Gas Quality Tracking in Distribution Grids

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E.ON Ruhrgas has initiated a research project to develop a method for tracking the superior calorific value (SCV) of gas in regional and local distribution grids. The method uses standard load profiles in combination with a new correction algorithm to determine the volumes taken at exit points. Including further input information it is possible to determine for each network node an SCV which can be traced to verified SCVs measured at entry points. The method will allow accurate and selective invoicing of customers in supply areas with several natural gas and/or biogas injection points. Cost-intensive conditioning of biogas to be injected into the grid will then no longer be necessary, thus improving the economics of biogas plants.

The method is being tested on a regional distribution grid of E.ON Avacon into which both group H-gas and biogas are injected. The calculation results are validated with a mobile process gas chromatograph (PGC) commissioned in December 2010 and installed at several points along the grid. The calculated and measured SCVs compared in this paper confirmed agreement within approx. 0.2%.

1. Introduction

National gas markets growing together to form a European gas market and rising imports of liquefied natural gas (LNG) to Europe have led to stronger variations in gas quality and thus in SCVs over the past few years. The trend has been reinforced by increasing volumes of biogas to be injected into regional and local distribution grids. Before injection biogas must be conditioned to obtain the SCV prevailing in the grid. In group H-gas areas this is achieved by admixing propane.

In Germany, the SCVs in regional or local distribution grids are usually determined on the basis of measured values made available by upstream suppliers for the relevant entry points. DVGW Code G685 [1] stipulates that the SCV used in billing must not deviate by more than 2% from the actual SCV. Where natural gases of different qualities are injected at several points, this requirement is deemed to have been complied with if the volume-weighted SCV averages over the billing period do not deviate by more than 2%.

Gas quality tracking systems have been used in transportation networks in Germany for some years now and are state-of-the-art technology [2]. With such a system, the SCV of a gas can be calculated for any point in the network at any time. The input parameters required are verified measured values for the SCV of a gas at the entry point and the respective entry and exit volumes. It has not been possible so far to obtain the accuracy necessary in billing with a gas quality tracking system implemented in gas distribution. The problem is that measured volume data are often insufficient, in particular at exit points.

The method presented applies a new algorithm to determine exit volumes on the basis of standard load profiles using customer-specific consumption data for a previous billing period, current ambient temperatures, measured entry volumes and entry pressures.

2. Determination of exit volumes

For tracking the SCV in a regional distribution grid by way of calculation as shown in Fig. 1, the volumes at the entry and exit points of the relevant grid need to be known in addition to the SCVs of the gas volumes injected. Normally verified measured values based on hourly average values are available for the SCVs and volumes at entry points. The exit volumes, usually not measured directly, are derived from totalling all volumes delivered to the end users in the downstream local distribution grid. There are two categories of end users:
- customers with recorded demand measurement (RDM customers); and
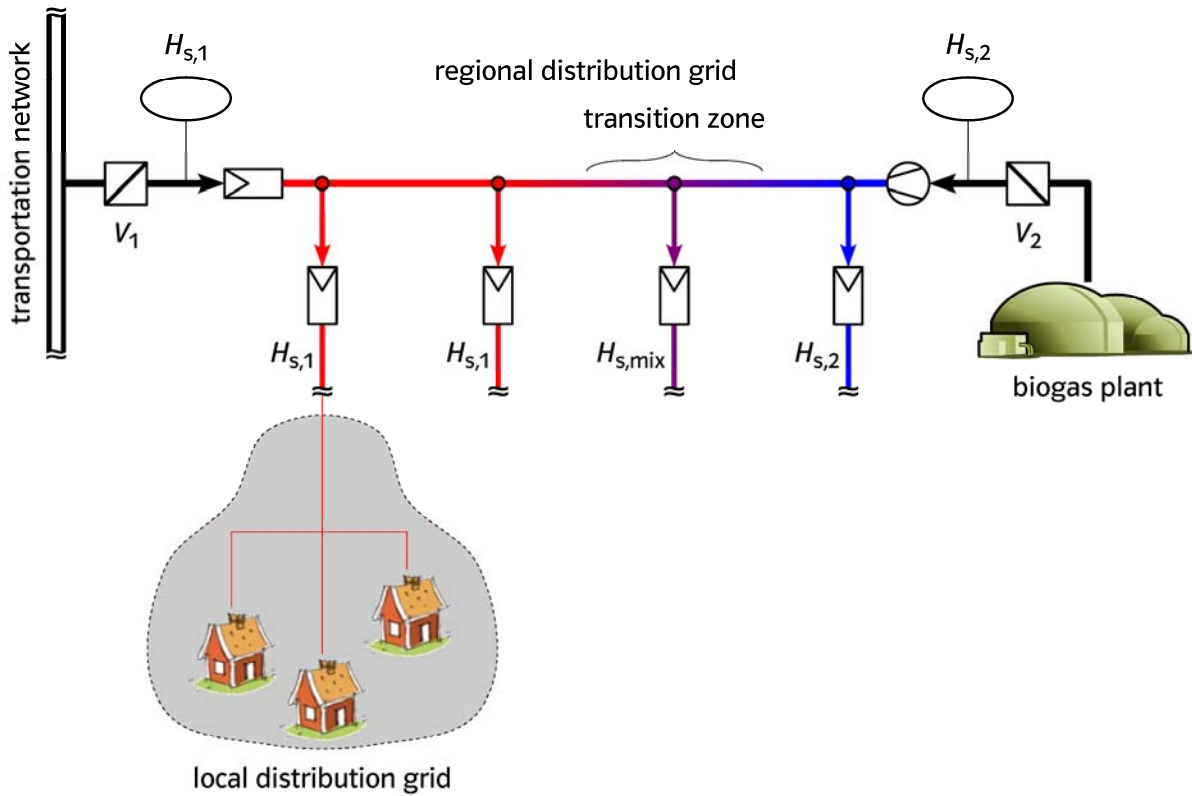- customers with standard load profiles (SLP customers).

