20TH SYMPOSIUM OF THE INDUSTRIAL APPLICATION OF GAS TURBINES COMMITTEE
BANFF, ALBERTA, CANADA
OCTOBER 2013

13-IAGT-NEW GT UNITS & UPGRADES

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Keywords: *Power generation, reliable, proven, safe*
Oil & Gas application
Crude Oil application

0. Abstract

The North American need for reliable and proven cogeneration and power generation is well recognized. Customer expectations are focusing on operational flexibility and the capability to operate on various fuels, considering a significant cost pressure. Minimal downtime for outages and maintenance is also of great importance. To accommodate these requirements a gas turbine package has to be robust, flexible and cost effective. Siemens Fossil Power Generation incorporates decades of operating experience into the robust design of the Siemens SGT-2000E Gas Turbine series. This paper will provide information on the broad range of SGT-2000E 60Hz applications with emphasis on reliability and operational flexibility as well as part load capability and emission compliance (single-digit NO_x) while running in the coldest of temperatures . An overview of erection and commissioning approaches, including modularization of the gas turbine package, and service capabilities will also be described. Cold ambient performance and operation where the Siemens E-Class Packages provide customer solutions are also considered. These SGT-2000E applications deliver answers with respect to safety, reliability, serviceability and performance based on references all over the world.

1. Introduction SGT-2000E Series

1.1. Proven Design

The SGT-2000E series is the E-class working horse of Siemens. It has been available for more than 30 years. During these years the SGT-2000E series has satisfied demands of Power Generation market as well as Industrial- and Oil and Gas-applications.
Key factors for this success are the continuous design improvements resulting in a unique engine maturity and the ability to respond to a broad range of specific requirements.
The series proved an availability of up to 95%, reliability is even higher and achieves up to 99%.
The starting reliability can achieve outstanding 99, 6%.
These world class figures are based on a deployment of around 300 engines with far more than 20 Mio Total EOH (Equivalent Operating Hours) in the 50Hz and 60Hz market.
The SGT-2000E Series is appreciated for its light-weight design enabling a broad range of operational modes. The engine serves in continuous duty as well as in cyclic duty covering peak loads, providing an excellent start up capability and proves that it is possible to reconcile ambitious economic and environmental targets. Despite its high flexibility in terms of operation and fuels, the NO_X and CO_2 emissions are minimized.

