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Load Optimization By Steam And Blade Washing In A Flash Type Power Plant-A Case Study Of Olkaria II.

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Abstract: *With generator load as the key factor, this paper focuses on both maintenance and running equipment parameters and their effect on the load. The parameters of interest in this studywere turbine inlet pressure, steam flow rate, steam chest pressure (Bowl pressure) and generator loading. For this study, Olkaria II power station data was used. From this data, it was observed that after a few years of operation, even with the steam chest pressure increasing from 2.5 bar g to 4.1 bar g and increase in steam consumption the turbine power generation decreased to 26.4Mw out of the rated capacity of 35.0Mw. This led to dismantling of the turbine in question for inspection which led to the discovery that significant Sulphur deposition, scaling and related compounds had occurred thus reducing the turbine efficiency. The purpose of this research was to explore blade washing and steam washing operation procedures for removal of silica scaling and deposition at the turbine blades and nozzles, improving the geothermal power plant efficiency through addressing scales and mineral deposition for improvement of plant performance and productivity.*

***Key words**: Generator, Load, Nozzles, Scales, Silica, Turbine.*

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I. Introduction

Fouling of steam turbine blades has become a major problem in power generating steam plants due to its annoyance, revenue losses due to repairs and the downtime this causes the power plant according to the plant performance records in Kengen.[1]

With the increase in the generating capacity and pressure of individual units in the 1960s and 70s, there was need for studying large steam turbine reliability to help increase its efficiency with early studies being carried out by the likes of Parker et al [2]. This happened with the modifications in turbine design and size considering the extreme conditions the turbine blades are subjected to in their operation.

As the world moves towards affordable clean energy, this study is vital in making sure the Geothermal energy is best utilized [3]. This involves understanding the energy resources, energy generation processes and facilities, and laying down elaborate maintenance strategies for their performance improvement and maximum resource utilization[4] [5].

Dissolved solids and gases in the geothermal fluids induce scaling during well operation which reduces the efficiency of the power plant. Elrod et al[6] compared plant performance with the rough deposits helping this research conclude that silica scaling must be maintained at a minimum using processes like steam washing, blade washing and plant overhauls. It is for this mineral deposition of the type of silica scaling that this project has been developed to reduce its effects on the geothermal power plant in Olkaria II power Station by use of steam washing exercise which is preferred to an overhaul.

This research confined itself into getting to know the effect of steam and blade washing on load optimization at Olkaria II power station at Olkaria field in Naivasha-Kenya. The experiment was carried out with aim of exploring blade washing and steam washing operation, improving efficiency of the geothermal power plant and finally to ensure that there was real time data analysis from Olkaria II power station on plant performance and productivity.

II. Scaling In Geothermal Systems

From various geothermal explorations, it is evident that the different type of scales present challenging operating problems for geothermal plants [7]. Inside the wells, there are certain points where the internal diameter is considerably larger, making them the flush points. Most of the time, the scale precipitates there, but the flush points are not stationary due to other factors such as pressure in fluid reservoirs [8].The Table 1,

presents typical minerals identified in scales inside the productionpipes.The major species of scale in geothermal brine typically include calcium, silica and sulphide
Compounds

Table 1: Typical Minerals Identified in Scales Inside Production Pipes

Mineral	Formula	Mineral	Formula
Anhydrite	$CaSO_4$	Montmorillonite	$(Na,Ca)_{0.3.3,}$ $(Al,Mg)_2Si_4O_{10}(OH)_2.nH_2O$
Anglesita	$PbSO_4$	Magnetite	Fe_3O_4
Calcite	$CaCO_3$	Pyrrhottite	FeS
Chalcopyrite	$CuFeS_2$	Quartz	SiO_2
Galena	PbS	Sphalerite	ZnS
Gypsum	$CaSO_4.2H_2O$	Silvite	KCl
Halite	NaCl	Talc	$Mg_3SiO_4O_{10}(OH)_{2.5}.nH_2O$
Luzonite	Cu_3AsS_4	Verniculite	$(Mg, Ca)_{0.9}(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_{2.5}H_2O$
Magnesioferrite	$MgFe_2O_4$		

2.1 Types of Scaling
According to Miller [9],boiling point scaling in production wells which is caused by sudden pH changes due to boiling and involves precipitation of calcium carbonates and metal sulphides.

