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IMPACT OF FUEL CONTAMINANTS ON GAS TURBINE OPERATION

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Abstract

Today's highly efficient gas turbines rely on high-quality alloys to permit increased firing temperatures to be achieved and to maintain acceptable product life. Therefore more attention has to be placed on the quality of the fluids, from all sources, entering the gas turbine, especially the fuel. Gas Turbines can - and do - use a wide range of gaseous and liquid fuels and the subject of fuel quality is a major topic to consider in more depth.

All Gas Turbine OEMs, including Siemens, provide comprehensive specifications covering the fuel quality permitted for use in a gas turbine. These are used to ensure fuel quality is defined at the onset of a project and throughout the lifetime of the turbine and are prepared to ensure acceptable turbine operation is achieved with little or no impact on major turbine component life.

This paper provides an insight and understanding of fuel composition so that measures can be taken to minimize the impact of any major constituents of the fuel, along with the potential impact on turbine components of any identified contaminants and ways to mitigate this impact. Compositions of gaseous fuels, for example, can vary quite widely depending on their source and can contain a number of hydrocarbon species along with inert gases as well as contaminants. Liquid fuels are also commonly used, often as a back-up fuel, and these can also contain potentially harmful contaminants.

1 Introduction

Modern highly efficient gas turbines rely on high-quality alloys to permit increased firing temperatures to be achieved, whilst still maintaining acceptable product life. To ensure this is achieved, far more attention on the composition of the fluids, from all sources, entering the gas turbine is necessary, including air, lubricating oil and fuels. Indeed Gas Turbines can - and do - use a wide range of gaseous and liquid fuels and the need to maintain high quality is paramount.

The subject of fuel quality is a major topic of its own, but some of the fundamental requirements associated with fuel quality and storage are discussed below, along with potential issues associated with poor fuel quality.

All Gas Turbine OEMs provide comprehensive specifications covering the fuel quality permitted for use in the gas turbine. These are used to ensure fuel quality is defined at the onset of a project and throughout the lifetime of the turbine and are prepared for good reason: to ensure acceptable turbine operation is achieved with little or no impact on major turbine component life. It is necessary therefore to understand the fuel composition and the supply conditions in more detail, so that measures can be taken to minimize the impact of any constituents of the fuel gas or the contaminants contained within it. Identification of contamination has become particularly necessary as this can have a detrimental impact on exotic materials used in turbine blading. In some instances, constituents of and contaminants within the fuel can impact combustion emissions, whether the turbine is fitted with a diffusion flame or a Dry Low Emissions combustor.

Compositions of gaseous fuels can vary quite widely depending on their source. 'Pipeline quality' gas is regarded as the "bench mark", a suitably clean fuel. Associated, or wellhead, gas may be the source with suitable treatment of pipeline fuels, but they may also be derived from waste streams from industrial processes. Liquid fuels are also commonly used, mainly as a back-up fuel but sometimes as the primary fuel, and these can also contain potentially harmful contaminants.

Contaminants of potential concern discussed below include:

- Higher hydrocarbons
- Water
- Inert gases (Nitrogen and Carbon Dioxide)
- Sulphur
- Carbon monoxide
- Hydrogen
- Alkali metals (Sodium and Potassium) and Heavy Metals (Vanadium, Nickel, Lead)
- Solids
- Organic Contaminants (Tars, Asphaltenes)

The means of assessing the suitability of fuels is not covered in this paper but it is worth mentioning the need to ensure the correct dew point of a gaseous fuel is determined, which makes full allowance for all hydrocarbons specified in the fuel composition along with the presence of water. This requires a comprehensive analysis and composition to be provided at the onset of a project. Appendix 1 outlines a typical range of species acceptable for use in industrial gas turbines.

2 Impact on Fuel Composition

2.1 Higher Hydrocarbon Species

Associated gas from oil production is a common gas turbine fuel. Methane is usually the major constituent but associated gases can be 'rich', containing considerable quantities of heavier hydrocarbons (ethane, propane, butane, pentane and potentially even longer hydrocarbon chains). In some instances, heavier hydrocarbons may be considered a waste product from gas processing and can be used either on their own (ethane, propane, LPG) as a gaseous fuel or deliberately blended into a methane-rich gas and used as a gas turbine fuel as a means of disposal. Higher hydrocarbons can also be used in liquid form: there are numerous gas turbines operating on LPG and naphtha fuels.

