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GAS TURBINE FAILURE DUE TO WATER WASH AND EXTRACTION LINE BLOCKAGE

Abdulmajeed A. Ali
Saudi Aramco, Yanbu NGL Fractionation Department
Industrial City, Yanbu, Saudi Arabia
abdulmajid.ali@aramco.com

ABSTRACT

A Hot Gas Path Inspection (HGPI) of GE Co-Generation train revealed an extensive failure of the turbine blades and vanes in the first, second, third stages and combustion chamber cross firing tubes.

Subsequent investigation effort indicated that commissioning activities of associated compressor water wash system allowed large volumes of water to penetrate the compressor and combustion chamber due to improper instrumentation interlock configuration of MOV-20TW-1 (Offline compressor water wash motor operated valve) and MOV-20TW-3 (Online compressor water wash motor operated valve). The field wiring for the valves was incorrectly interchanged causing the offline water wash valves to be operated while commanding the online water wash valves to operate and vice-versa.

Compressor water wash system is typically used to remove fouling deposits from compressor components to maintain the equipment efficiency, power output and reduce corrosion rate. Vendor recommends daily online water wash while the offline water wash shall be performed whenever the equipment is not working.

As a result, cross firing tubes were exposed to sudden quenching during the water wash activities causing tube fragmentation, which found its way through the exhaust stream to the turbine chamber - colliding with associated buckets and nozzles - eventually resulting in the reported damage.

Water seeped into the air extraction line and settled in the dryer skid system, resulting in desiccant contamination. Following turbine shutdown for correcting the instrumentation loop configurations of subject MOVs, the contaminated desiccant flowed to the combustion chamber, blocking the extraction line and the drain lines. After successful configuration of compressor water wash system MOVs, the turbine was put back in operation mode. The contaminated desiccant blocked the air passage of the combustion chamber, which consequently melted the cross firing tubes and contributed to the overheating of first stage buckets.

Investigation concluded that the inadequate pre-commissioning procedure – for the Co-Generation train compressor water wash interlock system – were the root cause behind the subject incident. The immediate cause was determined to be water penetration to the compressors and combustion chamber internals during machine operation.

INTRODUCTION

The co-generation facility was relocated and commissioned in April 2005 to provide the required electrical power demand for the Yanbu' NGL Fractionation Plant and to provide an additional level of redundancy to the high pressure steam production for the plant.

The new facility consists of three co-generation train skids, each co-generation skid constitute by a GE FRAME 6 Combustion Gas Turbines Generator (CGTG) and Heat Recovery Steam Generator (HRSG). The CGTG was designed to accept a dual gas fuel system - with sales gas as the primary fuel and ethane as the secondary - with a power production capacity of 27 MW at 120 ^{o}F ambient temperatures. The HRSG designed to produce 60 and 600 Ib. steam (450,000 Ib/Hr) at site rated conditions.

The turbine HGPI indicated the following observation:

COMBUSTION CHAMBER:

- White scale element inside the combustion chamber casing at the lower section.
- White scale element in the liners of the combustion component blocking some of the air cooling passes.
- White scale element on the cross fire tubes blocking some of the air cooling passes. Also found more than one cross firing tube melted or with broken pieces. Those affected cross firing tubes are the ones located in the combustion component at the lower casing side.
- White scale element in the transition pieces. Those affected transition pieces are the ones located with the combustion component at the lower casing side.

TURBINE:

- White scale element on all first stage turbine nozzles (Vanes) surfaces.
- White scale element blocking the air cooling passes on all first stage turbine nozzles (Vanes).
- Evident burnout (overheating) and cracks of the all first stage turbine nozzles (Vanes).

- Small broken edges, dents on all first stage, second stage, third stage turbine buckets (Blades).
- Small broken edges and dents on all first stage nozzles (Vanes).
- Evident dents on all second stage and third stage nozzles (Vanes).
- Full blockage of the air extraction pipe with white solidified scale material from the tie-in point at the lower side of the combustion chamber till the air cooled heat exchanger of the dryer skids system.
- Full blockage of the drain pipe with white solidified scale material from the tie-in point at the lower side of the combustion chamber till the first isolation valve.

