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Data collection of failures of main components in GPP

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1 TABLE OF CONTENTS

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3 ABBREVIATIONS

EDS	Energy Dispersive Spectroscopy
FRP	Fibre Reinforced Plastic
GPP	Geothermal Power Plant
ID	Internal Diameter
IP	Indonesia Power
PGE	Pertamina Geothermal Energy
SEM	Scanning Electron Microscopy
SEWWGL	Star Energy Geothermal Wayang Windu Limited
XRD	X-Ray Diffractometry

4 Abstract

Reliability of Geothermal Power Plants (GPP) component is an important aspect to be considered to keep the stability of electricity supply. GPPs supply base load electricity, which means the plants supposed to operate continuously. It is important to maintain the performance of the component so that the output of the GPPs component does not goes outside the specified performance rating. Proper strategy needs to be formulized to keep the plant performance, and for this reliability data is important to prevent GPPs component failure.

Reliability information of some of the main geothermal power plant component are laid out in this report. The component covered here are separator, steam turbine, electrical generator, transformer, Gas Removal System, and the piping networks connecting these components. Data collected for each components are its specification, failure information such as location and its cause if there is any, its effect to the component, and the maintenance action done by operator to rectify the situation. Root-cause analysis is then performed based to get insight on main cause of the failure.

Reliability data are taken from several geothermal power plants in Indonesia such as Kamojang, Salak, and Wayang Windu geothermal field. Historical data from the beginning of the plant operation are taken for consideration. These information can be used as lessons in maintaining GPP reliability, especially in Indonesia.

5 THE OBJECTIVE OF THIS DOCUMENT

Within the GEOCAP project this project deliverable describes the reporting on failures in GPP. This document describes the way of data collection, and presents data collected from publication or about failures frequency, failure mode and root cause analysis (if any) in GPP components.

6 FAILURES IN GPP

Asset Integrity services are delivered throughout the lifetime of a plant. Examples of services that can be delivered are shown in Figure 1. Before a plant is built, a design is made, e.g. by the OEM. A client buying a geothermal plant wants to ensure that the design is profound and fulfils the clients requirements, e.g. in terms of electrical and heat output, but also in terms of structural integrity as described in applicable norms. (Stam, et al. 2017).

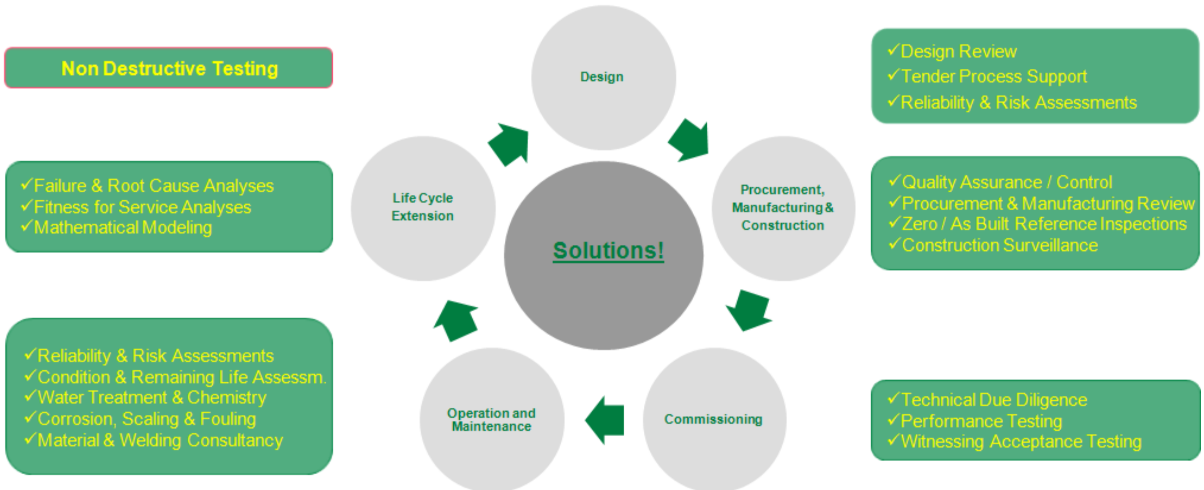


Figure 1 Asset integrity services throughout the lifetime of a plant

In order to assess the plant (or component) condition, estimate residual life and give recommendations, a staged approach consists of (Stam, et al. 2017):

- In general: Project Management (organize, co-ordinate and supervise the activities.
- Stage I Plant Review Activities
- Stage II NDT Inspections
- Stage III Final Reporting

6.1 Stage I Plant review

The goal of Stage I is to determinate the preliminary condition of the plant and to identify critical components in terms of life extension. This is divided in three main areas of expertise: mechanical, civil and electric condition assessment of specified parts. Based on the results of the plant review, an inspection program is defined to assess the condition of components that have been found critical or suspected, and those components which condition is unknown due to lacking historical information or specific operational conditions. This inspection program is part of Stage II. The site activities that are part of Stage I include:

- Gathering and reviewing design data (drawings) and historical data (inspection reports, operational process parameters, maintenance reports etc.
- Interviews with involved plant engineers
- Break down of installation/assets in components (material identification, design parameters, design or as built dimensions, construction details like welds)
- Evaluation of condition, based on received historical data
- Identification of active damage mechanisms and (root) causes of failures per component
- identification of criticality in terms of safety, reliability, performance
- Identification of critical components based on design, historical data and experience with similar equipment, and weaknesses in design
- During the Stage 1 site visit, an external visual inspection of specified parts will be performed (Walk down). Pictures will be taken in order to register the visual condition of parts and equipment.