The presence of higher hydrocarbon species in a gas fuel can lead to auto-ignition problems within the combustion system. The longer hydrocarbon chains can ignite spontaneously at temperatures below the compressor discharge temperature, so it is important to minimize the residence time of the fuel gas in the combustor so that controlled combustion occurs in the correct place.

Higher hydrocarbon species impact the hydrocarbon dew point of the gas fuel, and hence high supply temperatures are required to ensure these remain in the gaseous phase. If the gas fuel temperature is not maintained, then liquid dropout (condensate) will result and can cause problems in the fuel system, or, more seriously, impinge on combustor surfaces leading to localized burning and component failure, such as shown in Figure 1 below (which occurred very rapidly, order of milliseconds, and resulted in engine shutdown). As this issue occurred so rapidly no advanced warning was seen from either temperature or combustion dynamic monitoring devices.

When used as a liquid fuel, for example as an LPG, the issue is to keep the fuel in liquid form until it reaches the burner tip. This is achieved by using high fuel supply pressures, or by a combination of increased pressure and special burner designs which uses the latent heat of evaporation to cool the fuel in the burner. When heavy hydrocarbons are used in liquid form, special consideration must be given to the fuel system. For example, LPG has low viscosity and associated low lubricity requiring special pumps to overcome this problem. Control of the fluid is critical to ensure other problems are avoided such as:

- Waxing (fuel temperature too low)
- Exceeding flash point (temperature too high)
- Corrosion (particularly where copper is present)
- Vapor lock due to premature vaporization of liquid

Higher hydrocarbon liquids, or condensate, when passed into the combustor, can combust in an uncontrolled manner, thus having a detrimental effect on operation and safety. Combustion of unmetered higher hydrocarbons can result in combustion hardware damage or failure, such as the burner gas gallery and passage blockage due to carbonization, as well as damage to downstream hot gas path turbine components. The higher temperatures required for gas fuels with high levels of higher hydrocarbon species

has some additional considerations in package design, such as the requirement for trace heating and lagging of the gas supply pipework and fuel system.

The presence of higher hydrocarbons can impact the emissions signature of a gas turbine. The longer hydrocarbon chains result in a higher flame temperature within the combustor, increasing the NO_x emissions, even when Dry Low Emissions combustors are used. In liquid form, NO_x emissions will be similar to those produced when operating on diesel fuel. NO_x formation can be by a number of ways, but thermal NO_x is by far the most dominant. Therefore, anything done to increase the combustion temperature, such as using fuels with higher hydrocarbon species will have a detrimental impact on NO_x emissions to atmosphere. It is possible to provide and apply a NO_x factor based on the assessment of a specific fuel. For example a fuel with high level of Ethane, C_2H_6 , for example 20mol%, may add as much as 10% NO_x to the total.



Figure 1: Combustor Pre-chamber damage as the result of hydrocarbon carry-over along with poor control of dew point

2.1 Water

Pipeline quality gas fuels are usually clean and dry, but there are occasions when fuels contain water, the presence of which can be problematic:

- Free water in the presence of hydrogen sulfide or carbon dioxide can form acids which can be highly corrosive to the fuel system and associated pipework
- Water may contain undesirable water-soluble contaminants, such as alkali metals
- The presence of water impacts the dew point (water dew point), hence supply temperatures must be higher than for the equivalent dry gas

Water in gaseous fuel can be tolerated, subject to correct control over dew point, but the water contained in distillate fuels is most concerning. It can be seen as dissolved, emulsified or free water.

- Dissolved water: chemically dissolved or absorbed into the fuel (e.g. sugar dissolved in hot drinks)
- Emulsified water: tiny droplets of water are suspended in the fuel, making it milky in appearance
- Free water: falls out of suspension and gathered at the bottom of a storage tank

It is these latter two types, emulsified and free water, which are of most concern, resulting not only in fuel system and engine damage, but also the promotion of bacterial growth. Removal of water, along with any bacterial growth, using best industrial practices should be considered. Water and sediment can be removed, or reduced, by filtration and centrifuge separation. This is the same for any liquid fuel, and prevents the formation of corrosive elements and bacterial growth, a pre-cursor to fuel degradation. Removal of the water also reduces the levels of water-soluble contaminants such as the alkali metals sodium and potassium. Where water is used specifically for injecting with or separate from fuels it has to meet strict quality standards and is to all practical purposes de-mineralised water. With such use of water recognition there will be a detrimental impact on service intervals has to be considered, which varies depending on the amount of water applied.