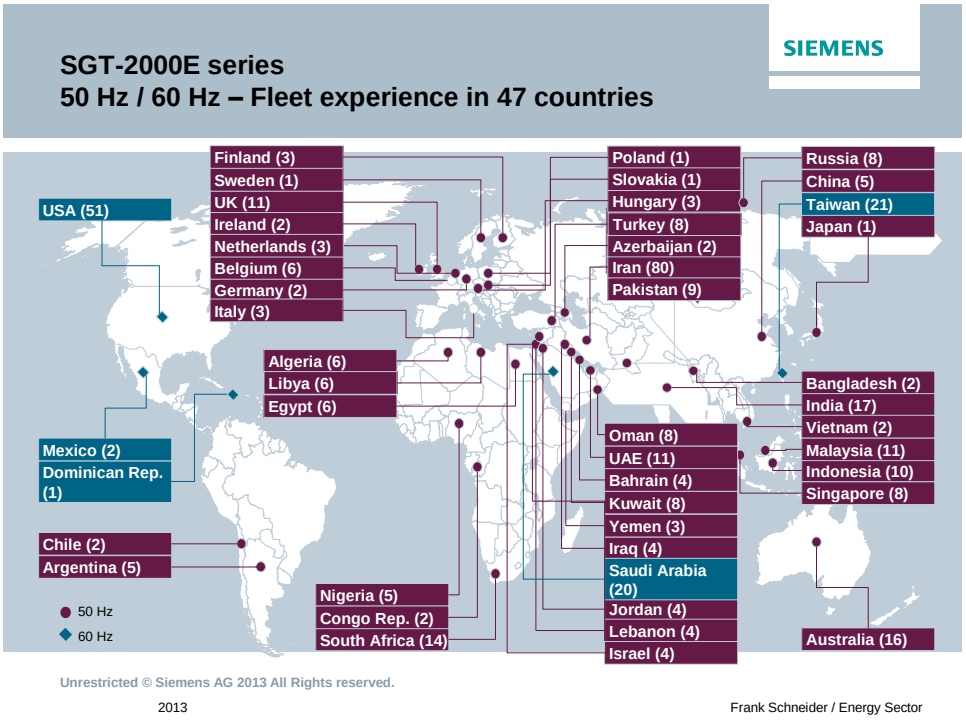

Figure 1: SGT-2000E experience

1.2. Design Features

Siemens 2000E series gas turbines are single-shaft machines. They are suitable both, as prime movers for industrial machines and for driving generators at constant speed in base load, part load and peak load operation. These machines can be used stand alone for peaking duty or in combined cycles and district heat applications. They are suitable for operation with gaseous or liquid fuels.

The main design characteristics are valid the 50Hz as well as for the 60 Hz version of the turbine. The dimensions of the respective engine are scaled according to the required cycles. The 60Hz version achieves a power output of around 70-75% of the 50Hz version, maintaining a similar level of efficiency. The emission behavior of both versions is comparable as well.

The main design characteristics of the turbine are described below.

1) Casing: Horizontally split turbine outer casings with separate vane and turbine carriers, free to expand with temperature
2) Rotor: Single shaft disc-type rotor with radial Hirth-serrations and one central tie rod
3) Compressor: 16 (50Hz) / 17 (60 Hz) stage compressor (with variable-pitch IGV-Inlet Guid Vane (IGV) vanes, fast acting for grid frequency stabilization)
4) Combustion system: Two large external silo-type combustors 2 x 8 (2 x 6 for 60 Hz) hybrid burners for 50 / 60 Hz; ceramic and metallic lining of the flame tubes
5) Turbine: Four stage turbine, Si3D (Siemens innovative 3D turbine blades and vanes design) for new apparatus and service modernizations
6) Welded design for hot gas casings
7) Axial exhaust for ease of combined cycle
8) Two bearings only: Combined thrust and journal bearing at compressor end (8a) and journal bearing at turbine end (8b)
9) Cold end drive