Fig. 1: Simplified presentation of natural gas / biogas injection into a
regional distribution grid with downstream local distribution grids.

RDM customers are usually customers with an hourly demand of more than 500 kW or more than an annual offtake of 1.5 million kWh. A simplified approach is adopted where offtake volumes are lower. In this case standard load profiles are applied which were developed at Munich Technical University on behalf of BGW, the Federal Association of the German Gas and Water Industries, and VKU, the German Association of Local Utilities [3].

The Sigmoid function h(υ) is used to determine relative consumption as a function of the weighted average daily temperature.

$$h(\vartheta) = \frac{A}{1 + \left(\dfrac{B}{\vartheta - 40°C}\right)^{C}} + D \qquad (1)$$

Parameters A, B, C and D stand for various types of load profiles (e.g. single-family home, multi-family home, municipality, retail). If the data from a previous customer readout interval are known (consumption Q over readout interval), a customer value KW (in kWh) can be determined which reflects customer-specific consumption. If the forecast temperature is known, for example from the meteorological office, a customer's expected hourly energy consumption (in kWh) is calculated as follows:

$$Q_{SLP} = KW \cdot h(\vartheta) \cdot F(d) \cdot SF(h, \vartheta) \tag{2}$$

where F(d) is the weekday factor and SF(h, ϑ) the hourly factor. Energy consumption is then converted to gas volume using the volume-related SCV.

$$V_{SLP} = \frac{Q_{SLP}}{SCV} \tag{3}$$

Using standard load profiles in gas network simulation eliminates the need for additional measurement equipment, thus avoiding substantial costs. But the volumes determined on the basis of SLPs are not sufficiently accurate for determining SCVs suitable for use in billing. This is why the correction method described in this paper was developed, which improves the level of accuracy significantly.

In the distribution grid considered, the assumption is initially made that normal volumes are measured at all entry points based on hourly values, which means the total volume injected is known accurately.

$$V_{entry}(h) = \sum_j V_{entry,j}(h) \tag{4}$$

The exit volume is now determined by totalling the measured volumes taken by RDM customers and the volumes taken by SLP customers in accordance with Eq. (3).

$$V_{exit}(h) = V_{exit,RDM}(h) + V_{exit,SLP}(h) = \sum_j V_{exit,RDM,j}(h) + \sum_i V_{exit,SLP,j}(h) \tag{5}$$

Taking pressure variations into account which may occur in a gas grid, the change over time in the gas volume contained in the grid (line pack) is determined in accordance with Eq. (6).

$$\Delta V_{grid}(h) = V_{grid}(h) - V_{grid}(h-1) = \frac{p(h) - p(h-1)}{p_n} \cdot \frac{T_n}{T} \cdot V_{geo} \tag{6}$$

The average grid pressure is determined by measuring pressure at representative points along the grid. Adopting a simplified approach, gas temperature is assumed to be constant (e.g. 8 °C).

