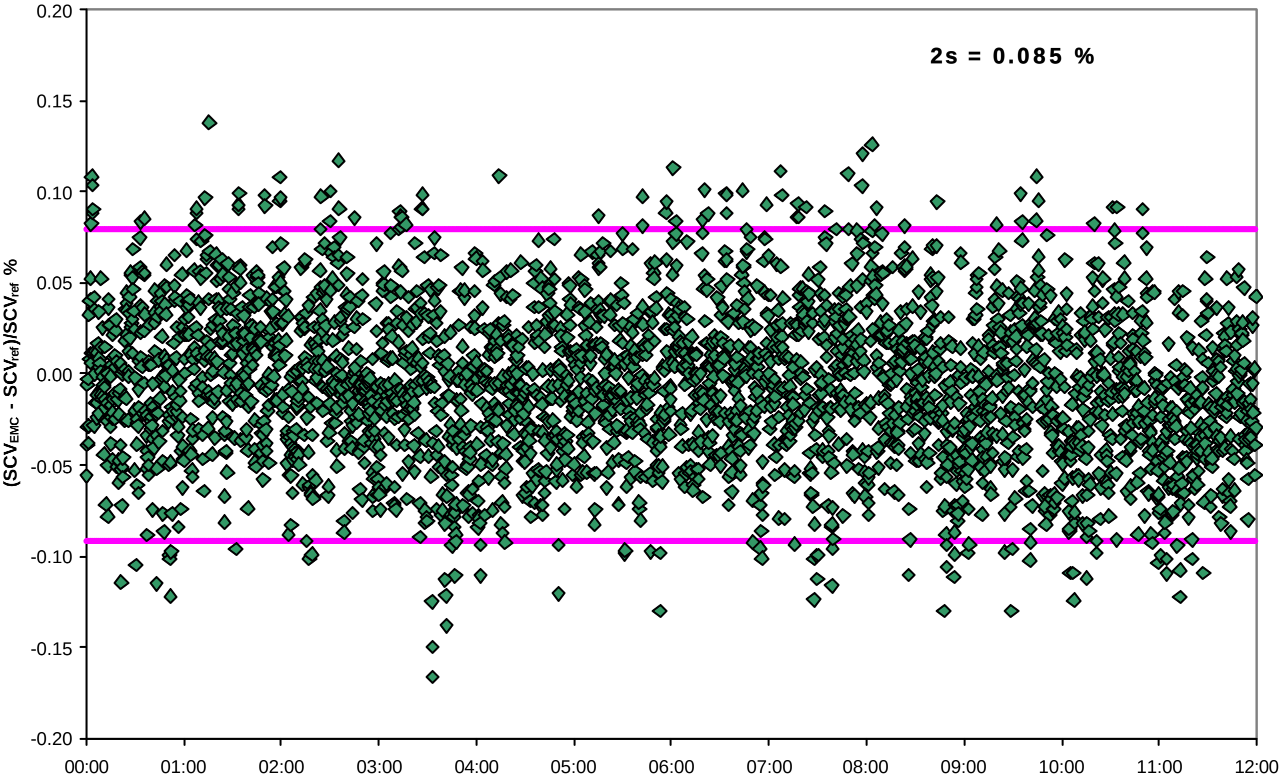

Figure 5: Repeatability on SCV – Measurements with pure methane over 12 hours

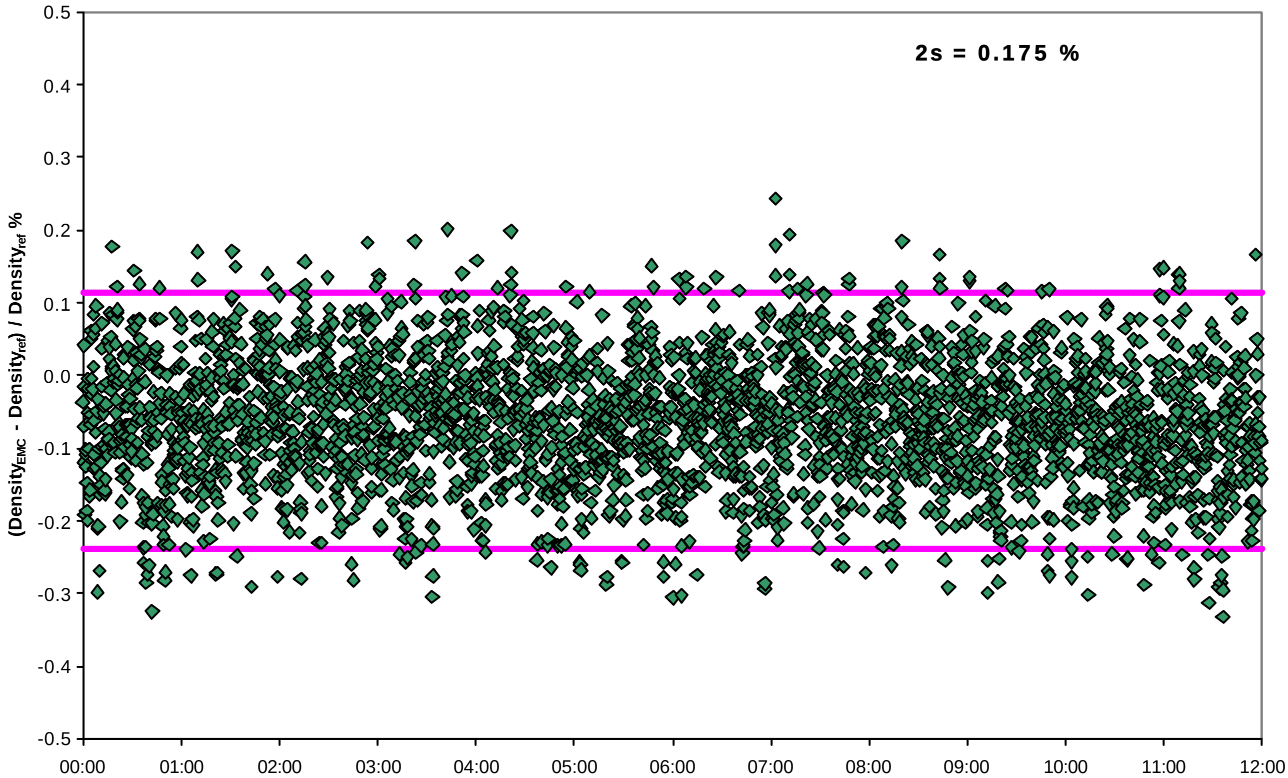

Figure 6: Repeatability on standard density – Measurements with pure methane over 12 hours

5.3.3 Response time

Response time may depend on the variation in SCV imposed. These tests showed that a gas front caused by a gas change from low SCV gas to high SCV gas, or vice-versa, which corresponds to a variation in SCV of 7.84 $MJ.m^{-3}$, requires 80 seconds before reaching 90 % of its final stable value. Variations of SCV values measured are given in Figure 7.