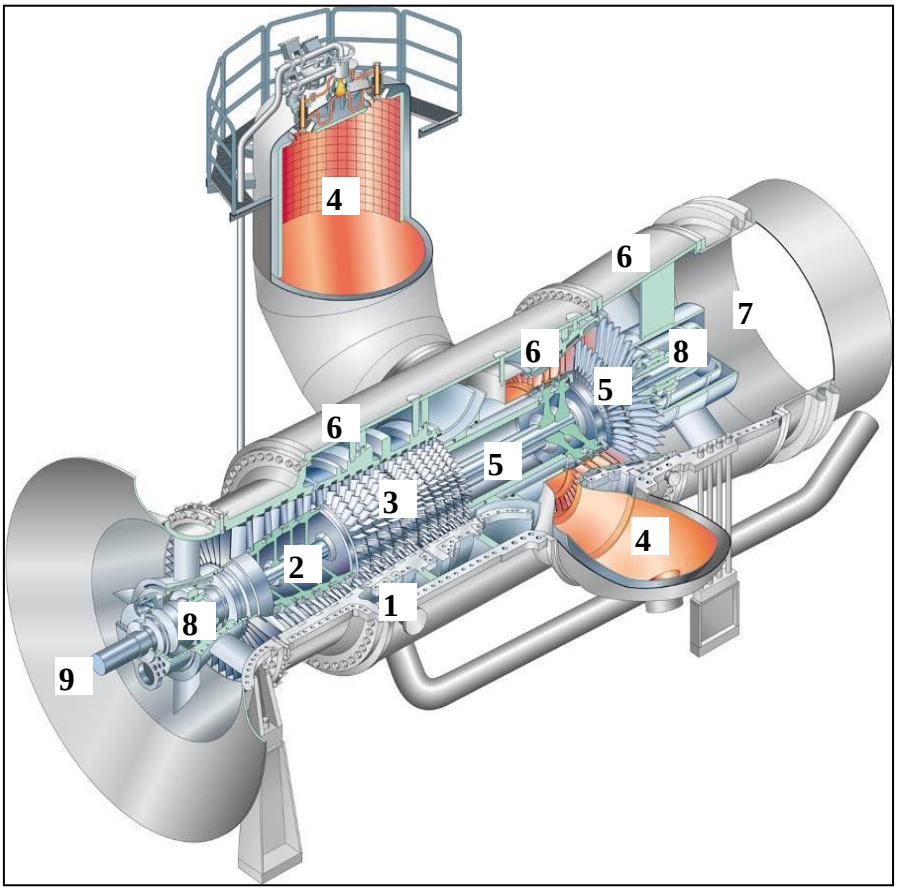

Figure 2: SGT-2000E Design

A typical Gas Turbine Package arrangement is shown in the following table:

(I) Gas Turbine:	E-Class SGT-2000E
(II) Auxiliary Systems:	(a) Module for Fuel Gas, Hydraulic Oil, Lube Oil (b) Module for Fuel Oil, NOx Water (Option)
(III) Air Intake System:	(a) Filter House, (b) Intake Duct
(IV) Exhaust Gas System:	(a) Diffuser (b) Stack or Diverter Damper with Bypass Stack (Option)
(V) Instrumentation & Control:	Operation & Monitoring, Automation, I/Os, Engineering, Diagnostics
(VI) Electrical Systems:	(a) Switchgear, Batteries, Static Excitation Equipment (SEE), Starting Frequency Converter (b) Transformers for SEE & SFC (not shown)
(VII) Power Control:	with I&C and Electrical equipment
(VIII) Enclosure for Gas Turbine:	(not shown)
(IX) Electrical Generator:	Air-cooled SGen-100A-2p