HEATERLESS DRYER:

- One Heater-less dryer tower tank vessel found empty of desiccant bed (activated alumina).
- Full blockage of four-way valves with white solidified scale material.
- Water trap valve located between air-cooled heat exchanger and dryer tank vessel is full blockage of white solidified scale material.
- Water traces in the intake filter sled cleaning pot.

LABORATORY ANALYSIS

The laboratory analyzed two samples of original desiccant and deposited powder material collected from the turbine unit using XRD and XRF techniques.

The objective of the analysis was to determine if the deposited powder material was from the original desiccant. The results would also help in the prohibition of the solidified powder deposition and avoidance of equipment failure in the future. The samples are described in table 1:

Sample No.	LIMS No.	Sample Description	Picture
1.	S-520-2010/00418	Original desiccant (white pellet).	
2.	S-520-2010/00419	Deposited powder material (white and pale brown) from the Gas Turbine Hot section.	

Table-1 Sample Description

The samples were ground to fine powder using an agate mortar and pestle. For XRD analysis, the fine powders were mounted in the XRD sample holder by back pressing. For WDXRF analysis, approximately 4g of each powder was mixed well and homogenized with 0.9g of binder (Licowax C micropowder PM (Hoechstwax)). Then, the powders were pressed with 20 tons to pellet with 31 mm diameter. The samples were analyzed by X-Ray Powder Diffraction (XRD) (SALAM 520-08 method) and Wavelength Energy Dispersive X-ray Fluorescence (WDXRF) Spectrometry (Omnian 27 method) (Amorphous, trace or organic compounds may not be identified by XRD method. The WDXRF method can only determine elements with an atomic number greater than eight).

1. WDXRF Analysis:

In this study, two samples were measured in briquettes. WDXRF data were obtained using software of IQ+ (Omnian 27 method) for elemental composition determination semi-quantitatively with PANalytical Axios Advanced spectrometer. WDXRF results are listed in Table 2 below (Note: the concentrations of O and H are not listed in the table as WDXRF can not measure them).

ELEMENT	Sample #1 Original desiccant WT%	Sample #2 Deposits from Gas Turbine Hot Section WT%
Al	45	38
Na	0.3	0.04
S	0.06	0.09
Si	0.03	0.04
Ca	0.03	0.03
Cl	0.01	0.01
Fe	0.01	0.5
Bi	0.01	-
Zn	0.007	0.008
Ga	0.006	0.006
Cr	0.005	0.004
K	0.004	0.006
P	0.002	0.004
Mn	-	0.003
Ni	-	0.002

Table-2 Elemental Results by WDXRF

2. XRD Analysis:

The identification of the crystalline phases was achieved by using JADE 8.0+ program. The semi-quantification of XRD data was calculated by using JADE 8.0+ Reference Intensity Ratio method. The XRD results are given in Table 3. XRD patterns along with reference patterns of the identified compounds are illustrated in Figure 1 and 2. The XRD results showed that the original desiccant mainly consists of γ-alumina (γ-Al_2O_3) (activated alumina) with minor amounts of boehmite-AlO(OH), whereas the deposited powder material contains boehmite -AlO(OH), bayerite-$Al(OH)_3$, and gibbsite-$Al(OH)_3$. Based on analytical results, it was concluded that the original desiccant was the source of the deposited material. The interpretation was that activated alumina desiccant can absorb the moisture (water) and be transformed into bayerite-$Al(OH)_3$, and gibbsite-$Al(OH)_3$ during the operation process

$Al_2O_3 + H_2O \rightarrow AlO(OH)$ and $AlO(OH) + H_2O \rightarrow Al(OH)_3$

It worth mentioning aluminum hydroxides of (bayerite-$Al(OH)_3$ and gibbsite-$Al(OH)_3$) are amphoteric and can react with both acids and bases according to the formula:

$H^+ + AlO2^- + H_2O = Al(OH)_3 = Al^{+++} + 3OH^-$

Adding an acid removes OH^-, driving the reaction to the right, while adding a base removes H^+, driving the reaction to the left. Since it can go either way, aluminum hydroxide is called amphoteric, and is an excellent example of this type. Also, aluminum hydroxide can be transformed into alumina (γ-Al_2O_3) through dehydration over about 1000 ^oC. Alumina (γ-Al_2O_3) is a very stable mineral with higher hardness.

