Gas Turbine Blade Failure Due To Hot Corrosion

by

Mohd. Nasrul Bin Mat Yusof

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the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
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(MECHANICAL ENGINEERING)

Approved by,

____
(Ms. Norlaili Bt. Amir)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD. NASRUL BIN MAT YUSOF

Abstract

This dissertation reported the result on the investigation of first stage gas turbine blade failure, which is due to hot corrosion. The objective of this project is to study the first stage gas turbine blade failure, to characterize the failure and to recommend the prevention methods for gas turbine blade failure. The proposed prevention methods are proper maintenance program and mitigation plan by installing scrubber and superheater. The problem encountered by gas turbine was that the mixture of air and fuel in the combustion contains contaminants of corrosion. This caused damages on the turbine blade that happened at high temperature such as loss of thickness at the blade tip and roughening of the surface in the vicinity of the platform. The beginning of this report shows how the gas turbine engine works and how the hot corrosion occurs. The experiments conducted on the sample of gas turbine blade failure were visual examination, scanning electron microscopy (SEM), X-ray diffraction (XRD), quantitative analysis of the base alloy and metallographic examination. The results were used to identify the causes of hot corrosion on the blade, characterize the materials of construction for the blade and suggest the prevention method to reduce hot corrosion from occurs. The blade failure sample studied was high pressure turbine blade from the Rolls-Royce Engine RB211 which failed in operation and obtained from X platform. The experiments conducted shown the evident of hot corrosion happened on the gas turbine blade. There are two type of hot corrosion been discussed which is hot corrosion type I and hot corrosion type II.

Acknowledgements

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

One of the advantages of gas turbine engine against other engines such as reciprocating engine is the great power-to-weight ratio and smaller counterparts of the same power. The main disadvantage of gas turbine is that they are expensive. This is because they spin at such high speeds and because of the high operating temperatures, designing and manufacturing gas turbines is a tough problem from both the engineering and materials standpoint. Gas turbines also tend to use more fuel when they are idling. One thing that makes gas turbines great for power plant is they prefer a constant rather than a fluctuating load.

Fuel classifications for gas turbines are listed in ASTM D 2880 Standard Specification for Gas Turbine Fuel Oils and ASTM D 1655 Standard Specification for Aviation Turbine Fuel [3] (Refer Appendix 1). The fuel system shall be operable with the normal fuel or any alternative or starting fuels. Gas should be dry at the turbine fuel nozzles to prevent over-temperature damage to the turbine due to burning condensate. The contaminants likely to be found in fuel gas depend on the kind of gas involved, such as natural gas, coke oven gas, water gas, producer gas, and refinery gas. The concentration of hydrogen sulfide, sulfur dioxide, sulfur trioxide, total sulfur, alkali metals, chlorides, carbon monoxide, and carbon dioxide will be specified so that proper precautions can be taken, if necessary, to prevent elevated-temperature corrosion of turbine hot gas-path components.

1.2 Problem Statement

The main concern of this project is to prevent the gas turbine blade failures due to hot corrosion from reoccurring. The information that was needed for this project was the gas composition inside the combustion chamber, materials selection for turbine blade and prevention method against hot corrosion. Most of the information must be obtained from the manufacturer itself such as data or log of operation. Other problem is in Universiti Teknologi PETRONAS does not has gas turbine engine in the lab for experimental. It needs to go to the manufacturer itself to experiment it. Beside that, they can provide clear view on the testing for the gas composition, material selection, and prevention method which currently used by them.

1.3 Objectives and Scope of Duty

In this FYP 2 continuing from the FYP 1, this project is about the study of the gas turbine blade failure. Here are the objectives of this project:

- To study the failure of first stage gas turbine blade as the effects of gas composition at combustion chamber to the turbine blade.
- To identify the causes due to hot corrosion on the gas turbine blade failure.
- To characterize the gas turbine blade failure
- To recommend the prevention method for gas turbine blade failure.

Through out this semester should be able to run the experimental on the sample of gas turbine blade failure. The experiments that will be conducted are visual examination, scanning electron microscopy (SEM), X-ray diffraction examination, quantitative analysis of the base alloy and metallographic examination.

CHAPTER 2

LITERATURE REVIEW & THEORY

2.1 Review on Past Researcher's Work

Rybnikov A.I, Getsov L.B and Leontiev S.A. studied the failure analysis of gas turbine blades. Different failures of blades made from superalloys may be observed during gas turbine plant testing and operation. The cause of these failures is usually identified both by metallographic methods (microstructural studies, fractograhpy, X-ray crystal analyses), bench and laboratory strength tests and by strength calculation methods, including non-conventional method [11].

M. R. Khajavi and M. H. Shariat studied on failure of first stage gas turbine blades. Gas turbine must exhibit a high level of resistance to the oxidizing and corrosive environment generated by the combustion gases and be resistant to any associated mechanical failure mechanism such as erosion. In this paper different types of hot corrosion with their microscopic characteristics are viewed, and a case study on the first stage blades of a (GE-F5) gas turbine presented [5].

2.2 Gas Turbine Process

Gas turbine comprises a compressor to which air is fed from the external environment so as to bring up the pressure. The air under pressure passes into a series of combustion chambers which terminate in a nozzle and into each of which an injector feeds fuel which is mixed with the air so as to form a combustible air mixture to be burned. The turbine converts the enthalpy of the gases combusted in the aforementioned combustion chamber into mechanical energy available for a user [6]. **Figure 1** shows the process in a gas turbine.

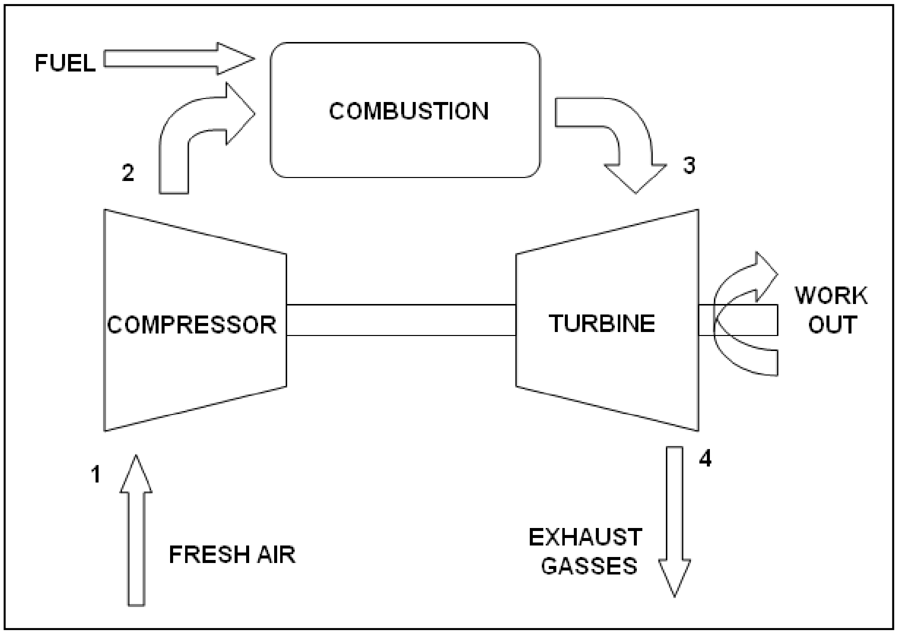


Figure 1: The process in a gas turbine

2.3 Failure of First Stage Gas Turbine Blades

In utility gas turbines the air and fuel encountered frequently contain corrosive contaminants that can cause serious hot corrosion problems. A wide range of fuel can be used in utility turbines (ranging from clean gas to crude oil) and these fuels can contain sulfur, sodium, potassium, vanadium, lead, and molybdenum as contaminants. [5]

The airborne pollutants entering with the inlet air depend on the turbine location, but include sodium, sulfur, chlorine and calcium. These impurities in the fuel and the air can lead to the deposition of alkali metal sulfates on the blade or vane surfaces, resulting in the hot corrosion attack.

When the salt arrives on a surface already covered with a protective oxide, there is initially no reaction. In order for accelerated oxidation to occur, the protective oxide must be destroyed. This can happen in four distinct ways. The first is the mechanical disruption of the oxide; i.e. by erosion, thermal cycling, and by elastic strain of the substrate putting the oxide in tension. A second method is by diffusion of sulfur through the oxide until chromium-rich sulfides form within the metal; later development of the external oxide or its reformation if it is mechanically removed, is inhibited. The third method is dissolution (or fluxing) of the protective oxide by the salts, and finally during ignition, a local reducing environment may form due to incomplete burning of fuel. Such a reducing atmosphere can damage the protective surface oxide layer, especially in the presence of contaminants such as Na_2SO_4.

2.3.1 Hot Corrosion

Hot corrosion may be defined as an accelerated corrosion, resulting from the presence of salt contaminants such as Na_2SO_4, NaCl, and V_2O_5 that combine to form molten deposits, which will damage the protective surface oxides.

Sodium sulphate is a well-known corrosive agent that is formed in the flame from sodium chloride or other sodium compounds and sulphur containing organic compounds, which are present in almost any fuel:

oxygen + sulphur + sodium = sodium sulphate (from air) (from fuel and/or sea salt)

On a thermodynamics basis, sodium chloride is unstable in the presence of even small concentrations of sulphur in an oxidizing environment; the following reaction has been proposed by DeCrescente and Bornstein.

$$2NaCl+SO_3+1/2O_2=Na_2SO_4+Cl_2$$

Of course other reactions may occur to form sodium sulphate (Na_2SO_4):

$$2NaCl+SO_3+H_2O=Na_2SO_4+2HCl$$

$$2NaCl+SO_2+O_2=Na_2SO_4+Cl_2$$

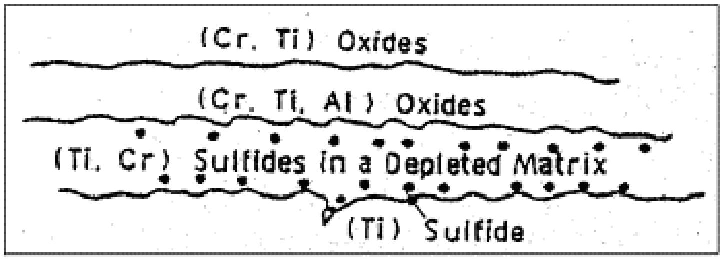
In general, the rate of attack increases with increasing amount of contaminant, although it generally reaches a saturation level above which there is little further effect if the amount of corrodent is increased further.