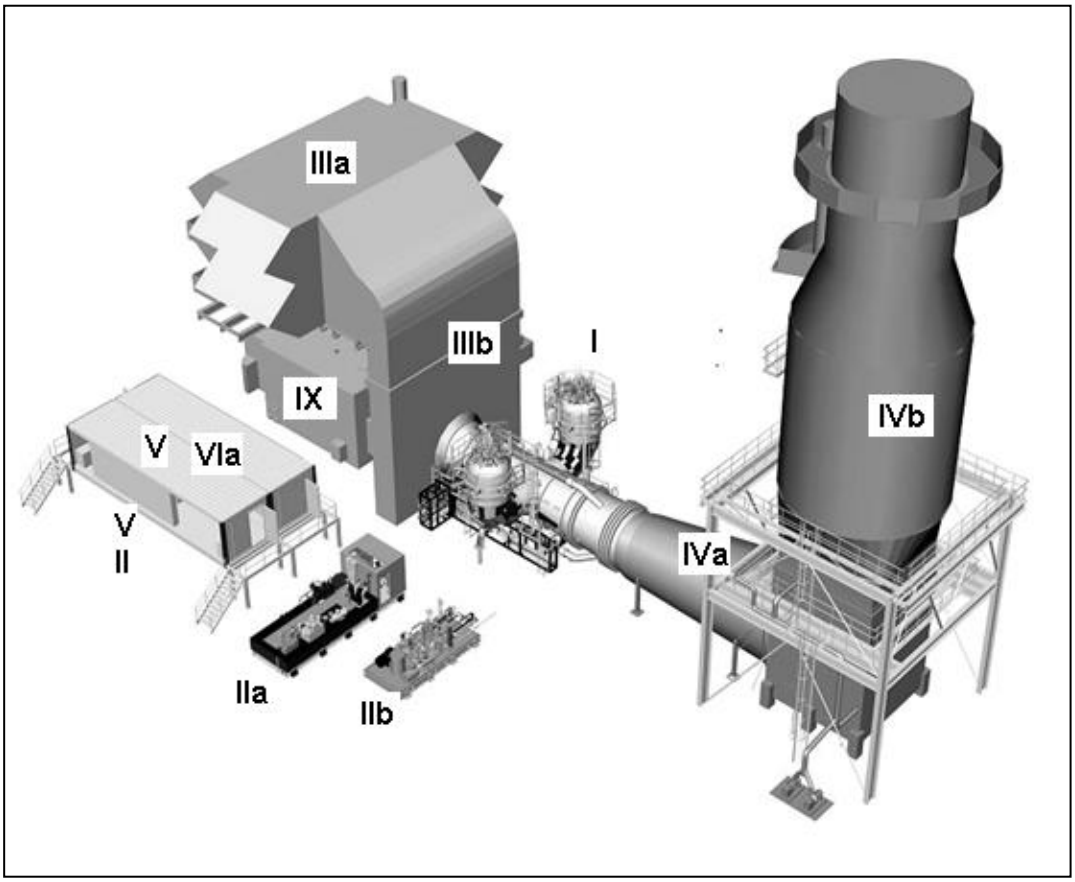

Figure 3: SGT-PAC 2000E Arrangement

1.3. Current Applications

The SGT5-2000E is characterized by large volume-combustion with moderate turbine inlet temperatures. The result is a very robust engine with a simple hot gas path design allowing a broad range of applications.

Standard Fuel Gas Application
The standard fuel gas operation for the fossil power generation covers the majority of the operating fleet.

IGCC Application
Within IGCC-applications (Integrated Gasification Combined Cycle) the SGT-2000E series proved the ability to handle challenges such as safe ignition and the flashback risk in China and the Netherlands.

Crude Oil and Heavy Fuel Oil Application
The SGT 2000E is even able to handle liquid fuel of many level of the refinery process. Solutions in fuel treating are part of the Siemens portfolio as well as the ability to cover the contaminations in less refined products and the resulting deposits within the engine.

Oil and Gas applications
Oil and Gas applications are driven by the outstanding maturity and robustness, proven by more than 30 years of successful operation all over the world. The engine offers solutions for oil and gas exploitation infrastructures..

Cold Ambient Capabilities
The target of the cold ambient program is to extend the operation limit from -15°C to down to -45°C. Within this program all components were regarded and critical components were identified, such as the cold compressor and casing parts of the engine. Moreover all operation conditions were analyzed and the influence of the very cold ambient conditions on the combustion regulation, rotor clearances and the secondary air system were evaluated.
As an example, a whole core engine thermal analysis was conducted to ensure that the expected temperature differences will cause no material stresses beyond a critical point.
Furthermore the clearance limits, especially during the warm up phase of the engine, were evaluated and the clearances tolerances were adapted accordingly in order to avoid damages for the rotating equipment.

2. Current Version

Although the SGT 2000E has more than 30 years experience, Siemens constantly develops the engine to satisfy even in the future the E-Class market demands.
The paradigm for these developments has been to maintain maturity, robustness and availability by keeping the proven design features as described above.
The features described in the following are the most recent innovations that push the engine forward with respect to power and efficiency increase as well as operational flexibility.

Si3D-Features

Figure 6: Si3D design

The turbine stages 1 to 4, including blades and vanes, are redesigned with a three dimensional formed aerofoil and coil with improved cooling air outlets.

An aerodynamic redesign such as flow and pressure optimizations for improved performance and mechanical and material improvements for enhanced durability were implemented as well.

Both are further improvements in power, efficiency and maintenance intervals.
Including no additional charge the stand alone machine provides based on ISO conditions around 2 MW more Power and ca. 0,3 %-pts more efficiency.

The Si3D approach was able to gain experience in more than 600,000EOH and 12,000 starts with more than 25 engines world wide within new unit and service business.

