Latest Developments of Siemens Heavy Duty Gas Turbines for the Saudi Arabian Market

Adam Foust, 5000F Package Frame Manager
Agenda

- 5000F Evolution & Statistics
- Design Changes
- Package Overview
- Gas Turbine Overview
- Testing & Verification
- 5000F(5ee) Power
- 5000F(5) in Saudi Arabia
- Fuel Flexibility
- Service
- Air-cooled Generator
- Summary
SGT6-5000F Evolution
Successful Heritage of the 5000F Platform

SGT6-5000F Evolution

SGT6-5000F Experience

- 279+ units in operation
- 9.4+ million operating hours
- Reliability consistently >99%
  as reported by our customers (230 units)

F(4) fleet >99.6% reliability

<table>
<thead>
<tr>
<th>GTs in Operation</th>
<th>501F</th>
<th>FC</th>
<th>FD</th>
<th>FD2</th>
<th>F(3)</th>
<th>F(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>36</td>
<td>19</td>
<td>142</td>
<td>49</td>
<td>28</td>
</tr>
</tbody>
</table>

| Hours (fleet leader) | 158k+ | 109k+ | 124k+ | 96k+ | 40k+ | 23k+ |

- 34 F(5) units sold (24 units in KSA)
- 8 F(5ee) units sold (6 units in KSA)
- 12 F(3i) units sold configured for syngas (10 units in KSA)

Low Risk Evolutionary Design Approach with Proven Reliability

- 80 units in simple cycle
- 30 units in 1x1 cc
- 127 units in 2x1 cc
- 30 units in 3x1 cc
- 12 units in 4x1 cc
The F(4), F(5), and F(5ee) Have the Same Firing Temperature

- Improved rear stage aerodynamics from F(5) to F(5ee)
  - Stage 1 and Stage 2 validated in Service fleet (37K+ hours)
  - Similar exhaust on 4000F

- Single tie bolt rotor for F(4), F(5), F(5ee)
  - 22K+ hours on lead 5000F unit
  - Similar single tie bolt rotor on 4000F and 8000H

- 13-stage compressor for F(4), F(5), F(5ee)
  - 22K+ hours on lead 5000F unit

- Enlarged compressor inlet from F(4) to F(5)/F(5ee)
  - Same compressor in commercial operation on 8000H
  - Base load achieved on F(5) in commercial operation
The SGT6-5000F Package is Well-Suited for the KSA Environment
SGT6-5000F
Gas Turbine Design Features

The Most Powerful 60Hz F-Class Gas Turbine in the World

- **Combustion**
  - Wide Wobbe operation
  - Sub 9ppm emissions

- **Compressor**
  - 13 stages

- **Turbine**
  - 4-stages
  - Conventionally cast parts

- **Rotor**
  - Constant rotor cooling air temperature
  - Steel discs w/ Hirth serrations

- **Lowest firing temperature in the market:**
  - Low NOx emissions
  - Longer part life
  - Conventionally cast turbine material (no need for single crystal material)

- **High power output on hot days:**
  - More mass flow via opening IGVs (no change in firing temperature)

- **4-stage turbine:**
  - Reliable part life due to lower aerodynamic loading when compared to a 3-stage turbine at the same power output

- **Constant rotor cooling air temperature:**
  - Constant temperature up to 55°C ambient
  - Predictable rotor life regardless of ambient temperature
**SGT6-5000F Development**

**Testing and Verification Before Implementation**

<table>
<thead>
<tr>
<th>Test Date</th>
<th>5000F(3)</th>
<th>5000F(4)</th>
<th>5000F(5)</th>
<th>5000F(5ee)</th>
</tr>
</thead>
</table>

**Test Date**
- 2003
- 2005
- 2006
- 2013/2014

**Off nominal testing…**
- Compressor surge limits
- Transient operation
- Fuel transfers
- Load rejections

**Turbine Rear Stage Aerodynamics**

and Optimized Diffuser Flow Path
SGT6-5000F(5ee) Berlin Testing Update

Mechanical Verification and Performance Testing have been Successfully Completed in the Berlin Test Facility!