Two distinct forms of hot corrosion have been reported, high temperature (type I) and low temperature (type II). Various parameters may affect the development of these two forms, including alloy composition, gas composition and velocity, contaminant composition and fluxing rate, temperature and temperature cycles, thermo mechanical and erosion processes. It should be noted that the classification of the form of the attack (type I or type II) is primarily based on the morphology of the attack, and not the temperature.

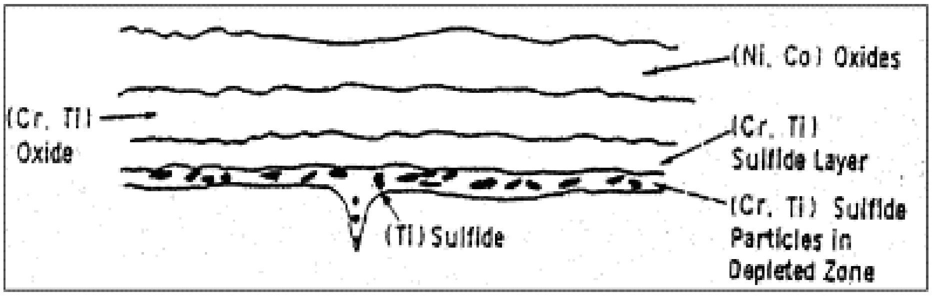
2.3.2 Hot Corrosion Type I

High temperature hot corrosion (HTHC) has been known since the 1950s. It is an extremely rapid form of oxidation that takes place at temperatures between 815 and 926 °C in the presence of sodium sulfate. Other impurities either in the fuel or in the air, such as vanadium, phosphorus, lead and chlorides can combine with sodium sulfate to form a mixture of salts with a lower melting temperature, thus broadening the range of attack. Potassium sulfate behaves similarly to sodium sulfate in regard to HTHC. Sulfur is released by the reduction of sodium sulfate. The sulfur diffuses inward and then reacts with chromium from the substrate to form chromium sulphides. As corrosion proceeds, and phase stability adjusts to changing chemistry, the sulphides are converted to complex unstable metal oxides and the sulfure thus released diffuses more deeply into the substrate where it forms more sulphides.

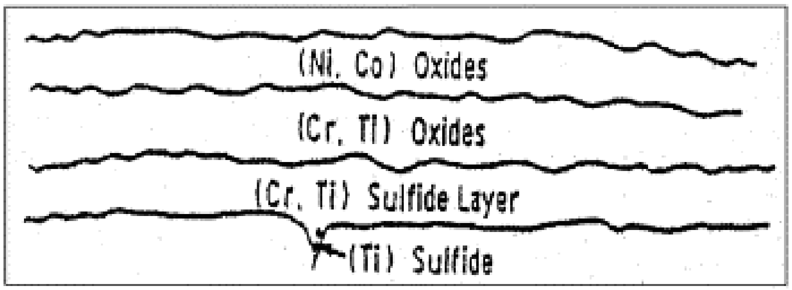
This type features intergranular attack, sulfide particles and a denuded zone of base metal. Using an electron beam microanalyzer, it is found that discrete sulfide particles of chromium and titanium are present in a region depleted in these elements, below the scale. The surface scales consist of chromium oxide (**Figure 2a**).



a) High temperature high corrosion



b) Transition corrosion



c) Low temperature hot corrosion

Figure 2: Schematic characterization of hot corrosion products

In a particular example, the reaction had started at the mid-airfoil location along the high pressure (concave) side of the blade. The high pressure side of the blade is a favorable location for the start of the type I reaction because sulfur rich gas entrained contaminant strikes this location first. In another study it was confirmed that HTHC occurs away from the edges (i.e. middle of airfoil). With increasing height from the platform, the extent of this type of corrosion increased.

2.3.3 Hot Corrosion Type II

Low temperature hot corrosion (LTHC) was recognized in the mid-1970s as a separate mechanism of corrosion attack. This attack can be very aggressive if the conditions are right. It takes place at temperatures in the 593–760 °C range and requires a significant partial pressure of SO_3. It is caused by low melting eutectic compounds resulting from the combination of sodium sulfate and some of the alloy constituents such as nickel ($NiSO_4$–Na_2SO_4). It seems likely that the amount of attack is related to the quantity of mixed salt present, which is stabilized by a high SO_3 pressure˙ The equilibrium Pso_3/Pso_2 ratio increases with decreasing temperature and it is generally accepted that this accounts for the observed high rates of corrosion at low temperatures. Furthermore, the SO_3/SO_2 equilibrium is very dependent on the presence of a catalyst, which may be present in operating turbines.

High rates of attack exhibiting the pitting morphology particularly for gas turbine components operating in a marine environment have been observed. Low temperature corrosion characteristically shows no denuded zone, no or little intergranular attack, and a layered type of corrosion scale and also no subscale sulfide particles.

Using an electron beam microanalyzer, it is found that the chromium and titanium sulfides form a continuous layer. The surface scale in this case contains only the relatively unprotective oxides of nickel and cobalt (**Figure2c**).

At the platform region, the temperature is usually lower than that seen by the airfoil and therefore these regions could be prone to type II hot corrosion attack. Another study reported that LTHC was confined mainly to the trailing and leading edge regions. With increasing height from the platform, the extent of this type of corrosion decreased.

2.3.4 Transition Type

It is worthwhile to mention that both of the temperature ranges given above are approximate, and depend on the compositions of the molten salts, the combustion gas composition, and the composition of the surface in contact with the salt (coating or the base metal). As mentioned before the classification of the form of the attack (type I or type II) is primarily based on the morphology of the attack, and not the temperature. Examples of type I attack, for example have been reported at metal temperatures as low as 700 °C. In practice there are features that have characteristics of both types of corrosion, hence the name transition hot corrosion (THC). Using an electron beam micro analyzer, it is found that the sulfides of chromium and titanium are increasingly agglomerated into large interconnecting sulfide networks and surface scale contains predominately the oxides of nickel and cobalt (**Figure 2b**).

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification and Flow Chart

The whole project will be carried out in two semesters. As for the first semester, the main goal is to study the gas turbine blade failure and the cause of the failure due to hot corrosion. The criteria that cover under the study are gas composition used in the combustion chamber, turbine blade materials and prevention method for the gas turbine blade failure. For this second semester is to run the experiments mentioned earlier and characterize the material used by the gas turbine blade. Then result from the experimental will be used to propose the prevention method to reduce hot corrosion from occur. The tasks that are to be completed are shown in the **Figure 3**.

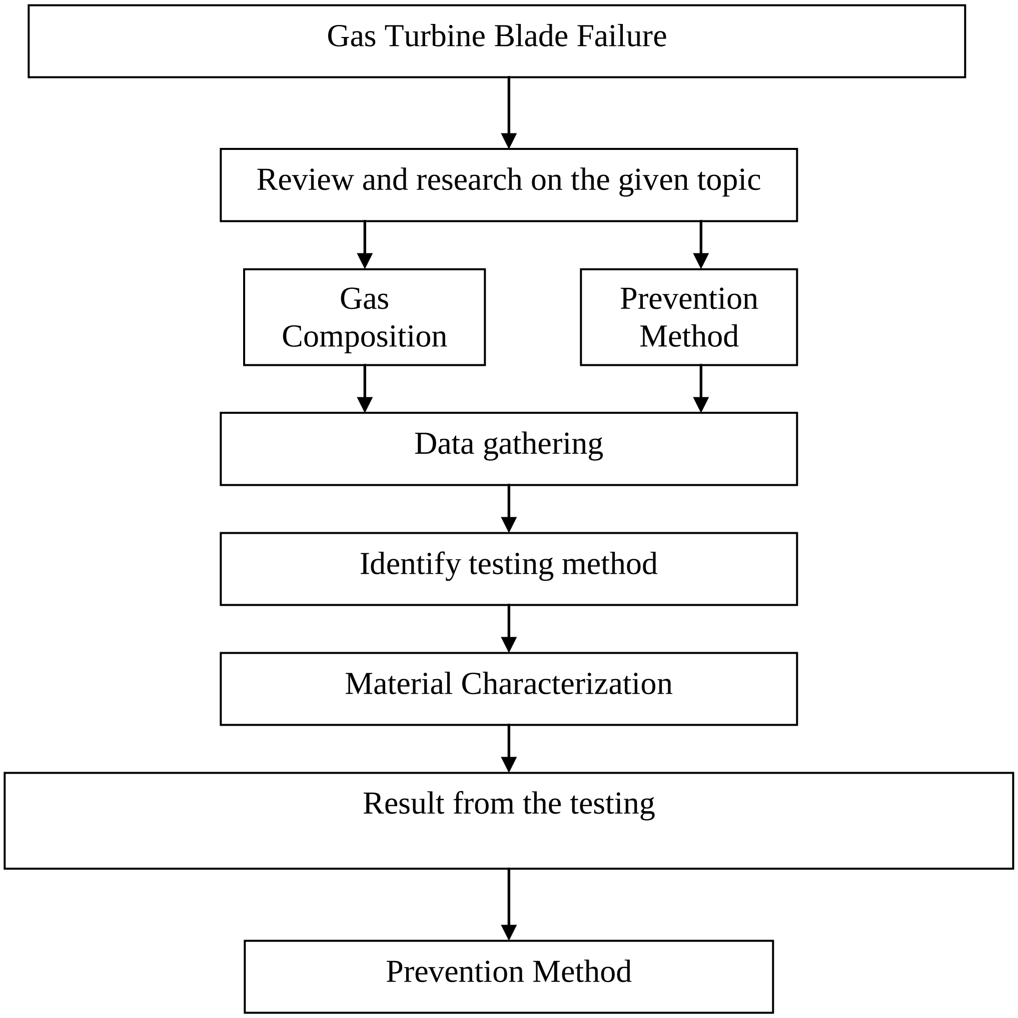


Figure 3: Flow chart shows the whole process

The whole process can be divided into 4 stages:

- Research and literature review stage
- Data gathering stage
- Testing stage
- Result Stage

3.1.1 Research and Literature Review Stage

Soon after the project's title was given, some researches on gas turbine blade failure and the prevention method are done which includes the internet websites, journals, and books. For example, there was a journal entitled 'Failure Analysis of Gas Turbine Blades by Rybnikov A.I., Getsov L.B., and Leontiev S.A..

