Danish CHP plants put gas imports to the test

Since 2010 Denmark and Sweden have been importing gas with a lower calorific value. The Danish Gas Technology Centre has been examining the impact of the new gas flows on CHP unit performance, seeking out differences in performance or emissions that might be gas quality-related, writes Jan de Wit.

Since 2010, imports via Germany have introduced gas with a lower calorific value to Denmark
Source: Energinet.dk

Denmark and Sweden started importing gas via Germany for the first time in 2010. Previously, only gas with high calorific value from Denmark's North Sea fields had been used. So, before the German imports started, studies and discussions with suppliers took place, as did lab tests on small household appliances. But it was not possible to perform tests on medium-size and large-scale CHP plants. Consequently, in autumn 2010, the TSO ordered a test import of the new gas quality to a restricted area, allowing for some field-testing with large- and small-scale appliances. Later on, commercial imports were allowed, permitting testing on some low Wobbe gas close to the lower limit of acceptance.

We now have field-test results from a series of measurements made at three gas engine based units and a gas turbine in CC configuration. The measurements were made both during a period of imported low Wobbe gas and at a time when high Wobbe North Sea gas was supplied to the units. The tests highlight some of the operational problems and challenges faced by CHP customers.

Natural gas supply

Natural gas was introduced in Denmark in 1982. For a short time the gas was supplied from Germany, but from 1984 supplies from Denmark's fields in the North Sea accounted for all the supply. Gas was originally supplied from the Tyra field, but later from other North Sea fields and wells. The gas was used in Denmark and exported to Germany and Sweden. Gas chromatographs in the transmission grid are in continuous operation at five strategic locations. Danish annual gas consumption is about 5 billion mn³/year with the power production and cogeneration sector consuming some 25–30% of this volume.

In 2010, gas imports via Germany started. This was due to a deregulated gas market. This imported gas has a lower calorific value and thus a lower Wobbe index than the North Sea gas, typically some 5–8%.

Gas regulation requirements

The Danish natural gas requirements for gas quality are found in Gasreglement A (Danish Gas Regulations). The natural gas distributed must be Type 2, H series. The Wobbe index must be within the 51.9–55.8 MJ/m³ (14.1–15.5 kWh/m³) range during normal supply situations. For certain short and extraordinary situations supplies with higher Wobbe index might be allowed. Customers with sensitive equipment must be warned prior to such extraordinary supply situations. Until imports of natural gas via Germany started the gas quality was extremely stable and the supplied Wobbe range was predominantly 15.0–15.5 kWh/m³.

Natural gas fired CHP units

About 700 natural gas-fired engines (1000 MWe) are installed for decentralized cogeneration. More than 25 different makes are represented, many of them with two, three or more engine series present. However, gas engines from Caterpillar, Jenbacher, Rolls-Royce/Bergen and Wärtsilä account for more than 90% of the power production or gas consumption in this segment. Most engines were installed during the mid-90s. The pre-chamber engines account for around 50% of installed gas engine capacity.

A total of some 44 gas turbines (eight different makes) are installed (725 MWe) and a number of single-cycle gas turbines typically rated 4–10 MWe