Taking line pack into account and assuming constant gas densities in the relevant gas grid or grid section, the volume balance is as follows:

$$\Delta V_{balance}(h) = V_{entry}(h) - V_{exit}(h) - \Delta V_{grid}(h) \tag{7}$$

Assuming that the uncertainties involved in both line pack and measured volumes V_{entry} or $V_{exit,RDM}$ are relatively low, it may be concluded that any balance losses are basically due to uncertainties involved in the volumes determined for SLP customers. The difference in volume determined in accordance with Eq. (7) can therefore be used to correct the volumes of customers in the same load profile category proportional to consumption.

$$\hat{V}_{SLP,j} = \left(1 + \frac{\Delta V_{balance}}{V_{SLP}} \right) \cdot V_{SLP,j} \qquad (8)$$

The total volume at an exit point corresponds to the total of the volumes taken by customers downstream of the network node.

To evaluate the correction method described, tests were made on the E.ON Avacon distribution grid at nodes fitted with volume measurement systems. As an example Fig. 2 shows the result for a node in the Schladen-to-Hordorf grid section for two time intervals in 2008: (a) 1 to 15 July; (b) 1 to 15 December. The diagrams plot measured volumes against values determined on the basis of standard load profiles, initially in accordance with Eq. (3) (not corrected) and then in accordance with Eq. (8) (corrected). The result confirms a significant improvement in accuracy for the correction method.
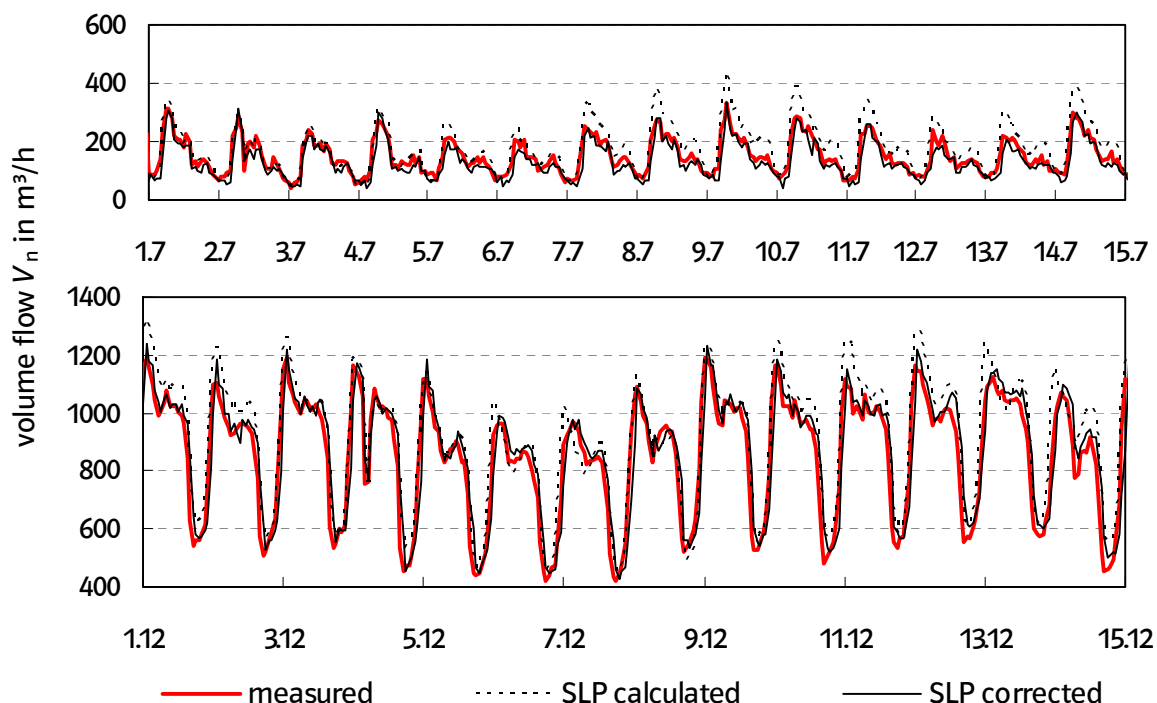

Fig. 2: Measured volume flows at an exit node vs. values determined on the basis of standard load profiles in accordance with Eq. (3) (not corrected) or Eq. (8) (corrected) for two time intervals selected as examples (summer / winter).