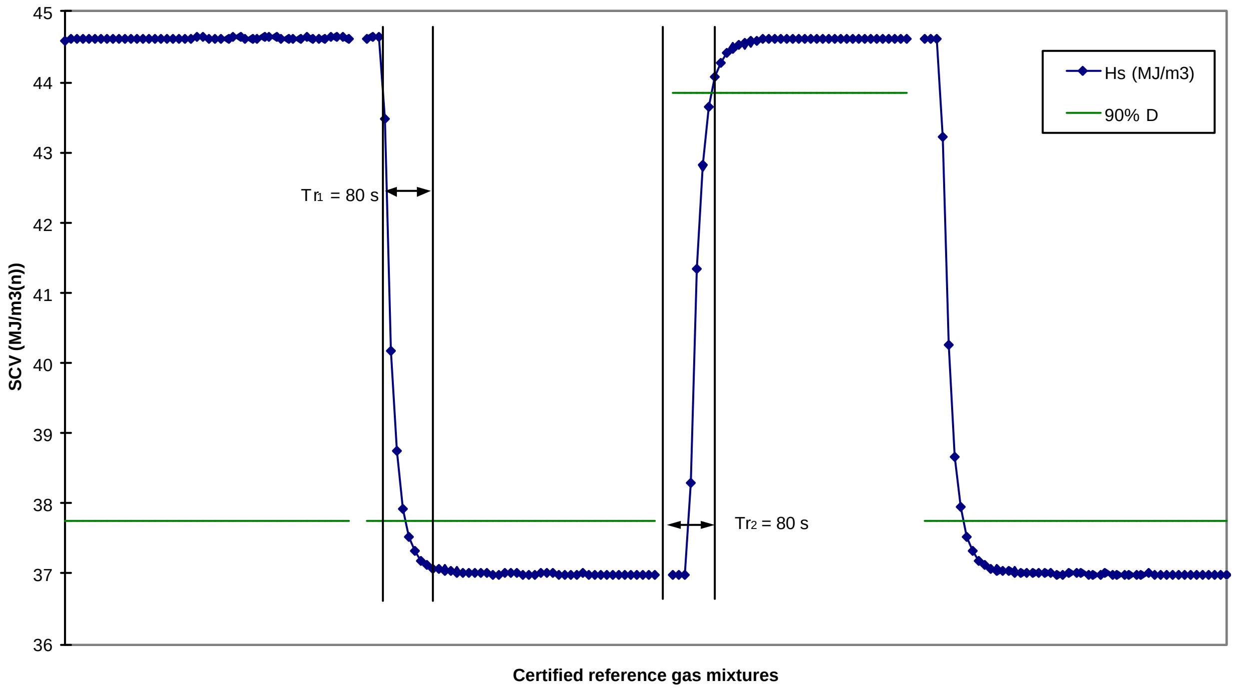

Figure 7: Response time of the calorific value from a gas change: response time T90 = 80 s.

5.3.4 Stability

The stability of the instrument was tested on a single reference gas mixture. This test was performed under laboratory conditions. Values measured were recorded at regular intervals, every week, over a period of approx. two months. Measurements were recorded every 20 seconds during a 30 minute period. It should be noted that during these two months of tests, the instrument was not calibrated.

Figure 8 presents the changes in superior calorific value over this period. This variation was expressed in relative standard deviation from the SCV of the reference gas mixture.

