The 12th ISRAELI SYMPOSIUM ON JET ENGINES AND GAS TURBINES

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Maintaining Gas Turbine Compressor Efficiency

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ZOK International Group Limited

In Partnership with: ARAVA Technologies Limited

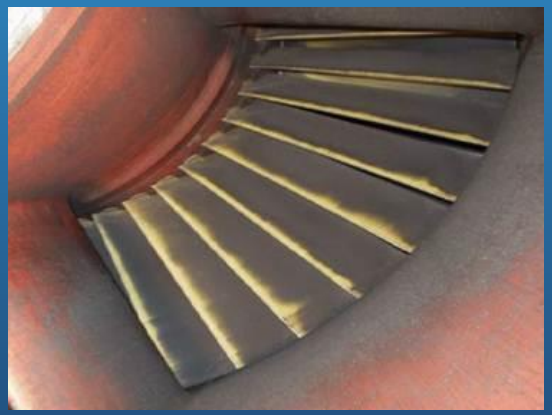
Presentation Outline

- Introduction
- Basic principles and compressor pressure / volume
- Compressor Performance and types of contamination
- Airfoil efficiency and contamination
- Corrosion and Erosion
- Compressor Damage – causes and preventative actions
- Why wash & cleaning methods
- Case study
- Laboratory Testing Service
- In summary

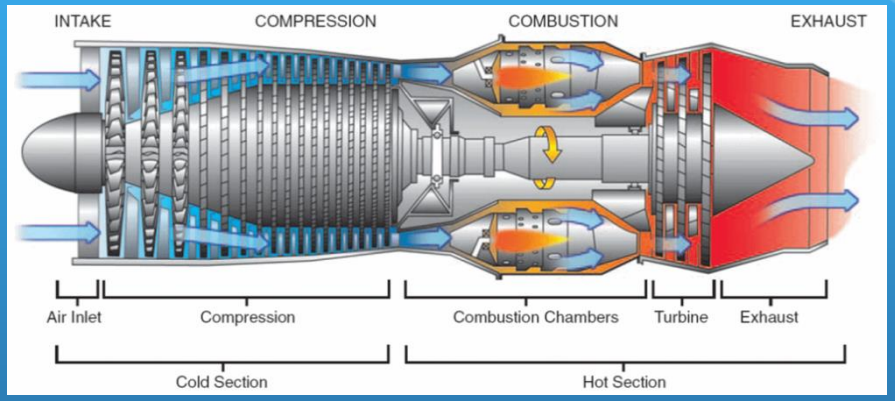
Introduction

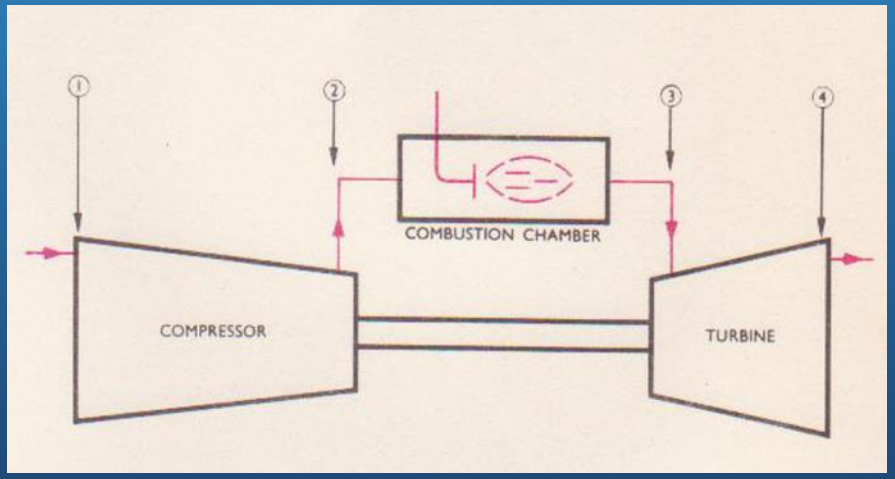
Why is Compressor Efficiency so important?