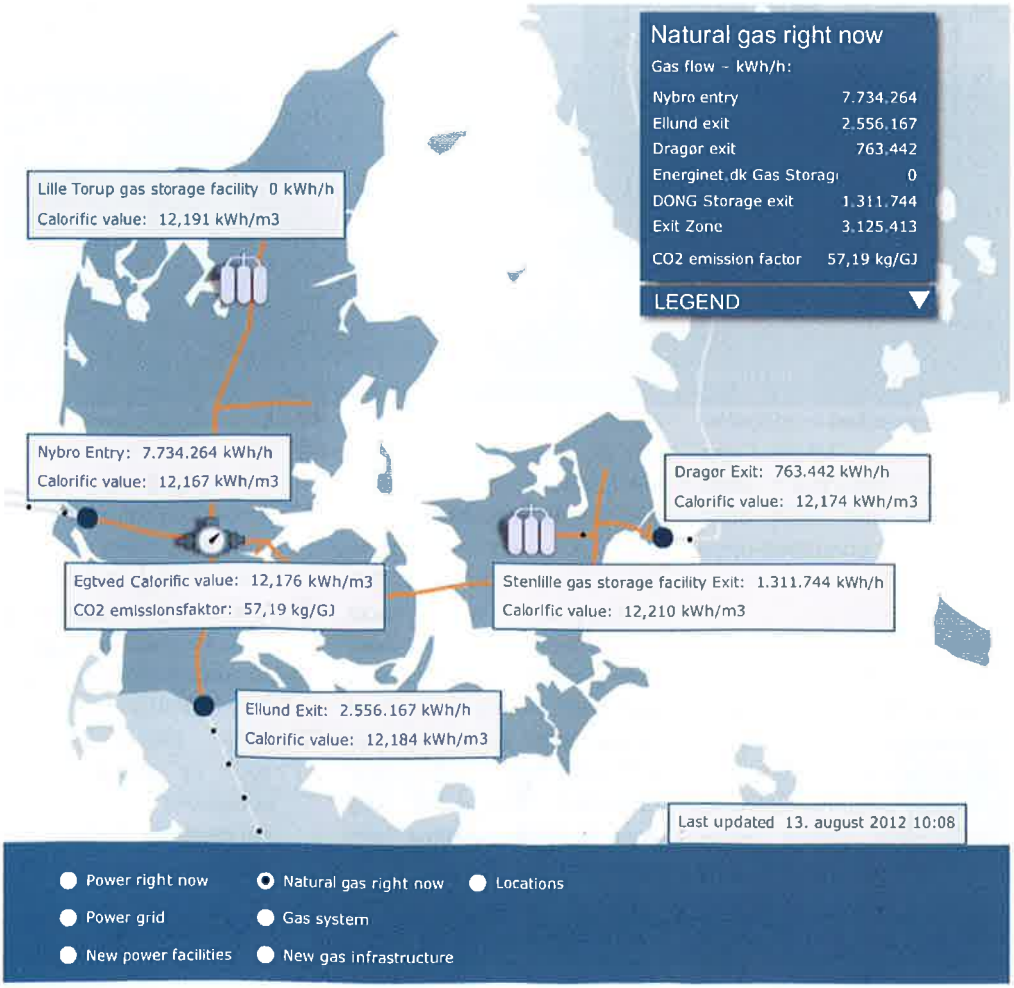

Figure 1. The Energinet.dk overall gas transmission system including information on actual supply situation. Published at www.energinet.dk. Screen dump dated 13 August 2012

