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THE IMPACT OF NATURAL GAS COMPOSITION VARIATIONS ON THE OPERATION OF GAS TURBINES FOR POWER GENERATION

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ABSTRACT

Modern low emissions gas turbines are sensitive to variations in natural gas composition. As variations have typically been relatively small and slow this has not historically caused major problems. Throughout Europe, the increasing dependence on natural gas imports is leading to increased gas composition variation within the distribution system. Due to the increasing diversificiation of natural gas supply, variations in gas quality have the potential to be very rapid, e.g..a rate of change in Wobbe Index of 1%/minute has caused issues at one E.ON site. It is anticipated that fuel variability will be an increasing issue in the future.

Evaluation of operating data for a range of gas turbines within E.ON's UK gas turbine fleet has shown clear trends in pollutant emissions and combustion dynamics with changing fuel composition. These changes can result in forced reductions in power output. Rapid changes in composition have also resulted in emergency shutdowns due to control issues, which have an adverse impact on revenues and component life.

This paper presents real examples of the above findings for a range of gas turbines from most major manufacturers. It also discusses how these findings may inform our understanding of the risks associated with increased fuel composition variation.

INTRODUCTION

The European natural gas transmission system is made up of the transmission systems of different European gas companies linked by interconnections. Increased gas demand and depletion of traditional stocks are leading to a growing requirement for the transport of gas around the system and import of gas to the system. This has led to increased gas import from Russia, Eastern Europe and the Near East via pipelines, and from around the world in the form of Liquefied Natural Gas (LNG).

The UK in particular has in recent years imported increasing amounts of LNG, which has very different compositions and combustion properties than a typical natural gas. The contribution of LNG to the UK's gas supply has increased from practically zero to over 25% since 2008, as shown in Figure 1. Gas from Norwegian gas fields is also a large contributor to the UK gas supply. However, this supply is expected to remain at similar levels in the near term and reduce in the mid-term, whilst at the same time North Sea gas production will continue to decline (National Grid, 2011). LNG is likely to make up any shortfall in UK gas supply and could contribute over 50% by 2030 (National Grid, 2011).

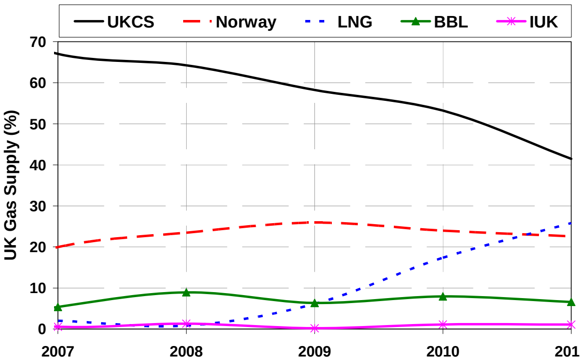


Figure 1: Major sources of UK gas supply (National Grid, 2011) (UKCS: UK Continental Shelf, Norway: Statfjord and Langeled pipelines, LNG: Liquefied Natural Gas, BBL: Balgzand Bacton Line, IUK: Interconnector UK).

A key parameter in assessing fuel quality is the Wobbe Index (WI), and typical values experienced within Europe together with national specifications are illustrated in Figure 2.

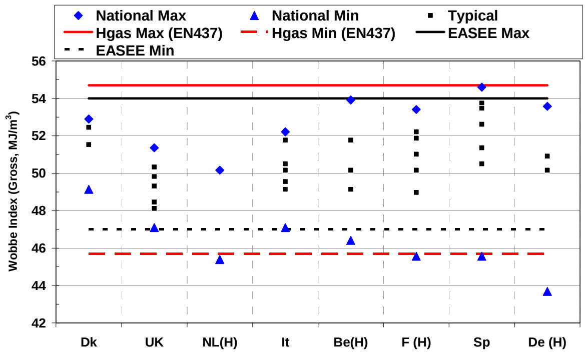


Figure 2: National gas specifications and typical gas compositions (Derived from: Groenendijk, 2006; EASEE-Gas, 2005; and EN ISO 437, 2003; corrected to reference conditions of 15°C and 1atm).

The range of compositions allowed by the national standards is much greater than the typical variation. The significant differences in national specifications cause problems for international natural gas trading, thus harmonisation of fuel quality standards may be desirable. To address this issue the European Commission (EC) issued a mandate in 2007 for the European Committee for Standardization (CEN) to draw up European Standards for gas quality. It is anticipated that these standards will be published in 2014-15 (Kovács, 2012).

Before the EC mandate (in 2002) the European Association for Streamlining of Energy Exchange (EASEE) established a group, EASEE-Gas, to “develop and promote the simplification and streamlining of both the physical transfer and the trading of gas across Europe”. EASEE-Gas produced a specification (EASEE-Gas, 2005) aimed at maximising the flexibility of natural gas transfer without compromising gas appliance operability. This formed the basis for the development of the mandated CEN standard.