Figure 2 shows a breakdown of a geothermal power plant, which might be helpful in determine the several parts of the GPP to be analysed and inspected.

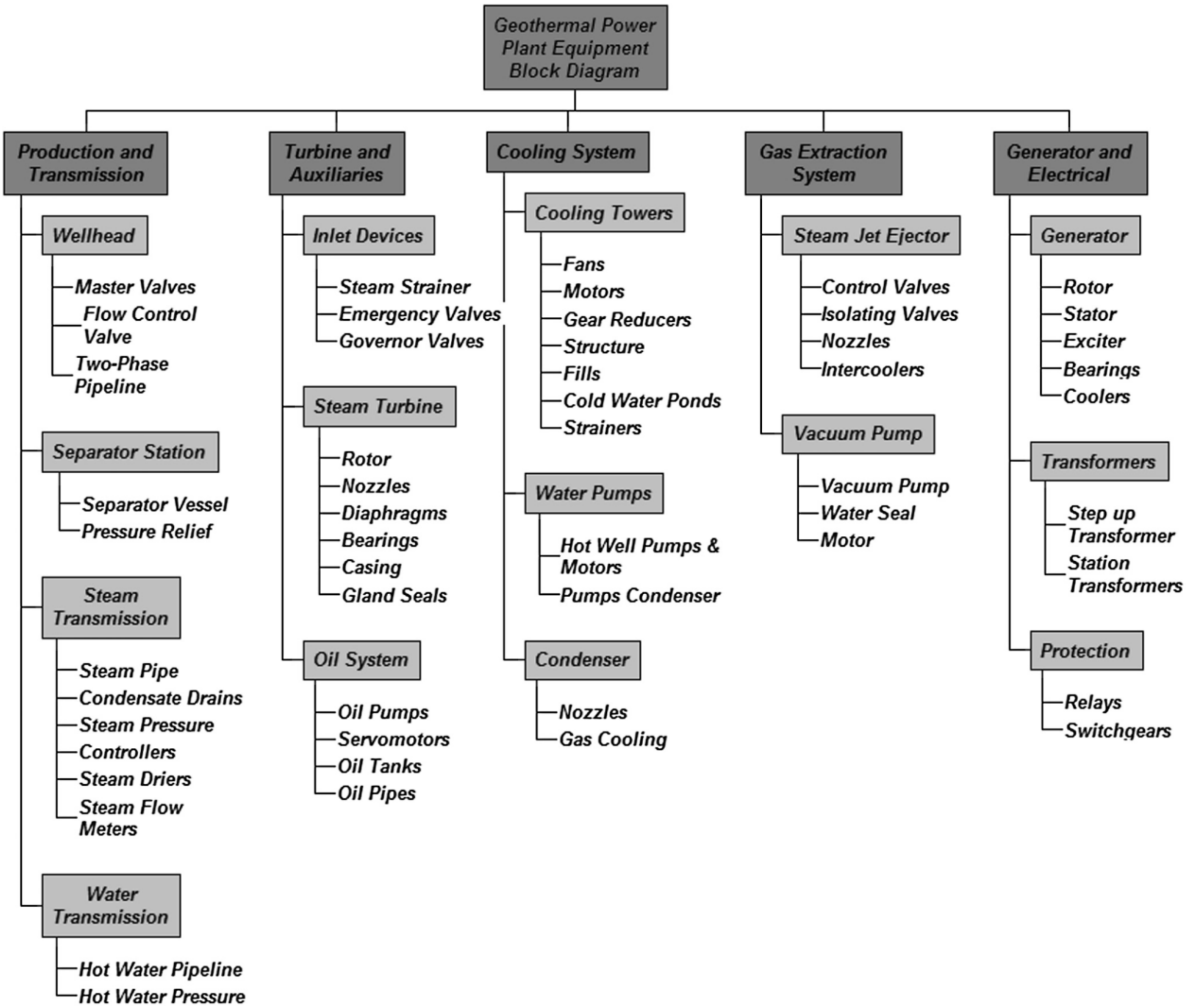


Figure 2 Geothermal power plant analysis structure showing the various components

6.2 Stage II NDT Inspections

Based on the results of Stage I, a detailed inspection, testing and measuring program can be conducted if necessary, in order to complete the results of Stage 1 inspection. The test program describes which tests or measurements are needed in order to get a complete picture of the assets, based on VT, MT and UT (i.e. non-volumetric) inspection techniques, for determining the condition and estimate remaining life. An example of a test program is shown in Figure 3.