"Up to 60% of the power produced by a Gas Turbine Engine is consumed by the compressor assembly"

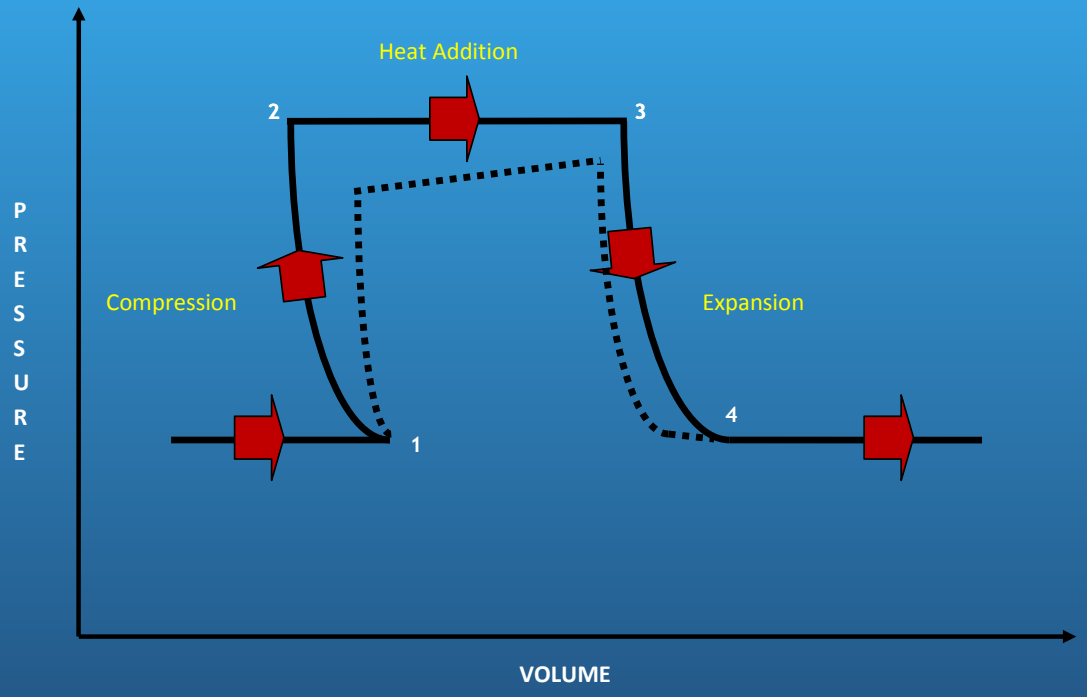


Understanding the basic principles



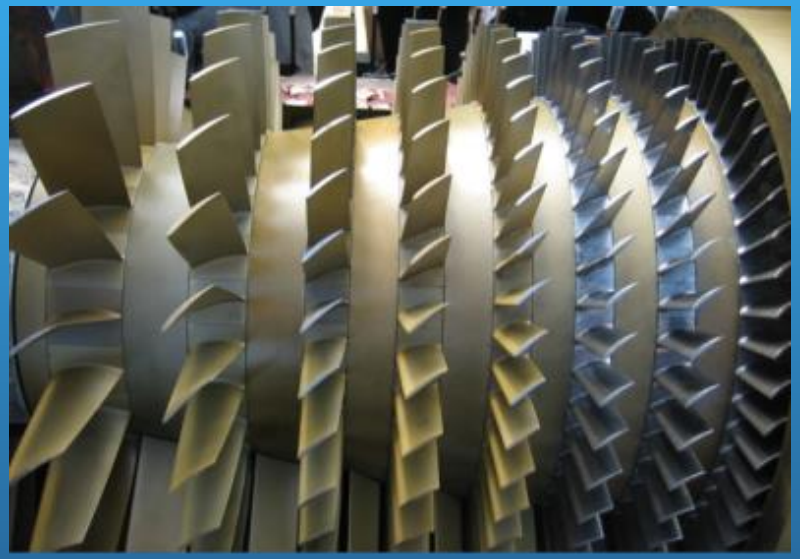


Compressor Pressure & Volume



1 – 2 Compression (Compressor)
2 – 3 Heat Addition (Combustion Chamber)
3 – 4 Expansion (Turbine)