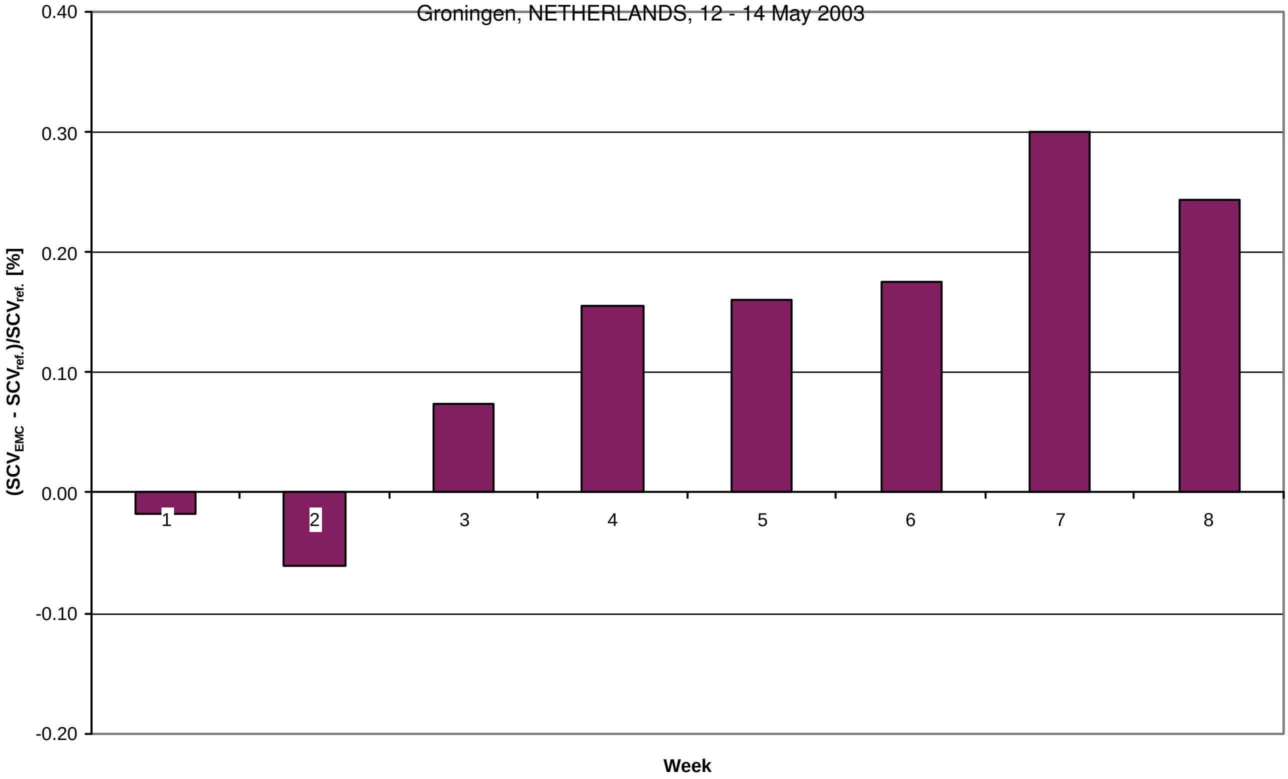

Figure 8: Stability measurements on a single gas mixture over two months

6. Field tests results

6.1. Long term stability

So as to study the long-term stability of the measurement, the device was installed in field conditions in a dispatching station of Gaz de France. This site is equipped with a process gas chromatograph carrying out gas analysis with a total cycle time of 6 minutes.

Field tests began in April 2002 and ended in December 2002. Over this period of eight months, the device operated weekly calibrations with pure methane (99.95 %) in accordance with recommendations from RMG.

It then analyzed three reference gas mixtures (CRMs), at regular intervals from 23 April 2002 to 6 December 2002. The device