Steam line, Unit #4 , #5				
component	**detail**	**inspection item**	**technique**	**interval (yrs)**
turbine stop valves	-spindle -valve mating surface -valve seat -internal surface -strainer	-straightness, wear, surface damage -cracks, wear -cracks, wear -cracks -erosion, wear	VIS MT+VIS MT+VIS MT VIS	4 to 8
turbine control valve	spindles valve mating surface valve seats linkage (cantilever) housing	-straightness, wear, surface damage -cracks, wear -cracks, wear -wear -cracks in internal surface	VIS MT+VIS MT+VIS VIS MT	4 to 8
nozzle boxes (control stage)	nozzles nozzle box	-erosion -cracks	VIS MT	4 to 8
curtis wheel (control stage)	blades balance holes in rotor disk	-rivets of shroud -FOD -cracks -cracks	UT VIS MT/ET MT	4 to 8
diaphragms	diaphragm unit	-guide vanes (FOD, cracks) -welds of guide vanes (erosion) -deflection of diaphragm	MT+VIS VIS VIS	4 to 8
rotor blades	blade	-erosion of leading edge (last stages) -cracks (all blades) -blade foot (last stages)	VIS MT/ET MT	2 4 to 8 4 to 8
labyrinth seals of diaphragms and rotor	labyrinth seals	-wear	VIS	4 to 8
rotor	all diameter transitions	-flange and all other diameter transitions -grooves -seal area -blade grooves (only possible after removal of blades)	MT MT MT + VIS MT/UT	4 to 8
gland seals	labyrinth seals springs below seal teeth	-wear -fixation -check for movement and broken springs	VIS VIS VIS	4 to 8
casing	inner surface outer surface	-wall thickness transitions -diaphragm grooves -gland carrier grooves	MT MT MT	4 to 8
casing bolts	bolts	-cracks in transition thread to shaft -local reduction of area in shaft	MT+VIS VIS	4 to 8

MT = magnetic particle testing
VIS = visual inspection
UT = ultra sonic testing (e.g PE, TOFD, PA)
ET = eddy current testing
all turbine parts should be cleaned by glass pearl blasting prior to NDT

Figure 3 Example of test program (NDT activities) resulting from Stage I activities

6.3 Stage III Final Reporting

The report will several aspects for describing the failure in the database. The following aspects thereby should be taken into account, and in Figure 4, on page 12, a example of a template for the database has been given.

- Present condition of inspected components with details of tests done, and results to justify the conclusion
- Recommendation for refurbishment of parts including method and further test that are required to be done in the future
- Recommendation for replacement of parts, which have to be done immediately
- Recommendation for renewal of parts for improvement of performance
- Recommendation for regular tests recommended to be done in the future and the time schedules for these tests
- Material required being ready for replacement, to enable destructive tests, which are needed to be done to evaluate condition of parts, should be informed in advance in your program schedule.
- Recommendation for parts required to be ready for replacement as an insurance spare
- Suggestion regarding modification and replacement schedule, as well as renovation proposal.

General information	
Type of installation	Dry steam / flash / binary cycle / ORC
Component	(e.g. turbine)
Failure ID number	(to be entered by database manager)
Code	(e.g. KKS-code, is something in use in Indonesia?)
Year	Year when failure was evident
Source	Reference to failure report
Plant Info	
Company / plant / unit	(e.g. Patuha unit 1)
Operating hours since	(e.g. 100,000 hrs)
System / component	(e.g. turbine blade, L-0)
Type	
Operational conditions	at failure location according to design
Operating pressure / temperature	On location of failure
Medium / flow velocity	e.g. steam pressure, composition, etc.
Sampling	
Sample location	Location of sampling (as specific as possible)
Sample material	
Sample dimensions	
Diagnosis	
Shape of failure	E.g. fatigue, creep, corrosion, erosion, scaling,..
Location of failure	
Cause of failure	To be extracted from report
Advise	To be extracted from report

Figure 4 Example datasheet failure reporting GPP

In the following three figures (Figure 5, Figure 6 and Figure 7) a example of a failure report has been filled in:

General information	
Type of installation	Single Flash
Component	Demister Rupture Disk
Failure ID number	
Code	BS&B / S90
Year	2016
Source	Laporan Gangguan / Kerusakan Peralatan Nomor : 004/ KIT.05.04/ LHD / 2016
Plant Info	
Company / plant / unit	PT. PLN (Persero) / PLTP Lahendong / Unit II
Operating hours since	72,648.16 hours
System / component	Demister / Rupture Disk
Type	Single Flash – Condensing Turbine
Operational conditions	
Operating pressure / temperature	12.2036 Bar gauge / 174,4 °C
Medium / flow velocity	Steam / 148.5 ton/h
Sampling	
Sample location	
Sample material	316 SS
Sample dimensions	Diameter of 3”
Diagnosis	
Shape of failure	Rupture, explode
Location of failure	1.2550628 , 124.8230258
Cause of failure	The part could not handle the overload pressure of steam due to system encountered a unit blackout
Advise	Prevent a unit blackout and keep the system controlled

Figure 5 Failure case #1

General information	
Type of installation	Single Flash
Component	Gear Reducer of Fan Cooling Tower A
Failure ID number	
Code	SN (3000 0711 D69036 7.91)
Year	2016
Source	Laporan Gangguan / Kerusakan Peralatan Nomor : KIT.05.04 / LHD / 2016
Plant Info	
Company / plant / unit	PT. PLN (Persero) / PLTP Lahendong / Unit II
Operating hours since	72,758.46 hours
System / component	Fan Cooling Tower / Gear Reducer
Type	Single Flash – Condensing Turbine
Operational conditions	
Operating pressure / temperature	
Medium / flow velocity	Lubricating oil / -
Sampling	
Sample location	
Sample material	
Sample dimensions	
Diagnosis	
Shape of failure	Oil leakage
Location of failure	1.2550628 , 124.8230258
Cause of failure	The lifetime of its oil seals and failure on the bearing due to overheated
Advise	Replace the part with the new one and do maintenance on it periodically