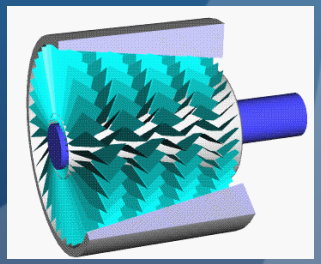
Compressor Assembly



Rotor Assembly

Stator Assembly

"Increase the pressure of the air passing through it"



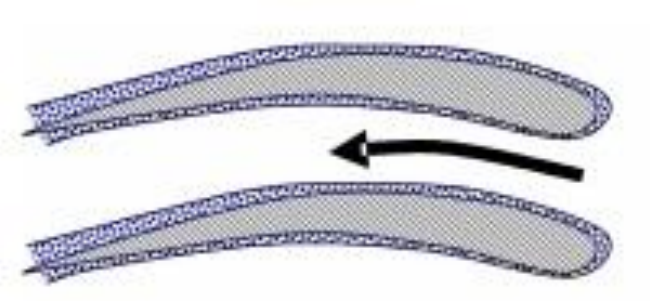
Factors that contribute to a loss in Compressor Performance

- Contamination of the Airfoil Surfaces
- Corrosion of the Airfoil Surfaces
- Erosion of the Airfoil Surfaces
- Peripheral Equipment Degradation
- Distortion and Wear of the Casing and Rotor Assy
- Foreign or Domestic Object Damage

Types of Contamination

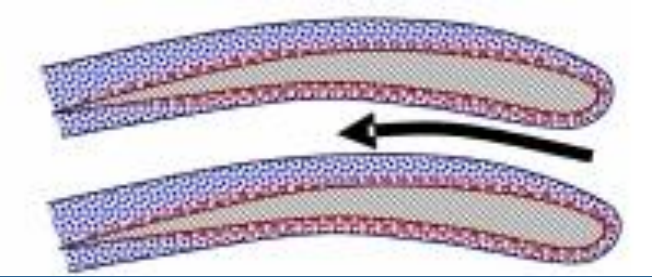
- Aerosols
- Dust
- Insects & Organic Matter
- Rust or scale from the inlet duct work
- Dissolved solids
- Oil and Hydrocarbon deposits

Contaminated Airfoils affect Efficiency



Clean Compressor:

- Airfoil Surface is clean & undisturbed
- Boundary layers are thin
- Airfoil operates at maximum efficiency

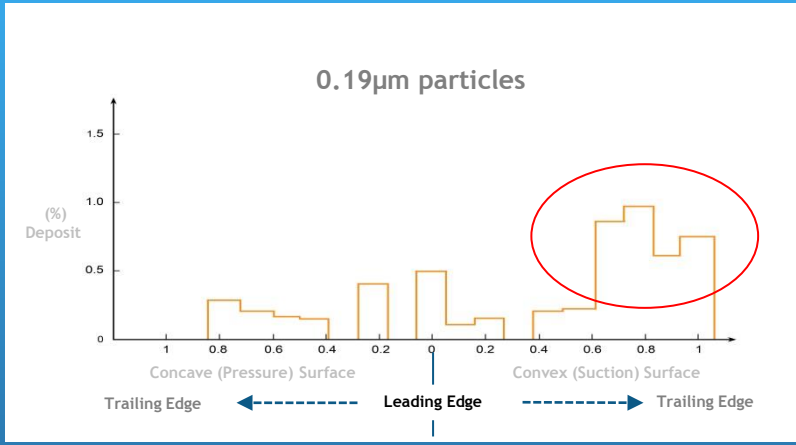


Contaminated Compressor:

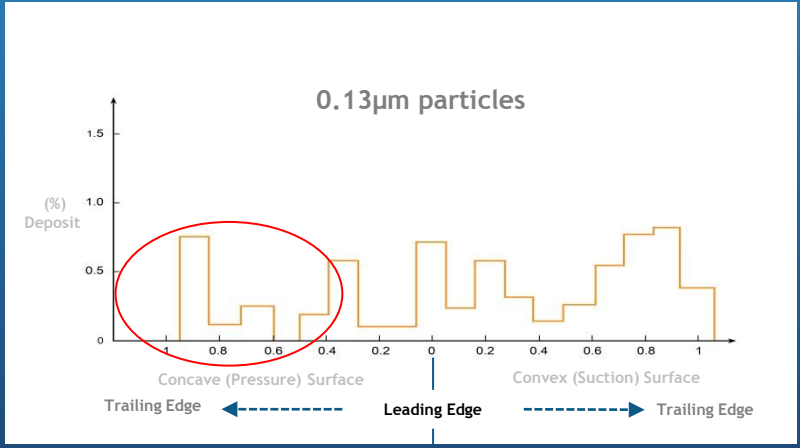
- Airfoil surface is rough
- Boundary layers are thick
- Efficiency is reduced which results in:
  - An increase in the work input required to compress the flow

Does particle size matter and where does it stick?

Contamination size and distribution



Highest level of contamination observed on suction (top) surface where the boundary layer is thick and turbulent



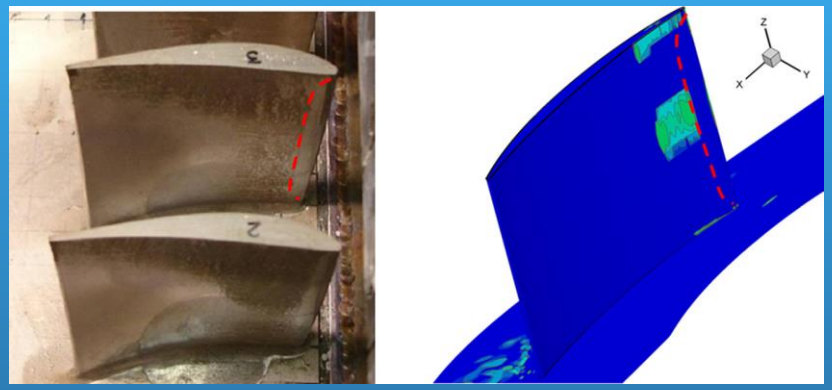
Smaller particles stick to the pressure (bottom) surface

Particle Size Matters!

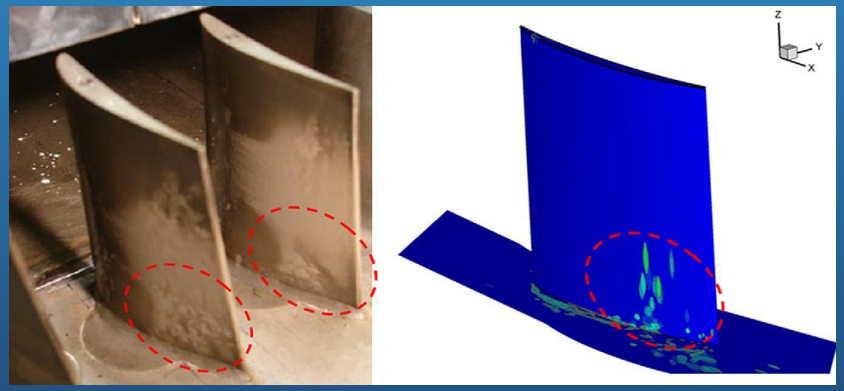
Contamination of the Airfoil Surfaces
Corrosion of the Airfoil Surfaces
Erosion of the Airfoil Surface

Ref: [2]

Location of Contamination



Deposits on the pressure (bottom) surface – dashed line indicates the ‘clean’ leading edge region



Deposits on the suction (top) surface – the circles show the deposit induced by the presence of large recirculation due to the development of hub vortex

Corrosion of Airfoil Surfaces

Chemical – Industrial Environment
(Sulfur or Chlorine)

Electrochemical – Galvanic reaction (moisture induced)

Both types will result in Pitting, Roughening and Material Loss = decrease in compressor efficiency

Contamination of the Airfoil Surfaces
Corrosion of the Airfoil Surfaces
Erosion of the Airfoil Surface