2.2 Silica Rich Scale
When it comes to Amorphous–silica Swanteson et al discuss thatboiling increases concentration of dissolved SiO_2 in injection pipelines particularly in wells after separator stations and surface equipment[10].When the fluid reaches saturation with respect to quantities it causes problematic Silica solubility and scaling curves[8].

2.2.1 Silica rich scales: common solutions to the problem
Many treatment methods have been applied to reduce silica scaling in production wells and equipment. In order to avoid amorphous silica scaling in wells, it is common practice, whenever possible, to operate the wells at wellhead pressures higher than those corresponding to amorphous silica saturation.

- Separating steam at high pressure –Wasteful, a lot of thermal energy wasted
- Diluting separated water with condensate–Can cause corrosion
- Acidification –Can cause corrosion
- Crystallize silica in suspension [Crystallizer-Reactor-Clarifies process (pumping from conditioning ponds after it has cooled down and the silica has polymerized)] –Costly

When considering injection of cooled wastewater into either cold or hot ground water, the possible effects of mixing the two compounds of silica, Mg-silicate or Al-silicate deposition should be specifically looked at.

2.3 Power Plant Fluid Chemistry from the Well
Deep reservoir fluid chemistry is influenced by boiling processes, fluid-rock interactions and mixing processes. There are two main categories namely:

- Mineral forming components: SiO_2, Na, K, Ca, Mg, S-H_2S and SO_4, C-CO_2, F, Al, Fe, Mn, etc. give information on deep reservoir temperatures, and boiling and mixing processes.
- Conservative components, e.g. Cl, B, and stable isotopes of deuterium and oxygen, are useful in determining reservoir recharge and re-injection[12].

Hauksson et al [13] stated that Silica scaling experienced in high temperature geothermal installations can be reduced by maintaining the temperature above the solubility level for amorphous silica. In low temperature geothermal systems, the silica content is governed by the solubility of the silica mineral chalcedony at low temperature and quartz at higher temperature. In water from the low-temperature areas, although it is cooled in the district heating systems down to about 20°C, silica saturation does not occur.

According to Gunnarssonet al [14] scaling is a common phenomenon in all geothermal installations in the world. It occurs due to interaction of geothermal water with rocks and boiling processes deep in the reservoir, resulting in supersaturated water due to the dissolution of minerals. Dissolution may be accelerated by temperature and, sometimes, it may be retrogressive depending on the solute [14]. Calcite, silica and metal pyrite deposition are the most common scales sited in Olkaria Northeast field.

Calcite scaling is largely confined to wet wells and occurs when geothermal water becomes supersaturated with calcite due to a decrease in partial pressure of carbon dioxide leading to its precipitation. It occurs in both low- and high-temperature geothermal installations as polymorphs of calcium carbonate which include vaterite and aragonite. Calcite deposition is highly controlled by water temperature and pH asshown in the following equation [15]:

$$Ca^{2+}_{(aq)} + 2HCO^{-}_{3(aq)} = CaCO_{3(s)}\ (Calcite) + CO_{2\,(g)} + H_2O\ (l) \qquad (1)$$

The solubility of silica in geothermal fluid is very dependent on temperature, the initial degree of super-saturation, salinity, pH, and the presence (or absence) of colloidal particles. Thus, separation temperatures of geothermal fluid need to be carefully chosen so that much of the silica will remain in solution or allow it to come out of solution before injection. Silica is mainly deposited as quartz or amorphous silica. Quartz (controls solubility of hot reservoir fluid) is deposited in the temperature range of 100-250°C and amorphous silica (controls solubility of low temperature fluid) in the range of 7-250°C [14],[15] depending on saturation, according to the equation:

$$OFeOH\,.H_2O\ +\ Si\,(OH)_4\ =\ Fe\,(OH)_3.SiO_2(s)\ +\ 2H_2O) \qquad (2)$$

III. Methodology

3.1 Steam Washing

The actual process involved injecting steam condensate into the steam flow up-stream of a final separator/scrubber thus collecting unwanted substances entrained and dissolved in the steam into the wash water. The arrangement for steam washing can be seen in the figure below.