2.2 Inert Gases: Nitrogen (N₂) and Carbon Dioxide (CO₂)

Many associated gases and biogases contain inert gases, often in significant quantities (50%, or higher, by volume is not unknown). While these gases are generally benign, CO₂ can react in the presence of moisture producing a weak acid. Generally gas turbines are able to operate on gases with high inert gas contents.

Inert gases act as a diluent, reducing the heat content available in the fuel, and so greater fuel volumes are required to achieve the same output power compared to standard natural gas. This necessitates a redesign of the fuel system to handle the higher gas volumes, and potentially the need to enlarge the burner gas passages and injectors. The higher mass flow caused by the need for greater fuel volumes can boost the power output available from the gas turbine, providing other design limits are not exceeded.

From a NO_x emissions perspective, inert gases help to reduce the NO_x emissions in all types of combustor, as they quench the flame temperature and reduce the formation of thermal NO_x. Combustor rig testing and operational experience have demonstrated the presence of elemental nitrogen, in the fuel gas, does not increase NO_x emissions. However, this is not the case for Fuel Bound Nitrogen (FBN), for example if constituents such as ammonia (NH₃) are present in the fuel gas: in such instance of high FBN, complete conversion to NO_x has been observed.

2.3 Sulfur

Sulfur can occur in both gaseous and liquid fuels. In gas fuels it is usually present as hydrogen sulfide (H₂S), although elemental orthorhombic sulfur occurs in shale gas. Liquid fuels, especially Heavy Fuel Oils, can contain very high levels of sulfur, although increasing legislation is driving operators to use low sulfur diesels or fuel oils.

Hydrogen sulfide is highly toxic and can pose unique challenges to operators as well as in the operation of gas turbines. Besides specific health and safety requirements, H₂S (also sulfur in liquid fuels) can combust producing SO_x (SO₂/SO₃) emissions to atmosphere, which react in the presence of moisture resulting in weak acid production (acid rain). Where SO_x legislation exists, treatment of the fuel at source to remove or lower H₂S (or sulfur in liquid fuels) is necessary. As well as the environmental issues caused by SO_x, it can also have an impact on the design of Waste Heat Recovery Units (WHRU) and the overall energy efficiency of Cogeneration plant: stack exit temperatures on the WHRU must stay higher than would normally be the case, and boiler feedwater

temperatures elevated to prevent acid gas condensation within the chimney or the economizer, as this can lead to metal corrosion.

In the presence of sodium, potassium or vanadium, contaminants commonly found in air in off-shore or in coastal environments or in liquid fuels, further assessment will be required as the reaction of these metals and their salts with sulfur results in the production of sodium and potassium sulfates or vanates which are highly corrosive to modern materials, such as nickel alloys used in the hot gas path components, for example turbine nozzle and rotor blades. Figure 2 below is an example of such corrosion, which occurred after many operating hours. Older turbines with lower operating temperatures and using components with high chromium contents show more resistance to attack from sulfur compounds and may be a more reliable option if a gas turbine is required to operate on high sulfur content fuels.

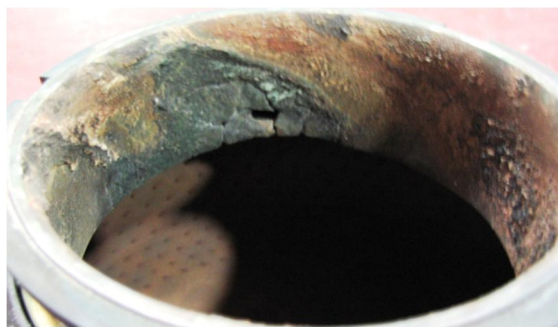


Figure 2: Combustor Pre-chamber damage as the result of sulfur-induced oxidation

There are proprietary methods available, such as Pressure/Temperature Swing Adsorption or molecular sieve, to remove sulfur from both gaseous fuels (as H_2S) and from liquid fuels, but are subjects beyond the purpose of this paper. The materials used, particularly in the hot gas path section of gas turbines, will determine the extent of sulphur allowed in fuels without impacting service regimes. Turbines such as the Siemens product SGT-300 and SGT-500 have high chrome content blade materials thus making them less susceptible to oxidation/ sulphidation attack and therefore suitable for fuels containing high levels of H_2S . It is worth noting SO_x emission to atmosphere (following combustion of H_2S , for example) need to be part of the assessment as this is regulated in many parts of the world.

