Enhancing Gas Turbine Performance by Correct Washing Procedures

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AIRCRAFT AIRWORTHINESS AND
SUSTAINMENT CONFERENCE

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Lessons learnt in the industrial world that can be applied to Aeronautical Engines

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Disclaimer

Data compiled for this presentation was accumulated through the use of ZOK products.

Other compressor washing products will not necessarily replicate these data sets.

Firstly, let it be emphasised that there is no difference, except in some instances for size, between and aeronautical and industrial gas turbine engines. In fact, many industrial engines are aero-derivatives.

Two classic examples in wide spread use in Australia and New Zealand are:

The GE LM6000

Pratt & Whitney FT-4.

Firstly, let it be emphasised that there is no difference, except in some instances for size, between and aeronautical and industrial gas turbine engines. In fact, many industrial engines are aero-derivatives.

One noteworthy difference, however between industrial and aero engines is:-

FILTRATION

Hence the running hours you will see

What is the purpose of correlating data between Industrial and aero engines?

It is easy (possible) to measure output on industrial engines

Therefore it is easy to measure energy losses

This allows us to better trend performance degradation and recovery

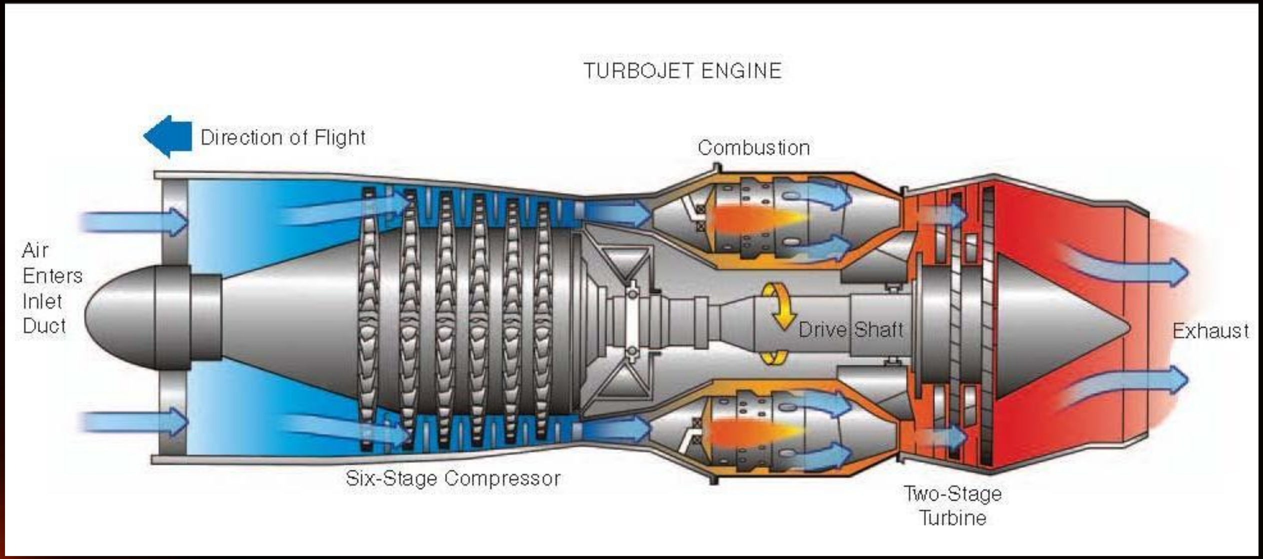
Why do we need to do this?

A fouled engine

- Uses more fuel
- Is more prone to failure
- Wears out faster
- Is more prone to corrosion

What is the cause of these issues?

<u>Gas Turbine 101</u>



What is the cause of these issues?

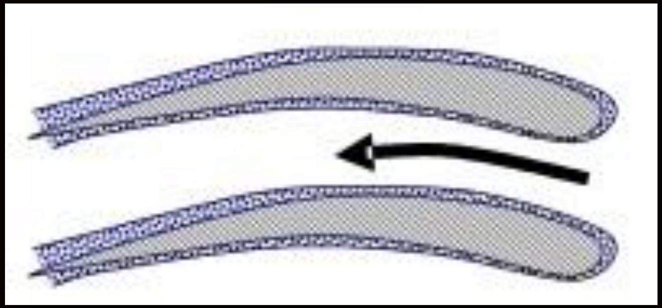
Gas Turbine 101

~60% of the energy produced by a gas turbine engine is absorbed by the compressor

Less than 40% of the energy produced is available for the intended application

As the compressor blades foul, the system looses efficiency

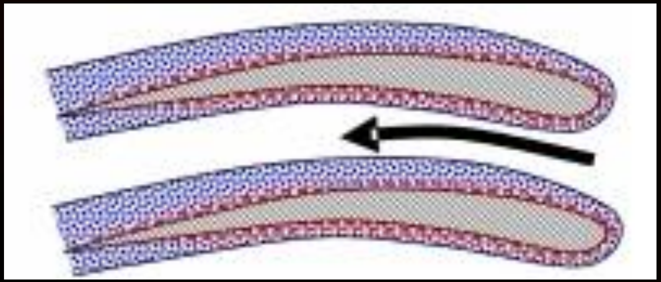
Contaminated Air Foils affect Efficiency



Clean Compressor:

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

Contaminated Air Foils affect 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

Getting back to the facts.