3. SCV tracking

The method described in Sect. 2 for determining exit volumes is a key prerequisite for calculating gas flow in a grid, in particular flow velocity, and thus for simulating SCV distribution. But similar to existing SCV tracking systems, SCV distribution can only be determined accurately if the input information listed in Table 1 is available.

For implementation of the method E.ON Ruhrgas developed a software tool based on MATLAB. The tool is interfaced with SIMONE [4], a simulation software product mainly serving to calculate the flow velocities at all network nodes. The new tool analyses standard load profiles, handles data input and output and visualises the results obtained, which means the SCVs determined for the network nodes as hourly average values.

Table 1: Input information required for SCV tracking

Input information	Data source
SCVs at entry points	Measured values (verified)
Normal volumes at entry points	Measured values (verified)
Normal volumes at exit points	Determined on the basis of SLP data; corrected volume balance
Network pressures	Pressures measured at representative points
Topology data (such as line lengths, line diameters, surface roughness)	Data obtained from network operator

4. Validation

The method is currently being validated in cooperation with E.ON Avacon. The test grid is the Lüchow-to-Dannenberg section in Lower-Saxony. The section carries group H-gas with an SCV of approx. 11.3 kWh/m³ injected at three points as well as biogas produced in the biogas plant at Lüchow (approx. 600 m³/h). Prior to injection propane is admixed for biogas conditioning to obtain the SCV of the natural gas in the distribution grid. Fig. 3 shows the 16 bar section of the distribution grid, the pressure being as low as 8 bar at some points. The section is 80 km long and has 40 exit points with downstream local distribution grids operated at 1 bar. It is particularly suitable for validating the simulation results as the natural gas volumes injected can be varied to create diverse flow situations.
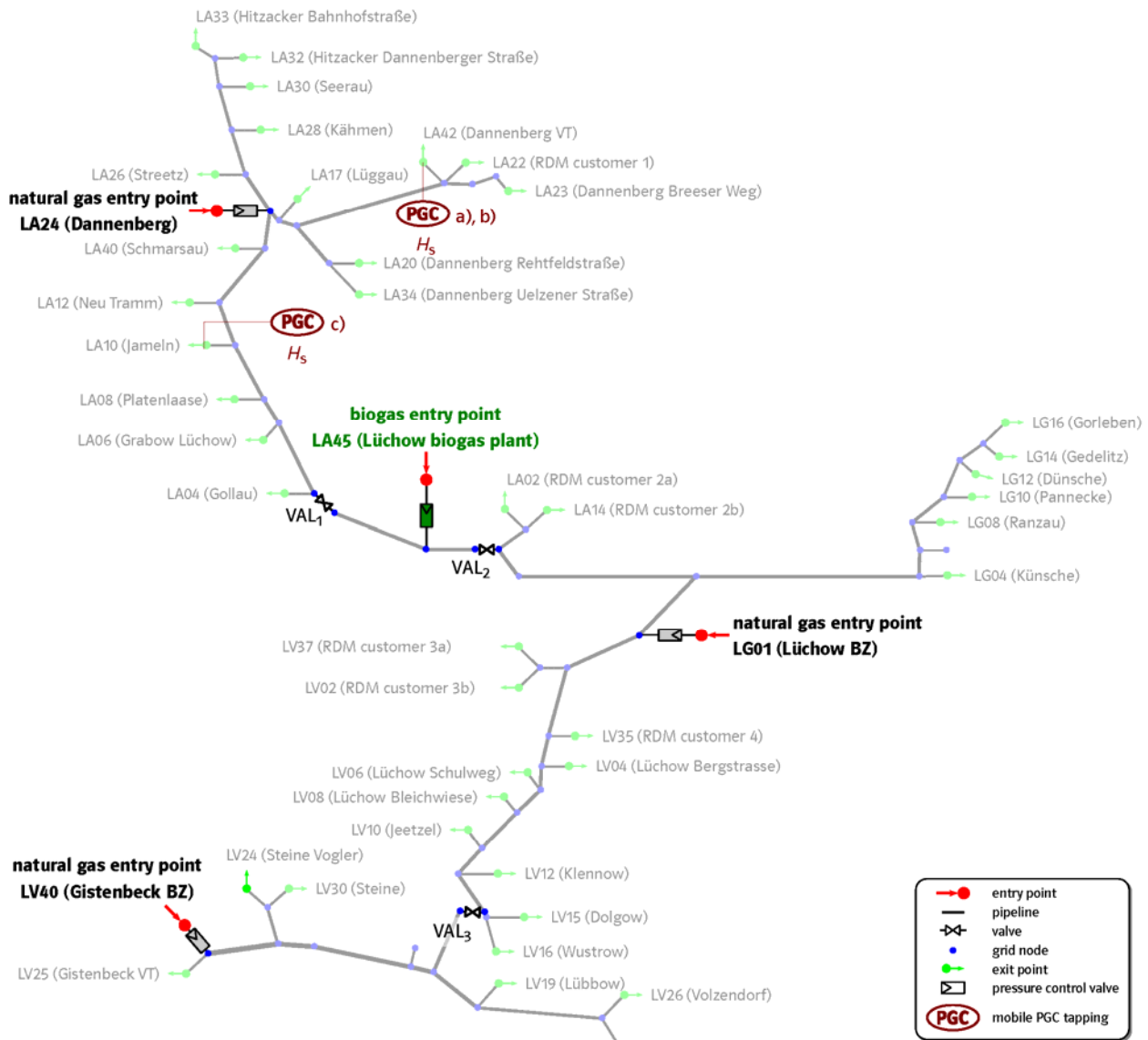
Fig. 3: Lüchow-to-Dannenberg grid section with three natural gas injection points and one biogas injection point.