2.4 Hydrogen and Carbon Monoxide

These readily combust, but require special understanding before they can be accepted as a gas turbine fuel. Both exacerbate combustor flame speed, and can result in flashback - where the flame velocity exceeds the local combustor velocities. This makes these types of fuels less suited for lean pre-mix type combustion systems. However, conventional diffusion flame combustion systems are more tolerant to such fuels, subject to full assessment and application of appropriate safety measures. One aspect to consider is hydrogen embrittlement; therefore delivery systems and pipework have to be of suitable materials. Martensitic steels are particularly susceptible so the use of suitable stainless steel materials must be considered. Appendix B identifies some of the operational limits for fast flame speed species, such as hydrogen and carbon mon-oxide.

3 Contaminants found in Fuels

3.1 Alkali Metals and Heavy Metals

While alkali metals (especially sodium) can be found mainly as air-borne contaminants, both alkali metals and heavy metals occur as contaminants in liquid fuels, especially Heavy Fuel Oils and Crude Oils.

Such fuels need to be treated in order to meet industrial gas turbine limits for alkali metals (sodium and potassium) and heavy metals (Vanadium, Nickel, etc.) which if introduced into the combustion system can result in accelerated deposit formation and high temperature corrosion in gas turbine hot gas path components. The metallic contaminants react with oxygen and with any sulfur present to form highly corrosive compounds.

Major corrosive constituents include Vanadium pentoxide (V_2O_5), sodium sulfate (Na_2SO_4) and aggressive low melting forms in the $Na_2SO_4 - V_2O_5$ and $Na_2O-V_2O_5$ systems. Determination of the ash sticking temperature is usually a good feature to use, and should be $>900^\circ C$ if corrosion of the blade is to be avoided. While alkali metal contamination can be reduced by removal of any water in the fuel, vanadium and other heavy metals are oil-soluble and can only be treated through chemical dosing, so that combustion creates high melting temperature compounds. A magnesium-based additive is commonly used to treat fuels with heavy metal contamination, and whilst this reduces the risk of high temperature corrosion, it increases the frequency of turbine washing to maintain performance. For dosing, the normal ratio is 3 parts magnesium to one part vanadium to ensure maximum conversion, but as this suggests the amount of ash produced increases by dosing.

3.2 Organic contaminants (tars and asphaltenes)

Tars tend to be present in small quantities in process gas fuels, such as those from the conversion of coal to coke, resulting in production of Coke Oven Gas, COG, or through the gasification of waste applying air or Oxygen blown systems. Asphaltenes are small solid particles found in some distillate fuels. These can combine to form a more homogenous mass affecting the filtration system, or collect at the bottom of storage tanks forming a sludge like substance. If these pass to the GT it can result in blockage to passages in the fuel delivery system or worse blocked injector passages in the burners.

4 Other sources of Fuels

4.1 Biogas

Biogas tends to cover gaseous fuels derived from the decomposition of waste, such as in a landfill, anaerobic digester or waste water treatment. These gas fuels contain a unique contaminant in various amounts. Silica used in modern health and beauty products result in a complex range of silica based compounds being found in landfill gas and digester gas. Under the generic name Siloxanes these tend to be converted in the combustion process into silica oxide compounds which sublime in the turbine section of the gas turbine resulting in hard – glass like – deposits which impacts performance of the turbine, Figure 3 below. Treatment of the raw gas before passing to the gas turbine is the only way to prevent these deposits and today there are several proprietary methods to limit siloxane in bio-gas fuels.



Figure 3: Silica Oxide deposits on turbine nozzle

5 Handling and House Keeping Associated with Liquid Fuel

5.1 Fuel Storage

Mostly related to liquid fuels, the handling, storage and maintenance of such fuels can be the difference between acceptable turbine operation and one where extensive site maintenance may be required. Storage of fuel comes under the general heading of fuel handling best practices, some aspects of which are highlighted:

- It is necessary to ensure fuel is sourced from good suppliers to approved specifications
- Routine monitoring and recording from sampling and analysis of fuels is critical to achieving good turbine operation
- Applying best industry practice in receipt, unloading, storage and transfer of liquid fuels is essential to achieving and maintaining fuel to the highest standard and quality
- Using centrifuges, filters and coalescers at each storage tank will help maintain the fluid in the correct condition
- Prevention the ingress of water which can under ideal conditions result in the formation of bacterial growth, which can impact the efficiency of filters and even result in blocked fuel system passages
- Ensure tank design meets best industrial standards, including, but not limited to, floating suction take-off to supply the gas turbine; bottom drain for sediment and water; and allowing for sufficient settling time after introducing new supply to tank
- 'Turning' over the liquid fuel, i.e. using it all on a regular basis, minimizes deterioration and will also help in the long term quality control of the fuel.