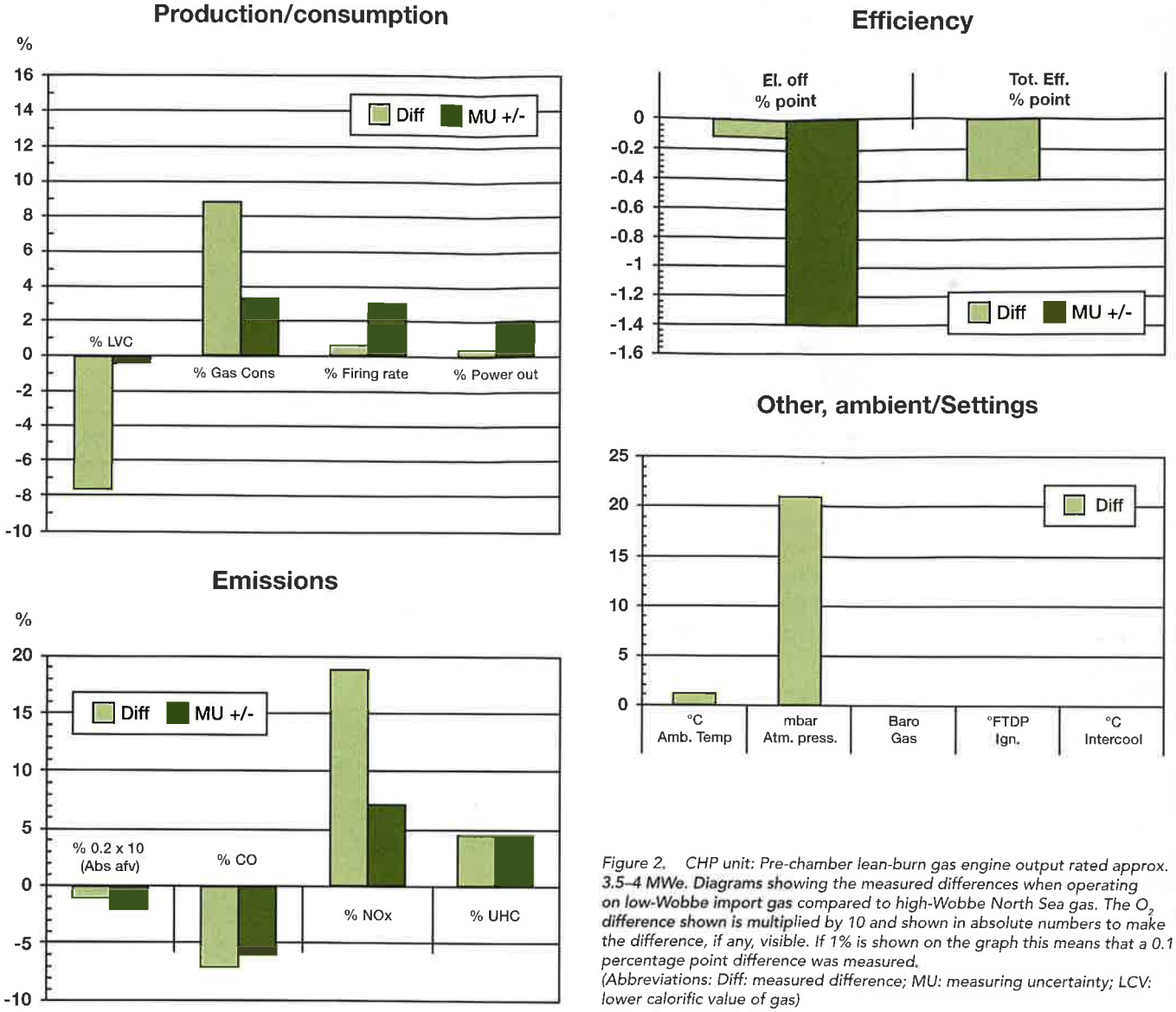

Figure 2. CHP unit: Pre-chamber lean-burn gas engine output rated approx. 3.5–4 MWe. Diagrams showing the measured differences when operating on low-Wobbe import gas compared to high-Wobbe North Sea gas. The O_2 difference shown is multiplied by 10 and shown in absolute numbers to make the difference, if any, visible. If 1% is shown on the graph this means that a 0.1 percentage point difference was measured.
(Abbreviations: Diff: measured difference; MU: measuring uncertainty; LCV: lower calorific value of gas)

each are installed for industrial cogeneration. Larger gas turbines, including aero-derivatives, are most often installed as combined-cycle units.

Field test measurements during import/export

In spring 2011, two series of measurements were made at CHP units near the gas import entry point in southern Jutland. These measurement series were made during a supply situation with high-Wobbe North Sea gas and a supply situation with low-Wobbe import gas, respectively.

The measurement series were performed at three gas engine CHP units (one medium-size open-chamber and two pre-chamber units) and a combined-cycle gas turbine installation. The measurements were made at full load during a two-hour period. The same gas and heat meters were used during both series. For the emission tests high-quality laboratory equipment was used, calibrated before and controlled after the test.

The following key data was measured during each period:

- Gas consumption,
- Electricity production,
- Heat production (if heat meters were installed),
- Actual gas composition at site (three samples were taken during each test),
- Ambient conditions (temperature, atmospheric pressure, gas supply pressure),
- Prime mover settings, such as ignition timing, intercooler temperature, temperature before first row of turbine blades (GT),
- Air excess (O_2 measurement),
- Emissions (CO, NOx and UHC),
- Gas composition (three samples taken on site during each measurement).

The measurements were taken without prior extraordinary adjustments of the units. The results can be presented in many ways. This paper focuses on possible differences between the two supply situations; therefore the differences between the two sets of measurements on each site are shown. By doing this, systematic measurement uncertainties/errors are eliminated.

