Impact of Fuel Quality on Gas Turbine Components

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ABSTRACT:
Most industrial gas turbines operate with various gaseous and liquid fuels. For effective and sustainable performance, it is essential to determine the best fuel suitable for the operation of the gas power system. The heating value, Joule Thompson coefficient, dew point, Wobbe index, and other physical characteristics of the suggested fuel must be ascertained. This research explains a means of providing consistent treatment to determine the listed physical properties. It also reviews the impact that specific fuel characteristics have on the combustion process, as well as the overall operation of a gas turbine and its components.

Keywords: gas turbine, liquid fuel, dew point, heating value, power generator.


INTRODUCTION

Studies have indicated that fuel quality has an impact on a gas turbine engine’s performance. A combustor provides heat input to the gas turbine Brayton cycle. Shaft work is produced in the gas turbine by the high-pressure, high-temperature gaseous combustion products that enter it during the Brayton cycle [1]. Electric power is generated by the gas turbine, which also powers the compressor. Since electrical energy is becoming increasingly scarce, gas turbine power-generating devices are widely used in developed areas. Fuel functions as a working fluid in a turbine power plant. The air is compressed by the compressor, and then it is heated by burning fuel in the chamber. The stage of the fuel combustion process inside the combustion chamber is one of the goals [2].

An analysis of performance metrics, such as fuel consumption for gas and gasoil and power generation, is conducted. Low-quality fuel leads to incomplete combustion and higher fuel consumption, which interacts with the turbine blade surface to produce erosion, roughen the surface of the blade, and disrupt gas flow. As a result, the turbulence flow of these gases will increase, causing the separation of gas boundary layers over the suction surface of the blade. Consequently, there will be less gas extracted, which will result in retreat work being done by the turbine [3]. This will lower power and gas turbine power plant efficiency, which will lower the amount of electricity generated. The cycle performance moves toward favorable conditions as a result of fuel quality, which is a strong function of specific fuel consumption and its effects on the power generation and efficiency of gas turbine power plants.

The hot, high-pressure air is then directed to the gas turbine, where it expands and mechanical work is introduced. By means of a gas turbine, mechanical energy is transformed into electrical energy.
Fuel flexibility, substantial power, small size, lightweight, quick installation, low engineering cost, fuel adaptability, reduced pollution, and easy maintenance are the benefits of gas turbines for power plants [3].

The combustion chamber receives and accepts filtered and compressed air from the axial compressor and delivers it at an elevated temperature and pressure for the combustion process. This invariably turns out as the prime mover of the turbine blades (ideally with no pressure loss). Thus, the combustor is a direct-fired air heater in which fuel is burned almost stoichiometrically with one-third or less of the compressor discharge air. In contrast, the remaining compressed air is converted for internal combustion parts and turbine vane and blades cooling. To reach an appropriate turbine inlet temperature, combustion products are combined with the residual air [4].

Although there are many different kinds of combustors, the three main varieties are annular, can-annular, and tubular (silo). Gas turbine combustion chambers vary widely in design, but they all have three main components: a dilution zone, a burning zone that includes a recirculation zone, and a recirculation zone. Within the recirculation zone, the fuel vaporizes, partially burns, and gets ready for rapid combustion in the remaining burning zone. Ideally, at the end of the burning zone, all fuel should be burned so that the function of the dilution zone is solely to mix the hot gas with the dilution air [5].

Complex engine turbine blades and first-stage vanes require the mixture exiting the chamber to have a temperature and velocity distribution that are suitable. Fuel rates are load-dependent, and for flow ranges up to 100:1, fuel atomizers might be needed. Nonetheless, there is typically no more than a factor of three difference in the fuel-to-air ratio between idle and full-load conditions. During transient conditions, fuel-to-air ratios vary. A much higher fuel-to-air ratio is needed at light-off and during acceleration because of the higher temperature rise. On deceleration, the conditions may be appreciably leaner. So, the control system is made simpler by a combustor that can run over a wide range of mixtures without running the risk of blowouts [5].

The three primary determinants of combustor performance are efficiency, the pressure drop inside the combustor, and the consistency of the outlet temperature profile. Combustion efficiency is a measure of combustion completeness. Since unburned fuel's heating value isn't utilized to raise the turbine inlet temperature, combustion completeness directly influences fuel consumption. The mass flows of fuel, gas, and enthalpy of gas entering and exiting the combustor are all taken into account when calculating the combustion efficiency because they all relate to the actual heat increase of the gas. Pressure loss in a compressor can have a big impact on fuel consumption and power output. Typically, total pressure loss falls between 2 and 8% of static pressure. This loss is the same as a decrease in compressor efficiency. This leads to reduced power output and higher fuel consumption, which have an impact on the engine's size and weight [6].