The subject of liquid fuel handling, storage and house-keeping is a major subject in own right and this section is all but a small fraction of the subject and is provided as a flavor in the context of this paper.

5.2 Liquid Fuel 'Polishing'

In order to further improve or maintain liquid fuels local treatment systems can be applied to the various storage tanks such as settling or day tanks, as well as the main receiving tank.

Introducing filters, centrifuging and coalescers help to ensure the quality of the diesel fuel is maintained at the highest level. The benefit of this may be seen with increased storage life, typical of intermittent plant operation on liquid fuels. Such systems also remove water thus preventing formation of bacterial growth.

6 CONCLUSIONS

The understanding of fuels used in modern high performance, high efficiency gas turbines, and the contaminants contained within these fuels, is critical in achieving the goals of high availability and reliability, but at the same ensuring the environmental needs are fully met. Supply of the fuels of the right quality, or with the correct fuel treatment and handling methods, can result in achieving these goals, while the use of fuels outside the advised specifications can result in increased maintenance requirements or premature component failure.

7 REFERENCES

Turbine Fuel Contaminants BM Igoe & MJ Welch
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Appendix A

Gas Fuels acceptance criteria

Guidelines of the range of major constituents for acceptable fuel composition are shown in Table A1. Pipeline quality natural gases which meet these requirements and have net CV's in the range 37 - 49 MJ/kg are likely to be acceptable. However, a detailed fuel specification needs to be supplied in order to ensure acceptable gas properties. Table A2 defines the typical values applied to some of the higher hydrocarbon species. These are not 'limits' but one where no additional margin over dew point needs to be considered.

Constituent	% volume
Carbon Dioxide	0 - 2.9
Methane	81.3 - 96.7
Ethane	1.0 - 9.1
Propane	0.3 - 5.4
Nitrogen	0 - 14.4

Table A1: Typical Natural Gas Composition

Species No of C atoms	Limit % vol, mol%
C4	5.0
C5	1.5
C6	0.45
C7	0.25
C8	0.005
C9	0.001
C10	0.005

Table B2: Recommended limits for higher hydrocarbon species (note – higher levels may be permitted subject to review, but require additional superheat to be applied for dew point control)

Appendix B

Hydrogen content of combustion configurations

In this example Siemens Industrial Turbomachinery Limited, SITL, limits hydrogen content depending on combustor and engine type

Product Type	Hydrogen Content %vol	
	Diffusion Flame	Lean Pre-Mix (DLE)
SGT-100	13	5
SGT-200	85	5
SGT-300	13	5
SGT-400	N/A	5

Appendix C

SGT-500: Fuel specification for use with heavy or crude oils

Table 1. Heavy fuel oil requirements.

Property	Unit		Note ¹⁾	Test method ²⁾
Density at 15°C	kg/m ³	< 991		SS-EN ISO 3838
Viscosity at 50°C	mm ² /s (=cSt)	≤ 700	a	ASTM D 445
Flash point	°C	Report	b	ASTM D 93
Pour point	°C	Report	c	ASTM D 5950
Total sulphur content	%wt	≤ 4.5	d	ASTM D 4294
Carbon Residue, Up to 15% part load above 15% load	%wt %wt	≤ 0.3 ≤ 18	e	ASTM D 4530
Water	%wt	≤ 0.5		ASTM D 4928
Sediment including Catalyst fines (Al+Si)	%wt	≤ 0.01		ISO 10307-1
Ash content	%wt	≤ 0.15		ASTM D 482
Heavy metal content (V+Pb+Ni+Zn)	mg/kg	≤ 300	f	ASTM D 3605
Sodium and potassium (Na+K)	mg/kg	≤ 0.5		ASTM D 3605
Calcium (Ca)	mg/kg	≤ 2		ASTM D 3605
Ash sticking point temp	°C	≥ 900	g	SIS 15 51 37
Other contaminants		Report	h	