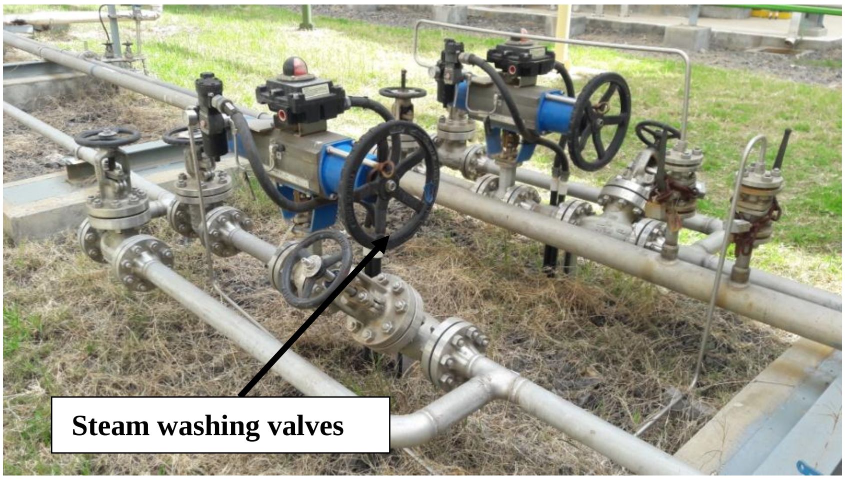

Figure 1: Steam washing valve arrangements

Before the process began, the researcher ensured that the turbine was shut and that all other conditions necessary for the task to be carried out were fulfilled.The actual operation was then remotely started via the Distributed Control System(DCS) with the initial condensate water injection at 2.5 ton/hr with gradual increase upto 6 ton/hr for maximum atomized condensate spray. During all this, the researcher monitored the instruments around Turbine and the wash system then measured and recorded, Main steam pressure, main steam temperature, main steam flow, condenser vacuum, GV Opening, Load output, Steam chest pressure, Vibration, Rotor position, Bearing metal temperature, Wash water flow, Wash pump discharge pressure, Steam scrubber level, Conductivity and Gas analysis.

IV. Results And Discussion

4.1 Analysis of Blade Washing Outcomes at Olkaria II Power Plant

From **t**he analysis of samples collected from the steamscrubber gave the following composition by weight: iron (36.67%), silica (0.91%), calcium (0.04%) and traces of sulphur. In the vent station, the dominant compound was silica (37.70%) and iron compounds (6.09%).

4.2 Effect of Blade Washing on Main Steam Flow Rate

The results from the blade washing method for the two days this experiment was carried out are represented in the Table 2 and Table 3 below. The main steam flow according to the records in Tables 2 and 3 was 253.94 ton/hr. at 1235 hrs before the washing had begun. During the first blade wash at 1635 hrs, the main steam flow reduced to 253.85 ton/hr. showing a steam flow rate decline of 0.09 ton/hr. This is an excellent indication as the Load generated was being recorded with reduced steam consumption. The Turbine efficiency then slightly went up as steam washing continued.

Table 2: Data Records from Experimental steam and blade washing method (Day 1)

		ITEM TO BE MEASURED			UNIT	BEFORE BLADE WASH	BLADE WASH 1	AFTER BLADE WASH 1	BLADE WASH 2	AFTER BLADE WASH 2
STEAM & BLADE WASH		Time hours			Hours	1235	1635	2035	0035	0435
	1	Generator load			**MW**	26.4	25.9	28.5	30.3	33.5
	2	Blade wash water flow			T/H	3.8	3.9	0	3.9	0
	3	Main steam flow			T/H	253.94	253.85	249.35	246.1	244.5
	4	Main steam pressure		Interface	Bar g	4.45	4.38	4.3	4.28	4.22
				LH		4.15	4.12	4.08	4.04	4.02
				LH		4.16	4.12	4.07	4.05	4.03
	5	Main steam temperature		Interface	C	151.34	151.5	151.6	151.7	151.0
				LH		150.3	150.1	150.3	150.4	150.3
				RH		150.3	150.1	150.3	150.5	150.3
	6	Steam chest pressure			Bar g	3.638	3.52	3.22	3.15	3.00
	7	Condenser vacuum			Bara	0.077	0.079	0.077	0.075	0.075
	8	GV position		LH	%	61%	60.5	53.3	52.2	50.8
				RH		59%	58.5	52.9	51.8	50.5
	9	Bearing metal temperature		#1	C	66.5	66.7	66.4	66.3	66.2
				#2		63.5	63.6	63.4	63.2	63.1
				#3		62	62.3	61.9	61.8	61.6
				#4		60.8	60.9	60.6	60.5	60.3
	10	Bearing vibration	#1	X	Micron P-P	18	17	14	14	14
				Y		19	18	15	14	14
			#2	X		24	23	17	17	17
				Y		24	24	19	18	19
			#3	X		32	32	31	31	33
				Y		20	21	20	20	21
			#4	X		24	24	25	24	26
				Y		29	29	29	29	32
	10	Rotor position			Mm	-0.09	-0.09	-0.11	-0.11	-0.11
	12	Differential expansion			Mm	1.11	1.11	1.15	1.16	1.24
	12	Thrust bearing metal temperature (Gov side)			C	58.2	58.3	57.6	57.4	57.3
	13	Thrust bearing metal (gen side)			C	44.1	44.2	43.9	43.8	43.6