- Performance (base load, part load)
- Operations (start-up, off-speed, trip, restart, etc)
- Combustion stability and emissions
- Turbine row 4 blade flutter
- Rotor dynamics
The SGT6-5000F(5ee) has High Power Output on Hot Days

Inlet chilling

Evap Cooling (10% rel. humidity)

Evap Cooling (30% rel. humidity)

Evap Cooling (60% rel. humidity)

F(5ee) Power without TIAC
First SGT6-5000F(5) Achieves Base Load And Exceeds Performance Guarantees

First 5000F(5) gas turbine achieves base load at the Ras al Khair site in the Kingdom of Saudi Arabia

5000F(5) gas turbine shipping to the Kingdom

232 MW Net Power

First Fire: Jan 16th, '14
FSNL runs: Day 2 & 3
Day 4
Siemens is committed to the Energy Demands and Fuel Flexibility Policies of the Kingdom of Saudi Arabia

<table>
<thead>
<tr>
<th>Syngas</th>
<th>ASL</th>
<th>Condensate</th>
<th>Low Btu gas (~40% inerts)</th>
<th>AXL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Operation</td>
<td>Tested</td>
<td>Testing planned (April / May ’14)</td>
<td>Testing planned (April / May ’14)</td>
<td>Testing tentatively planned (early 2015)</td>
</tr>
</tbody>
</table>

Additional fuel capabilities:
- Bio-diesel
- Natural gas + \( H_2 \)
- High Wobbe Index fuels

30 SGT6-5000F units in KSA w/ ULN Nozzles

10 SGT6-5000F units in KSA w/ DF42 Nozzles
Oil Status ➔ Siemens sets a new benchmark for emissions “25ppm NOx”

“Siemens SGT6-5000F sets a new benchmark in the industry demonstrating 25ppm NOx emissions on fuel oil.”

Siemens is the leader in fuel oil technology and has set the benchmark in the industry.
KSA Liquid Fuels

- Viscosity, flashpoint, vapor pressure and boiling temperature properties different than Diesel Oil.
- ASL, AXL, and Condensate evaporate at lower temperatures compared to standard Diesel Oil and this creates potential combustion flashback risk.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Distillate#2</th>
<th>ASL Typical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flashpoint</td>
<td>60°C</td>
<td>-25°C</td>
</tr>
<tr>
<td>Vapor pressure (40°C)</td>
<td>7.0 kPa</td>
<td>52.7 kPa</td>
</tr>
<tr>
<td>Kin. Viscosity (40°C)</td>
<td>3.0 mm²/s</td>
<td>1.25 mm²/s</td>
</tr>
<tr>
<td>Calorific value, lower</td>
<td>43,000 J/g</td>
<td>42,494 J/g</td>
</tr>
<tr>
<td>Density (15°C)</td>
<td>840 kg/m³</td>
<td>780.8 kg/m³</td>
</tr>
</tbody>
</table>

Combustion flashback identified as potential risk with light oils (ASL, AXL, Condensate)
Arabian Super Light crude oil
Testing Completed to Guarantee ASL Performance

Rig testing confirmed the 5000F is capable with ASL fuel

ASL composition differs from typical diesel oil thus rig testing was completed to qualify the fuel

ASL is 100% vaporized @ ~1,050°F
Diesel oil is 100% vaporized @ ~700°F

American Petroleum Institute Gravity = \left[ \frac{141.5}{SpecificGravity} \right] - 131.5

Light crude oil has a low specific gravity (high API gravity) due to the presence of a high proportion of light hydrocarbon fractions and typically has a low wax content.

Full Pressure and Full Firing ASL Rig Testing Completed in July '13.
Arabian Super Light crude oil Logistics

Testing and Handling of ASL Confirmed that No Pre-treatment of ASL was Necessary for Pumping or Combustion.

ASL was transported from KSA to Germany in 5 tank-tainers (~755 barrels) and stored at a fuel depot until the start of testing.

Testing facility (tanks and forwarding system) was modified to accommodate ASL fuel.
Testing established that combustion dynamics, flashback, and emissions on ASL are similar to diesel oil.