The measurement uncertainties for the various

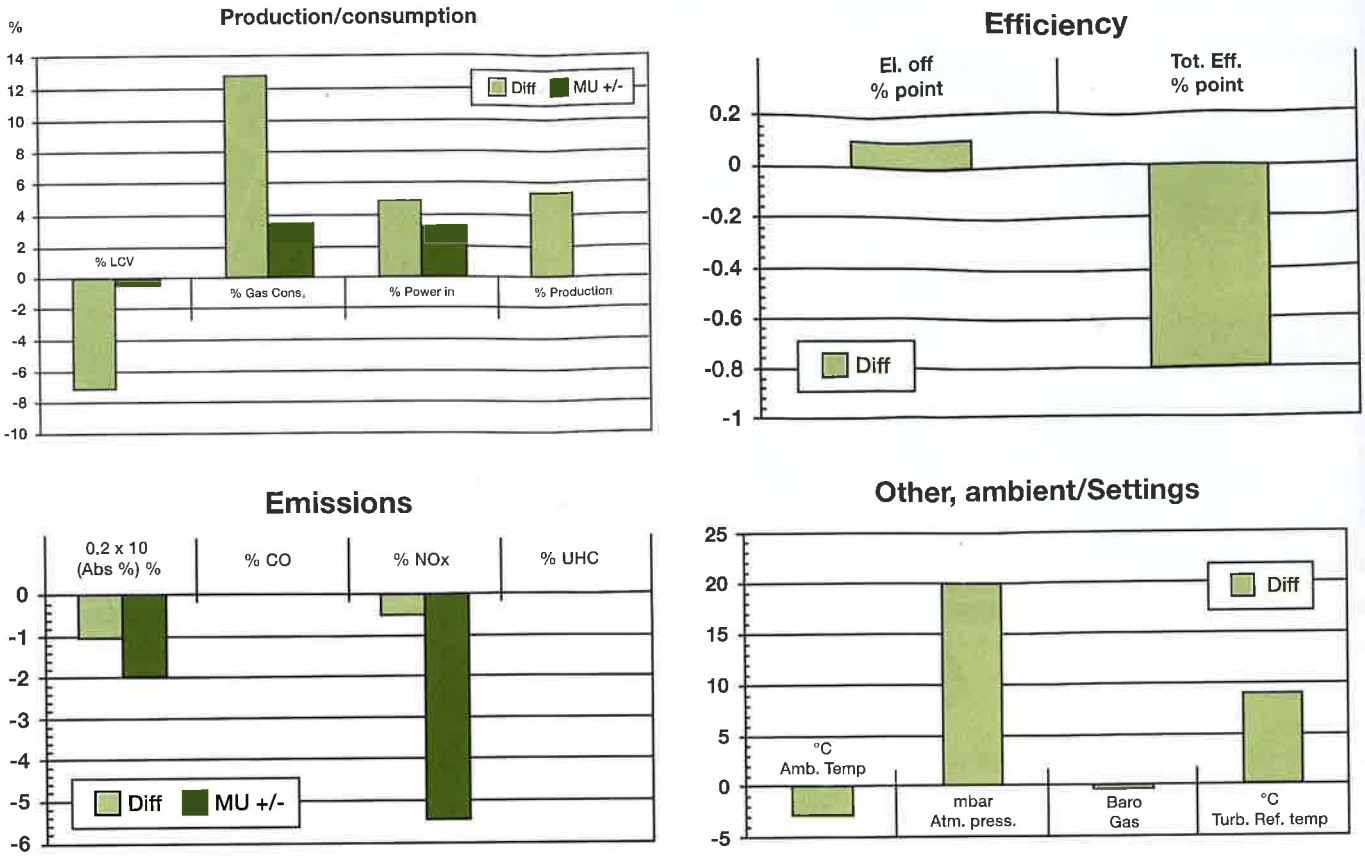

Figure 3. CHP unit: Gas turbine, nominal output 40 MWe. Diagrams showing the measured differences when operating on low-Wobbe import gas compared to high-Wobbe North Sea gas. The O_2 difference shown is multiplied by 10 and shown in absolute numbers to make the difference, if any, visible. If 1% is shown on the graph this means that 0.1 percentage point difference was measured.
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parameters are shown in connection with possible measured differences. However, the uncertainty shown is, as a rule, the absolute accuracy of one measurement series only. The uncertainty of the difference is expected to be less. However, since the possible systematic error/uncertainty is not known, the most likely uncertainty of the differences cannot be shown.

Based on experience gathered, new control system settings might have been introduced for a number of CHP plants. This may result in different efficiencies and emissions than shown here.

The measurement results from the four sites are presented as Figures 2 and 3. As stated, the diagrams show the measured differences in per cent when operating on low-Wobbe import gas compared to high-Wobbe North Sea gas.

The measurement results

For two of the three gas engine units only very small and insignificant differences were measured regarding firing rate, power output and efficiency when using low-Wobbe import gas compared to high-Wobbe North Sea gas.

For all three gas engine units increased emission was found when operating on low-Wobbe import gas. In a number of cases this difference was below the uncertainty of the measuring equipment. But differences in atmospheric pressure and a slight decrease in air excess were seen between the two measurement series, which might be the reason for the rise in NOx rather than the gas itself.