At the end of day two of the steam washing process (at 0035 hrs. on day 2), the steam flow rate had declined to 225.2 ton/hr. This is a total decline of steam consumption by up to 28.74 ton/hr. Using steam consumption alone, the overall Turbine efficiency may be calculated as follows;

Initial steam consumption =**253.94 tons/hr.**

Final steam consumption =**225.2 ton/hr**

Overall Turbine Efficiency (Using steam consumption alone) ~ **(253.94-225.2) =28.74 ton/hr**

Efficiency = **(28.74 ÷ 253.94*100) =11%**

The total decrease in the consumption has led to the Turbine increase in Efficiency of about 11**%** and this is a saving on Energy which could be put into other uses such as direct use or for well head power generators.

Table 3: Data Records from Experimental steam and blade washing method (Day 2)

		ITEM TO BE MEASURED		UNIT	BEFORE BLADE WASH	BLADE WASH 1	AFTER BLADE WASH 1	BLADE WASH 2	AFTER BLADE WASH 2
STEAM & BLADE WASH		Time hours		Hours	0835	1235	1635	2035	0035
	1	Generator load		**MW**	33.5	34.10	35.22	35.12	36.5
	2	Blade wash water flow		T/H	4.0	4.0	4.0	4.0	4.0
	3	Main steam flow		T/H	241.6	235.5	230.35	228.5	225.2
	4	Main steam pressure	Interface	Bar g	4.28	4.38	4.3	4.28	4.22
			LH		4.05	4.03	4.02	4.02	4.02
			LH		4.05	4.04	4.03	4.03	4.03
	5	Main steam temperature	Interface	C	151.8	151.5	151.3	151.3	150.9
			LH		150.3	150.1	150.3	150.4	150.2
			RH		150.3	150.1	150.3	150.5	150.3
	6	Steam chest pressure		Bar g	3.05	3.03	2.95	2.65	2.50
	7	Condenser vacuum		Bara	0.075	0.075	0.076	0.075	0.075

	8	GV position		LH	%	50.9%	51.5	50.3	50.2	50.1
				RH		50.7%	51.5	50.5	50.4	50.2
	9	Bearing metal temperature		#1	C	66.5	66.7	66.4	66.3	66.2
				#2		63.5	63.6	63.4	63.2	63.1
				#3		62	62.3	61.9	61.8	61.6
				#4		60.8	60.9	60.6	60.5	60.3
	10	Bearing vibration	#1	X	Micron P-P	18	17	14	14	14
				Y		19	18	15	14	14
			#2	X		24	23	17	17	17
				Y		24	24	19	18	19
			#3	X		32	32	31	31	33
				Y		20	21	20	20	21
			#4	X		24	24	25	24	26
				Y		29	29	29	29	32
	10	Rotor position			Mm	-0.09	-0.09	-0.11	-0.11	-0.11
	12	Differential expansion			Mm	1.10	1.12	1.13	1.15	1.17
	12	Thrust bearing metal temperature (Gov side)			C	58.2	59.3	57.95	57.66	57.33
	13	Thrust bearing metal (gen side)			C	45.1	44.93	43.9	43.88	43.65

4.3 Effect of Blade Washing on Turbine Load

The graph in figure 2 shows data recorded in the control room by the operator. The load had reduced drastically to 26.4 MW against a turbine rating of 35 MW. This Load kept reducing each day a phenomenon associated with silica scaling and an increased steam chest pressure. This therefore meant that steam washing ought to have been started or the turbine overhaul initiated to take care of the silica scaling menace.