No flashback at base load conditions and 115 bara ASL supply pressure

W/F ratio

NOx emissions

NOx calibration
Arabian Super Light crude oil
Combustion Operability During Loading

The same ULN combustion system can accommodate diesel oil and ASL by varying the water / fuel ratio

![Graph showing the relationship between water/fuel ratio and normalized gas turbine load. The graph compares typical diesel oil water/fuel ratio with ASL water/fuel ratio.](image-url)
Arabian Super Light crude oil
Auxiliary System

The only modifications in the auxiliary system are the oil pump (suitable for ASL specific gravity) and the water injection system (higher capacity).

- ASL operating temperature should be the same as diesel oil (5°C to 40°C)
- No ASL pretreatment is required (fuel factor accounts for composition difference to diesel oil)
Contaminant limits are valid with project specific configuration, performance, fuel factors, and service agreements.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Units</th>
<th>Suggested Limits¹</th>
<th>Rabigh II</th>
<th>Diesel oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>ppm</td>
<td>3.0</td>
<td>3.0</td>
<td>0.01% wt</td>
</tr>
<tr>
<td>Na + K²</td>
<td>ppm</td>
<td>&lt;2.1</td>
<td>2.1</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Lead</td>
<td>ppm</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Vanadium³</td>
<td>ppm</td>
<td>&lt;0.5</td>
<td>0.5</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Wax⁴</td>
<td>%</td>
<td>3.0</td>
<td>0.0</td>
<td>N/A</td>
</tr>
<tr>
<td>Pour Point</td>
<td>°C</td>
<td>-30</td>
<td>-35</td>
<td>-23</td>
</tr>
<tr>
<td>Cold Filter Plug Point</td>
<td>°C</td>
<td>-5</td>
<td>-7</td>
<td>-15</td>
</tr>
<tr>
<td>Carbon Residue</td>
<td>% wt</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
<td>&lt;0.15</td>
</tr>
<tr>
<td>Calcium</td>
<td>ppm</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Sulfur</td>
<td>% wt</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

¹ If the composition of the actual fuel supplied to the gas turbines exceeds these suggested composition limits, the auxiliary systems and gas turbine operation may be impacted requiring modification, fuel treatment, or adjustment of the fuel factor.

² If the suggested Na + K limits exceed 2.1 ppm, an oil washing system can be implemented to reduce levels or the fuel factor applied to turbine parts can be adjusted based on the validation inspections planned for the lead unit.

³ If the suggested Vanadium limits exceed 0.5 ppm, inhibitors can be added to the fuel or the fuel factor applied to turbine parts can be adjusted based on the validation inspections planned for the lead unit.

⁴ 3.0% wax content is acceptable as long as the Cold Filter Plug Point (CFPP) and Pour Point temperature limits are not exceeded.
Arabian Super Light crude oil
Test Results Summary

ASL testing has confirmed that reliable base load performance will be guaranteed with the existing ULN combustion hardware:

- SGT6-5000F(5ee) design is capable with ASL fuel from start-up to base load.
- GT performance and emissions will be guaranteed on ASL fuel.
- The potential risk of combustion flashback was mitigated by varying the water / fuel ratio.
- Service Intervals will be guaranteed with an ASL fuel factor. A fuel factor of 3.0 is applied to combustor parts only during ASL operation (fuel factor for turbine parts remains at 1.3).

Combustion hardware was instrumented to measure flashback, dynamics, metal temperatures, and emissions
Gas Turbine Service Intervals
5000F Hot Gas Path Inspection @ 22,000+ Hours

Lower Firing Temperature = Lower Risk in Service Operation

F(4) parts shown are identical to F(5) and similar to F(5ee)
SGen6-1000A
Air Cooled Generator

- Air cooled configurations (OAC and TEWAC) to meet the environmental conditions in the region
- 12 OAC in the Kingdom
- Air cooled for simplified plant interfaces
- 30 year design life @ IEEE Class F temperature rise
Thank You from the Orlando, FL, USA Office!

Gas Turbine Manufacturing in the Kingdom of Saudi Arabia

Charlotte, North Carolina, USA

Gas Turbines

Dammam, Saudi Arabia

Generators

Steam Turbines
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