GAS TURBINE FUEL SPECIFICATIONS

There is a common misconception that gas turbines (GTs) can burn any combustible gas and that fuel variability is not a significant issue. It is true that there are GTs firing a wide range of gases including natural gas, syngas (from coal, biomass and wastes), steelworks gases (coke oven gas and blast furnace gas) and gases with high hydrogen content (such as refinery gases). However, individual GTs can only tolerate limited changes in composition, depending on the GT design and the set-up of the hardware and controls, and must be tuned for the required fuel composition range.

Before the regulation of emissions of acid gases such as the oxides of nitrogen (NO_X), GTs typically had diffusion flame combustors. These were very stable and tolerated wide ranges of fuel composition, but resulted in high NO_X emissions. Due to regulation, most European power generation GTs installed since the mid 1990s have some form of lean premixed combustion system, often referred to as Dry Low NO_X (DLN) or Dry Low Emissions (DLE) combustors. These systems are significantly more sensitive to fuel variations because their operation has been optimised for a narrow range of conditions to minimise emissions. For GT operators, key issues are:

Efficiency
Operability
Reliability
Emissions [Oxides of Nitrogen (NO_X) and Carbon Monoxide (CO)]
Component Life

All these may be adversely affected by variations in fuel composition, and GT manufacturers provide operators with specifications of allowable fuels. Typically these are not published in the open literature and are often contractual documents applying to particular installations and cannot be referenced directly. Though these specifications are in principle installation-specific, there is a significant amount of commonality and typical requirements are outlined here.

The WI, as used in Figure 2 is the most commonly used parameter for specifying the acceptability of a gas fuel. Equation (1) shows the typical definition of WI.

$$\mathrm{WI} = \frac{\text{Calorific Value (volumetric)}}{\text{relative density}^{0.5}} \qquad (1)$$

Unfortunately WI is not a dimensionless parameter and depends on the units and reference conditions used. Different manufacturers and workers in the field use different definitions and reference conditions, thus care should be taken when comparing information from different sources. In this paper the WI is based on the gross (higher) calorific value (CV) expressed in MJ/m^3 at metering and combustion reference conditions of 15°C and 101.325kPa. For conversions between different reference conditions and a list of reference conditions typically used in different countries refer to EN ISO 13443 (2005).

The significance of WI is that for given fuel supply and combustor conditions (temperature and pressure) and given control valve positions, two gases with different compositions, but the same WI, will give the same energy input to the combustion system. Thus the greater the change in WI the greater the degree of flexibility in the control and combustion systems needed to achieve the design heat input. Some manufacturers use modified definitions of the WI that take into account the supply temperature rather than the reference conditions. This is useful from an operational point of view, but because the supply temperature is a variable these modified versions of the WI cannot be used in fuel suppliers' specifications.

In addition to the WI, manufacturers also often specify limits on the Heating Value and other bulk properties of the fuel. GT manufacturers typically specify that their turbines are capable of operating over a wide range of WI and Heating Value. Ranges in excess of ±10% of mid-range values are normal. However, it is unlikely that this could be accommodated without re-tuning and some combustors may need minor hardware changes. For a particular GT installation a range of ±5% of the tuned value of WI (and/or Heating Value) is typical. For some GTs a range as low as ±2% of the WI has been specified.

The detailed composition also affects combustion performance including flame stability, emissions, flashback, and ignition properties. Manufacturers' specifications account for such compositional changes in different ways, but typically specify maximum levels of higher hydrocarbons (ethane, propane, butane etc), minimum methane and/or maximum inerts. These specifications aim to ensure that the fuel gas is predominantly methane, and that gases which contain both high levels of inerts and higher hydrocarbons, but are still within WI limits, are not allowed.

MODERN GT COMBUSTION SYSTEMS

Typically modern GT combustion systems consist of a series of lean premix burners/injectors firing into one or more combustors. In the injector, fuel is introduced into a swirling air flow. The fuel injection is widely distributed and an air/fuel mixing zone is provided to ensure even mixing of the fuel and air. High quality mixing is essential to ensure an even temperature within the flame which leads to low NO_X emissions when operating under lean conditions. The swirling flow tends to enhance mixing and generate the correct aerodynamic conditions for flame stabilisation in the combustor.