Corrosion of Airfoil Surfaces – Main contributors

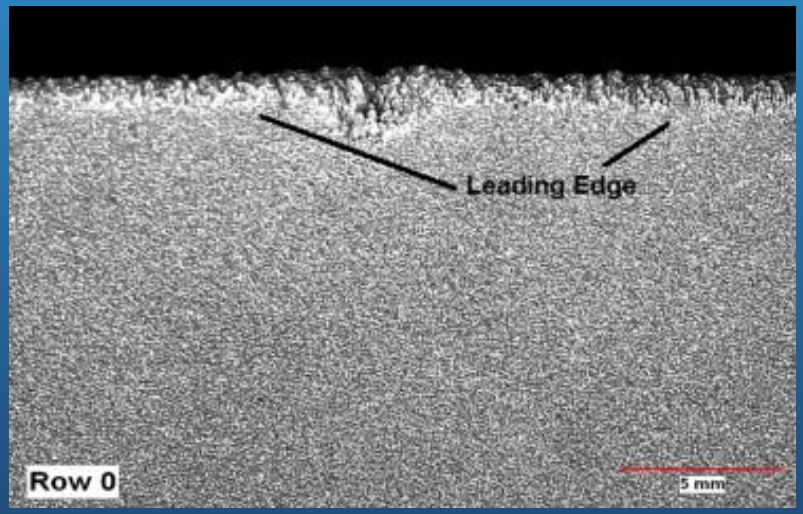
- Airfoil composition and surface finish
- Atmospheric concentrations of moisture, salt and sulfur
- Maintenance Protocols

Contamination of the Airfoil Surfaces
Corrosion of the Airfoil Surfaces
Erosion of the Airfoil Surface

Erosion of Airfoil Surfaces

Erosion causes a change in the airfoil profile, resulting in:

- A decrease in the thickness of the airfoil
- Airfoil roughness
- Increase in tip clearance

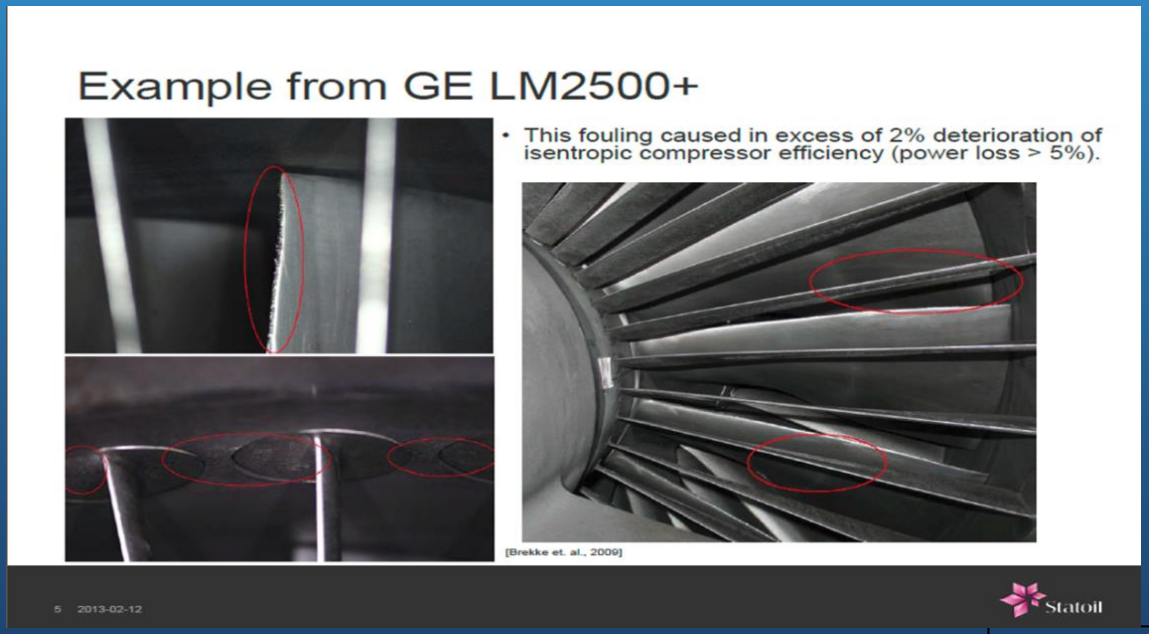


Contamination of the Airfoil Surfaces
Corrosion of the Airfoil Surfaces
Erosion of the Airfoil Surface