Wet Compression - WetC

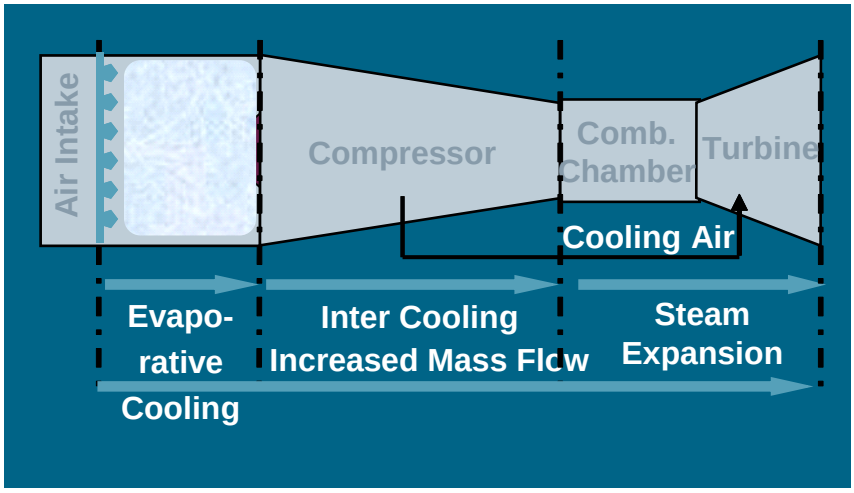

Figure 8: Wet Compression Principle

The Wet Compression offers a significant higher operational flexibility by providing additional power on demand.

Wet Compression is mass flow increase on demand for the gas turbine by controlled injection of water in front of the compressor.

Siemens as an OEM has the experience to provide:

- Optimized droplet size for best vaporization effect and minimized erosion and corrosion
- experience to handle large quantities of demineralized injected water in GT Water factor in EOH-formula same like Power Augmentation / NOx-Water
- axial thrust compensation, surge protection and controlled combustion dynamics
- Complete system check (gas turbine - components) for the combination with Wet Compression

With Wet Compression an increase of the power output beyond 10MW and an efficiency improvement up to 0.8%-pts are possible.

Wet Compression was developed in 1995 and introduced for the E class engines in 2003. More than 45 Wet Compression systems have been installed and have operated since that year. More than 10,000 EOH are logged mostly in the regions of North Africa and Middle East.

Fuel Flexibility

[1] The increasing demand for energy and the continuing increases in prices for standard fuels demand greater flexibility in the use of fuels in gas turbines.
Besides the standard fuels natural gas (typical heating values between 39 to 46 MJ/kg) and Diesel No. 2 fuel oil (42 MJ/kg), there is increasing interest in low-BTU gases, synthetic gases (Syngas here) and even liquid fuels (e.g. heavy fuel oil, Naphtha and condensates).
Low-BTU gases refer to fuels with heating values between 10 and 35 MJ/kg. Syngas denotes synthetically produced gases that generally have even lower heating values, between 4 and 12 MJ/kg.