Figure 6 Failure case #2

General information	
Type of installation	Single Flash
Component	Drain Valve of Main Stop Valve B
Failure ID number	
Code	SAPAG / AR 5316 W
Year	2015
Source	Laporan Gangguan / Kerusakan Peralatan Nomor : 077/ LHD / 2015
Plant Info	
Company / plant / unit	PT. PLN (Persero) / PLTP Lahendong / Unit II
Operating hours since	111,232.34 hours
System / component	Main Stop Valve / Drain Valve
Type	Single Flash – Condensing Turbine
Operational conditions	
Operating pressure / temperature	
Medium / flow velocity	Main steam / -
Sampling	
Sample location	
Sample material	Casting Iron
Sample dimensions	Drain Valve - DN25
Diagnosis	
Shape of failure	Part stacked and can't be moved
Location of failure	1.2550628 , 124.8230258
Cause of failure	Corrosion and Scalling
Advise	Maintain the part periodically to prevent corrosion and scalling and also extend the lifetime of part

Figure 7 Failure case #3

A more extensive overview of failure data is given in the following chapters for various elements in the GPP:

Indonesia Failure Data (chapter 7)

- Separator, Demister and Flash Tank
- Piping
- Turbine
- Condenser
- Pump
- Cooling Tower
- Generator
- Trafo
- Gas Removal System

International Failure Data (chapter 8)

- Piping
- Turbine
- Gas Removal System

7 INDONESIA FAILURE DATA

1. SEPARATOR, DEMISTER AND FLASH TANK

Plant information					
Operator of GPP	Indonesia Power	Indonesia Power	Indonesia Power	Indonesia Power	Indonesia Power
Field name-Number of unit	Kamojang-Unit 2	Salak-Unit 3	Salak-Unit 3	Salak-Unit 3	Salak-Unit 3
Operating hours	-	-	-	-	-
Type of GPP	Dry steam condensing system	Single flash condensing system	Single flash condensing system	Single flash condensing system	Single flash condensing system
Component information					
Component/System	Drain valve at separator	Separator	Scrubber	Demister	Strainer
Type	-	-	Cyclone	-	-
Year of installation	1987	-	-	-	-
Year of replacement	2008	-	-	-	-
Lifetime	-	-	-	-	-
Design & operating pressure	10 bara	-	-	-	-
Design & operating temperature	205 °C	-	-	-	-
Max. allowable & actual flow rate	-	-	-	-	-

Medium	Dry steam or superheated steam	Two phase fluids	Steam	Steam	Steam
Diagnosis					
Year of failure evident		2004-2005	2004-2005	2004-2005	
Field observation/Laboratory analysis		1. Visual inspection 2. Material testing & analysing: a. SEM b. EDS c. XRD	1. Visual inspection 2. Material testing & analysing: a. SEM b. EDS c. XRD	1. Visual inspection 2. Material testing & analysing: a. SEM b. EDS c. XRD	1. Visual inspection 2. Material testing & analysing: a. SEM b. EDS c. XRD
Failure mode		Chemical materials deposit: SiO_2, NaCl, and $FeCO_3$	Chemical materials deposit, dominated by Fe and S	Chemical materials deposit, dominated by Fe and severe surface corrosion	Deposit in the steam strainer was classified into: • Smooth particles • In the form of plaques and particle unification • Combination of them
Failure location		The inlet, outlet, inner shell, bottom side and internal element in separator	The inlet, outlet, inner shell, bottom side and internal element in scrubber	The steam inlet side and inner shell, also on the demister element holder	Interior side of the strainer
Failure cause		Separator was not effective at filtering out Si, Na, Ca, and S	Chemical reaction between Fe cation from all components	Steam carried particles	Chemical reaction between Fe cation from all components

			built in iron material and O^- and C^- anions from steam		built in iron material and O^- and S^- anions from steam
Failure effect		Decline in separation efficiency	Decline scrubber performance	Decline efficiency of capturing water in steam	Decline efficiency of steam cleaning by filter out the solid particles
Mitigation					
Mitigation		-		Change the 6 mm corroded holder material with 8 mm without changing the material	

Plant information					
Operator of GPP	Indonesia Power	Indonesia Power	Indonesia Power	Indonesia Power	Indonesia Power
Field name-Number of unit	Kamojang-Unit 2	Kamojang-Unit 2	Kamojang-Unit 2	Kamojang-Unit 2	Kamojang-Unit 2
Operating hours	-	-	-	-	-
Type of GPP	Dry steam condensing system	Dry steam condensing system	Dry steam condensing system	Dry steam condensing system	Dry steam condensing system
Component information					
Component/System	Separator	Separator	Demister	Demister	Demister
Type	Static cyclone	Static cyclone	Vertical drum	Vertical drum	Vertical drum
Year of installation	-	-	-	-	-

Year of replacement	-	-	-	-	-
Lifetime	-	-	-	-	-
Design & operating pressure	10 bar abs	10 bar abs	11 bara (design) / 6.5 bara (operating)	11 bara (design) / 6.5 bara (operating)	11 bara (design) / 6.5 bara (operating)
Design & operating temperature	205 °C	205 °C	161 °C (operating)	161 °C (operating)	161 °C (operating)
Max. allowable & actual flow rate	-	-	400 ton/h	400 ton/h	400 ton/h
Capacity	-	-	19.5 m^3	19.5 m^3	19.5 m^3
Medium	Dry steam or superheated steam	Two phase fluids	Steam	Steam	Steam
Diagnosis					
Year of failure evident	1993	2007-2008	1993	2008	2008
Field observation/Laboratory analysis	-	-	-	-	-
Failure mode	Broken	Unknown	Broken	Unknown	Broken
Failure location	Drain valve (seal packing)	Flash tank (2007), drain valve (2008)	Drain (seal packing)	Drain (drain trap, drain valve, gland valve)	Drain (element plate)
Failure cause	-	-	-	-	-
Failure effect	-	-	-	-	-
Mitigation					
Mitigation	Replaced with a new one	Replaced	-	Replaced	Replaced