3.1.2 Data Gathering Stage

Data gathering about gas turbine performance and operation have to get from the manufacturer itself. From this stage also identifying the testing method will be done in order to know the testing method that can be or currently used for gas composition in the combustion chamber, gas-to-liquid fuel ratio before entering the turbine, materials for turbine blade and prevention method for turbine blade failure. More research will be done for prevention method or can be obtain from the manufacturer.

3.1.3 Testing Stage

In this stage, the appropriate testing will be used for material characterization. This is to identify the causes due to hot corrosion on the blade and characterize the gas turbine blade material. (Refer to the flow chart above). Some specific tools will be required for this part. The testing that will be conducted are visual examination, scanning electron microscopy (SEM), X-ray diffraction examination, quantitative analysis of the base alloy and metallographic examination.

3.1.4 Result Stage

As the result, we can identify what are the causes due to hot corrosion on the gas turbine blade failure. We also can know what the material being used. Then can compare the result from other case studies. From the result of the testing, some prevention method will be proposed in order to prevent the gas turbine blade failure due to hot corrosion.

3.2 Table of Experiments

Table 1 below shows the list of experiments that were conducted and can be proposed for future work, and description of results obtained or should be achieved from each experiment.

Experiment	Feature	Example
1. Visual examination	- Loss of materials and thickness - Erosion	- Loss of thickness at the blade tip. - Roughening of the surface in the vicinity of the platform and at the trailing edge; broadening of the leading edge
2. Metallographic examination	Show three types: - Regions near the blade tip, type I was evident - Type II was dominant close to the platform - Areas that had a rough macroscopic surface	- Type I hot corrosion, grain boundary diffusion and subscale sulfide particles are seen - Type II hot corrosion, no grain boundary diffusion and subscale sulfide particles are seen - High temperature hot corrosion without surface scale (i.e. HTHC-erosion). - Low temperature hot corrosion without surface scale (i.e. LTHC-erosion).
3. Scanning Electron Microscopy (SEM)	- Revealed the presence of Ni, Cr, Al, Ti, Co, S, V, Zn, Si and Fe elements in the scale	- X-ray map of different elements at a region close to platform, on the convex side
4. Quantitative examination of the base alloy	- Quantometery analysis of the base alloy.	0.003% P, 0.004% S, 0.02% Zr, 0.05% Mg, 0.09% C, 0.44% Fe, 0.99% Nb, 1.94% Mo, 3.2% W, 3.7% Ti, 4.0% Al, 8.18% Co, 15.92% Cr, and balance Ni

Experiment	Feature	Example
5. X-ray diffraction examination	- Showed that the principle constituent in the deposits was generally spinel compounds	- These compounds, mainly about midway along the length of the blade, consisted of iron oxides - On the platform were Cr2O3, NiO, V2O3, TiO2 and FeNi. Both Cr2O3 and NiO have a greenish color

Table 1: Table of experiments

3.3 Gas Turbine Blade Failure

This is the high pressure turbine blade failure from the Rolls-Royce Engine RB211 that studied in this experiment shown in **Figure 4** below.

Front **Back**

Figure 4: The gas turbine blade failure

3.4 Cutting the Sample

From the sample of gas turbine blade failure, there are 3 areas that will be named as Sample A, B and C. The machine used to cut the sample from the blade is Electro Discharge Machine (EDM) Wire Cut (see **Figure 7**) in Building 16 room 16-00-05. The picture of the each sample and its location on the blade are as previewed below **(Figure 5 and 6).** Sample A had experienced type I hot corrosion because has greenish appearance. Whereas sample B had been exposed to type II hot corrosion because has whiteness appearance [5]. Sample C is taken from the area with no corrosion appearance. The size for each sample is about 1 cm x 1 cm with small thickness.

 Sample A (greenish appearance)	 Sample B (whiteness appearance)	 Sample C (no corrosion appearance)

Figure 5: Samples

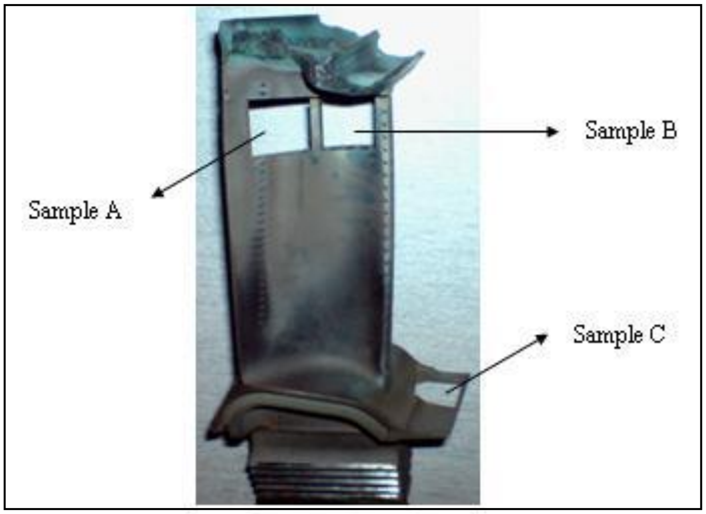


Figure 6: Sample location on the blade failure

Figure 7: Electro Discharge Machine (EDM) Wire Cut

CHAPTER 4

Results and Discussion

4.1 Gas Composition

The gas composition used in the Rolls-Royce Engine RB211 from X platform is stated as below. From **Table 2**, there are many type of gas composition being used in the gas turbine engine.

Gas Composition	Percentage, %
C1	81.74
C2	8.09
C3	3.54
IC4	0.82
NC4	0.73
IC5	0.23
NC5	0.12
C6	0.39
C7	0.10
C8	0.02
C9	0.00
C10	0.00
C12	0.00
N2	0.62
CO2	3.59
H2O	0.01
TOTAL	100

Table 2: Gas composition

4.2 Visual Examination

In the vicinity of the platform, the convex side had whiteness appearance and concave side had a greenish and whiteness appearance. Loss of materials and thickness (that may have been caused by interaction of different mechanisms such as hot corrosion and creep or fatigue) was observed at the top of the blade and green coloration on the concave side (**Figures 8**). The trailing edge was distorted in the shape of small cups and cones. The leading edge, towards the platform was broadened. From the evidence at the edges, it may be concluded that erosion has occurred. On both sides of the blade, there is also evidence of impact by small particles which indicated by red circle (**Figures 9**). Eliaz and et al. [2], have reported that a greenish color is a macroscopic feature of HTHC. This is in contradiction with the results of metallographic and X-ray mapping examination in the present work. Some color change was also seen near regions where LTHC had occurred.

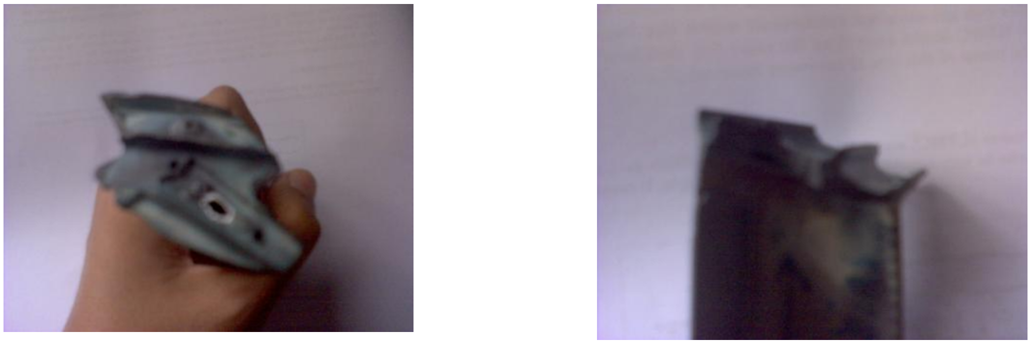


Figure 8: Loss of thickness at the blade tip.

Figure 9: Impact by small particles

4.3 Scanning Electron Microscopy (SEM)

4.3.1 Metallographic Examination

This experiment was done at Building 17, ground floor, room 13 (**Figure 10**). Metallographic examination showed three different types of features, depending on the location of the specimen. Generally in the regions near the blade tip, type I was evident. Type II was dominant at the concave region **(Figure 11).** The third type of features belongs to those areas that had a rough macroscopic surface.