For validating the simulation results a mobile PGC (Fig. 4) of Open Grid Europe has been used since December 2010. The paper presents the results for three different time periods as examples (Fig. 5). The flow situation may vary considerably in the cases described. In the first example (case a), the grid mainly receives biogas from the Lüchow biogas plant and natural gas injected at the Lüchow entry point. A mixture of natural gas and biogas is therefore present at exit point LA42 where the mobile PGC is installed. In the next example (case b), the grid receives biogas from the Lüchow biogas plant and natural gas injected at the Dannenberg entry point. Valve 2 is closed at the time in question.

Fig. 4: Mobile measurement vehicle of Open Grid Europe with GC9000 PGC of RMG admissible for use in verification measurements.

In case c), the mobile PGC is located at exit point LA10 (valve 2 is open). The grid is supplied with natural gas from the Dannenberg entry point and biogas from the biogas injection point. At exit point LA10 biogas or a mixture of biogas and natural gas is present depending on the volumes taken (transition zone).

To be able to better validate the quality of the simulation results the biogas plant conditioning system was stopped during the three relevant periods causing the SCV of the biogas injected to fall to approx. 10.9 kWhh/m³. Fig. 5 (diagrams a) to c)) shows the calculated and measured SCVs over time for each case. The diagrams also show the SCVs of the natural gas and biogas injected. The results confirm very good agreement of the calculated and measured SCVs over the entire period; deviations are usually below 0.2%.