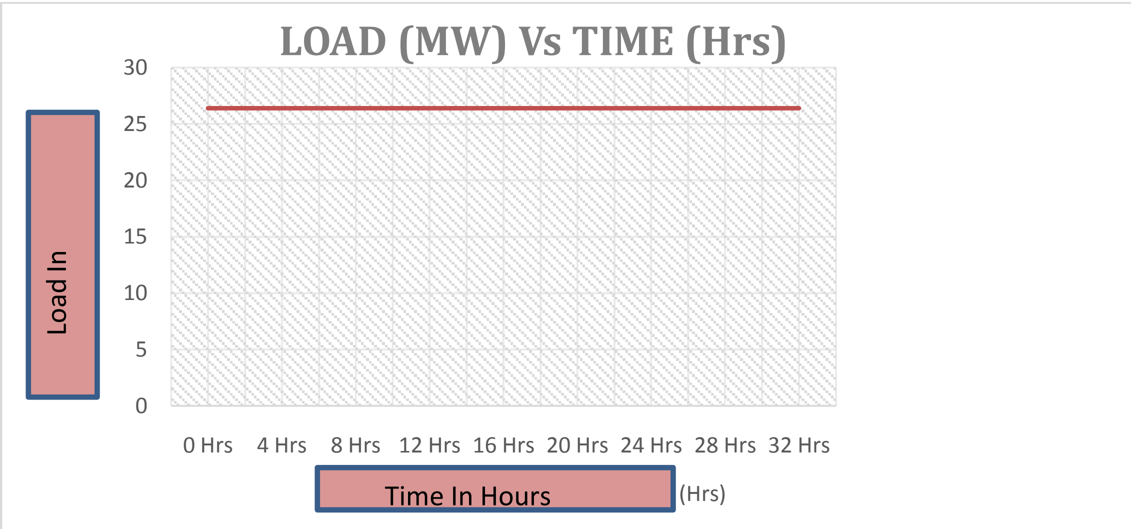

Figure2: Graph of Load vs. Time before Blade & Steam washing.

According to the findings of this study before the blade and steam wash of the turbine at Olkaria II power station the generator load read 26.4 MW, while during the blade wash the load reduced a little bit to 25.9 MW. After the second turbine blade wash procedure, the Load recorded remained fairly unchanged (constant) at 1635 Hrs showing that there was no significant change caused by the blade washing. From the findings that were done by the researcher with the assistant of other engineers at the plant it clearly shows that the generator load decreased with 0.1% of the reading at 1635 Hrs when blade washing was started.

After a number of data readings were recorded during the course of the study and by taking the readings after every four hours, significant changes began to be recorded and this clearly proved the worth of the blade washing procedure. During the later hours of the steam washing method, positive results started being recorded as the procedure proved successful. The load then moved to a high of 35 MW in accordance to the turbine designed loading as can be seen in the graph in figure 3.

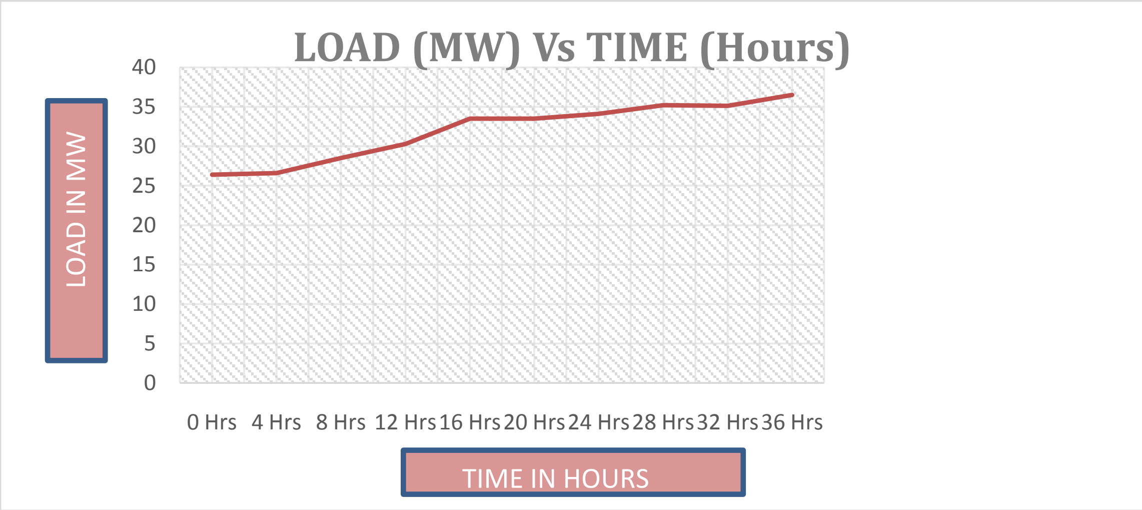

Figure 3: Graph of Load vs. Time with significant Changes in Load after Blade washing