The design must generate acceptable combustion performance by ensuring:

- The flame stabilises at the burner exit at the upstream end of the combustor without propagating upstream into the mixing zone (flashback) or lifting from the burner and blowing-out
- Excessive combustion dynamics are not produced (see below)
- Flame temperature and temperature distribution do not deviate significantly from design values (to prevent component overheating or excessive thermal stresses)
- Low levels of pollutant emissions

Combustion dynamics (acoustic pressure fluctuations within the combustor) can occur in any combustion device, but lean premix GT combustors are particularly susceptible. Because it is common, different manufacturers and workers in the field use different names such as pulsations, dynamics, acoustics, instabilities, humming, screech and others.

Combustion dynamics occur due to the coupling of acoustic pressure oscillations in the combustion system with the energy release within the flame. These oscillations can reach high amplitudes and induce vibration in the combustor components. This leads to increased wear, reduced component life or in extreme cases catastrophic component failure. Instances of component failure can occur particularly when the characteristic combustion dynamics frequency couples with the structural response of the system.

The fuel composition together with the air fuel ratio, flow properties (e.g. flow speed, turbulence etc), fuel placement and mixing quality all have a significant influence on flame behaviour (flashback, blow-out, dynamics and emissions). The details of how these effects influence combustion performance depend on the details of the combustion system design and this is why different GT manufacturers have different fuel specifications and use a range of parameters to specify acceptable fuel quality.

Considering the key parameter of WI, Figure 2 shows the allowable range of WI in several European countries; this varies from about ±4% to ±10% of the mid-range value, thus in many locations, fuels can be delivered that are outside the range typically allowed by the manufacturers. Historically this has not been a significant problem because the actual variation (Figure 2) has typically been less than about ±3% at most locations. However, with increasing fuel trading and import the variation is increasing and will continue to increase. This may be affected by the proposed harmonisation of European fuel quality specifications.

PRACTICAL EXAMPLES OF THE IMPACT OF FUEL QUALITY VARIATION ON GT OPERATION

Even within existing fuel variations, the impact on GT operation can be detected and can be significant. The following examples are all using fuels within the allowable range for the UK shown in Figure 2.

Variation in Wobbe Index / Calorific Value

NO_X and CO emissions depend on factors including operating load, ambient conditions and fuel composition. NO_X tends to increase with increasing WI and Figure 3 shows base-load NO_X emissions over a three month period for four GTs at one location. These units are nominally identical, but differences in build, ageing and tuning result in different emission characteristics.

Although there is significant scatter due to changes in ambient temperature, pressure and humidity there is an upward trend in NO_X for units A and C. The trends for units B and D are less pronounced and may not be statistically significant. This shows a clear impact of fuel composition on GT emissions, but even for the similar machines the response to changes in fuel composition can be quite different.

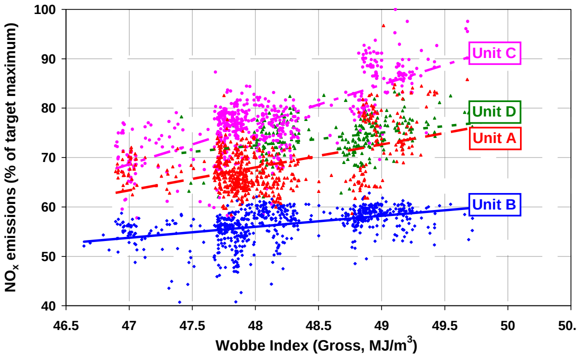


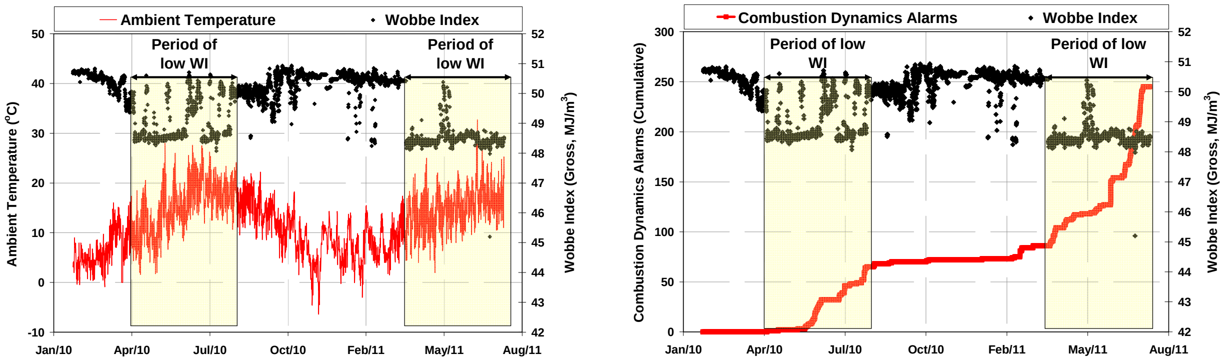
Figure 3: Impact of fuel composition on NO$_X$ emissions for four similar GTs.