An Engine Gas Path water cleaning with detergent provides the most effective method to clean the engine compressors*

Engine gas path cleaning restores engine efficiency by the removal of particle contaminants from the primary airflow path.

Typically between 6° and 10° EGT margin and 0.5% specific fuel consumption can be gained from an effective compressor wash.

*Boeing CFM56-7 AMM Ref: B00676 [CP1041]

Gas Turbine Performance - simple data capture

Parameter	Pre Wash	Post Wash	Δ	%
1. NGP - %	100	100	0	0
2. PCD - barg	7.29	7.42	0.13	1.78
3. T5 - Avg °C	461.64	434.43	-27.21	-5.89
4. Fuel Flow Gas - (scfm)	471.42	444.17	-27.25	-5.78

Standard Cubic Feet / Minute:	*One SCF = 1020 BTU's*
NPT = Compressor Speed	
NGP = Gas Turbine Speed	

Measuring Gas Turbine performance recovery – case 1

GT-4
Mitsubishi MF111
ZOK mx
1 x Pre, 1 x detergent, 6 x rinse
Since last wash: 931 hrs

GT-4 (ZOK mx)					
No	Parameter	Unit	Pre Wash	Post Wash	Δ (%)
1	NGP	%	100	100	0
2	PCD	barg	12.4	12.55	1.21
3	T5 Avg (BPT Avg)	°C	473	467	-1.27
4	Fuel Gas Flow	kg/h	2734	2718	-0.58
5	Active Power (at SP= 8.0 MW)	MW	8.035	8.035	0
6	ΔP across filter housing	mmH2O	46	47	2.17
7	T1 Avg	°C	30.1	28.2	-6.31
8	Engine running hours sice last washing	hours	931		
9	PCD drop per run hour	%	0.0013		

Measuring Gas Turbine performance recovery – case 2

GT-5
ABB GT10
ZOK 27
1 x Pre, 2 x detergent, 7 x rinse
Since last wash: 2117 hrs

GT-5 (ZOK 27)					
No	Parameter	Unit	Pre Wash	Post Wash	Δ (%)
1	NGP	%	100	100.2	0.2
2	PCD	barg	11.56	11.63	0.6
3	T7 Avg	°C	520	494	-5
4	Fuel Gas Flow	MJ/s	51.8	50.44	-2.62
5	Active Power (at SP= 15.0 MW)	MW	14.46	14.53	0.48
6	ΔP across filter housing	mmH2O	20.63	21.53	4.36
7	T1 Avg	°C	28.75	27.5	-4.34
8	Humidity	%	69.09	68.39	-1.01
9	Engine running hours sice last washing	hours	2117		
10	PCD drop per run hour	%	0.000283		

The effect of over-SOAKING

MHI 701F – 1 hour SOAK (3.8MW (3.54%) Increase in Power Output)

		100 MW				Max			
Measured Parameter	UoM	Pre Wash	Post Wash	%	∆	Pre Wash	Post Wash	%	∆
Power Output	MW	100.53	100.07	-0.46	-0.46	103.40	107.20	3.54	3.80
Corrected Power	MW	98.11	98.05	-0.06	-0.06	100.77	105.97	4.91	5.20
Fuel Gas	kNm³/h	31.27	30.83	-1.43	-0.44	32.00	32.63	1.93	0.63
HHV Fuel Gas	BTU/SCF	1074.76	1073.49	-0.12	1.27	1074.76	1073.79	-0.09	0.97
HHV HSD	kcal/kg	-	-	-	-	-	-	-	-
SG	kg/m³	-	-	-	-	-	-	-	-
Ambient Temp	°C	28.00	28.50	1.75	0.50	28.00	29.50	5.08	1.50
Compressor Outlet Temp	°C	405.43	396.93	-2.14	-8.50	409.67	406.67	-0.74	-3.00
Compressor Outlet Press	kg/cm³	12.27	12.20	-0.57	-0.07	12.33	12.57	1.91	0.24
Compressor Efficiency	%	85.28	87.16	2.16	1.88	85.38	87.15	2.03	1.77
Blade Path Average Temp	°C	535.00	523.80	-2.14	-11.20	545.23	542.13	-0.57	-3.10
Exhaust Gas Average Temp	°C	516.10	507.30	-1.73	-8.80	526.90	523.97	-0.56	-2.93
GT Heat Rate	kcal/kWh	3,143.97	3,112.07	-1.03	-31.90	3,128.51	3,074.58	-1.75	-53.93
GT Corrected Heat Rate	kcal/kWh	3,168.20	3,130.31	-1.21	-37.89	3,153.17	3,080.10	-2.37	-73.07
GT Efficiency	%	27.35	27.63	1.01	0.28	27.49	27.97	1.72	0.48
GT Corrected Efficiency	%	27.14	27.47	1.20	0.33	27.27	27.92	2.33	0.65