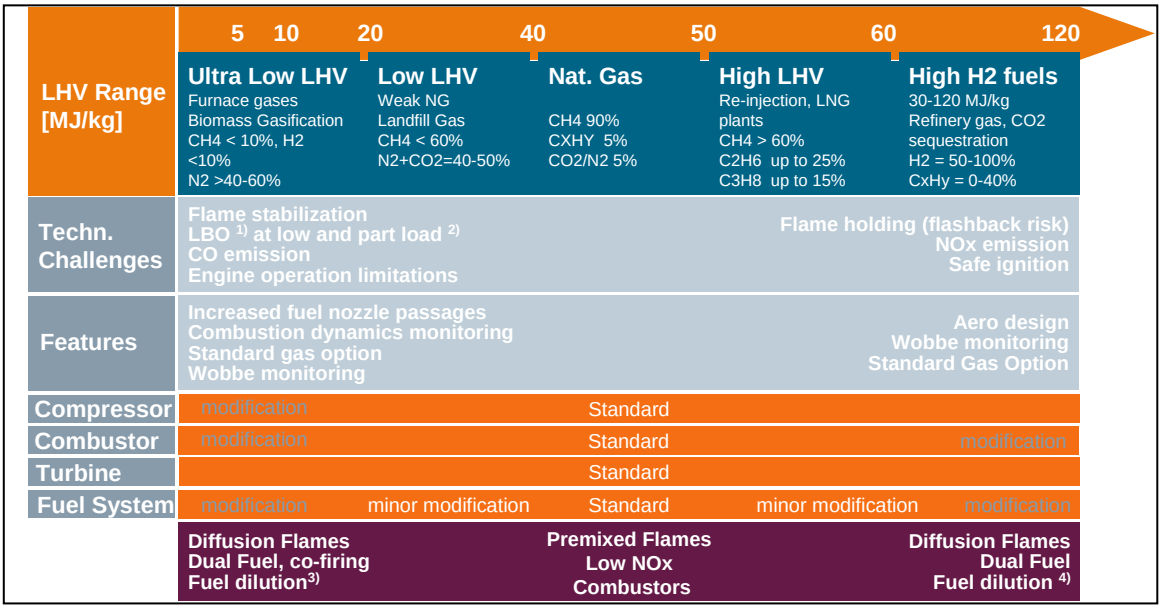

Figure 9: Gaseous Fuels for SGT-2000E

With liquid fuels the engine faces different challenges. The less the liquid fuel is refined, the more it is necessary to treat the fuel with respect to viscosity and contamination. Some contaminations such as sodium and potassium can be washed out of the fuel. Some other contaminations such as vanadium or lead remain within the fuel and have to be treated with inhibitors. This inhibition causes ash, so the engine has to be able to deal with the ash (see Figure 11).
An increasing fleet of engines that are running the Crude Oil application proves the ability to guarantee the habitual high standards with respect to reliability and availability.