Compounds	Sample #1 Original desiccant WT%	Sample #2 Deposits from Gas Turbine Hot Section WT%
γ-alumina-γ-Al_2O_3	Major	Trace
Boehmite-AlO(OH)	Minor	37%
Bayerite-Al(OH)3		47%
Gibbsite- Al(OH)3		16%

Table-3 X-Ray Diffraction (XRD) Results

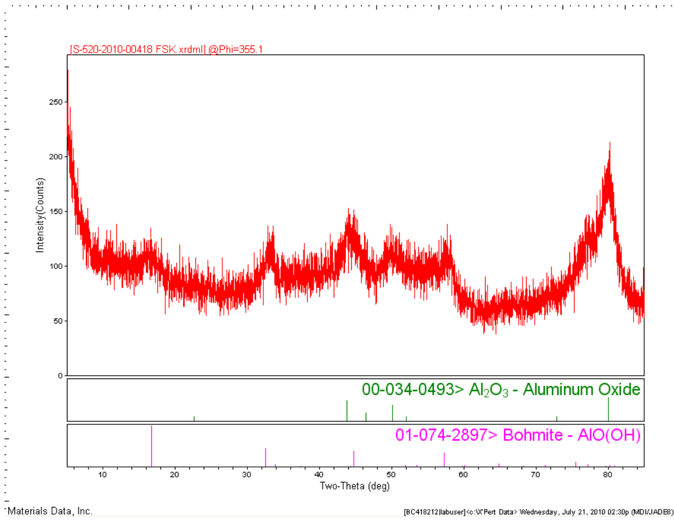

Figure-1 XRD Diffractrogram of Sample #1 Original Desiccant

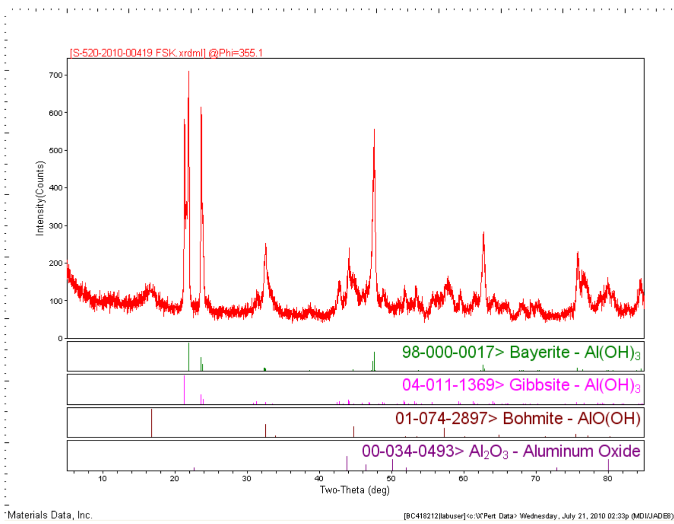

Figure-2 XRD Diffractrogram of Sample #2 Deposited Powder

LABORATORY ANALYSIS CONCLUSION

The XRD results showed that the original desiccant mainly consists of γ-alumina (γ-Al_2O_3) (activated alumina) with minor amounts of boehmite-AlO(OH), whereas the deposited powder material contains boehmite -AlO(OH), bayerite-$Al(OH)_3$, and gibbsite-$Al(OH)_3$. WDXRF results confirmed XRD findings. Based on analytical results, it was concluded that the original desiccant is the source of deposited material, as activated alumina desiccant can absorb the moisture (water) and be transformed into bayerite-$Al(OH)_3$, and gibbsite-$Al(OH)_3$ during the operation process ($Al_2O_3 + H_2O \rightarrow AlO(OH)$ and $AlO(OH) + H_2O \rightarrow Al(OH)_3$)