Erosion of Airfoil Surfaces

Factors contributing to an increase in Erosion damage:

- Prolonged ingestion of Liquid or Solid Particles
- Impact Velocity and Incidence Angle
- Concentration and size of Particles
- Surface Material (coatings and resistance to impact damage)



Contamination of the Airfoil Surfaces
Corrosion of the Airfoil Surfaces
Erosion of the Airfoil Surface

Causes of Compressor Damage

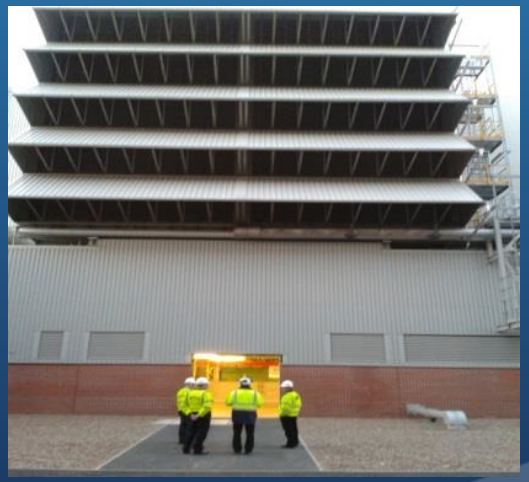
- Incorrect operation of IGVs and bleed valves
- High cycle fatigue
- Pitting due to corrosion
- Erosion and fouling of airfoils and airfoil coatings:
  - Excessive vibration
  - Surge due to fouling, erosion and airfoil roughness

Compressor Damage : Preventative Actions

- Inlet Filtration
- Routine compressor washing
- Monitoring changes in vibration
- Periodic inspection of the airfoil surfaces for pitting, erosion and coating integrity
- Functional testing of the operation and positional settings of the IGV's and bleed valves

Inlet Filtration

- HEPA, Fine and Course
- PTFE, nano or micro glass fibre based
- Effective at removing particles >0.01 - 10 microns
- Not effective at removing aerosols that contribute to a build-up of sticky contamination
- Incorrect filter selection can be costly
- Soluble contaminants



Routine Compressor Washing

- Maintain your Compressor at maximum efficiency
- Maintain Engine Reliability and Performance

"as the compressor consumes a significant amount of the energy produced – maintaining an efficient compressor will … "

Why wash an engine at all?

Restore blade aerodynamics & compressor efficiency

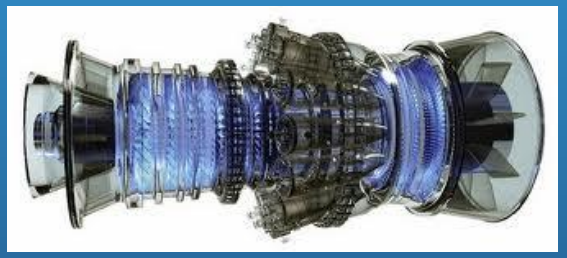
That will contribute towards:

- Maximum available power output
- Improve fuel efficiency
- Reduce hot section deterioration
- Can provide corrosion inhibiting protection

Cleaning Methods

Off-Line (dry crank) Cleaning:
= Power Recovery

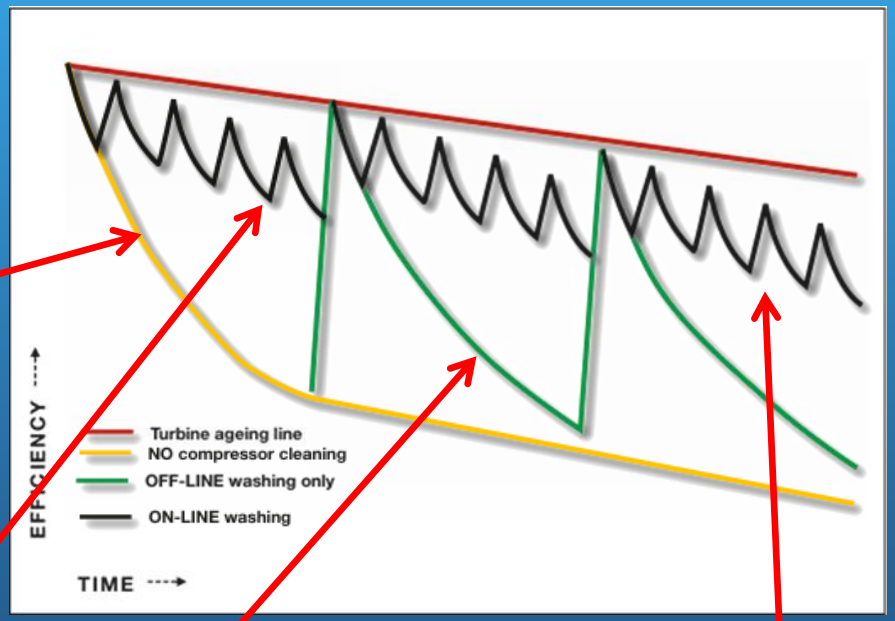
On-Line (hot cleaning under reduced load):
= Power Maintenance