2. PIPING

Plant information		
Operator of GPP	Pertamina Geothermal Energy	Star Energy Geothermal Wayang Windu Ltd.
Field name-Number of unit	Kamojang-Unit IV	Wayang Windu-Unit 1 and 2
Operating hours	-	-
Type of GPP	Dry steam condensing system	Single flash condensing system
Component information		
Component/System	Elbow pipe of steam pipeline in production well KMJ-X7	Condensate reinjection pipe
Material Grade/Type	API 5L Grade B	API 5L Grade B
Diameter	10.75" of OD	16" of OD
Nominal Thickness	9.271 mm (Sch. 40)	12.7 mm (Sch. 40)
Thermal Insulator	Calcium Silicate 5"	-
Year of installation	2009	2000
Lifetime	-	30 years
Corrosion allowance	-	3 mm/year
Design & operating pressure	16.7 kg/cm^2 or 237 psi & -	28.1 barg & -0.002 to 10.62 barg
Design & operating temperature	187°C & -	100°C & 51°C
Max. allowable & actual flow rate	-	177 kg/s & 100-150 kg/s
Medium	Dry or superheated steam	Condensate

Diagnosis		
Year of failure evident	2011	2008 to 2011
Field observation/Laboratory analysis	1. Visual inspection 2. Review of design, operation and inspection of the pipeline 3. Metallographic studies, mechanical testing, and material composition 4. Modeling and simulation using FLUENT®	Visual inspection, X-ray diffractography, chemical analysis of condensate fluid
Failure mode	Erosion and corrosion	Erosion and corrosion
Failure location	Bend pipe of steam pipeline	Condensate reinjection pipe in the first downhill area
Failure cause	High content of silica sand (SiO_2), CO_2 and H_2S of steam	Flow-induced oxygen corrosion
Failure effect	Metal loss and pipes leaking within 2 years operation, noise exposure and H_2S exposure to the environment	Leak of condensate pipeline
Mitigation		
Short-term mitigation	Temporarily, the leakage of the bend pipe still covered by using a mechanical clamp to reduce steam leakage	Partial pipe spool repair were conducted by patching, pipe lamination with FRP coating, pipe replacement with newly pipe and pipe rotation.
Long-term mitigation	Pipe replacement by considering the prediction of its operating life using FLUENT® simulation	Pipe replacement with non-metallic material. High density Polyethylene (HDPE) is selected and suitable to replace reinjection pipe material because its flexibility, tough and corrosion free material.

3. TURBINE

Plant information			
Operator of GPP	Indonesia Power	Indonesia Power	Indonesia Power
Field name-Number of unit	Kamojang-Unit 1	Salak Awibengkok-Unit 3	Kamojang-Unit 2
Operating hours	245,784	-	
Type of GPP system	Dry steam condensing system	Single flash condensing sytem	Dry steam condensing system
Component information			
Component/System	Mitsubishi turbine	Ansaldo turbine	Mitsubishi turbine
Type	Impulse double flow condensing turbine	6-stages double flow, double admission condensing turbine	Impulse double flow condensing, 5 (five) level
Year of installation	1982	-	-
Lifetime	30 years	-	-
Design & operating pressure	6.5 bara	6.5 bara	6.6 bar abs
Design & operating temperature	161.9 °C	162 °C	161 °C (actual)
Max. allowable & actual flow rate	-	439.9 ton/hour	389 ton/hr (actual)
Shaft Rotation Speed	-	-	3000 RPM
Fluids medium	Steam	Steam	Steam
Diagnosis			
Year of failure evident	1995	2004-2005	1993
Field observation/ Laboratory analysis	-	1. Visual inspection	-

		2. Material testing & analysing: a. Scanning Electron Microscopy (SEM) b. Energy Dispersive Spectroscopy (EDS) c. X-Ray Diffractometry (XRD)	
Failure mode	-	Chemical materials deposit, consist of S, O, and dominated by Fe	Erosion
Failure location	Bellows thrust bearing	1^{st}, 2^{nd}, 3^{rd}, and 4^{th} stages of turbine diaphragm and rotor	Turbine Casing
Failure cause	-	Chemical reaction between Fe cation from all components built in iron material before turbine (scrubber, demister, pipeline) and O^- and S^- anions from steam	-
Failure effect	5,832 hours of fixing time	1. Decline power output / De rating problem 2. Increase steam chest pressure 3. Decrease mass flow rate of steam into turbine	-
Mitigation			
Long-term mitigation	Changing of bellows thrust bearing in periodic time	1. Cleaned by using chisel chipping and fine	Repaired (Coating)

		grinding methods. It caused a rough surface on the diaphragm and rotor surface 2. Improve the steam wash system by changing the use of condensate water with the treated water which has lower dissolve oxygen	

Plant information	
Operator of GPP	Indonesia Power
Field name-Number of unit	Kamojang-Unit 2
Operating hours	-
Type of GPP system	Dry steam condensing system
Component information	
Component/System	Mitsubishi turbine
Type	Impulse double flow condensing, 5 (five) level
Year of installation	-
Lifetime	-
Design & operating pressure	6.6 bara
Design & operating temperature	161 °C (actual)