Based on similar studies of GTs in the UK, estimates have been made of the increase in NO$_X$ that would occur if GTs tuned on a gas with a WI in the middle of the allowable range (Figure 2) were supplied with gas at the top end of the acceptable range. For properly configured and tuned power generation GTs, increases of approximately 10% of target emissions were typical, with the range being 5 to 20%. Thus a significant margin has to be allowed for fuel composition changes when tuning a GT, which is a balance between optimising emissions, dynamics and integrity. The additional margin needed to guarantee meeting emissions targets may compromise dynamics and load limitation.

Seasonal variations in gas demand have been seen to affect gas flows around the UK gas distribution system. In some areas this has resulted in gas quality variation closely following ambient temperature variation, as shown in Figure 4 (a). This example, taken directly from an E.ON UK GT site, resulted in increased levels of combustion dynamics during warmer periods, where the gas supply WI decreased. The occurrence of combustion dynamics alarms clearly follows the trend in gas WI, as shown in Figure 4 (b). Increased combustion dynamics occurred as the GT was originally tuned during colder ambient temperatures on higher WI gas.

The decrease in gas WI weakens the burner pilot gas flow and in this case causes flames on the most sensitive burners to lift off from their normal stabilised position. This reduces the pressure drop through those particular burners, and so allows more air to pass through them, thereby maintaining the lifted-off flames in their new positions. The increased air flow through these burners produces a cold streak in the exhaust, which is detected by one or more of the twenty four thermocouples, as shown in Figure 5. Conversely, the unaffected burners experience a slight reduction in air flow, thereby increasing their temperature. Therefore a significant change in the exhaust temperature profile can be observed, and CO levels can increase at part load due to quenching of the lifted-off flame(s).

The flames that have lifted off stabilise in their new positions. It is common to have to reduce engine load to full speed, no load, or even to shut down the engine in order to return the flames to their original stabilisation positions. Additionally, the new flame configuration changes the acoustic driving characteristics of the flames and affects the acoustic behaviour of the combustor. In particular, the dominant frequency can move from a relatively harmless frequency range to one that is known to cause significant damage to this type of GT. Warnings associated with evidence of this change increased significantly during periods of low WI fuel supply (Figure 4(b)).



(a) (b)

Figure 4: (a) Variation in ambient temperature and gas supply Wobbe Index at an E.ON UK GT site. (b) Combustion dynamics alarms and variation in gas supply Wobbe Index at an E.ON UK GT site.

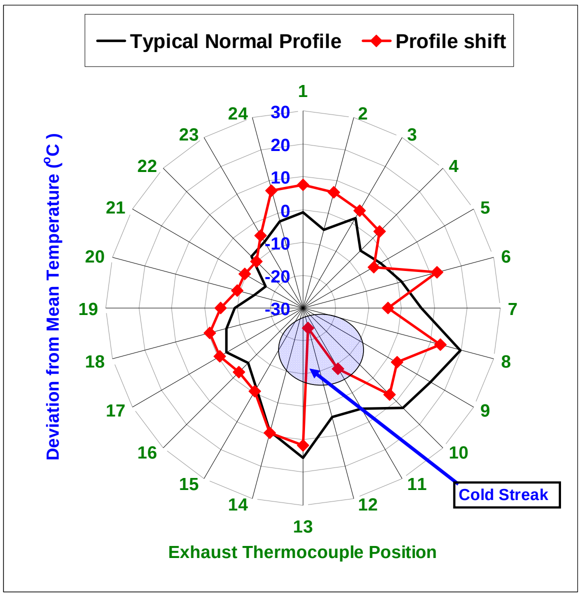
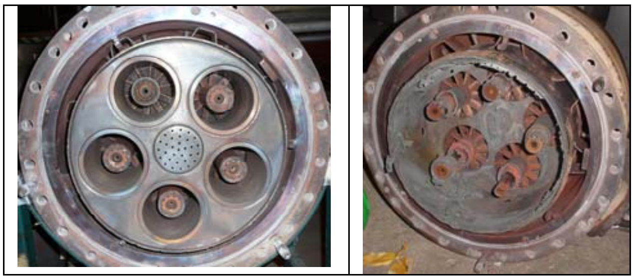


Figure 5: Example of lifted-off flame caused by gas quality variation.

High levels of combustion dynamics can cause hardware damage which ranges from wear of joints and seals to catastrophic failure, an example of which is shown in Figure 6 (b). Therefore, manufacturers typically specify maximum levels of damaging dynamics.