5. Conclusion

The results of the field test confirm that the 2% accuracy stipulated by German authorities [1] for SCVs used in billing is observed or that the level of accuracy is even significantly better. Following agreement with the verification authorities of Lower-Saxony, measures have been taken to have the method approved for use in end user billing. Cost-intensive conditioning with propane would then no longer be necessary for biogas to be injected into the grid.
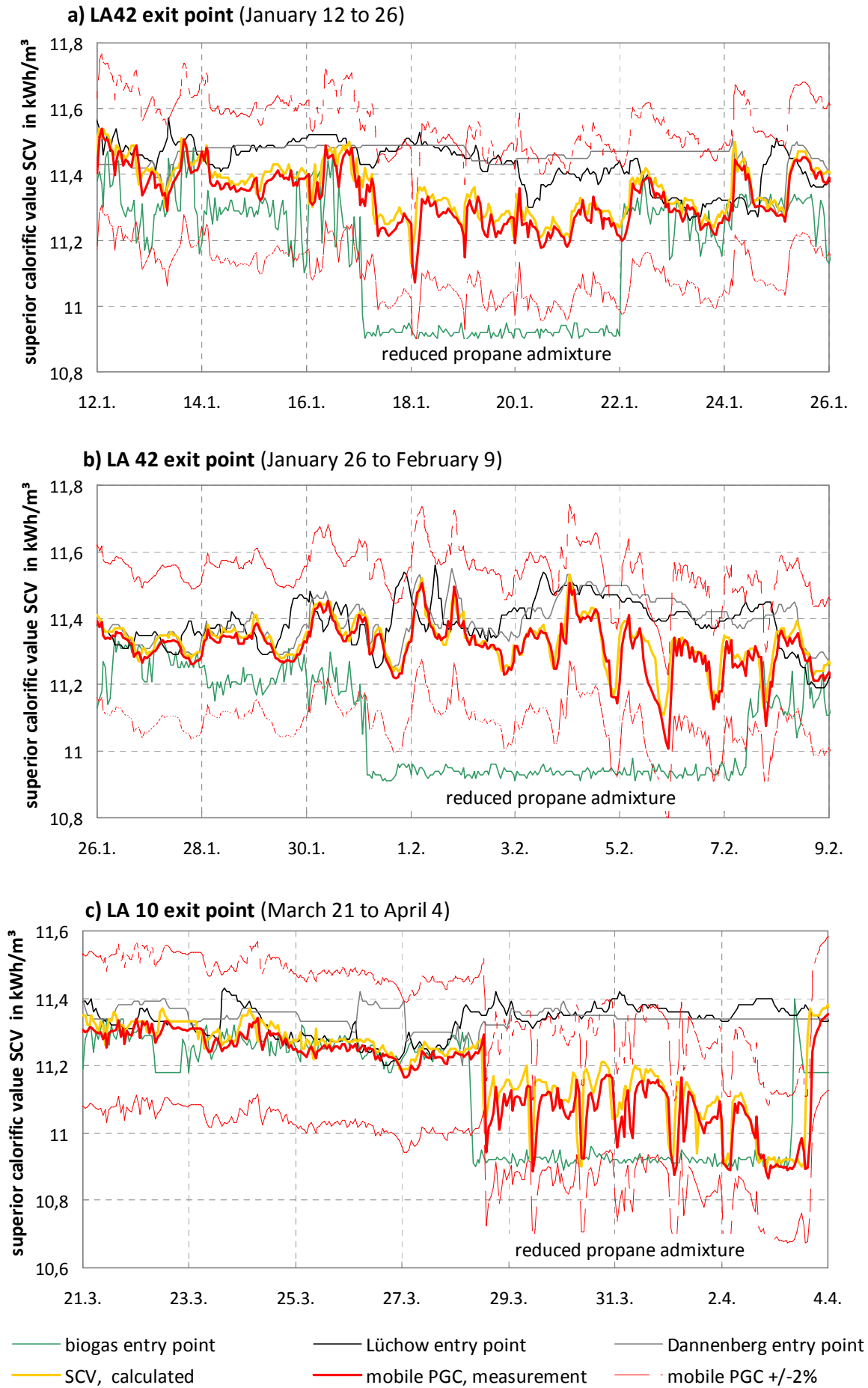
Fig. 5: Measured vs. calculated SCVs for three examples

References

[1] DVGW Code G685: Gas billing, DVGW Code of Practice, September 2008.

[2] K. Altfeld, J. Bödeker, H. Frieling, P. Schley and M. Uhrig: Modelling of Gas Flow in Pipelines Tracking Gas Quality. Proceedings of the 2008 International Gas Research Conference, Paris, 2008.

[3] Hellwig, M. (2003): Entwicklung und Anwendung parametrisierter Standard-Lastprofile, Munich Technical University, dissertation.

[4] Simone Software user manual, Version 5, Liwacom (2007).

Symbols

h	Sigmoid function
p	Gas pressure (absolute)
Q	Energy consumption (kWh)
T	Gas temperature (K)
υ	Ambient temperature (°C)
V	Normal volume

Indices

A	Exit point
E	Entry point
h	Referred to hourly average values
n	Normal conditions (p_n = 1,013.25 Pa; T_n = 273.15 K)
RDM	Recorded demand measurement
SLP	Standard load profile