Figure 10: Scanning Electron Microscopy (SEM) Machine

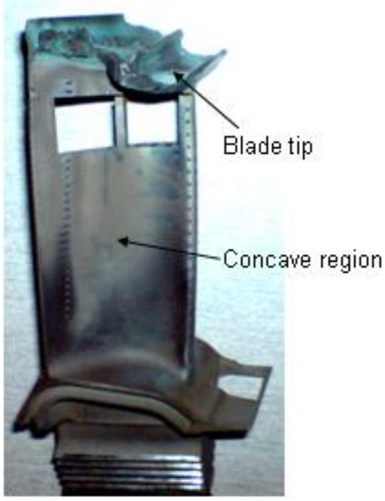


Figure 11: Blade tip and concave region

In this experiment, it was expected to capture the picture of grain boundary diffusion on the Sample A and B. If the grain boundary diffusion presented in the sample means that it having type I hot corrosion **(Figure 12)**. If not the sample having type II hot corrosion **(Figure 13).**

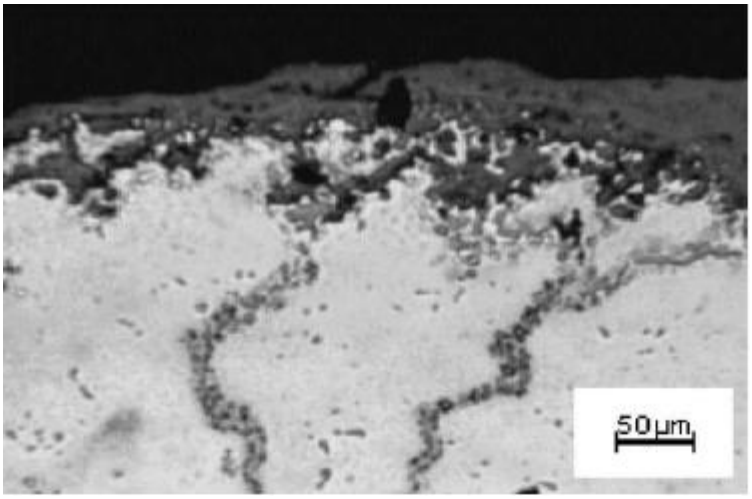


Figure 12: Type I hot corrosion, grain boundary diffusion is seen.

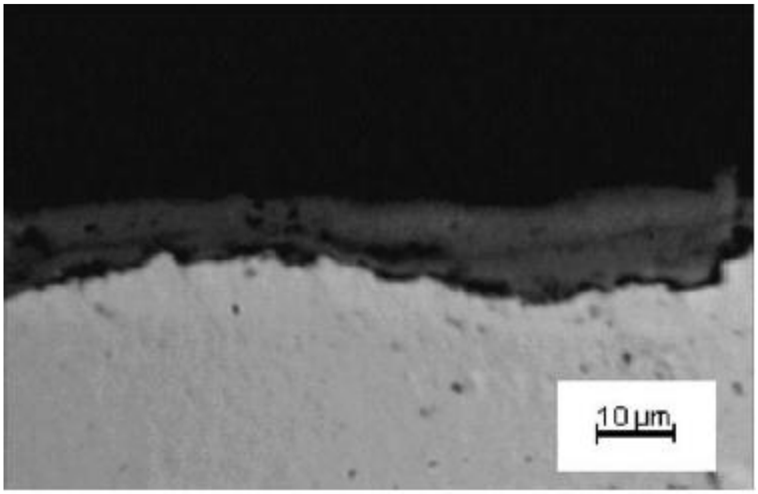


Figure 13: Type II hot corrosion, no grain boundary diffusion is seen

The result cannot be achieved due to the limitation work of SEM machine. The machine can only get the picture of the surface for each sample **(Figure 14 and 15)**. From these two pictures, we can obviously see the difference from the pattern of its surface. Sample A showed that it has more concentrated corrosion than the Sample B. This must be due to high temperature that had been experienced.

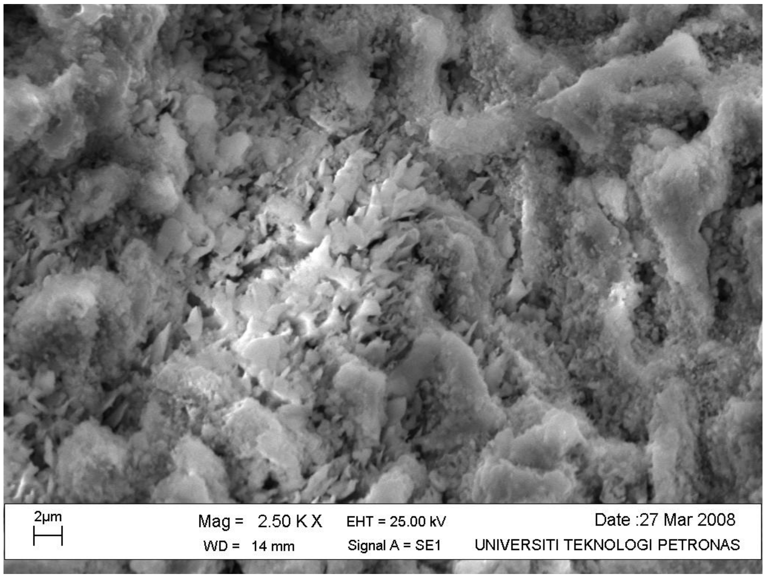


Figure 14: Type I hot corrosion, Sample A.

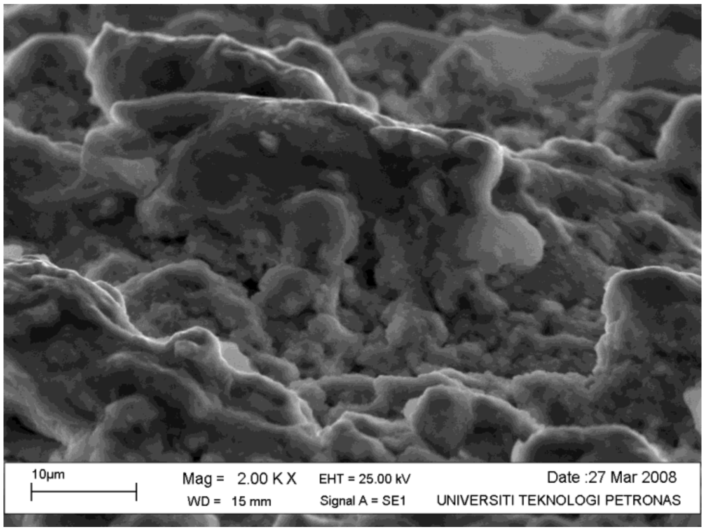


Figure 15: Type II hot corrosion, Sample B.

4.3.2 Energy Dispersive X-ray (EDX)

Using EDX analysis Sample A and B revealed the presence of C, O, Al, Cr, Co and Ni elements in the scale. From this result there was evident of coating. The EDX analysis showed the two different graphs for Sample A (**Figure 16**) and Sample B (**Figure 17**) material composition. **Table 3** below shows the table of material composition for both samples.

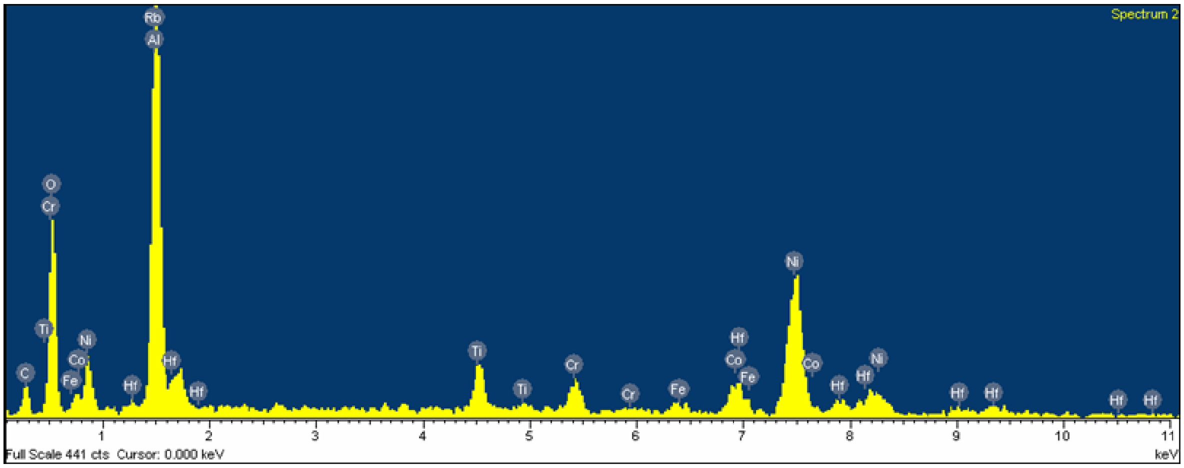


Figure 16: Graph of material composition for Sample A

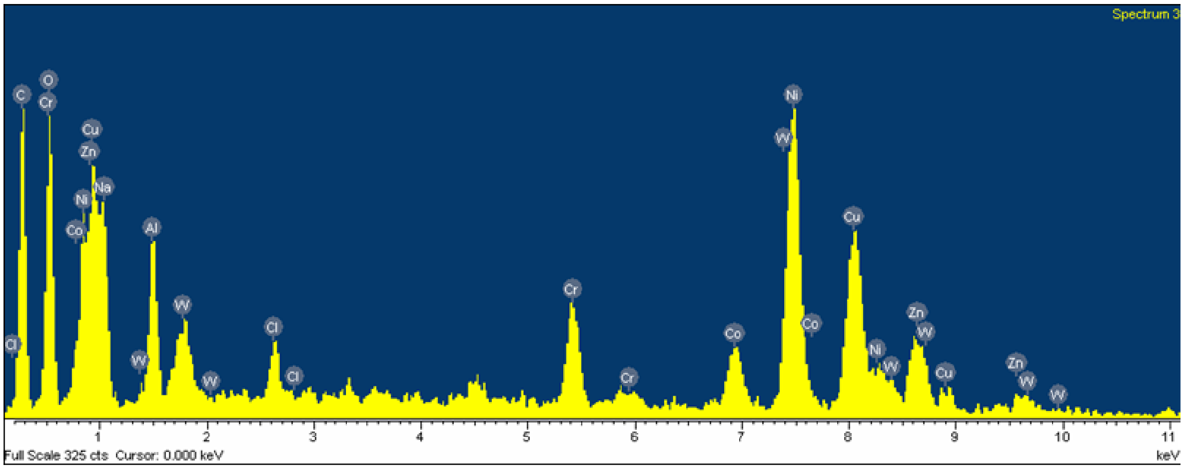


Figure 17: Graph of material composition for Sample B

Sample A

Element	Weight%	Atomic%
C	14.59	26.49
O	**35.03**	**47.75**
Al	18.88	15.26
Ti	**2.31**	**1.05**
Cr	**2.03**	**0.85**
Fe	**0.76**	**0.30**
Co	2.88	1.06
Ni	**15.92**	**5.91**
Rb	2.96	0.75
Hf	4.64	0.57
Totals	100.00	100.00

Sample B

Element	Weight%	Atomic%
C	39.11	60.28
O	**22.95**	**26.55**
Na	2.23	1.80
Al	2.59	1.78
Cl	0.66	0.34
Cr	**2.14**	**0.76**
Co	1.84	0.58
Ni	**11.53**	**3.63**
Cu	8.91	2.60
Zn	4.77	1.35
W	3.28	0.33
Totals	100.00	100.00

Table 3: Table of material composition for Sample A and Sample B

From this two results show that there are presence of contaminants in compound composition which are Cr_2O_3, NiO, TiO_2 and FeNi. Both Cr_2O_3 and NiO have a greenish color [5]. The red color from **Table 2** shows the corrosive element. This indicated that Sample A has more corrosive elements than Sample B.