BACKGROUND

Part of co-generation plant retrofit program, a new compressor water wash system was introduced to recover the turbine performance loss. During a gas turbines operation, the compressor can experience a loss of performance resulted from deposits and contaminant accumulation on the internal components surfaces, which can easily, indicated by an increase in the heat rate and a decrease in the power output.

The new water wash system consists of piping connection on the base, two motor operated water injection valve (MOVs), and the appropriate spray manifold for ON-LINE/OFF-LINE process. Drains from the inlet plenum, combustion area, exhaust frame, and the exhaust plenum are also provided. The schematic diagram on Figure-3 shows the on-base water wash layout.

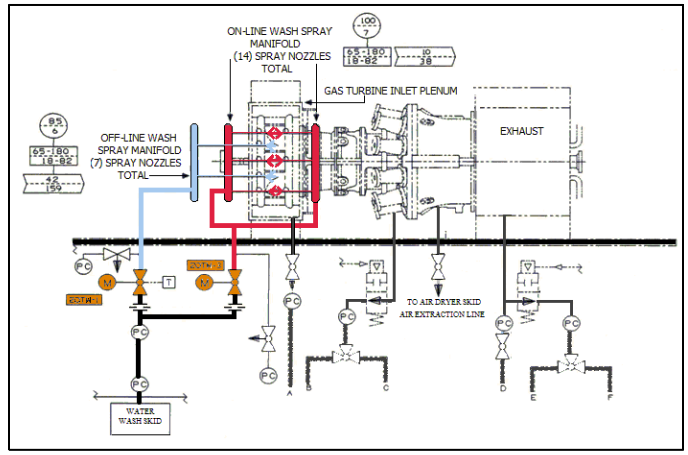

Figure-3 Compressor Water Wash Schematic Diagram

On-line water wash system consists of 14 spray nozzles on both sides of the turbine inlet plenum. The system is working in rated water pressure of 100 Psi (7 bar) at rated flow of 10 GPM (38 Ltr/min). The nozzles spray water at temperature between 65 – 180 ^{0}F (18 – 82 ^{0}C). On the other hand, the off-line water wash system consist of only 7 spray nozzles at rated pressure of 85 Psi (6 bar) and rated flow 42 GPM (159 Ltr/min) at same temperature.

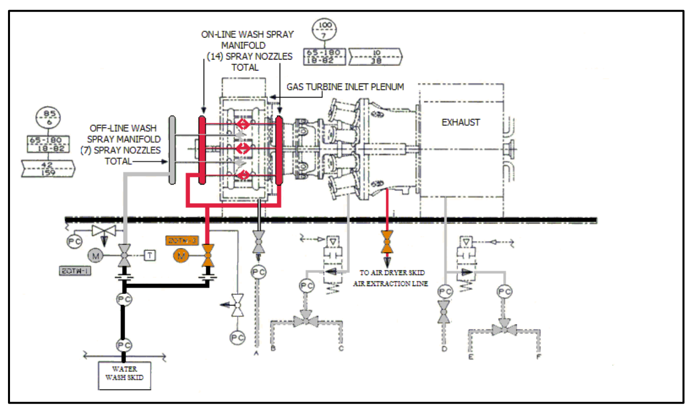

Figure-4 Compressor On-line Water Wash Path.