was equipped with three-way valves in order to select reference gases or natural gas coming from the transmission network.

Theses checking operations consisted in recording **minimum** and **maximum** calorific values given by the display of the device over a 15 minute period.

Figure 9 shows the relative standard deviation between these values and the reference calorific value given by certificates.

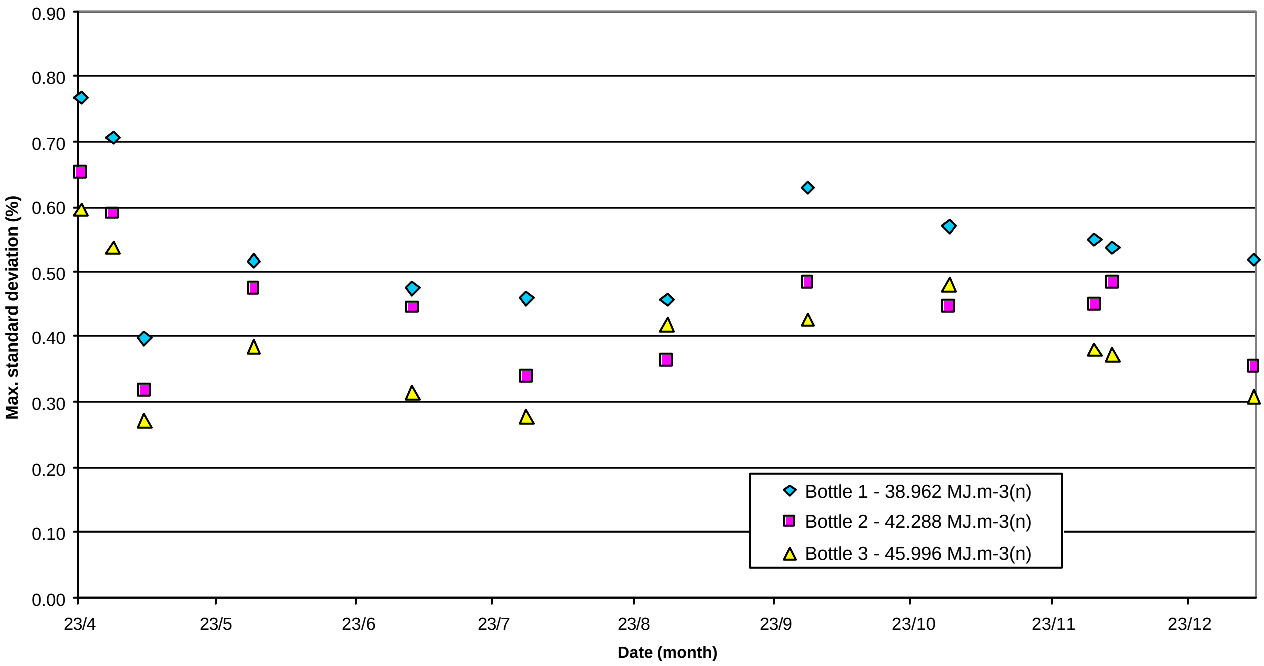

Figure 9: Measurements on three gas mixtures over eight months

Regardless of the gas mixture, the WOM 02 unit overestimates the SCV within +0.27 and +0.77 % with a systematic average offset of 0.4 %. Thereby, it has to be noted that the maximum relative standard deviation is stable over this time without any drift.