4.4 Quantitative Examination of the Base Alloy

In order to get the result on the quantitative examination of the base alloy, some preparation has to be done first. Here is the preparation on the Sample C. This preparation is done at Building 16 room 16-00-11.

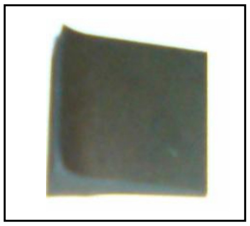


Figure 18: Sample C

Sample C first will mounted by the Auto Mounting Press machine. The material that used together with Sample C for mounting is Phenolic Thermosetting Powder which is in green colour.

Auto Mounting Press Machine

Phenolic Thermosetting Powder

Sample C (Mounted)

Figure 19: Preparation for Sample C

After the mounting process, the Sample C has to be polished by Grinder/Polisher machine.

Figure 20: Grinder/Polisher Machine

After that, the Sample C will be cleaned by alcohol, nital and water before dried with hair drier. Then the sample will be brought to the Scanning Electron Microscopy (SEM) lab for quantitative examination of the base alloy. The quantitative examination of the base alloy is repeated the metallographic examination and EDX analysis. The result is stated below.

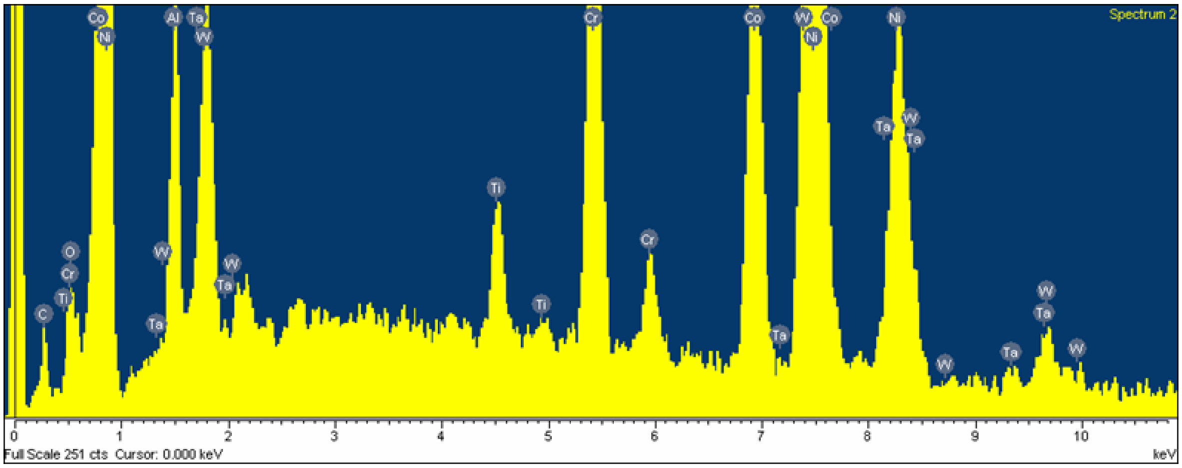


Figure21: Graph of material composition for Sample C

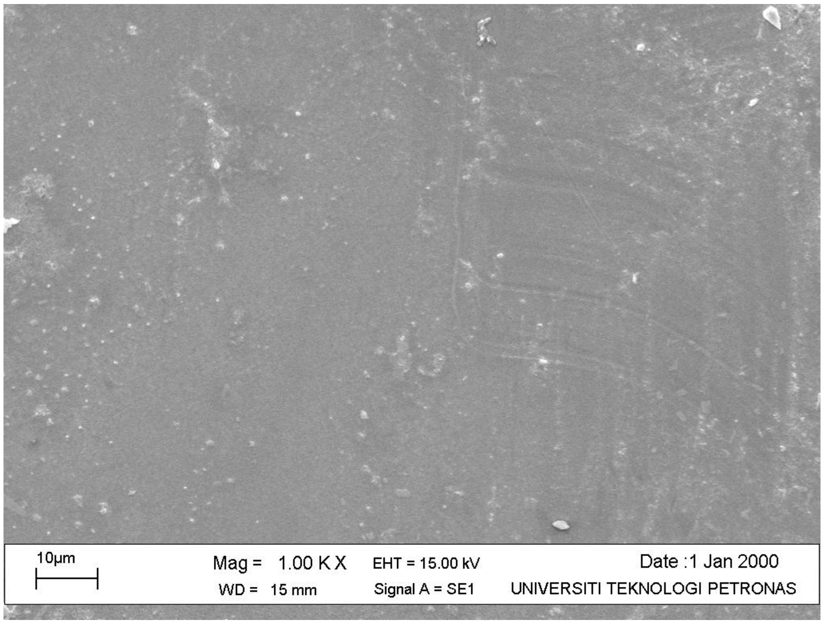


Figure 22: Surface of Sample C

Element	Weight %	Atomic %
C	5.84	22.64
O	1.57	4.58
Al	5.28	9.11
Ti	1.36	1.32
Cr	8.63	7.74
Co	9.70	7.67
Ni	**55.17**	**43.78**
Ta	2.76	0.71
W	9.69	2.46
Totals	100.00	100.00

Table 4: Table of material composition for Sample C

From this result shows that the surface for Sample C which has no corrosion appearance is very smooth and clean. The material composition is lesser than the Sample A and Sample B. This blade is mostly Ni based alloy because has the highest percentage in weight and atomic element. This is shown by red color in **Table 4**. However the value of carbon is too high for each sample. It should lower than 0.1% in weight. In EDX analysis, carbon concentration is not accurate. EDX cannot be used to quantify carbon.

CHAPTER 5

Recommendation

5.1 Prevention Method

5.1.1 Proper Maintenance Program

The gas turbines need to oblige a proper maintenance program such as 4K, 8K and overhaul. 4K means after the gas turbine had run for 4000 hour, a maintenance process will be done on the gas turbine. This is same happen to 8K which is 8000 hour of operation time. The tables located at the **Appendix 2** indicate items that must be performed to maintain the gas turbines at a minimum level of operational readiness. Due to the many variations in engine age and design that may be encountered, not all of the items listed will be applicable for all facilities. In addition, the timing of the maintenance schedule for major maintenance items can vary significantly based on the engine design and operating conditions. All maintenance must be performed in accordance with the engine manufacturer's published maintenance schedule and procedures for the specific engine installed. Maintenance actions included in the **Appendix 2** are for various modes of operation, subsystems, or components. **Table 2-1** provides maintenance information for gas turbines in standby mode. **Table 2-2** provides maintenance information for gas turbines operating in short-term activities. Short-term activities are those scheduled maintenance activities with a frequency of 1,000 hours run time or less. **Table 2-3** provides maintenance information for gas turbines operating in long-term activities. Long-term activities are those scheduled maintenance activities with a frequency greater than 1,000 hours run time.

5.2 Mitigation Plan

Some mitigation plan can be done to the fuel process system to reduce the amount of liquid going into the engine such as by installing scrubber or superheater.

5.2.1 Scrubber

Scrubber systems are a diverse group of air pollution control devices that can be used to remove particulates and/or gases from industrial exhaust streams. Traditionally, the term "scrubber" has referred to pollution control devices that used liquid to "scrub" unwanted pollutants from a gas stream. Recently, the term is also used to describe systems that inject a dry reagent or slurry into a dirty exhaust stream to "scrub out" acid gases. Scrubbers are one of the primary devices that control gaseous emissions, especially acid gases. The exhaust gases of combustion may at times contain substances considered harmful to the environment, and it is the job of the scrubber to either remove those substances from the exhaust gas stream, or to neutralize those substances so that they cannot do any harm once emitted into the environment as part of the exhaust gas stream. The diagram for gas turbine – scrubber can be seen from **Appendix 3**.

5.2.2 Superheater

The superheater function is to reheat the fuel to increase its temperature. From that the amount of liquid in the fuel can be reduced. The superheater can be installed inside the gas turbine between the combustion chamber and the turbine. The diagram for the installation area can be seen from **Appendix 4**.

CHAPTER 6

CONCLUSION

As the conclusion, this project manage to fulfill the four objectives which to study on the first stage of gas turbine blade failure, to identify the causes due to hot corrosion on the gas turbine blade failure, to characterize the gas turbine blade failure and to recommend some of prevention methods. The experiments that been conducted through out this semester are visual examination, scanning electron microscopy (SEM), X-ray diffraction examination, quantitative analysis of the base alloy and metallographic examination. However, for X-ray diffraction examination cannot be conducted due to not flatted shape of each sample. For the testing for the gas composition and gas-to-liquid fuel ratio, it is hard to do in UTP because there is no gas turbine in the laboratory. In the other hand, UTP’s laboratory did not have testing kit like bore scope and light source that will be used to inspect inside the gas turbine. The result from all experiments showed that this blade suffered from both of hot corrosion. Type II hot corrosion was dominant.