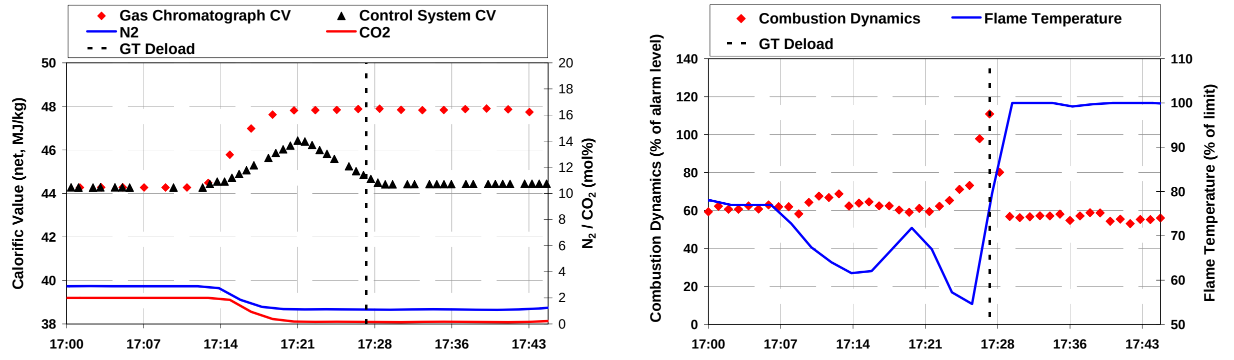
(a) (b)

Figure 6: (a) New Burner. (b) Burner damage following component failure due to excessive dynamics.

Large variations in gas quality have occurred at one E.ON UK site, which have resulted in GT trips. At this site, the control system for the aeroderivative GT uses gas CV (mass basis) and Relative Density (RD) to determine fuel splits to the various burner pathways. This enables the control system to maintain flame temperatures in each region of the combustor and provide acceptable levels of combustion dynamics and NO_X and CO emissions. When consecutive CV or RD measurements from the gas chromatograph vary above a set amount the control system assumes that the gas chromatograph measurements are faulty and switches to pre-defined default values.

Figure 7 (a) shows an example of the control system switching to a default CV when the gas supply CV increased by 7% in six minutes. The change in gas CV resulted from a reduction in the inert species content (carbon dioxide and nitrogen) and is likely to have occurred due to LNG supply reaching the site from either a local storage site or LNG terminals located south of this site. The default CV value set within the control system was designed for a typical natural gas usually received at this site, which was a much lower value than the gas being received during this time. With the GT now using the default CV value, non-optimised fuel splits were applied to combustion system. This resulted in varying flame temperatures and combustion dynamics exceeding the allowable level, as shown in Figure 7 (b). The control system then applied protective action and de-loaded the GT.

Variations in gas quality similar to the event described above have been seen at this site on numerous occasions, which have resulted in GT trips, GT de-loads, increases in emissions and increases in combustion dynamics. In order to mitigate the impact of gas quality variation, changes to the control system settings were made to allow for a larger variation in gas chromatograph measurement before the control system switches to the default CV or RD values. These changes have been effective in reducing the occurrence of these incidents and may be applied to other E.ON sites with similar GTs in future. However, these changes have increased the risk of spurious trips or de-loads due to faulty gas chromatograph readings. A long term solution for this issue may involve the use of a fast response gas quality measurement system. This system could be combined with the gas chromatograph readings, whereby the fast response system gives the control system a rapid indication of gas quality variation trends. These can then be checked against the gas chromatograph at each measurement interval to enhance measurement accuracy. The combination of these two measurements would provide enhanced protection for the GT.



(a)

(b)

Figure 7: (a) Large fuel quality change at an E.ON UK GT site, resulting in the control system switching to a default value of gas CV. (b) Combustion dynamics and flame temperature changes resulting from default gas CV being used, causing a GT de-load.

Variation in gas composition

Changes in gas quality arising from gas composition changes do not always result in significant variations in WI or CV. For example, a gas containing a higher proportion of higher hydrocarbons (C2+) than a typical natural gas can have a similar WI and CV on a volumetric basis if higher inerts are also present. This situation has been seen when the supply source of gas switches from a typical natural gas to one that is supplied from an LNG terminal. In order to produce gas that is within the WI range acceptable for the UK gas grid, LNG terminals may ballast their LNG with nitrogen. The effect on gas CV (volumetric) with varying levels of C2+ and inerts is shown in Figure 8.

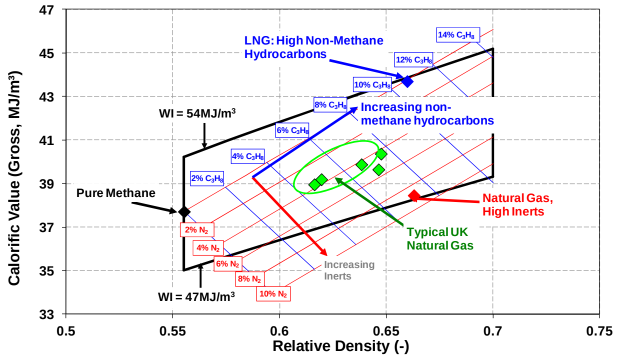


Figure 8: Gas gross (volumetric) CV and Relative Density with varying C2+ and inerts contents (black line represents EASEE-Gas quality specification (EASEE-Gas, 2005).