As represented in Figure 3 below, the Load was recorded with every four hours of steam washing. As the steam washing progressed silica cleansing occurred and this had a positive influence on the Load generated. The Load generated was boosted by the fact that the steam chest pressure was brought down (from **3.638 bar g to 2.5 bar g**) and this made the Turbine nozzles (clearances) more opened and therefore improved the turbine overall efficiency. The lower steam chest pressure meant cleaner turbine nozzles and this guaranteed the improved Turbine Loading of the rated turbine capacity of **35 MW**. For future turbine designs the steam washing process needs to be automated such that with every increase in the steam chest pressure by a certain value then the steam washing be started automatically to mitigate on the condition and the overall generator loading.

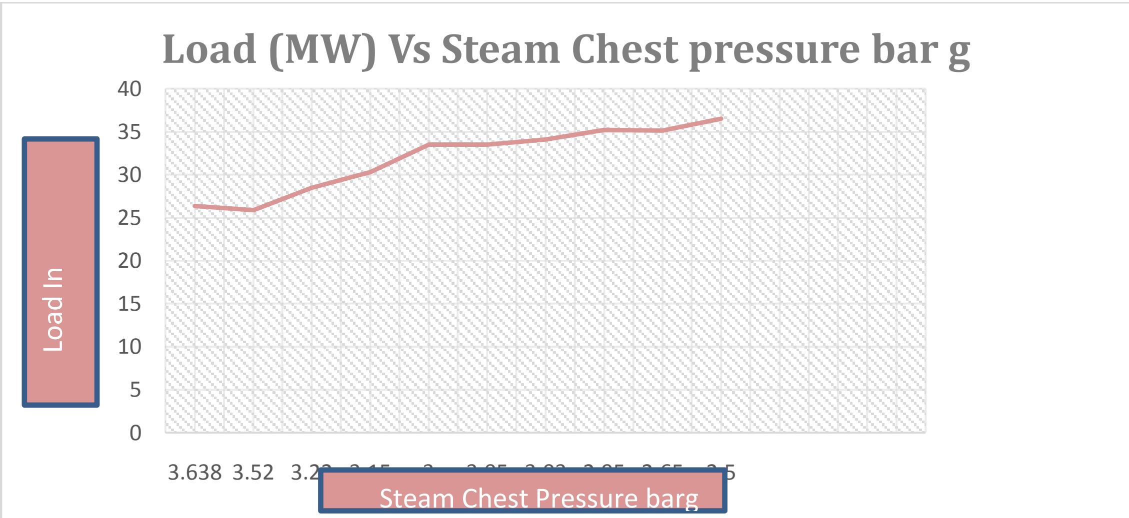

Figure 3: Graph of Load (MW) Vs. Steam chest pressure (bar g)

V. Conclusion

The results from the experiment show significant improvements in plant performance after blade washing. This goes a long way in confirming that silica deposition has major negative effects in a steam power plant. This paper recommends that the blade washing methods used in the experiment to be incorporated as a solution to silica scaling in the Olkaria geothermal power plants. In addition to this, good records should be maintained for these incorporated methods backed up with great analysis and graphical representations of the same to ensure a ready summary for project financiers and the project implementation teams as well as the company stakeholders and investors.

In the future, the research should focus on the implementation of an automated steam blade washing method that will be triggered by a notable rise in steam chest pressure. An alarm system should also be implemented to point out when steam is misused in reference to the generated load.

In the course of this experiment, there were a few challenges that we came through. To start, the geothermal environment is very corrosive especially the steam emanating from acidic environments. As the steam is transported to the separators a lot of carbon dioxide is lost thereby making it acidic in nature. The acid then attacks most metallic and other non-metallic materials. So, all experimental research equipment must be protected from that kind of environment. Challenges were also faced when getting permission from the KenGen Company management especially on the use of its data for any academic research.

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