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APPENDIX

8.0 Appendix

Appendix 1: ASTM D 2880 and ASTM D 1655

a) ASTM D 2880 Standard Specification for Gas Turbine Fuel Oils

1. Grade 0-GT includes naphtha, Jet B, and other light hydrocarbon liquids that characteristically have low flash points and low viscosities compared to those of kerosene and fuel oils.

2. Grade 1-GT is a light distillate fuel suitable for use in nearly all gas turbines.

3. Grade 2-GT is a distillate that is heavier than Grade 1- GT and it can be used by gas turbines not requiring the clean burning characteristics of Grade 1-GT. Fuel heating equipment may be required by the gas turbine depending on the fuel system design or the ambient temperature conditions or both.

4. Grade 3-GT may be a distillate that is heavier than Grade 2-GT, a residual fuel oil that meets the low ash requirements or a blend of a distillate and a residual fuel oil. If Grade 3-GT is specified, the gas turbine will require fuel heating in almost every installation.

5. Grade 4-GT includes most residuals and some topped crude. Because of the wide variation and lack of control of properties, the gas turbine manufacturer should be consulted about acceptable limits on properties.

b) ASTM D 1655 Standard Specification for Aviation Turbine Fuel

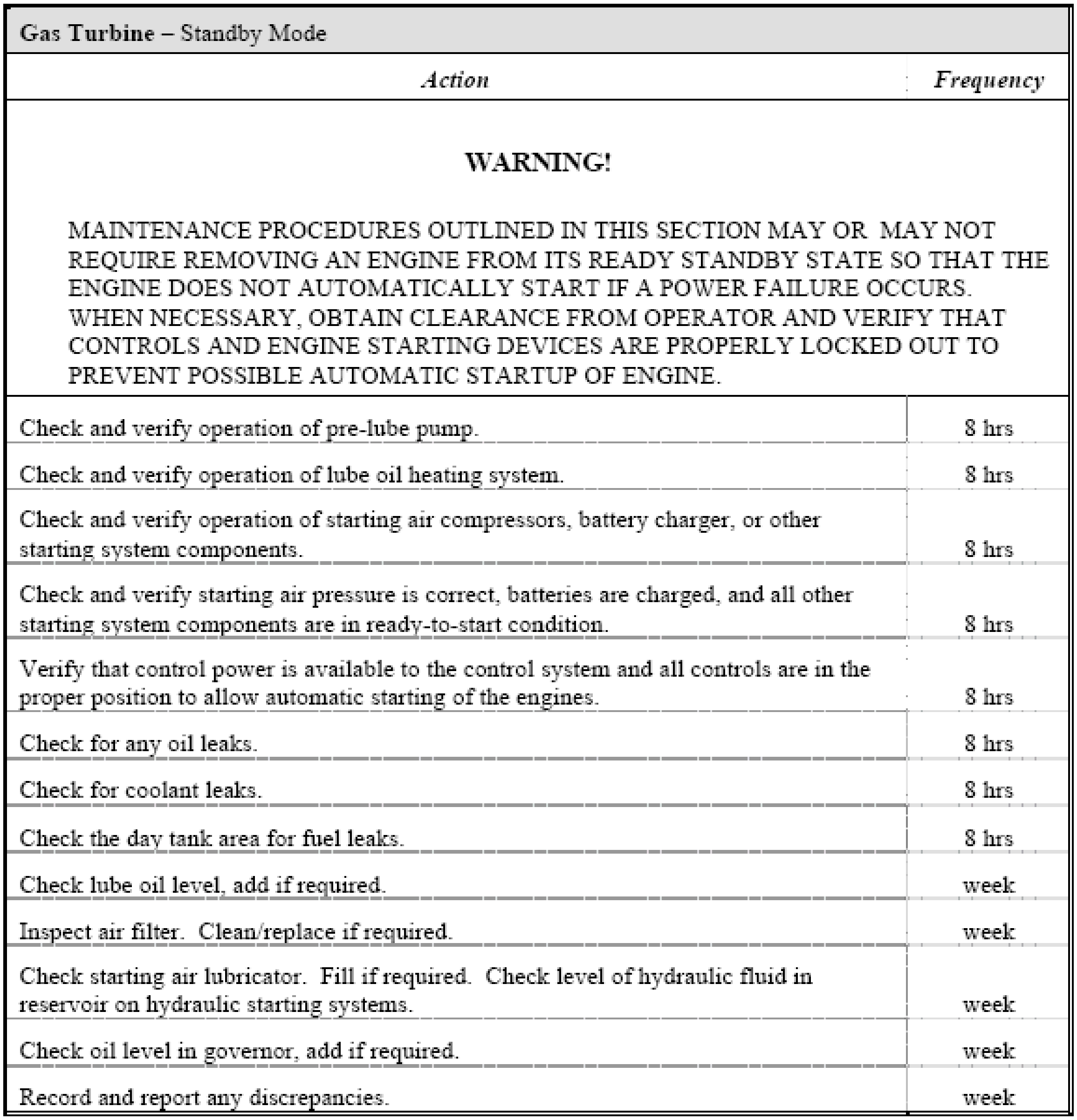
1. Jet A and Jet A-1 are relatively high flash point distillates of the kerosene type. They represent two grades of kerosene fuel that differ only in freezing point.

2. Jet B is a relatively wide boiling range volatile distillate.

Appendix 2: Maintenance Activities

Table 2-1: Gas Turbine – Standby Mode

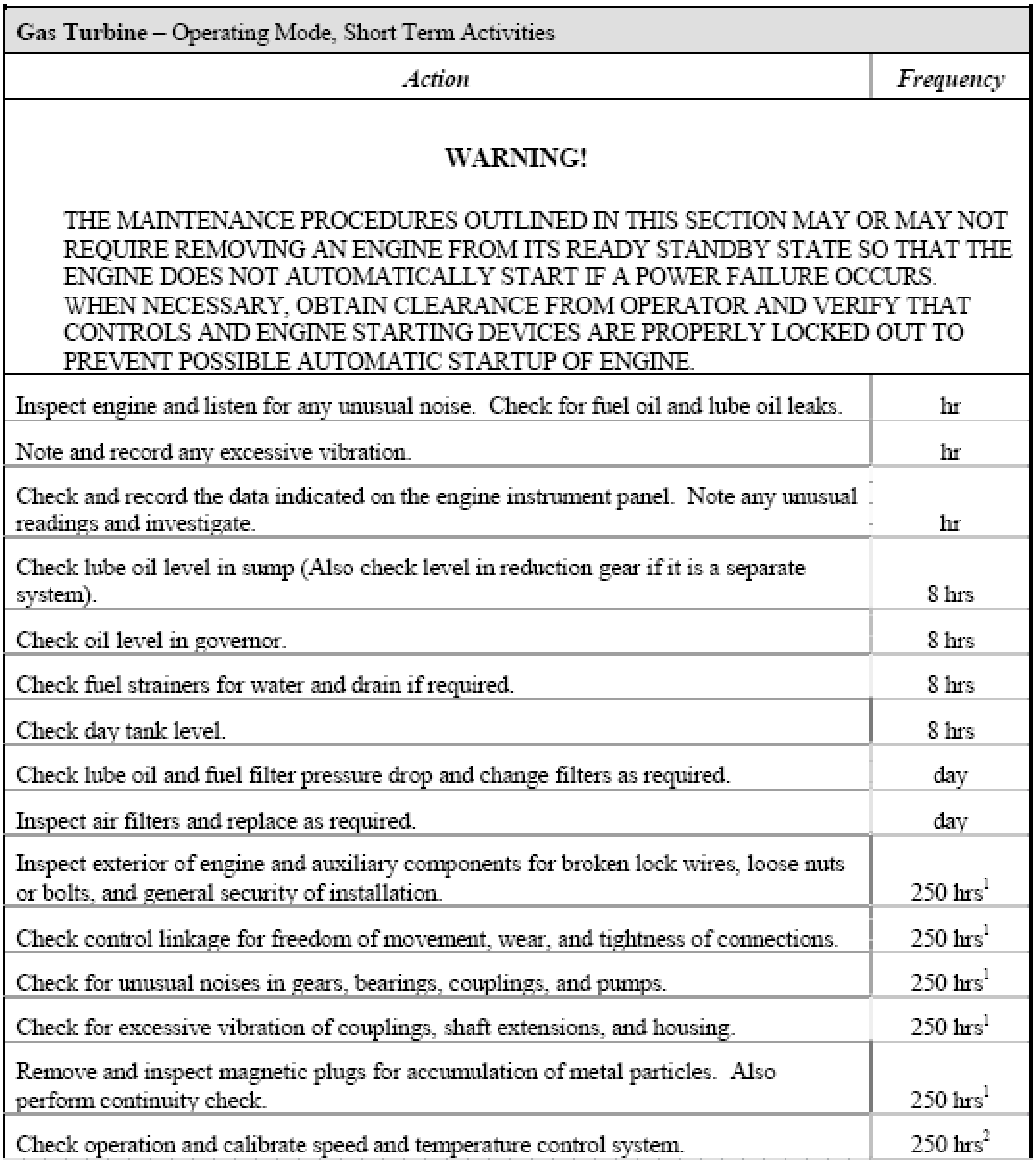
(Source: http://www.usace.army.mil/publications/armytm/tm5-692-1/c-4.pdf)