The effect of over-SOAKING

MHI 701F – 20 min SOAK (6.73 MW (6.16%) Increase in Power Output)

		100 MW				Max			
Measured Parameter	UoM	Pre Wash	Post Wash	%	Δ	Pre Wash	Post Wash	%	Δ
Power Output	MW	99.73	100.17	0.44	0.44	102.60	109.33	6.16	6.73
Corrected Power	MW	100.88	97.83	-3.12	-3.05	103.76	104.48	0.69	0.72
Fuel Gas	kNm^3/h	31.27	30.83	-1.43	-0.44	31.83	33.10	3.84	1.27
HHV Fuel Gas	BTU/SCF	1072.40	1070.80	-0.15	1.60	1072.40	1070.48	-0.18	1.92
HHV HSD	kcal/kg	-	-	-	-	-	-	-	-
SG	kg/m^3	-	-	-	-	-	-	-	-
Ambient Temp	°C	32.00	25.00	-28.00	-7.00	32.00	25.00	-28.00	-7.00
Compressor Outlet Temp	°C	418.13	397.50	-5.19	-20.63	419.73	405.20	-3.59	-14.53
Compressor Outlet Press	kg/cm^3	12.40	12.23	-1.39	-0.17	12.40	12.70	2.36	0.30
Compressor Efficiency	%	84.87	86.17	1.51	1.30	84.86	86.26	1.62	1.40
Blade Path Average Temp	°C	535.80	525.37	-1.99	-10.43	545.13	542.77	-0.43	-2.36
Exhaust Gas Average Temp	°C	517.00	505.77	-2.22	-11.23	526.20	521.90	-0.82	-4.30
GT Heat Rate	kcal/kWh	3,162.26	3,065.36	-3.16	-96.90	3,129.61	3,048.25	-2.67	-81.36
GT Corrected Heat Rate	kcal/kWh	3,128.34	3,065.36	-2.05	-62.98	3,096.66	3,083.05	-0.44	-13.61
GT Efficiency	%	27.20	27.75	1.98	0.55	27.20	28.21	3.58	1.01
GT Corrected Efficiency	%	27.49	28.06	2.03	0.57	27.77	27.89	0.43	0.12

Fouling Deposits
-Summary-

- Water wettable, water soluble and insoluble materials
- Very often lower than pH 4
- If left untreated, fouling leads to pitting corrosion and as the deposits bond through the ageing process the cleaning potential reduces
- Water soluble contaminants – sodium and sulphides which contribute towards hot section corrosion can be rinsed out (but can also become embedded in the water-insoluble compounds)
- Water –insoluble contaminants – organic hydrocarbon residues

Deionised Water – A side issue?

Deionised water should always be used for washing/rinsing turbines

Why?

Deionised water will not degrade detergent quality and performance

Deionised Water – A side issue?

Deionised water should always be used for washing/rinsing turbines

Why?

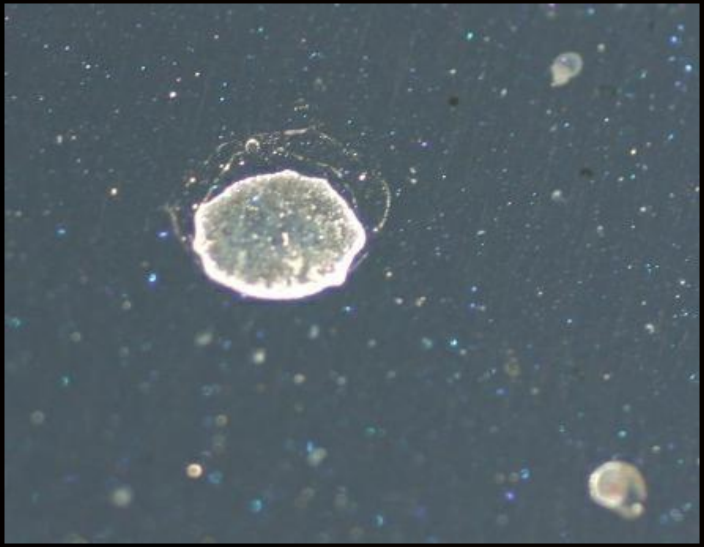
Is better able to remove contaminants and residues

Deionised Water – A side issue?

Deionised water should always be used for washing/rinsing turbines

Why?

Gives a better and more effective rinse.



Spotting or calcium build up

Lastly: Water Temperature

Manuals generally call for a water temperature of between 45^0 – 60^0 Celsius.

The reality is that these temperatures are based on OHS and NOT cleaning efficiency.

Fully automated wash skids where human contact or intervention is impossible can use water temperatures up to 90^0 C. (For water only rinsing)

Lastly: Water Temperature

Why?

Heat enhances cleaning efficiencies

Without the science,
Try washing a greasy baking tray in the kitchen sink with clod water………..
We all know hot works better.

What are we cleaning off the engine internals?
Oils and hydrocarbons.

Case Closed


THANK YOU FOR LISTENING
ANY QUESTIONS?