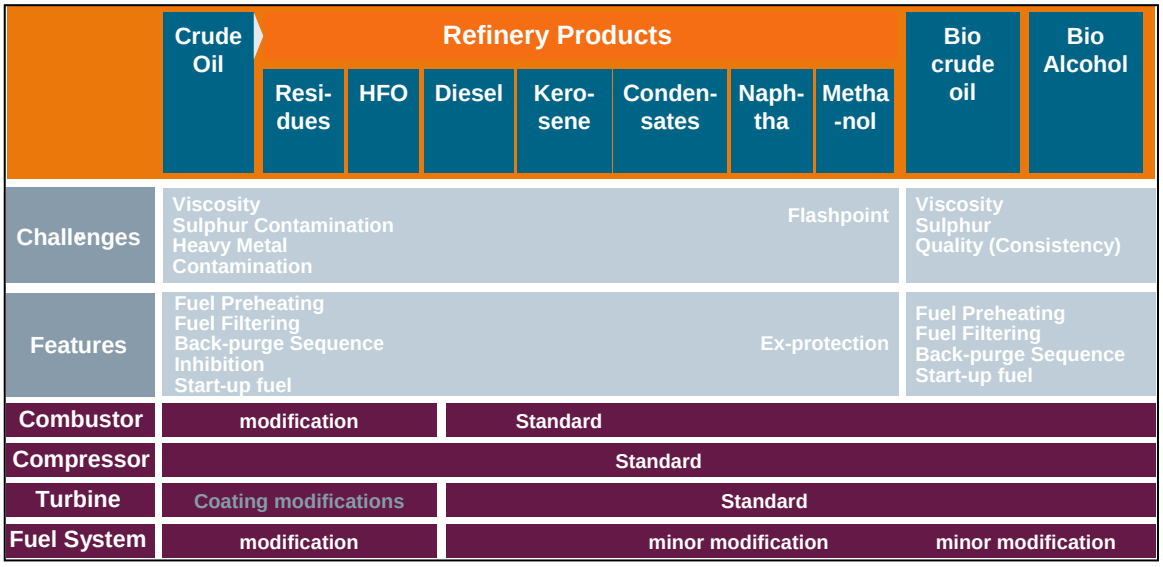

Figure 10: Liquid Fuels for SGT-2000E

[1]Siemens already has extensive operating experience with a broad range of proven and reliable gas turbines. The first major criterion for successful use of fuels is the combustion stability, with appropriate consideration of emission limits and guaranteed values to be met with respect to output and efficiency. The second is the validation of proper combustibility of the requested fuel types during development and prior to the delivery of the gas turbine to customer's site. This ensures highest confidence in the combustibility of these non-standard fuels.

3. Crude Oil

3.1. Requirements, Market, Footprint

With the background of far more than 200,000 operating hours running Heavy Fuel Oil (HFO) in several projects, Siemens decided in 2007 to set up a generic Crude Oil program, dedicated to serve the 60Hz market in Saudi Arabia. Within a very short time this approach became a success story. Today Siemens has delivered more 20 engines for several projects.

The SGT6-2000E Crude Oil offers 102.7MW (ISO).

The whole layout is designed to serve even under the specific ambient conditions, especially the extraordinary hot climate.

The Crude Oil engines have been proving in the field the common SGT 2000E strengths such as robustness, availability and reliability.
The operation excels, besides the modesty against the ash deposits, the Service friendliness, the Hot Gas Path accessibility and long lasting Intervals.

3.2. Crude Oil specific Optimizations

Due the robustness and maturity of the SGT 2000E the base design of the gas turbine remained unchanged even for Crude Oil applications.
However some optimizations for the combustion and hot gas parts as well as adaptations for fuel treatment and the auxiliaries had been taken into consideration.

Combustor
The inhibitor, added to the fuel, aiming to treat the heavy metal contaminated fuels causes ash within the combustion process. Although the engine is able to handle these kinds of deposits, it is essential to remove it to mitigate the resulting degradation in power and efficiency.
A Turbine Wash System, providing nozzles to inject water into the turbine section was implemented to leverage the regularly necessary procedure.

Figure 11: Ash Deposits caused by Crude Oil contamination

Coating
The Inner Casing and the parts of the Turbine section are equipped with coatings to withstand the erosive impact of Crude- and Heavy Fuel Oil.

Fuel Oil System
It is essential to provide the engine constantly with a predictable and consistent fuel quality. The operator of a Crude Oil Gas Turbine requires a fuel oil system that is designed

- to heat up the fuel to guarantee the required viscosity
- to wash out soluble contaminations such as sodium and potassium
- to add a certain amount of inhibitors aiming to bind heavy metal contaminations within the fuel
- to enable a switchover capability between Crude Oil and Diesel operation