It is important to consider the fuel properties, as well as heat conditions and specifications, required to get the maximum output efficiency of a gas turbine. This chapter describes the parameters of relevance and provides a database to cover all needs for such analysis and calculations. Most gas turbines are designed to operate under specific heat conditions with required chemical elements in their appropriate ratio. The vast majority of gas turbine engines employ direct firing where the fuel is injected into the engine combustion chamber and then burnt. This is the case for the three primary fuels; kerosene, diesel and natural gas, and also for a number of less common fuels [7].

The efficiency of the gas turbine plants is dependent on a number of factors and some of the factors includes the power rating of the turbine plant, the compressor power, the economic analysis, the mass flow rate and pressure of the mixing compressing constituents, relative humidity of the environment in which the gas turbine plant is subjected to, air quality and the ambient inlet air temperature, the type and quality of fuel used, Work ratio, net power, moisture content, specific fuel consumption, Wobbe Index WI, LLV, HHV, heat rate, the calorific Value of gas CV, specific gravity of gas with respect to air SG.

Indicating the interchangeability of fuel gases, such as town gas, liquefied petroleum gas (LPG), and natural gas, the Wobbe Index (WI) or Wobbe number is often specified in the requirements of gas supply and transport utilities. The Wobbe index (WI) can be calculated as WI = CV/(SG) ^1/2, where CV is the fuel's HHV value and SG is its specific gravity. Calculate the Wobbe index for a typical fuel.
The approximate specific gravity of natural gas is 0, and its HHV is 1,050 Btu/cubic foot. Using
the Siemens SGT5-2000E heavy-duty gas turbine as a case study, this research and data analysis
are conducted [8].

With exceptional fuel flexibility and low NOX emissions, the SGT5-2000E is a reliable engine suitable
for the 50 Hz market. 16 compressor stages, 2 silo combustion chambers, 2 gas generator turbine
stages, 2 power turbine stages, a DLE system, an approximate weight of 189,000 kg, and
approximate dimensions of the SGT5-2000E single shaft are among the performance data and
design features of this model (3 × 4.0 × 4.0 m3). Gas engines, boilers, and gas turbines are examples
of power engines that can run on lower-heat-value fuel (LHVF). Limited work has been done on the
micro-gas turbine, although some laboratory and pilot work has been completed. Micro-gas turbines
intended for natural gas may operate differently depending on the properties of LHVF. The
application of LHVF to micro-gas turbines was discussed, along with a few potential adjustment and
modification techniques. An analysis of the micro-gas turbine’s functioning was conducted on a
single type of representative LHVF [9].

The temperature field and the non-uniformity scale of the temperature distribution of the combustor
were calculated using ANSYS FLUENT. The feasibility of different adjustment and modification
methods was analyzed according to the efficiency, output power, and non-uniformity scale of
temperature distribution [9]. It has been found that a cooler environment increases the efficiency of
a gas turbine plant because the compressor needs to work less.

The fogging technology has been a good and efficient way to reduce the ambient inlet air
temperature of the plant in a low humidity and high temperature environment. Research has also
shown that fuel conditions and heat design expectations also affect the emission of the gas plant,
which operates optimally in areas with low ambient temperatures and high moisture content.
Observation has proven that plant net output and efficiency for Natural gases are higher compared
to Diesel and bunker oil and with higher output efficiency when without moisture [10].

Adequate Power generation and steady supply in Nigeria is a major problem and one of the major
demands of the current development and economic status of the country. Given that the gas power
turbine is one of the major sources of generating power (electric power), research has shown that
the inefficiency of most of these GTs is a result of the ignorance displayed in the aspect of Fuel
supply into the system, either in quality or conditional state of the fuel gas. Hence there is much need
to research, study and improve upon existing research on fuel (gas) and its effect on gas turbines' perfections and output [11].

This research is important to the development of the power sector - generation, distribution and
transmission. Understanding and improvement on the existing research study on fuel quality and the
state of optimum performance and efficiency of gas turbine will help in Gas Turbine future invention
and design. Equally, this will help in the operation and maintenance of the Gas Turbine (GT).

This study aims to address the issue of incomplete combustion in gas turbines, which leads to
internal combustion hardware deterioration, wear, and breakdown. The current study's specific goals
are to: (1) analyse the fuel composition that the gas turbine is using; (2) analyse the data that the
gas turbine has provided; (3) increase the gas turbine's output power; and (4) reduce high moisture
content during the combustion process by installing an electric heater at the end of the combustion
chamber of the gas turbine, which raises the fuel's temperature.