6.2. Field test on natural gas

Figure 10 shows the hourly average calorific value measured from the WOM 02 device and from a GC analyzer over a one month period.
The hourly average of the GC analysis was calculated from 5 consecutive analyses. These values were compared with hourly average of WOM 02 calculated on the basis of continuous measurement.
During this test period the calorific value of the natural gas changed several times, with a maximum variation of 2.6 MJ.m^{-3}(n). Figure 11 shows the relative standard deviation of the WOM 02 compared to the GC analyzer. These deviations remain within ± 0.3 %. However, the maximum deviation was obtained when the calorific value suddenly changed owing to the different response time of devices.

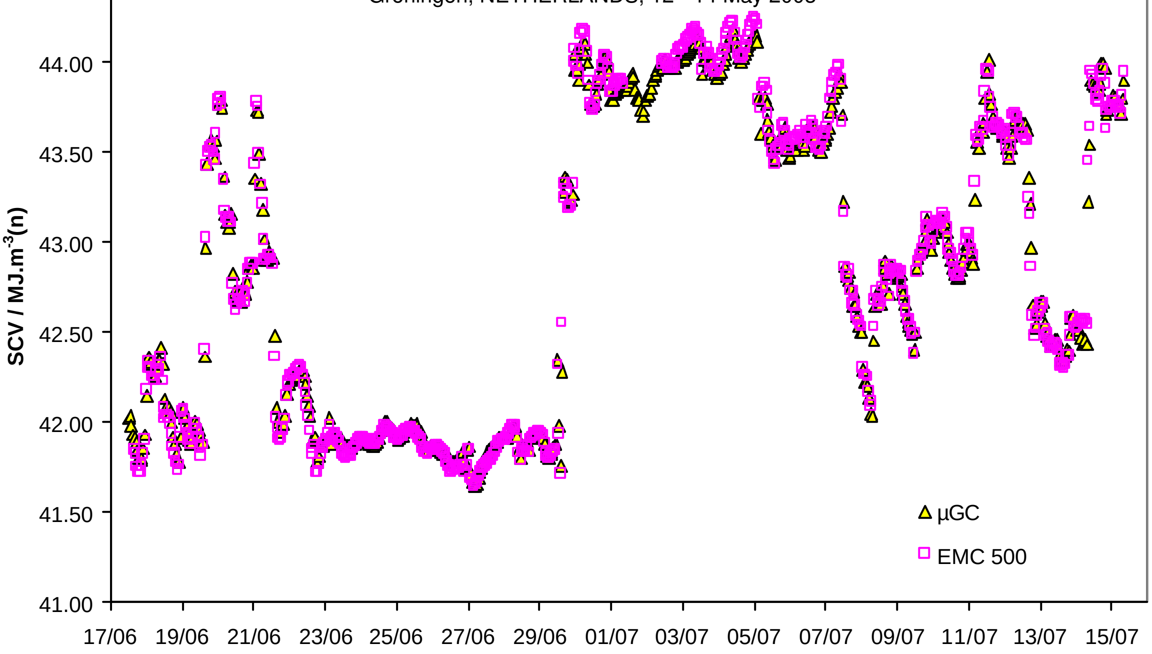

Figure 10: Field test on natural gas – Hourly average calorific value of WOM 02 and GC analyzer over one month