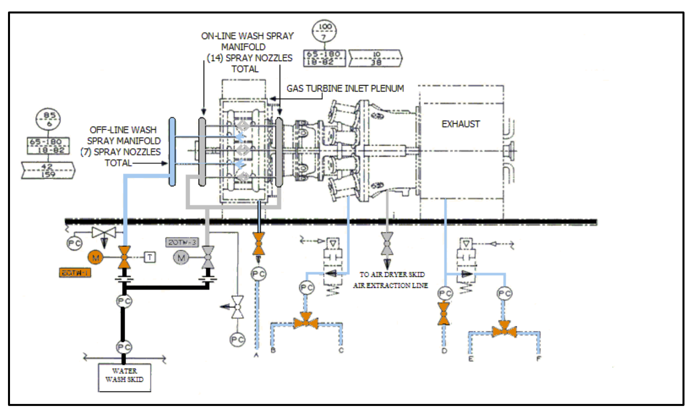

Figure-5 Compressor Off-line Water Wash Path.

FAILURE CAUSE ANALYSIS

The compressor water wash system was commissioned recently and found the main water wash system MOV's configuration (MOV-20TW-1: Offline compressor water wash motor valve and MOV-20TW-3: Online compressor water wash motor valve) was swapped, causing the off-line compressor water wash to be activated instead of the online compressor water wash and via versa. This observation was followed by the immediate shutdown action of compressor water washes system until proper correction with the aid of the vendor (GE). The compressor water wash system was recommended by GE – because of the system's advantage in fouling deposit removal from compressor components - to maintain equipment efficiency, power output and reduce corrosion rate.

Improper MOV configuration lead to a large volume water supply to the compressor and combustion chamber while the turbine unit was in the operating mode, and the isolation valve of the air extraction pipe was lined up in the open position, while all drain lines were lined up in a closed position (correct line up in the operating mode). This made water strike the cross firing tubes that were extremely hot, causing quenching of the material and sudden shock cooling, resulting in material fracture. The fracture material flowed with the exhaust stream, hitting turbine buckets/nozzles and magnifying damage that lead to more fracture material from the turbine buckets and nozzles.

A massive amount of water flowed from the air extraction pipe to the heater-less dryer skid system, with the aid of the pressurized air from the compressor (120 psig and 670 ^{0}F). This influx resulted in dissolving the desiccant in the dryer tower tank vessel and blocking the dryer downstream skid valves. This blockage trapped air in the dryer system under positive pressure (see figure 5).

While the turbine unit was under shutdown mode (proper interlock configuration of compressor water wash MOVs with GE support) the dissolved desiccant flowed back to the combustion chamber since the pressurized air from the compressor was neutralized to atmospheric pressure, and positive pressure in the heater-less dryer skid system aided the flow route.

After successful MOV configuration - with proper commissioning and verification of the compressor water wash system to satisfactory results - the trapped dissolved desiccant in the combustion chamber was forced to flow. The desiccant moved with the pressurized air stream, along with the combustion chamber components, during the startup of the turbine unit (operating mode); since the contaminated desiccant solidified in the air extraction line. The flowed contaminated desiccant dried in the combustion chambers component and was subjected to extreme heat flux. The result was blocked air cooling passes, causing overheat (burnout) and melting of some combustion chamber components and first stage turbine nozzles.

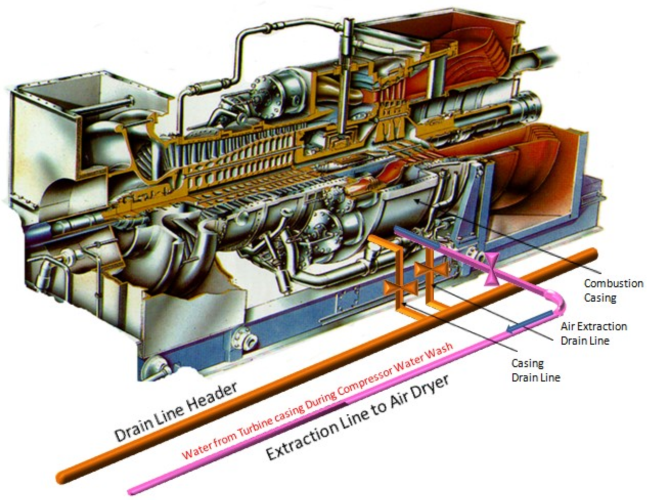

Figure-4 Drain and Air Extraction Line Configurations

The investigation committee studied the case and found the white scale in the combustion chamber and in the air extraction line and drain lines. This scale was the same material used in the air dryer towers tanks vessel (desiccant activated alumina used to extract humidity from the compressed air, as part of the air dryer skid system). Samples studied by the laboratory and confirmed the material match.