Gas Turbine – Standby Mode

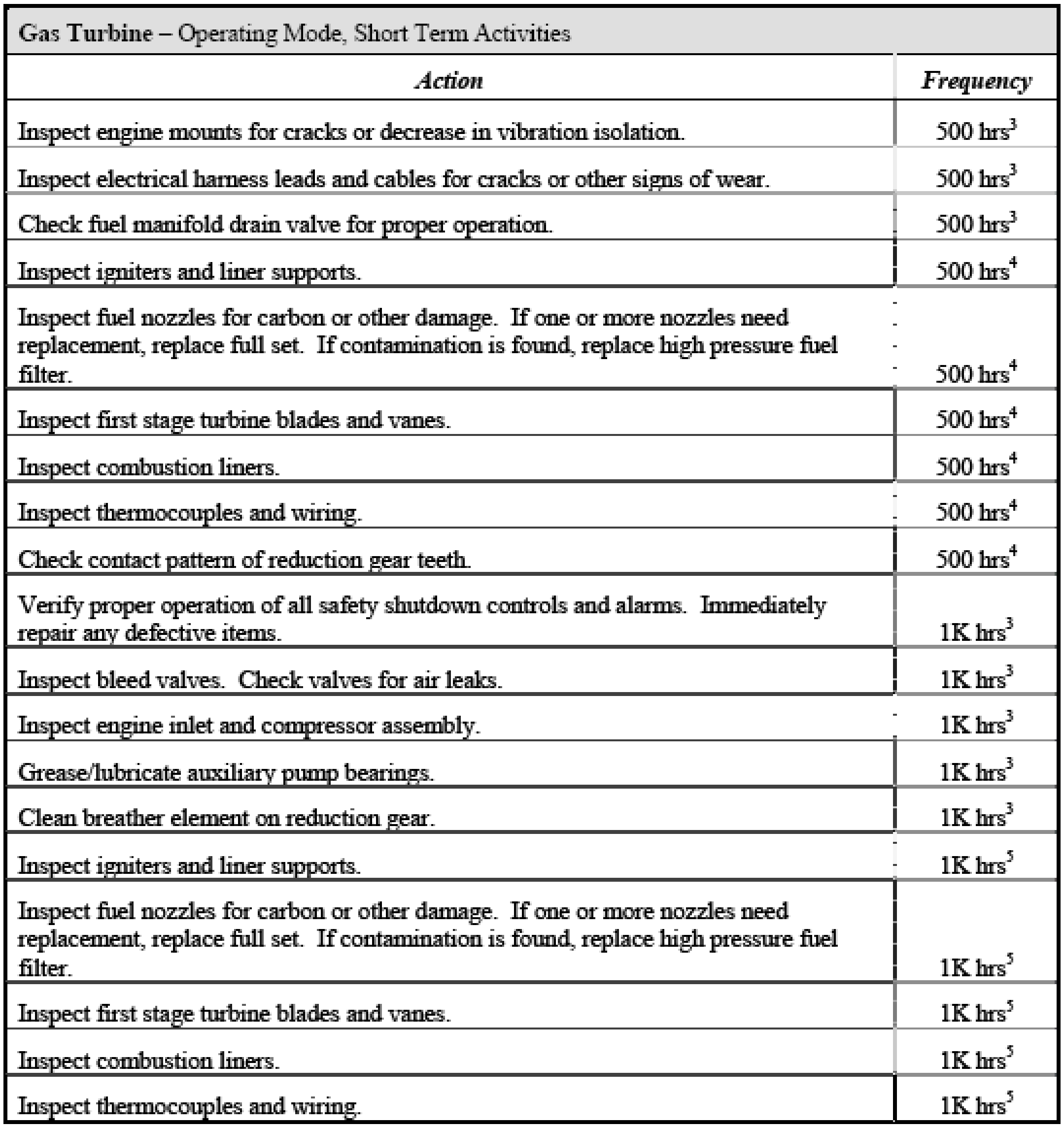
Action	*Frequency*
WARNING! MAINTENANCE PROCEDURES OUTLINED IN THIS SECTION MAY OR MAY NOT REQUIRE REMOVING AN ENGINE FROM ITS READY STANDBY STATE SO THAT THE ENGINE DOES NOT AUTOMATICALLY START IF A POWER FAILURE OCCURS. WHEN NECESSARY, OBTAIN CLEARANCE FROM OPERATOR AND VERIFY THAT CONTROLS AND ENGINE STARTING DEVICES ARE PROPERLY LOCKED OUT TO PREVENT POSSIBLE AUTOMATIC STARTUP OF ENGINE.	
Check and verify operation of pre-lube pump.	8 hrs
Check and verify operation of lube oil heating system.	8 hrs
Check and verify operation of starting air compressors, battery charger, or other starting system components.	8 hrs
Check and verify starting air pressure is correct, batteries are charged, and all other starting system components are in ready-to-start condition.	8 hrs
Verify that control power is available to the control system and all controls are in the proper position to allow automatic starting of the engines.	8 hrs
Check for any oil leaks.	8 hrs
Check for coolant leaks.	8 hrs
Check the day tank area for fuel leaks.	8 hrs
Check lube oil level, add if required.	week
Inspect air filter. Clean/replace if required.	week
Check starting air lubricator. Fill if required. Check level of hydraulic fluid in reservoir on hydraulic starting systems.	week
Check oil level in governor, add if required.	week
Record and report any discrepancies.	week

Table 2-2: Gas Turbine – Operating mode, short term activities



Gas Turbine – Operating Mode, Short Term Activities	
Action	*Frequency*
WARNING! THE MAINTENANCE PROCEDURES OUTLINED IN THIS SECTION MAY OR MAY NOT REQUIRE REMOVING AN ENGINE FROM ITS READY STANDBY STATE SO THAT THE ENGINE DOES NOT AUTOMATICALLY START IF A POWER FAILURE OCCURS. WHEN NECESSARY, OBTAIN CLEARANCE FROM OPERATOR AND VERIFY THAT CONTROLS AND ENGINE STARTING DEVICES ARE PROPERLY LOCKED OUT TO PREVENT POSSIBLE AUTOMATIC STARTUP OF ENGINE.	
Inspect engine and listen for any unusual noise. Check for fuel oil and lube oil leaks.	hr
Note and record any excessive vibration.	hr
Check and record the data indicated on the engine instrument panel. Note any unusual readings and investigate.	hr
Check lube oil level in sump (Also check level in reduction gear if it is a separate system).	8 hrs
Check oil level in governor.	8 hrs
Check fuel strainers for water and drain if required.	8 hrs
Check day tank level.	8 hrs
Check lube oil and fuel filter pressure drop and change filters as required.	day
Inspect air filters and replace as required.	day
Inspect exterior of engine and auxiliary components for broken lock wires, loose nuts or bolts, and general security of installation.	250 hrs[1]
Check control linkage for freedom of movement, wear, and tightness of connections.	250 hrs[1]
Check for unusual noises in gears, bearings, couplings, and pumps.	250 hrs[1]
Check for excessive vibration of couplings, shaft extensions, and housing.	250 hrs[1]
Remove and inspect magnetic plugs for accumulation of metal particles. Also perform continuity check.	250 hrs[1]
Check operation and calibrate speed and temperature control system.	250 hrs[2]

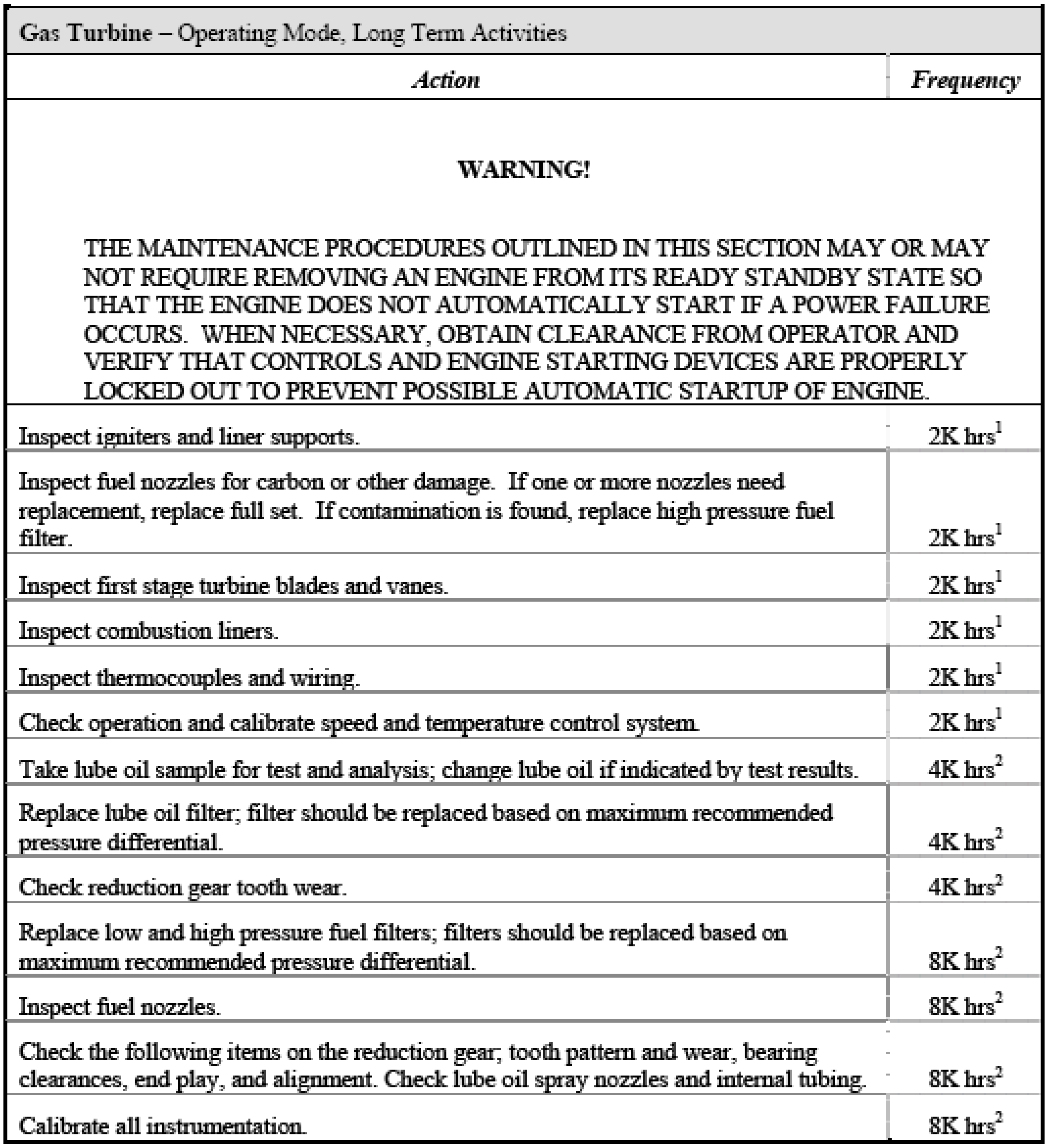
Table 2-2: Gas Turbine – Operating mode, short term activities (Continued)