This current study covers the selection of fuel with the best characteristics and properties for
optimum efficiency in a GT, calculating and determining the Heat specification best suitable in for
designing a GT and description and evaluation of natural gas (NG) and reasons why it's the best
option in choosing the working fuel for a GT.

**DESIGN AND METHODOLOGY**

To achieve the aim and objectives in this study it is important to set up a Power gas plant where the
Fuel gas is being conditioned and as well study and calculate the properties and required
composition of which the Gas turbine operates .Volatile air impurities like SO2, NOx and VOC pass
the filter unhindered and also the small soot particles are hardly retained, hereby causing
deterioration, wear and subsequent damage of internal combustion hardware (components) turbine [7]. To have a perfect combustion for operation several calculative analysis like the Wobbe index of a gas was conducted. The Wobbe index (WI) of a gas (normally natural gas) is the indication of the heating value of the gas from the pipeline at the orifice where a burner is located; this could be a gas turbine or a boiler. It is expressed as follows: WI = CV/√SG; where CV is the calorific value of the fuel (BTU/SCF) and SG its specific gravity with respect to air.

Goffredo Wobbe, an Italian scientist, developed WI. Under specific pressure and orifice size conditions, he noticed that

- The relationship between the burner's heat output and flow volume per minute was linear.
- The specific gravity of the gas is directly correlated with the flow velocity.
- In proportion to the gas's specific gravity, its calorific value, or heating value.

Wobbe index measurement is an excellent method to monitor the performance of a gas turbine as in most cases they are fed with changing fuel gases. WI avoids the necessity of having to worry about the changing fuel gas composition rather with only the gas's heating value and its specific gravity the control loop can be tuned to regulate the fuel valves for achieving higher efficiency of the machine in a safe manner. The salts, dust as well as the organic air impurities precipitate on the compressor and the air path according to the local flow conditions. On the first rows the deposits consists to about 70% of organic matter, 30% dust and soluble salts [7].

The organic molecules in the sticker are serving as a binder for the salts and dust. Due to the high concentration of corrosive salts, compressor fouling not only results in significant power loss but also poses a serious risk of corrosion. As the later stages run dry during operation, the corrosion is limited to the initial stages of the inlet. However, concentrate brines are created when the hygroscopic salts in the deposits of the later stages become wet during standstill. If the salts are chloride-containing, they will corrode the wet deposits below. It is therefore important to observe regular compressor washing, cleaning, and drying for preserved and prolonged shut-down times.

The degree of performance degradation and, consequently, the intervals between repairs and overhauls of a gas turbine can be considerably influenced by appropriate maintenance and operating procedures. It is easier to apply gas turbines properly when one is aware of their performance characteristics. When a hydrocarbon fuel reacts exothermically with oxygen, it produces carbon dioxide and water, which is the process of combustion. A sound attenuator, also known as a duct silencer, is incorporated into the design of the gas turbine to lessen noise transmission and vibrations that arise during the filtering and compression of air.

The SGT5-2000E Siemens Gas Turbine (SGTTM), our well-known workhorse, was designed to meet these requirements. Because of its tried-and-true design, materials, and thermodynamic procedures, the SGT5-2000E continues to hold a dominant position in an extremely competitive market. For 60 Hz, the equivalent model is SGT6-2000E.

The well-known design concept of this machine, which incorporates a central tie bolt, a built-up rotor with Hirths serrations, a cold-end generator drive, and two rotor bearings, defines it. This well-proven design's innovative features, when combined, result in low investment costs per installed kilowatt, fuel flexibility, operational flexibility, low maintenance costs, a long service life, and a quick payback on capital invested [12].

Based on the common design principles of our modular reference power plants for multi-shaft applications, a number of SGT5-2000E solution packages have been identified. These packages, which range from components to the SGT-PAC to full turnkey solutions, meet all of your requirements. With so many modules and options available, our power plants' clever design offers you numerous advantages.
This gas turbine concept draws on decades of experience with heavy-duty gas turbines at Siemens. This accumulated experience guarantees a dependable, effective, and adaptable implementation and serves as the strong technical basis for this tested technology.