Hand Cleaning:
= Limited Power Recovery

Compressor Performance

On-Line Washing = Power Maintenance Off-Line = Power Recovery



Degradation Rate with no washing

Performance decay with ONLY On-line washing

Performance recovery with ONLY Off-Line washing

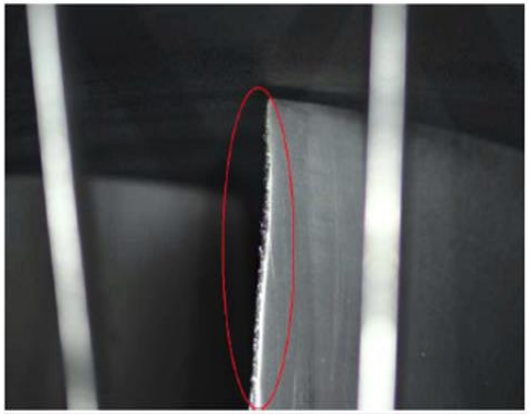
Compressor Efficiency recovery with On-Line & Off-Line Washing

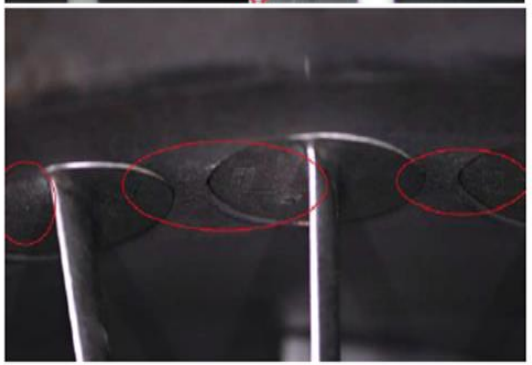
Using water based detergent to wash

- Eco-Friendly ✓
- Aqueous NOT Solvent based cleaners ✓
- Solvent based cleaners eventually harden internal seals ✗
- Solvent based cleaners – difficult to safely/environmentally dispose of ✗
- Unique formulated Surfactant - for increased penetration and removal of fouling ✓
- Wide range of approvals ✓

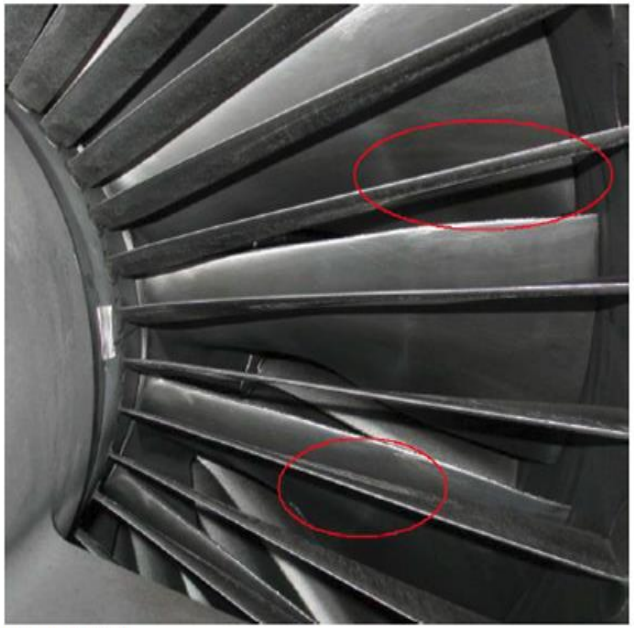
Case Study

Example from GE LM2500+





- This fouling caused in excess of 2% deterioration of isentropic compressor efficiency (power loss > 5%).