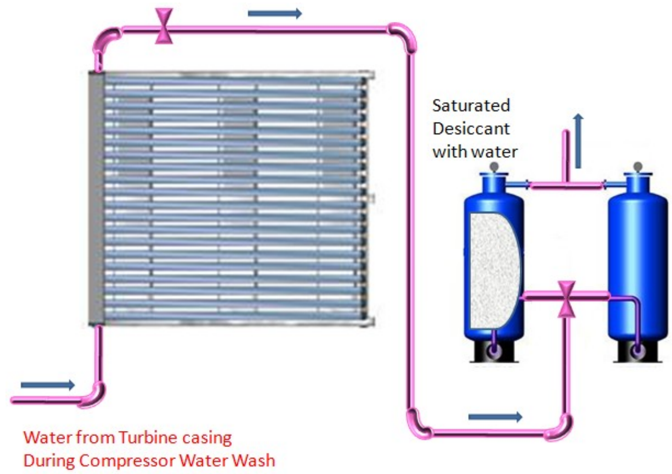

Figure-5 Heater-less Dryer Skid System

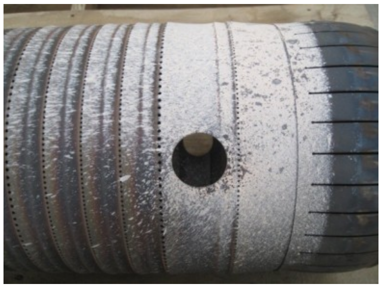

Figure No.6
White scale covering the combustion liner air passes.

Figure No.7
Air passes blocked by white scale on combustion liner.


Figure No.8
Melted and broken material of cross firing tube bodies.


Figure No.9
Broken and melted material from cross firing tube bodies.


Figure No.10
Cross firing tube air cooling passes blocked with white scale.


Figure No.11
Cross firing tube metals broken by quenching.


Figure No.12
White scale patterns sprayed on the transition piece.


Figure No.13
White scale element and burnout on first stage turbine nozzles bottom half.


Figure No.14
Signs of burnout on first stage turbine nozzles.


Figure No.15
Second stage turbine nozzles scaling the dents.

Figure No.16
First stage turbine nozzles bottom half, with signs of broken metal.

Figure No.17
Signs of broken metal and dents on first stage turbine nozzles upper half.

Figure No.18
Broken edges on first stage turbine bucket.

Figure No.19
Broken edges on first stage turbine bucket.

Figure No.20
Signs of dents on second stage turbine nozzles.

Figure No.21
Signs of dents and broken metals on second stage turbine bucket.

Figure No.22
Signs of dents and broken metals on second stage turbine bucket.

Figure No.23
Water trap valve cover and plunger covered with white solidified element (desiccant).

Figure No.24
Water trap valve body is covered with white solidified element (desiccant)

RECOMMENDATION

- Emphasizes the quality of commissioning and start-up check lists to ensure smooth and safe operation process.
- Install permanent non-return valve at the air extraction line.
- Conduct appropriate periodic preventive maintenance of the Heater-less Air Dryer System.

SUMMARY

The observed damage found in the turbine Hot Gas Path components resulted due to improper instrumentation interlock configuration and lack of quality commissioning checklist - between the online/offline compressor water wash motor operated valve - in addition to the lack of proper air dryer maintenance procedure, which resulted in a costly repair (material and manpower) within a timeframe of one month.

ACKNOWLEDGEMENTS

The author wish to gratefully acknowledge the contributions of the investigation committee and the R&D laboratory personnel for their contributions in the investigation, troubleshooting and analysis of the turbine failure caused by the water wash system blockage addressed above.

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