Some GT types can be particularly sensitive to the C2+ content of gas due to the different flame properties associated with these species compared to methane, e.g. flame speed, auto-ignition delay time, and auto-ignition temperature. Figure 9 shows the variation of dynamics with load for an E.ON GT in the UK. This GT can receive gas from different sources which have similar WI, but different proportions of higher hydrocarbons. Both fuels were within the turbine manufacturer's specification. The GT had been tuned on fuel from source 1 and operated well on this fuel. However, when operated on fuel from source 2, high levels of dynamics occurred above 95% of full load. To continue operation the turbine had to be de-rated with consequent loss of power and efficiency and thus revenue. In this instance, re-tuning the GT on fuel from source 2 eliminated the problem and allowed acceptable operation on both fuels. This illustrates that although it is a key parameter, the WI is not sufficient to fully characterise the fuel. Additional parameters are needed, but have yet to be universally agreed. It is anticipated that this will become increasingly important as further diversification of fuel supply occurs, e.g. from biogas sources, further widening the range of possible fuel supply composition.

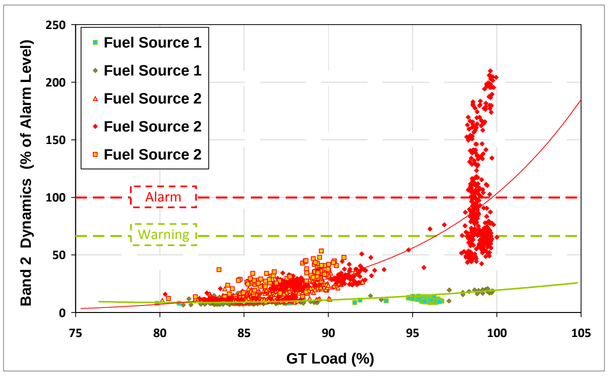


Figure 9: Levels of dynamics as a function of load for two different fuels.

Recently, an LNG terminal began operation nearby to a European E.ON GT site. During the LNG terminal's construction, the GT site was supplied with information on the gas quality expected from the new blending station. Gas composition delivered from the LNG terminal would be variable within a small range, to be achieved by nitrogen ballasting. However, there was still a risk of significant variation in the fuel composition delivered to the site. In order to mitigate the risks associated with the increase in gas quality variation, the GT manufacturer suggested installation of a system to automatically adjust the fuel temperature setpoint and a complete combustion system upgrade. Early discussions gained agreement that the LNG terminal would give the GT site as much warning as possible of large step changes in gas quality variation.

E.ON performed an analysis of the fuel temperatures required to maintain a modified WI (taking into account fuel temperature) within acceptable limits. This analysis was based on the range of fuel compositions likely to be received by the site. With the agreement of the GT manufacturer, a system to compensate for fuel composition changes by fuel heater setpoint changes was implemented without the need for a complete new combustion system. Several gas temperature setpoints were defined, to account for each of the expected gas compositions. After warning had been received from the LNG terminal of an upcoming change in gas composition type, the fuel temperature setpoint could be manually modified in time to prevent any adverse impacts on the combustion system. This system is now operational and has so far proved successful, whilst saving the GT site significant investment costs. Obviously, liaison and cooperation with the terminal owners and operators was essential in making this a viable option.

The gas supply C2+ content at another E.ON site in the UK has also been seen to affect combustion dynamics levels significantly. This site receives LNG injected into the local gas grid whenever a nearby LNG terminal is operating. Variation in the C2+ content of gas supplied to this site has been attributed to the switching of supply from the LNG terminal to other sources on the gas grid. Figure 10 shows a period where the C2+ content of gas supplied to the site increased from approximately 6% to over 9.5% in four hours.

This type of GT is particularly sensitive to the C2+ composition of gas due to the impact on flame properties, therefore, at this site, the gas C2+ content is measured by both a gas chromatograph and a fast response infrared technique. If the gas C2+ content exceeds specified limits the control system automatically applies changes to fuel splits to control unwanted effects. This effectively re-tunes the gas turbine combustion system for high C2+ operation.

The example in Figure 10 shows that combustion dynamics increase with C2+ content up until the limit is reached (9.5%). At this point the fuel splits are altered and further increases in C2+ do not result in increases in the combustion dynamics levels. In fact, combustion dynamics levels are slightly reduced with a C2+ content above the limit of 9.5% compared to when the C2+ content is just below this limit.