### Table 1. Performance Exception of the GT2000E Series

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Power output</td>
<td>120 Mw</td>
</tr>
<tr>
<td>Efficiency</td>
<td>34.7%</td>
</tr>
<tr>
<td>Heat rate</td>
<td>10,375 KJ/ Kwh</td>
</tr>
<tr>
<td>Heat rate</td>
<td>9,834 Btu/Kwh</td>
</tr>
<tr>
<td>Exhaust temperature</td>
<td>541°C / 1,005.8°F</td>
</tr>
<tr>
<td>Exhaust mass flow</td>
<td>525 Kg/s</td>
</tr>
<tr>
<td>Exhaust mass flow</td>
<td>1,157 Lb./s</td>
</tr>
<tr>
<td>Pressure ratio</td>
<td>12</td>
</tr>
<tr>
<td>Length; Width; Height</td>
<td>10; 12; 7.5 m</td>
</tr>
<tr>
<td>Weight</td>
<td>234 T</td>
</tr>
</tbody>
</table>

### Table 2: Siemens Combined Cycle Power Plant

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Net power output</th>
<th>Net efficiency</th>
<th>Heat rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi shaft 1x1</td>
<td>250 Mw</td>
<td>52.4 %</td>
<td>6,869 KJ/Kwh</td>
</tr>
<tr>
<td>Multi shaft 2 x 1</td>
<td>505 Mw</td>
<td>52.9 %</td>
<td>6,805 KJ/Kwh</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6,451 Btu/Kwh</td>
</tr>
</tbody>
</table>

The SGT-2000E series is compatible with a wide range of fuels, including low- to high- calorific gaseous and/or liquid fuels, as well as treated heavy oils. High hot gas casing availability and longer service intervals are made possible by the long dilution path and off-board combustion, which also removes direct flame radiation from the turbine blades [13]. Its fundamental robust design guarantees optimal flexibility, a broad range of fuel quality, low emissions even at lower partial loads, quick start-up times, adaptable grid support, low maintenance, extended maintenance intervals according to customer requirements, and first-rate accessibility, which facilitates manual turbine washing and inspection when using ash-forming fuel oil.

**Fuel Gas Supply System**

The purpose of the system is to supply the gas turbines and auxiliaries with gaseous fuel in accordance with the specified requirements. The Fuel Gas Supply System routes fuel gas from the terminal point of the gas supplier to the inlet flanges 14A (GT) of the gas turbine fuel gas skids (MBP). The Fuel Gas Supply System is designed for feeding 3 GTs in a gas turbine power plant (GTPP). The internal piping of the Fuel Gas Supply System is free of any solid matter, dust, gums, gum-forming constituents, rust, weld-slag, breaking parts of gaskets, sticky layers from lubricants, protection coatings on internal flanges, or anything else that might cause injury to or interference with proper operations of the fuel gas system components and equipment. The design and configuration, in terms of safety for all sections of the system, meet the requirements of the applicable codes, standards, and specifications. These both apply to aspects related to process engineering and to structural strength in respect of pressure and temperature [13].

The major components of the system are; pipeline, inlet shut off valve, knock-out drum, inlet filter unit, condensate tank, Joule Thomson heater, gas pressure regulating station, hot water heating
station, tariff metering, gas chromatograph, outlet shutoff valve, 60°C heater, 60°C heater hot water heating station, gas buffer volume, GT fuel-gas consumption metering, final filter, shut off and vent valve

Figure 1. Components of fuel gas supply system

RESULTS AND DISCUSSION

The data acquired in this research was recorded using the HMI (Human machine interface) via the DCS (Distributive control system). The Historical trend analysis is carried out so as to retrieve the data using the semen T3000 which is a software installed on the DCS.

Based on the continuous calorimeter, the high heat value at constant pressure (saturated) is measured and can be corrected to actual moisture in gas fuel HHV as described in Par.

The LHV (low heat value at constant pressure) is calculated as follows:

\[ \text{LHV} = \text{HHV} - 93.84H \text{ (gaseous fuel)} \]
where;

\[ H = \text{percent hydrogen in fuel by weight} \]

The difference between calculated and measured saturated heat values and specific gravities should be less than ± 0.2%. (AN PTC 22-1985 AMERICAN NATIONAL STANDARD GAS TURBINE POWER)

**Sample Calculations**

Typical Fuel Gas Analysis:

Compressibility Factor (\(z\))

\[ Z = 1.00369 - (0.0101) (0.58739) + (0.007) (0.99793) (0.58739) \]

Actual Gravity = 0.99793

Perfect Gas Heat Values: HHV (sat) (0.93351) (994.4) (0.03909) (1742.1) (0) (0.00331) (0) (0.00228) (2479.1) (0.00008) (3212.7) (0.00006) \(\beta\)939.7

Total = 1002.35, 1002.4 Btu/ft³

LHV (dry) = (0.93351) (0.03909)

\[ = (0.02167) (0.00331) \]

\[ = (0.00228) (0.00008) \]

Based on the continuous calorimeter, the high heat value at constant pressure (saturated) is measured and can be corrected to actual moisture in gas fuel HHV as described in Par. 4.12.5. The low heat value at constant pressure LHV is calculated from the high heat value at constant pressure HHV as follows:

LHV HHV — 93.84H (gaseous Fuel).