For gas engine 3 a decrease in electricity production efficiency of some 0.8 percentage point was measured when operating at low-Wobbe import gas. As also significant increased emissions of CO (+18%) and unburned hydrocarbons (+24%) were seen, this may indicate poor combustion and the need for new settings for this engine to achieve optimal operation on the import gas supplied.

At the gas turbine unit both a higher electrical output and also increased gas consumption were measured when operating on the low-Wobbe import gas. The electrical efficiency was improved by 0.1 percentage point (insignificant as measurement uncertainty was higher).

The above findings for the gas turbine are most likely a result of lower outdoor temperature and higher atmospheric pressure during the import gas supply situation.

No significant difference in emissions from the gas turbine was found.

Observations during gas import periods

Based on feedback from plant operators, gas companies and others, a number of other findings regarding CHP operation at the different supply situations were noted.

Little mixing seems to take place in the transmission pipes between the gases. The flow is a kind of plug-flow. Some equipment suppliers have specifications regarding allowed change in energy content of fuel gas

Figure 4. Detailed information points, from which data of measured or calculated actual gas composition can be found

per minute while others have no such specification in the specification sheets.

A few gas engine based units have experienced problems during cold start if gas quality has changed compared with what the engine was initially adjusted for.

A number of engine control systems are prepared to have different start settings for various gasses. A feed-forward signal regarding the actual gas quality at site is needed for efficient utilization of these.

Knowledge about the actual gas composition is preferred/needed when doing tuning/setting of a CHP unit. An on-line gas chromatograph or a portable Wobbe index device is needed.

There are challenges for correct gas billing of plants with abnormal operation pattern (peak shaving, industrial plants etc.). If the allowed Wobbe index (or gas calorific value) range and operation span is widened more than ±5% this will exceed gas supply warranty specifications for a number of gas turbine makes and possible also for some engine makes.

Text message service

A texting service (SMS service) is established to facilitate and service end-users, installers and others. A text message is transmitted when import starts and ends.

Analysis of influence on gas billing

Analyses were made for typical customers in the area closest to the entry point to find possible influence on the consumption weighted annual average heating value. Natural gas billing is (and has always been) corrected for the actual heating value of the gas supplied in a number of reference points in the system.

For consumers with a normal degree-day based gas consumption profile, these analyses have shown a possible uncertainty of <0.55 % near the gas import entry point.

For consumers with an abnormal consumption profile (industrial customers, peak load plants etc.) the billing uncertainty may possibly be larger; tests are now being made with small gas chromatographs installed at the end-user for onsite correction.

CHP supplier activities

The suppliers have been invited and most of them participated in information meetings.

The gas engine suppliers have followed the experience gained during the import periods with low Wobbe indexes. Within their own product programme, new initial settings have been considered and for some engine series a change of control systems and/or settings has been initiated. A number of advanced control systems are prepared for operation and start on different gases and two or more gases can be stored in the memory of the system. However, exact knowledge of the gas delivered when starting up is preferred. Such information could be derived from the Energinet.dk home page or by direct measurements on the gas supplied.

A number of smaller gas engine based units have been operated for years with a fixed gas/air mixture rate. These controls are now being replaced with adjustable venturi systems based on a feedback signal.

Conclusion

During the gas import periods no safety critical issues with the natural gas fired CHP units have been reported. During one of these periods, import gas with a Wobbe number very close to the national minimum requirement was supplied.

A measurement programme carried out during high- and low-Wobbe supply situation showed for some of the gas engine units differences in performance or emissions that might be gas quality related. However, the CHP units might not necessarily be fully tuned/adjusted or equipped for this new supply situation.

Re-adjustment, change of setting or modification of gas/air mixture systems at some engines may be needed. If the appliance is adjusted in the middle of the allowed Wobbe span for normal supply situation in the national requirements the possible Wobbe variation will be a little less than ±5 % as given as the limit in the specification sheets for a number of gas turbine makes. If the national Wobbe acceptance band is further widened, this limit might be exceeded.

So far, only little mixing in the transmission and distribution system has been reported; the flow pattern is much like plug-flow, giving abrupt changes in gas composition. Meanwhile, a number of gas company service initiatives have been developed and initiated to help customers find information of the supply situation, even down to the distribution system level.

By Jan de Wit and Steen D. Andersen of the Danish Gas Technology Centre, Denmark and Bjarne Koch of DONG Energy, Denmark

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