Gas Turbine – Operating Mode, Short Term Activities

Action	*Frequency*
Inspect engine mounts for cracks or decrease in vibration isolation.	500 hrs[3]
Inspect electrical harness leads and cables for cracks or other signs of wear.	500 hrs[3]
Check fuel manifold drain valve for proper operation.	500 hrs[3]
Inspect igniters and liner supports.	500 hrs[4]
Inspect fuel nozzles for carbon or other damage. If one or more nozzles need replacement, replace full set. If contamination is found, replace high pressure fuel filter.	500 hrs[4]
Inspect first stage turbine blades and vanes.	500 hrs[4]
Inspect combustion liners.	500 hrs[4]
Inspect thermocouples and wiring.	500 hrs[4]
Check contact pattern of reduction gear teeth.	500 hrs[4]
Verify proper operation of all safety shutdown controls and alarms. Immediately repair any defective items.	1K hrs[3]
Inspect bleed valves. Check valves for air leaks.	1K hrs[3]
Inspect engine inlet and compressor assembly.	1K hrs[3]
Grease/lubricate auxiliary pump bearings.	1K hrs[3]
Clean breather element on reduction gear.	1K hrs[3]
Inspect igniters and liner supports.	1K hrs[5]
Inspect fuel nozzles for carbon or other damage. If one or more nozzles need replacement, replace full set. If contamination is found, replace high pressure fuel filter.	1K hrs[5]
Inspect first stage turbine blades and vanes.	1K hrs[5]
Inspect combustion liners.	1K hrs[5]
Inspect thermocouples and wiring.	1K hrs[5]

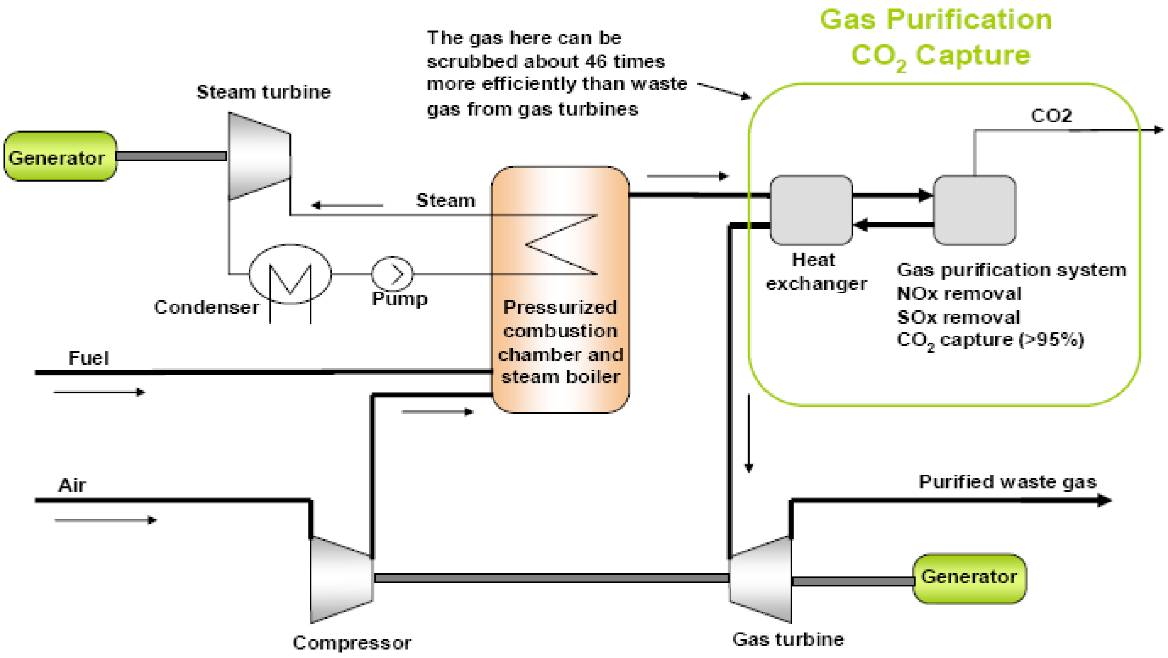
Table 2-3: Gas Turbine – Operating mode, long term activities



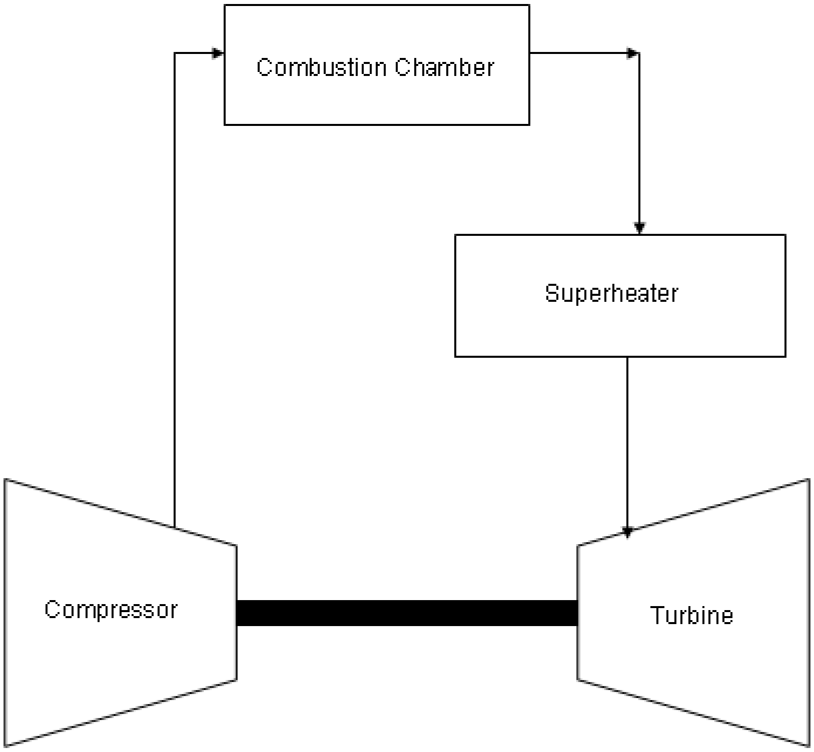
Gas Turbine – Operating Mode, Long Term Activities	
Action	***Frequency***
WARNING! THE MAINTENANCE PROCEDURES OUTLINED IN THIS SECTION MAY OR MAY NOT REQUIRE REMOVING AN ENGINE FROM ITS READY STANDBY STATE SO THAT THE ENGINE DOES NOT AUTOMATICALLY START IF A POWER FAILURE OCCURS. WHEN NECESSARY, OBTAIN CLEARANCE FROM OPERATOR AND VERIFY THAT CONTROLS AND ENGINE STARTING DEVICES ARE PROPERLY LOCKED OUT TO PREVENT POSSIBLE AUTOMATIC STARTUP OF ENGINE.	
Inspect igniters and liner supports.	2K hrs[1]
Inspect fuel nozzles for carbon or other damage. If one or more nozzles need replacement, replace full set. If contamination is found, replace high pressure fuel filter.	2K hrs[1]
Inspect first stage turbine blades and vanes.	2K hrs[1]
Inspect combustion liners.	2K hrs[1]
Inspect thermocouples and wiring.	2K hrs[1]
Check operation and calibrate speed and temperature control system.	2K hrs[1]
Take lube oil sample for test and analysis; change lube oil if indicated by test results.	4K hrs[2]
Replace lube oil filter; filter should be replaced based on maximum recommended pressure differential.	4K hrs[2]
Check reduction gear tooth wear.	4K hrs[2]
Replace low and high pressure fuel filters; filters should be replaced based on maximum recommended pressure differential.	8K hrs[2]
Inspect fuel nozzles.	8K hrs[2]
Check the following items on the reduction gear; tooth pattern and wear, bearing clearances, end play, and alignment. Check lube oil spray nozzles and internal tubing.	8K hrs[2]
Calibrate all instrumentation.	8K hrs[2]

Appendix 3: The Diagram for Gas Turbine – Scrubber

(Source:http://www.sargas.no/files/Sargas%20WG1%20CAPTURE%20ZEP%20%20mai %2006%20_2_.pdf)



Appendix 4: Superheater Installation



Appendix 5: Suggested Milestone for the First Semester of 2 Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	SW	EW
1	Selection of Project Topic	🟪	🟪														
	-Propose Topic																
	-Topic assigned to students																
2	Preliminary Research Work			🟪	🟪												
	-Introduction																
	-Objective																
	-List of references/literature																
	-Project planning																
3	Submission of Preliminary Report					17/8											
4	Project Work					🟪	🟪	🟪	🟪								
	-Reference/Literature																
	-Practical/Laboratory Work																
5	Submission of Progress Report									21/9							
6	Project work continue									🟪	🟪	🟪	🟪				
	-Practical/Laboratory Work																
7	Submission of Interim Report													26/10			
8	Oral Presentation														🟨	6/11	

Appendix 6: Suggested Milestone for the Second Semester of 2 Semester Final Year Project

No.	**Detail/ Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**SW**	**EW**
1	Project Work Continue		🟪	🟪	🟪												
	-Practical/Laboratory Work																
2	Submission of Progress Report 1				17/2	🟨											
3	Project Work Continue					🟪	🟪	🟪	🟪								
	-Practical/Laboratory Work																
4	Submission of Progress Report 2									29/3							
5	Project work continue									🟪	🟪	🟪	🟪				
	-Practical/Laboratory Work																
6	Submission of Dissertation Final Draft													26/4			
7	Oral Presentation														🟨	🟨	
8	Submission of Project Dissertation (Hardbound)																31/5

SW Study Week
EW Exam Week