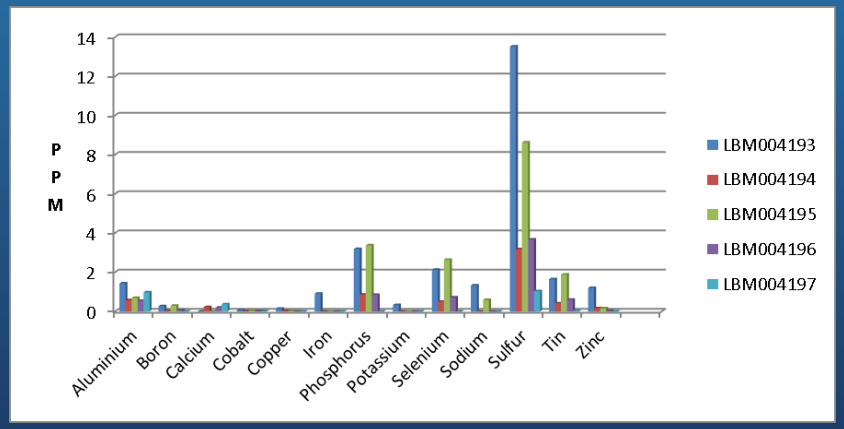


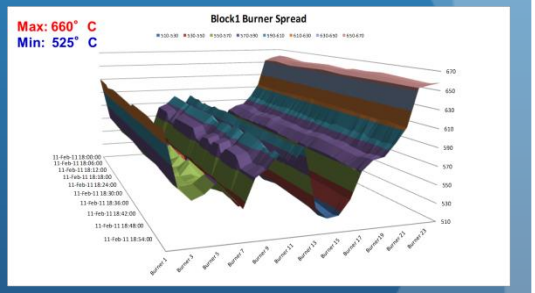
[Brekke et. al., 2009]

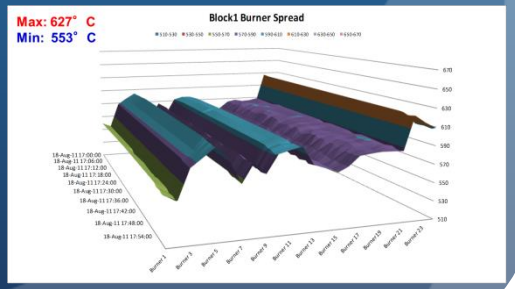
Statoil

Wash Sampling Analysis

- Wash samples are analysed in our fully integrated laboratory
- Tested key components of all the OEM specifications including:
  - Microscopy, Spectroscopy, Inductively Coupled Plasma
  - Comprehensive test results analysis







Wide Range of Approvals

MINISTRY OF DEFENCE

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

HAR 3A Sea King


MK 9A Lynx


FA-18 Super Hornet


P3 Orion


Blackhawk MH-90


SAAB 340

imagination at work

Kawasaki

Pratt & Whitney
A United Technologies Company

ROLLS ROYCE

MITSUBISHI

SIEMENS

Solar Turbines
A Caterpillar Company

ALSTOM

In Summary

Routine Gas Turbine Compressor Washing is the most cost effective means of maintaining an efficient compressor.

Up to 60% of the power produced by a Gas Turbine Engine is consumed by the compressor assembly

References:

- [2] Fouling Deposition Rates on Axial Compressor Airfoil (Parker & Lee, 1972), Electric Power Research Institute (ERPI), Axial Compressor Performance Maintenance Guide Update, February 2005
- [3] Experiments by Vigueras Zunga, An intergrated Particle Tracking Impact / Adhesion Model for the Prediction of Fouling in a Subsonic Compressor – Journal of Engineering for Gas Turbines & Power, Sept 2012, Vol. 134

Thank you !

Shaping the future of gas turbine washing