Max. allowable & actual flow rate	389 ton/hr (actual)			
Shaft Rotation Speed	3000 RPM			
Fluids medium	Steam			
Diagnosis				
Year of failure evident	2001	2001	2007	2008
Field observation/ Laboratory analysis	-	-	-	-
Failure mode	Erosion / Corrosion	Scratch	Broken	Erosion / Corrosion
Failure location	Casing bolt, Diaphragm (Seal strip at 2nd stage)	Coupling (Bolt)	Rotor gland (Packing ring), Coupling (Bolt)	Casing bolt
Failure cause	-	-	-	-
Failure effect	-	-	-	-
Mitigation				
Long-term mitigation	Replaced	Replaced		Replaced

Plant information	
Operator of GPP	Indonesia Power
Field name-Number of unit	Kamojang-Unit 2
Operating hours	-
Type of GPP system	Dry steam condensing system
Component information	

Component/System	Mitsubishi turbine		
Type	Impulse double flow condensing, 5 (five) level		
Year of installation	-		
Lifetime	-		
Design & operating pressure	6.6 bara		
Design & operating temperature	161 °C (actual)		
Max. allowable & actual flow rate	389 ton/hr (actual)		
Shaft Rotation Speed	3000 RPM		
Fluids medium	Steam		
Diagnosis			
Year of failure evident	2010	2010	2007-2008
Field observation/ Laboratory analysis	-	-	-
Failure mode	Erosion	Crack	Unknown
Failure location	Diaphragm (Seal strip at 1st and 2nd stage)	Rotor Blade (Gov side 3rd, 4th, and 5th stage)	Diaphragm (all side and stage)
Failure cause	-	-	-
Failure effect	-	-	-
Mitigation			
Long-term mitigation	Replaced	Replaced	Replaced

4. CONDENSER

Plant information		
Operator of GPP	Indonesia Power	
Field name-Number of unit	Kamojang-Unit 2	
Operating hours	-	
Type of GPP system	Dry steam condensing system	
Component information		
Component/System	Mitsubishi turbine	
Type	Direct contact, Spray/Tray jet	
Vacuum design	0.1 bara	
Cooling water temperature	29 °C	
Hot water temperature	49.6 °C	
Cooling water capacity	19.5 m^3	
Diagnosis		
Year of failure evident	2008	2008
Field observation/ Laboratory analysis	-	-
Failure mode	Scaling	Damaged
Failure location	Loop seal and valve	Sheet packing manhole
Failure cause	-	-

Failure effect	-	-
Mitigation		
Long-term mitigation	Replaced	Replaced

5. PUMP

Plant information			
Operator of GPP	Indonesia Power		
Field name-Number of unit	Kamojang-Unit 2		
Operating hours	-		
Type of GPP system	Dry steam condensing system		
Component information			
Component/System	Main cooling water pump		
Type	Sentrifugal, Double suction		
Number per Unit	2 (two)		
Capacity	6400 m^3 /hr		
Total Head	33 m		
Shaft Rotation	600 RPM		
Power	773 kW		
Diagnosis			
Year of failure evident	1993	1993	1993
Field observation/ Laboratory analysis	-	-	-
Failure mode	Erosion	Wear	Broken
Failure location	Pump 1 impeller, pump 2 impeller	Pump 1 ball bearing, pump 2 ball bearing	Pump 2 bearing house, casing (support)

Failure cause	-	-	-
Failure effect	-	-	-
Mitigation			
Short-term mitigation	Replaced with former backup	Replaced with a new one	Replaced with former backup

Plant information			
Operator of GPP	Indonesia Power		
Field name-Number of unit	Kamojang-Unit 2		
Operating hours	-		
Type of GPP system	Dry steam condensing system		
Component information			
Component/System	Main cooling water pump		
Type	Sentrifugal, Double suction		
Number per Unit	2 (two)		
Capacity	6400 m^3 /hr		
Total Head	33 m		
Shaft Rotation	600 RPM		
Power	773 kW		
Diagnosis			
Year of failure evident	2008	2008	2008

Field observation/ Laboratory analysis	-	-	-
Failure mode	Damaged	Expires operation	Over clearance
Failure location	Pump 1 shaft (mechanical seal and its case), Pump 2 mechanical Seal	Pump 1 ball bearing, pump 2 ball bearing	Pump 2 shaft (lower shaft sleeve), pump 2 bearing case
Failure cause	-	-	-
Failure effect	-	-	-
Mitigation			
Short-term mitigation	Repaired	Replaced with a new one	Replaced with spare at warehouse

6. Cooling Tower

Plant information					
Operator of GPP	Indonesia Power				
Field name-Number of unit	Kamojang-Unit 2				
Operating hours	-				
Type of GPP system	Dry steam condensing system				
Component information					
Type	Mechanical draught with Fan				
Incoming Water Temperature	43 °C				
Water Temperature Out	27 °C				
Fan Rotation	129 RPM				
Motor Rotation	1000/750 RPM				
Power	120 kW/cell				
Number of Cells	5				
Diagnosis					
Year of failure evident	2002	2003	2004	2004	2004
Field observation/ Laboratory analysis	-	-	-	-	-
Failure mode	Pitting	Erosion/Pitting	Broken	Corrosion	Erosion
Failure location	Cell 1 Fan Blade	Cell 4 Fan Blade	Cell 3 Disc Pack (Gear & Motor Side),	Cell 4 Distribution Valve Cell	Cell 4 & 5 Fan Blade