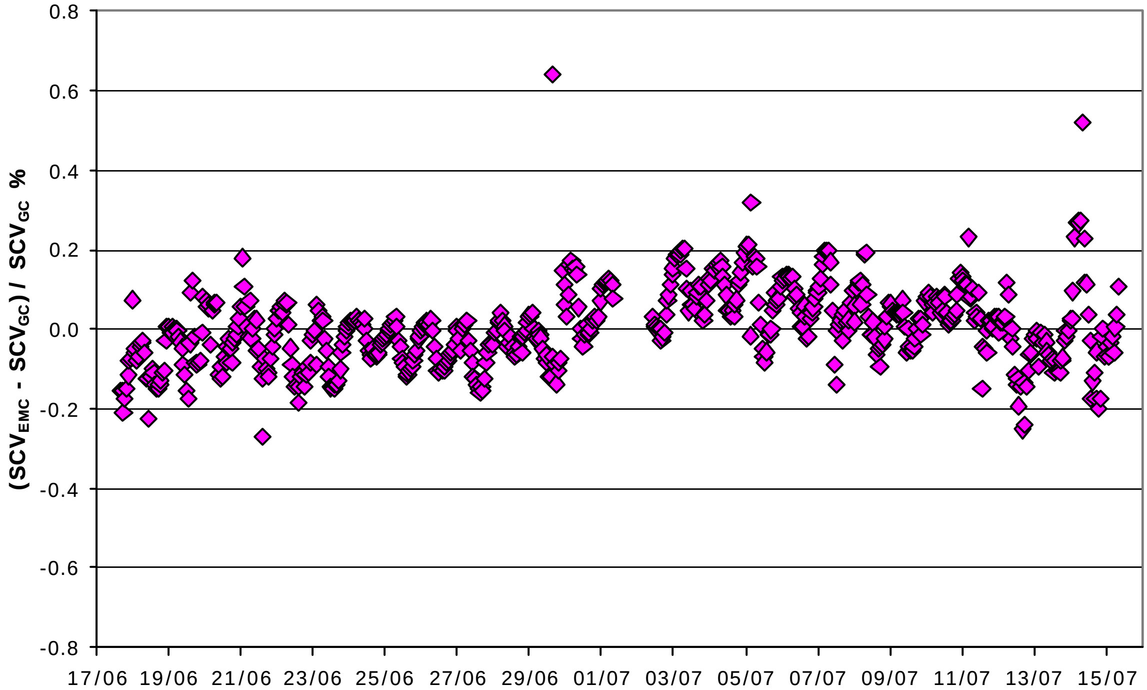

Figure 11: Field test on natural gas – Relative standard deviation of WOM 02 compared with µGC analyzer

6.3. Checking performances

After an eight month period of field tests, metrological performances of the device were controlled. Three certified reference gas mixtures (11 components – C_1 to nC_6) were used in order to check the trueness and the repeatability. Calorific values of these gas mixtures were within 38.96 and 46.00 $MJ.m^{-3}(n)$.
The average SCV was calculated on the last 15 minutes for each gas mixture (one measured value every 10 seconds). Trueness was determined from the "real SCV" value given by certificate.
Table 2 shows the results of these tests.

Certified gas mixtures	Reference SCV	SCV mean measured	Trueness	Repeatability	
	$MJ.m^{-3}(n)$	$MJ.m^{-3}(n)$	%	2 s ($MJ.m^{-3}$)	2 s (%)
Bottle 1	38.962	39.120	**0.41**	0.030	**0.077**
Bottle 2	42.288	42.408	**0.28**	0.033	**0.078**
Bottle 3	45.996	46.099	**0.22**	0.038	**0.083**

Table 2: Results of trueness and repeatability tests

The device systematically overestimated SCV measurements. The trueness after an eight month period of testing is better than 0.41 %. This value is similar to the trueness obtained during laboratory tests.

7. Conclusion

The measuring system WOM 02 presents the advantages that its new technology determines calorific values, standard density and Wobbe index with a satisfactory accuracy. Furthermore, such a device, designed for hazardous area, demands only a light and low maintenance: field tests showed its robustness.

In order to improve its device, RMG Messtechnik Company has integrated a CO_2 sensor based on IR absorption. Thereby, the new unit calculates the compressibility factor more accurately in accordance with the international standard ISO 12213.
The aim of these sensors and extended correlation with CO_2 value is to reach trueness on SCV and standard density better than 0.3%.

The WOM 02 unit, associated with the RMG flow computer ERZ 9104 T, is under approval in Germany by the PTB. A similar process has been initiated with the French legal metrology.

8. References

[1] Patent n° DE 4118781C2 – 2002 - Germany
[2] ISO 12213 Natural gas – Calculation of compression factor
Part 3: Calculation using physical properties
[3] ISO 13443:1996 Natural gas – Standard reference conditions
[4] ISO 6142:2001 Gas analysis – Preparation of calibration gas mixtures – Gravimetric method

[5] ISO 6976:1995 Natural gas – Calculation of calorific values, density, relative density and Wobbe index from composition