So far the operation of the fast response C2+ measurement system and C2+ mitigation measures have been successful at this site. Conversely, a different European site with similar GTs, has experienced issues when operating on gas with a very low C2+ content. When supplied with this type of gas these GTs emit high levels of CO at part load due to the lower reactivity of the gas with low C2+ content. A similar automatic re-tuning concept is applied to control part load emissions.

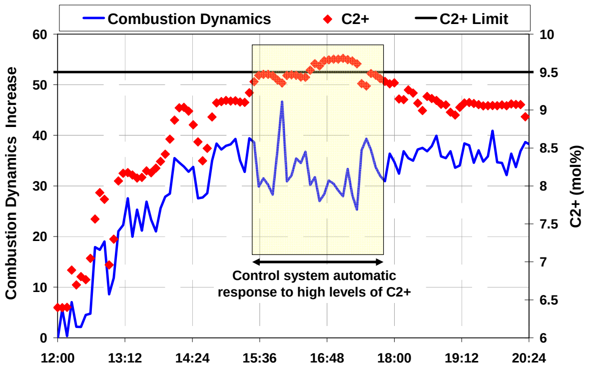


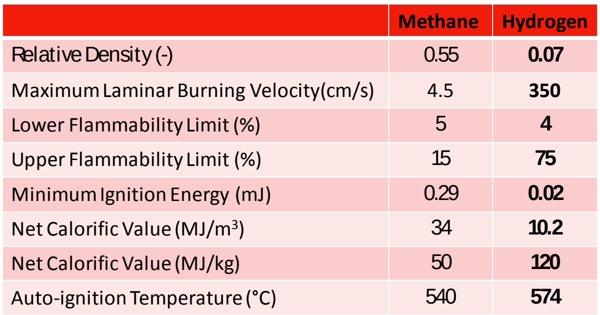
Figure 10: Combustion dynamics trend with gas C2+ content at an E.ON UK site.

The example in Figure 10 shows that for certain GT types, mitigation measures for fuel compositional changes are available and can be effective at preventing adverse combustion behaviour. For some GT types, mitigation measures are not currently available or are not installed at certain sites. Examples of severe catastrophic damage to combustion components due to fuel issues are rare. However, flashback and burner damage, as shown in Figure 11, have been linked to high levels of higher hydrocarbons. For the type of burner shown, the GT manufacturer has developed flashback resistant variants to eliminate this problem. However, there is still potential for flashback on some burners particularly with high levels of higher hydrocarbons or if proposals are implemented to store or transport energy by adding hydrogen to the natural gas transmission system (Altfeld and Schley, 2011; NaturalHy, 2012).

Figure 11: Flashback damage to burners has been linked to high levels of higher hydrocarbons.

Table 1 shows the combustion properties of methane and hydrogen. Hydrogen has a significantly higher flame speed than methane. This would certainly pose a flashback risk for current GTs if large quantities (10 to 20%) were introduced into national gas distribution systems. A recent publication modelled flame behaviour of a natural gas and hydrogen mixture at typical gas turbine operating conditions (Brower et al, 2012). The results showed that the addition of 20% hydrogen to a typical natural gas would result in an increased laminar flame speed of approximately 10%, an increased turbulent flame speed of approximately 40%, and a reduced auto-ignition delay time of approximately 20%. The paper concluded that the gas turbine types under consideration could in principle accommodate even higher hydrogen addition. However, such significant changes would not be acceptable for currently installed gas turbines without modification or additional control equipment.

Adding hydrogen to natural gas reduces the gas CV (volumetric) and RD. Figure 12 shows that if 20% H_2 were added to a typical natural gas found in the UK, it would take the gas outside the EASEE-Gas specification.



	Methane	Hydrogen
Relative Density (-)	0.55	**0.07**
Maximum Laminar Burning Velocity(cm/s)	4.5	**350**
Lower Flammability Limit (%)	5	**4**
Upper Flammability Limit (%)	15	**75**
Minimum Ignition Energy (mJ)	0.29	**0.02**
Net Calorific Value (MJ/m^3)	34	**10.2**
Net Calorific Value (MJ/kg)	50	**120**
Auto-ignition Temperature (°C)	540	**574**

Table 1: Combustion properties of methane and hydrogen (Reference conditions: 15^{o}C, 1atm), (Harris, 1983).

If in future H_2 injection into the natural gas grid becomes prevalent it would be possible for gas suppliers to modify their gas by also increasing the levels of higher hydrocarbons, i.e. propane, to bring the gas back within the specification. An example is shown in Figure 12 where 10% H_2 and 6% propane is added to a typical UK natural gas and the new CV (volumetric), WI, and RD is similar to the original gas. However, even though this new gas appears to have similar properties to the original gas, it will be more reactive and more prone to flashback, dynamics and emissions issues. The addition of H_2 into national gas grids will further reduce the relevance of WI and CV as indicators of fuel suitability and combustion behaviour. Currently there is no agreed or generally recognised parameter to replace or supplement it.