**Natural Gas Components**

MJ/m³ The heat value of natural gas is determined by its constituent parts. Methane is mostly found in natural gas (91.3%), ethane (5%), and propane (1%). The remaining 8% is made up of carbon dioxide, nitrogen, and butane (1% each). In extremely small amounts, it also contains helium and hydrogen sulfide. As a result, natural gas is highly flammable, odorless, and colorless. Natural gas producers add scent to the gas to reduce the danger and increase the visibility of leaks. Natural gas heat value (BTU/SCF and MJ/m³)

The thermal energy effectiveness of natural gas determines its heat value. The color or cost of the stove's flame has nothing to do with the heat content of natural gas.

"A derived unit of specific energy, heating value, energy content, or heat of combustion per unit volume is equal to a decimal multiple of a mega joule per cubic meter (MJ/m³)." In a nutshell, it shows how much energy (in mega joules) is released when 1 cubic meter of natural gas is combusted.

1 MJ/m³ = 26.83 BTU/SCF (British thermal unit per cubic foot)

The formula for converting BTU/Ft³ to MJ/m³ is 1 BTU per cubic foot = 0.0372589458073849 mega joules per cubic meter.

The formula used to convert MJ/m³ to BTU per cubic foot is:

1 mega joule per cubic meter = 26.839191993505 BTU per cubic foot. The heat content of natural gas might be different in various countries. For example, in Hungary, natural gas has an average heat value of 34.12 MJ/M³.

Other heating values are:

Petrol / gasoline; 44 - 46MJ/kg

Diesel fuel; 42 - 46MJ/kg

Crude oil; 42 - 47MJ/kg
Liquefied petroleum gas (LPG); 46 - 51MJ/kg
Natural gas; 42 - 55MJ/kg
Hard black coal (IEA definition); 23.9MJ/kg
Firewood (dry); 16MJ/kg

The scope is narrow, though, as producers of natural gas are required to fulfil numerous quality standards and requirements prior to exporting their product. The chromatograph measures the quality of natural gas and can determine the components of exported fossil fuels, so the heating value will also be known. People will begin to recognize that the heating value of natural gas is decreasing over time. It is not because of the quality they are receiving, but because the technology and heating systems become obsolete, thus the efficiency of these technologies will decrease. Season factors also affect the “feel” of a decrease in heating value. For instance, boiling tap water takes longer in the winter because it is colder. Thermal insulation, in addition to heating system maintenance, is an important factor in increasing heating efficiency. The components of natural gas, the calibre of the producers, and even the state of your home heating system all affect its heating value.

CONCLUSIONS

The importance of the heat condition of a gas turbine fuel and its effects on the efficiency of the gas turbine has been established. It is necessary to understand that the boilers, electric heaters and insulated joule Thompson heater (with lines of both hot and cold water) are components designed to this effect. The hot water is meant to heat up the gas as the gas is being sent through to the gas turbine (GT).

The current study project is to add to the already enormous scope of information and solidify the calculative analysis as well as solving problems of gas plant efficiency, i.e. increasing output power, high moisture content during combustion and low inlet-air temperature, incomplete combustion which causes deterioration, wear and breakdown of internal combustion hardware of the gas turbine bringing about change in maintenance frequency as well as the cost of the turbine plant, and NOX control or reduction.

The fuel compositions of a gas turbine have been analyzed and it has been shown that power output increases when the quality of fuel is being used. The installation of an electric heater at the end of the gas turbine combustion chamber has reduced the moisture content in the system.

RECOMMENDATIONS

The data acquired in this research was recorded using the HMI (Human machine interface via the DCS (Distributive control system). The Historical trend analysis is carried out to retrieve the data using the Siemens T3000 software installed on the DCS. Therefore, it is advised that the AXI international software and analysis by Epsilon be used in order to gather more and better data. In addition to conditioning the fuel gas in the gas turbine, it is advised that the air enter the combustion chamber be conditioned for maximum efficiency and power production.

REFERENCES