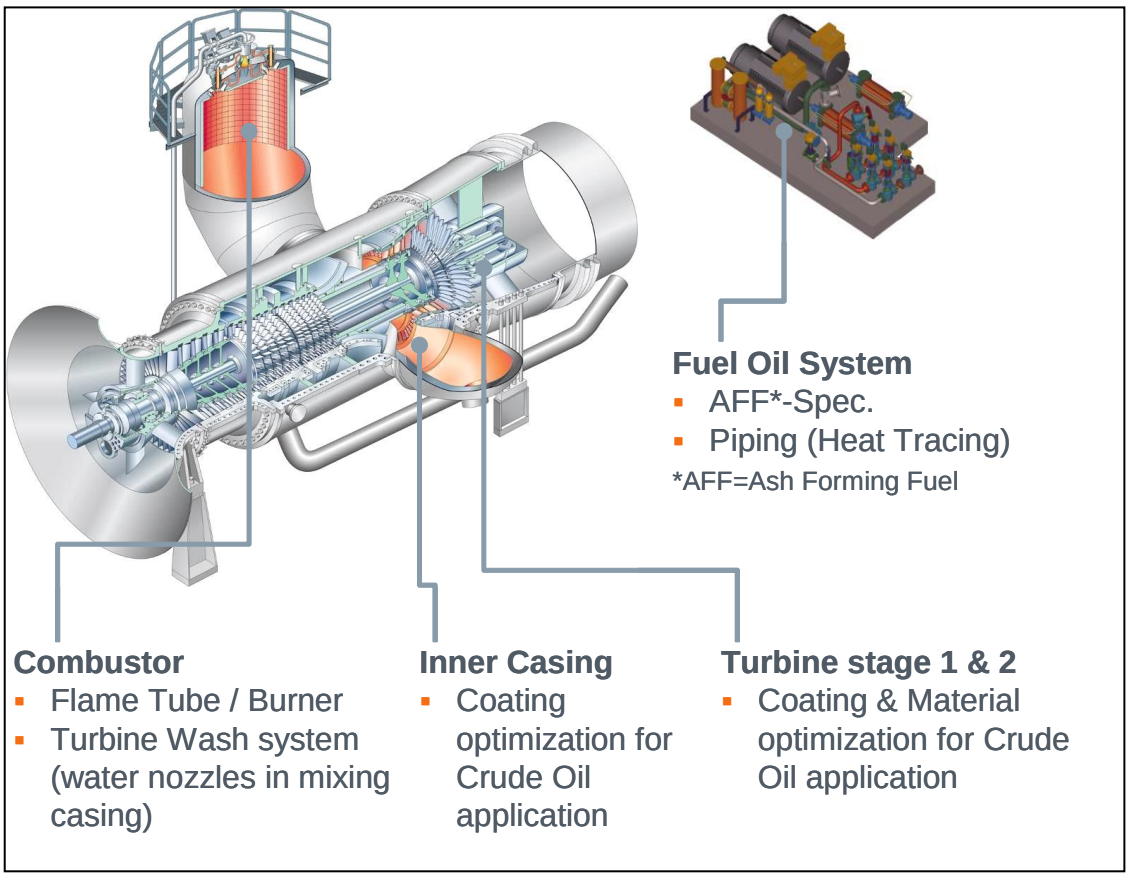

Figure 12: Crude Oil Modifications for SGT6-2000E

4. Oil and Gas

4.1. Market

The Oil and Gas market is being segmented into

- exploration and production (Upstream)
- supply, transport and storage (Midstream)
- refinery / petrochemical (Downstream)

The growing potential especially in the up- and midstream area appears significant due to the fact that O&G companies are expanding their value chain vertically.
The change from an established mechanical driven compressor infrastructure to an all electrical approach bears for the Oil and Gas companies the potential to decrease operational costs by increasing the availability. In some areas even the availability of a self-owned independent power supply becomes more and more crucial. The larger the exploration fields are, the more the advantage of an all electrical approach becomes obvious. This development leads to the expectation of a growing Heavy Duty Gas Turbine market within the Oil and Gas business.

The key success factor for Oil and Gas companies is a proven design that guarantees availability, reliability and safe operation.

The Siemens E-class gas turbine package is optimized to fulfill the following requirements:

- selected API- (American Petroleum Institute) codes,
- flexible application of different fuels,
- application of H2S rich gases increased reliability and starting reliability,
- extended maintenance concept,
- pre-packed solution for fast erection and service
- island operation

5. Lookout

The SGT-2000E series has a significant potential to adapt further requirements. Based on the maturity, developed over the years, the design is open for a broad variety of applications even beyond the power generation market.

6. Takeaways

The SGT-2000E is a well proven gas turbine that demonstrates its outstanding capabilities with respect to availability, reliability, safety and operational flexibility including start up behavior.
These advantages are appreciated not within the power generation market only.
With more that 50 engines running on the North American continent the engine has shown a significant maturity. The annual inquiries have verified the outstanding satisfaction of our customers with the frame for more than 30 years.

7. Literature

[1] Modern Gas Turbines with High Fuel Flexibility, Siemens AG, H. Hermsmeyer, V. Poloczek, October 2008