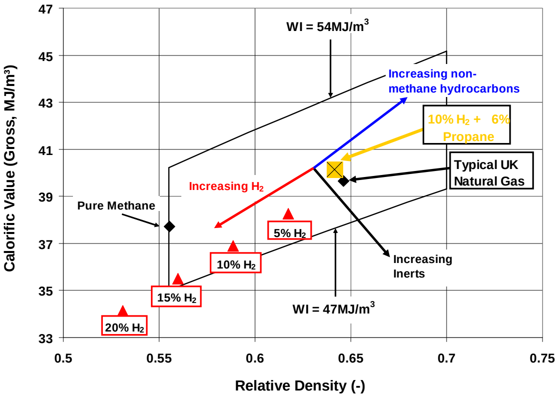


Figure 12: Gas gross (volumetric) CV and Relative Density with varying H_2, C2+ and inerts contents (black line represents EASEE-Gas quality specification (EASEE-Gas, 2005).

Fuel quality variation mitigation measures

Various options exist to mitigate the impact of fuel quality variation of GTs. These options can be separated into three categories, which are summarized below.

Combustion System Redesign

In some cases combustion systems have identifiable design weaknesses and the manufacturer can improve combustion performance through modified burner and/or combustor design. This has been successful in increasing the flashback resistance of a number of burner types.

Examples of burner design evolution include Siemens' H to HR3 burner for the SGT5-4000F GT; General Electric's (GE) DLN 2.0 to DLN 2.6+ burners for the 9FA GT; and ALSTOM's Advanced EnVironmental (AEV) burner for the GT13E2 GT. The manufacturers of these burner designs state that they are operable over a wider range of fuels and provide better flashback resistance.

On-line measurement of fuel composition and compensation through GT control or fuel heating

In some cases it is possible to effectively change control settings to adequately compensate for measured changes in fuel composition.

In some systems, where the WI is the critical feature, controlled fuel heating can be used to modify the effective WI in response to fuel composition changes, for example with GE's Fuel Quality Management System (Forte et al, 2008).

Gas chromatographs are used on the majority of modern GT sites to measure fuel composition. However, they have a relatively slow response time. Therefore, fast response gas quality measurement systems have been developed, such as the ALSTOM FIRGAS system for C2+ measurement (Riccius et al, 2005) and E.ON Ruhrgas AG's Gas-Lab Q1 for CV, WI and RD measurement (Schley et al, 2003). Siemens have developed the Integrated Fuel Gas Characterisation system, which integrates the measurements from a fast response Wobbe meter into their GT control system (Nag and Shoemaker, 2010).

Control system response to changes in gas turbine behaviour without fuel composition or property measurement

In some cases this may be as simple as a change in load in response to a problem such as high combustion dynamics or emissions. In the most complex cases full model based control is used to effectively continuously optimise system behaviour, such as General Electric's OpFlex Balance Autotune for the DLN 2.6+ combustion system (Morrell and Ho, 2011).

DISCUSSION AND CONCLUSIONS

Manufacturers are increasing the fuel flexibility of new GTs and developing retrofit solutions to mitigate the risks associated with fuel composition variation. Operators need to be aware of these developments to ensure that the risks from future fuel variations are properly considered.

The examples described show that operators also need to be aware of these issues to ensure existing turbines are appropriately tuned.

It is clear from the examples that fuel composition variation can impact on GT operation despite being within that allowed in the National Transmission System and manufacturers' specifications. Such examples are becoming more common as the variability in gas composition has increased and are likely to become more significant as fuel imports and international gas trading increase and specifications widen. The examples in this paper are predominantly from E.ON's UK gas turbine fleet but these issues are becoming more common throughout E.ON's European fleet.

Mitigation measures exist to protect GTs against fuel quality variations. However, some of these measures have been developed in recent years and are not yet widespread. More experience with these techniques is required to fully assess their effectiveness at mitigating the increasing variability of gas quality around Europe. The mitigation measures that have been developed may not be sufficient to deal with gas containing significant levels of hydrogen.

H_2 injection into natural gas grids for energy storage purposes may have significant benefits, but this will provide some challenges for the power generation fleet. The impact on individual gas turbines will need to be assessed and appropriate mitigation measures taken.

Although Wobbe Index is an important and useful parameter it does not fully characterise the fuel. This deficiency will be even greater if significant amounts of hydrogen are introduced into natural gas supplies. Reliable parameters to describe the combustion behaviour of natural gas (including the effects of added hydrogen) need to be developed to allow more robust and reliable fuel specifications to be established.

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