			Cell 5 Disc Pack (Motor Side), Cell 5 Oil Pump Cell		
Failure cause	-	-	-	-	-
Failure effect	-	-	-	-	-
Mitigation					
Short-term mitigation	Replaced with repaired result	Repaired	Replaced with 2 set gear side	Replaced with 2 pieces spare warehouse (original)	Repaired (Coating)

Plant information	
Operator of GPP	Indonesia Power
Field name-Number of unit	Kamojang-Unit 2
Operating hours	-
Type of GPP system	Dry steam condensing system
Component information	
Type	Mechanical draught with Fan
Incoming Water Temperature	43 °C
Water Temperature Out	27 °C
Fan Rotation	129 RPM
Motor Rotation	1000/750 RPM

Power	120 kW/cell				
Number of Cells	5				
Diagnosis					
Year of failure evident	2004	2004	2004	2004	2006
Field observation/ Laboratory analysis	-	-	-	-	-
Failure mode	Erosion/Pitting	Low Oil Pressure	Pitting	Unknown	Erosion
Failure location	Cell 3 Fan Blade	Cell 4 Oil Pump Cell	Cell 1 Fan Blade	Cell 5 Disc Pack (Gear Side)	Cell 4 Fan Blade
Failure cause	-	-	-	-	-
Failure effect	-	-	-	-	-
Mitigation					
Short-term mitigation	-	Replaced 1 piece (original)	Repaired (Coating)	Replaced with 2 set gear side	Repaired (Coating)

Plant information	
Operator of GPP	Indonesia Power
Field name-Number of unit	Kamojang-Unit 2
Operating hours	-
Type of GPP system	Dry steam condensing system

Component information					
Type	Mechanical draught with Fan				
Incoming Water Temperature	43 °C				
Water Temperature Out	27 °C				
Fan Rotation	129 RPM				
Motor Rotation	1000/750 RPM				
Power	120 kW/cell				
Number of Cells	5				
Diagnosis					
Year of failure evident	2006	2006	2007	2007	2007
Field observation/ Laboratory analysis	-	-	-	-	-
Failure mode	Rupture	Unbalance	Broken	Erosion	Unknown
Failure location	Cell 5 Fan Blade	Cell 5 Fan Blade	Cell 5 Gear & Bearing Reduction Gear Cell	Cell 2&5 Fan Blade	Cell 3 Gear & Bearing Reduction Gear Cell Cell 5 Disc Pack (Gear Side)
Failure cause	-	-	-	-	-
Failure effect	-	-	-	-	-
Mitigation					
Short-term mitigation	Replaced with former use from cell 4	Replace with former use from cell 2	Replaced	Replaced with a new one (original)	-

7. GENERATOR

Plant information					
Operator of GPP	Indonesia Power		Indonesia Power		
Field name-Number of unit	Kamojang-Unit 1		Kamojang-Unit 2		
Operating hours	245,784		-		
Type of GPP system	Dry steam condensing system		Dry steam condensing system		
Component information					
Type	Synchronous		-		
Year of installation	1982		-		
Lifetime	30 years		-		
Voltage	11,800 V		11,800 V		
Current	1,835 A		3,364 A		
Phase	-		3		
Rotation	3,000 RPM		3,000 RPM		
Frequency	50 Hz		50 Hz		
Output	30,000 kW		55,000 kW		
Diagnosis					
Year of failure evident	2012	2007	2007	2008	2010
Field observation/ Laboratory analysis	-	-	-	-	-
Failure mode	-	Distortion	Broken	Rupture	Broken

Failure location	Winding rotor	Stator Coil Lower (Isolation)	Rotor Coil (Fastener Bolt of Fan), Rotor Coil (Retaining Ring Mn18 Cr5)	Rotor Coil (Shroud Fan)	Rotor Coil (Retaining Ring Mn18 Cr5)
Failure cause	-	-	-	-	-
Failure effect	5,832 hours of fixing time	-	-	-	-
Mitigation					
Short-term mitigation	Re-isolation of rotor winding	Replaced	Replaced	Replaced	Replaced

8. Trafo

Plant information	
Operator of GPP	Indonesia Power
Field name-Number of unit	Kamojang-Unit 1
Operating hours	245,784
Type of GPP system	Dry steam condensing system
Component information	
Component/System	Trafo lepper dominit
Type	Impulse double flow condensing turbine
Year of installation	1982
Lifetime	30 years
Design & operating pressure	6.5 bara & -
Design & operating temperature	161.9 °C & -
Max. allowable & actual flow rate	-
Fluids medium	Steam
Diagnosis	
Year of failure evident	1995
Field observation/ Laboratory analysis	-
Failure mode	-
Failure location	Bellows thrust bearing

Failure cause	-
Failure effect	5,832 hours of fixing time
Mitigation	
Short-term mitigation	Changing of bellows thrust bearing in periodic time

9. GAS REMOVAL SYSTEM

Plant information	
Operator of GPP	Star Energy Geothermal Wayang Windu Ltd.
Field name-Number of unit	Wayang Windu-Unit 2
Operating hours	-
Type of GPP system	Single flash condensing system
Component information	
Component/System	After-condenser vessel of gas removal system
Material Grade/Type	Low carbon grade austenitic stainless steel / SS 316L (SA240/UNS-S31603)
Outer Diameter	42”
Nominal Thickness	6.35 mm
Year of installation	-
Lifetime	-
Design & operating pressure	8.18 barg
Design & operating temperature	175.56 °C
Max. allowable & actual flow rate	-
Medium	NCG, steam, water
Diagnosis	
Year of failure evident	-
Field observation/ Laboratory analysis	1. Visual examinations

	2. Metallography examinations 3. Hardness test 4. SEM and EDS examinations
Shape of failure	Cracks are mostly trans granular, propagated in stepwise manner on rolling direction aligned with ferrite stringers, and occupied with non-metallic inclusion
Failure mode	Cracking
Failure location	On the weld area or base metal of the vessels
Failure cause	1. By examining the orientation of cracks, it was affected by stress on longitudinal direction 2. Higher hardness level of vessel material leading to brittleness and reduction of toughness. Probably, it caused by wrong welding process during vessel fabrication 3. Hydrogen cracking due to combination of corrosive environment (Cl and H_2S content in operating fluid)
Failure effect	Cracks would initiate leak on vessel and decline the overall process of NCG extraction
Mitigation	
Long-term mitigation	1. Raw material for vessel should be heat treated by stress relieve instead of annealing process only. 2. Material should be corrosion tested in order to evaluate its cracking resistance of H_2S environment, based on NACE TM0284 and NACE TM0177 test procedure or standard 3. Welding procedure and implementation should be tightly controlled in order to avoid weld defect which may assist corrosion cracking mechanism 4. Periodic inspection for crack detection should be performed by using non-destructive test (NDT)

8 International Failure Data

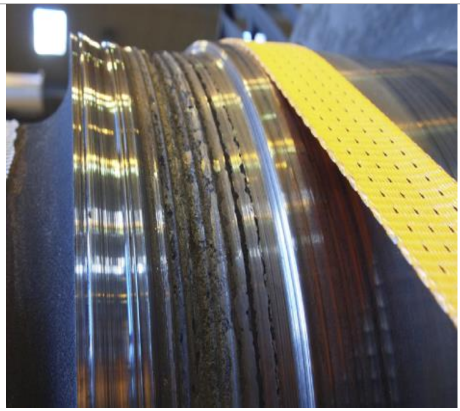
1. Piping

Plant information			
Operator of GPP	Salton Sea Power Plant	Contact Energy Ltd.	Contact Energy Ltd.
Field name-Number of unit	Salton Sea Geothermal System (USA)	Wairakei (New Zealand)	Wairakei (NZ)
Operating hours	-	-	-
Type of GPP system	-	Single flash with binary system	Single Flash with Binary System
Component information			
Component/System	Wellhead pipe	Steam pipe	Pipeline
Material Grade/Type	AISI 1020 carbon steel	-	-
Diameter	-	-	-
Nominal Thickness	-	-	-
Thermal Insulator	-	-	-
Year of installation	-	-	-
Lifetime	-	-	-
Corrosion allowance	-	-	-
Design & operating pressure	-	-	-
Design & operating temperature	302 °C	-	-

Max. allowable & actual flow rate	-	-	-
Medium	Hyper-saline brine	Steam	Steam
Diagnosis			
Year of failure evident	2016	2016	2016
Field observation/ Laboratory analysis	 		
Failure mode	General uniform corrosion	Cracking	Erosion corrosion
Failure location	Wellhead tee	Pipe flange	Pipe elbow
Failure cause	Chemical reaction due to discharge of acid-SO_4 chloride fluid from geothermal wells	Concentration of Hydrogen molecule formed from H_2S carried by geothermal fluid penetrate the components' crystalline structure, reducing its ductility and tensile strength	High speed geothermal fluid that hit pipe elbow. The protective film at that spot are damaged and cause corrosion speed increase at that spot.
Failure effect	Surface thinning with corrosion rate of 2.21 - 2.51 mm/y	-	-
Mitigation			
Short-term mitigation	-	-	-

2. TURBINE

Plant information	
Operator of GPP	ON Power
Field name-Number of unit	Nesjavellir Power Plant (Iceland)
Operating hours	-
Type of GPP system	Dry steam system
Component information	
Component/System	Turbine Mitsubishi Heavy Industries
Type	Single cylinder, single flow, condensing turbines with 8 stages and top exhausts
Year of installation	-
Lifetime	-
Design & operating pressure	-
Design & operating temperature	380 °C
Max. allowable & actual flow rate	-
Medium	Steam
Diagnosis	
Year of failure evident	May 2013

Field observation/ Laboratory analysis	
Failure mode	Erosion corrosion
Failure location	Turbine rotor & gland seal (labyrinth packing)
Failure cause	Combination of H_2S (11.3%) and CO2 (62.57%) that flows in low-pressure side of gland seal system and corrosive gas that condense with steam. Erosion from solid particle and water droplet also contribute.
Failure effect	The labyrinth packing and rotors become too wearied down and corroded for further usage.
Mitigation	
Short-term mitigation	Replacement of damaged components

3. Gas Removal System

Plant information	
Operator of GPP	Contact Energy Ltd.
Field name-Number of unit	Wairakei (New Zealand)
Operating hours	-
Type of GPP system	Single flash with binary system
Component information	
Component/System	-
Type	-
Year of installation	-
Lifetime	-
Design & operating pressure	-
Design & operating temperature	-
Max. allowable & actual flow rate	-
Medium	NCG, steam, water
Diagnosis	
Year of failure evident	2016

Field observation/ Laboratory analysis	
Failure mode	Pitting corrosion
Failure location	Gas ejector nozzle
Failure cause	Accumulation of sulphur deposit inside the nozzle
Failure effect	A hole is formed at the nozzle
Mitigation	
Short-term mitigation	Replace the nozzle with other equipment made with other material (Source does not specify)

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