Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Steam Purity Monitoring Using Statistical Process Control

Vilma T. Capuno, Napoleon L. Saporsantos, Maria Teresa F. Amorin and Sol K. M. Regalado

14th Floor, 6750 Building, Ayala Avenue, Makati City, Philippines, 1226

Keywords: Statistical Process Control, steamwash, separator level, separator pressure, principal components analysis, treatment combinations, chloride levels

ABSTRACT

Steam purity and steam quality must be controlled to minimize degradation of geothermal steam turbines. Poor steam purity and quality may be the result of inadequate separation and scrubbing systems, sub-optimal operating practices, or upset conditions during operational transitions. All operators monitor chemical indicators of steam purity by taking steam samples at regular intervals near the turbine inlet. Any deviation from the normal is explained by deviations in operating conditions. We have experimented with a statistical approach, borrowed from the discipline of experimental design and process control that required acquiring all operational data corresponding to the steam purity data from the turbine and statistically determining the optimal combination of operating parameters.

Such experiments were run at Satellite Station 4 (SS-4) in the Mak-Ban Geothermal Field and not surprisingly, running steamwash at a high rate was the single major factor in maintaining high steam purity. The other operational parameters shown to significantly affect steam purity were separator level and separator pressure. When all these three operational parameters were controlled within the recommended limits, chloride readings never exceeded 0.1 ppm in the power plant

1. INTRODUCTION

Processes make things work and the philosophy of process control to improve the quality is to manage those processes (Qualpro, 1999). Delivering high quality steam to the power plants involves a separation system with processes that can be monitored by physical and chemical measurements. Physical factors are easier to monitor than chemical factors in this system. Physical data are less expensive to acquire, are usually real-time, and can serve as early-warning indicator before an upset occurs. Chemical data is expensive, cannot be readily adopted to provide real-time data and usually provides information about this system after the upset has occurred.

This study recognizes that monitoring physical process parameters not only allows for a better understanding of the system and therefore, better control, but will also provide a way to ensure delivery of high quality (i.e. low-chloride) steam to the power plant at any time, without the need to continuously measure the actual chloride levels. This can be achieved if the relevant physical process parameters at the satellite station are identified and a relationship with chloride levels is established. SS-4 has been chosen because it is one of the two worst satellite stations in the system and therefore, whatever improvements applies to SS-4 can be applied to the less problematic satellite stations in the steam-gathering system.

The study treats the separation system as the source of the raw material for steam production for power generation. By managing the separation process, the quality of the end-product can be ensured. The study seeks to use the relationship between physical data and consumer quality requirements to produce the best possible raw material that would consistently produce the highest quality steam. The study has two main objectives and they are: (1) To determine what physical parameters in the process stream affect the chloride content of the steam exiting the primary scrubber and (2) To establish an upper and lower limit for the relevant physical parameter that will produce steam with consistently low chloride from the primary scrubber.

2. PHASE I

Satellite Station 4 (SS-4) is composed of a separator vessel and a primary scrubber vessel. The steam from the primary scrubber flows to a secondary scrubber in the Plant Station and on to the power plant. SS-4 is the key separation step in the steam-gathering process, hence the focus on managing this process. Managing a process means defining, understanding and controlling process parameters in order to produce a product that meets quality specifications.

2.1 Data Gathering and Sample Collection

The first step in understanding the process necessitates collecting a large amount of data on it. Since the SS-4 system that was investigated is not automated, field operators manually collected the data. Process data and corresponding chloride levels were collected every two hours for three months. The process data were: separator level, separator pressure, brine rate, steam rate, scrubber pressure, scrubber level, emergency dump valve (EDV), separator output, steamwash rate, date and time. The operators also collected corresponding condensate samples and submitted them to the laboratory for chloride analysis.

2.2 Data Evaluation and Results

In the resulting data set, the Cl data is characterized by several physical variables, which more often than not, are probably interacting and impossible to isolate and study individually. Multivariate methods of analysis, like Principal Components Analysis (PCA), allow us to consider changes in several properties simultaneously. PCA reduced the large set of variables to a few principal factors that still contains most of the information in the large set. PCA was used on the data to determine which of the process parameters significantly affect chloride levels out of the primary scrubber. An evaluation of the PCA results also provided the upper and lower limits of these parameters to be used in the next experiment.

Out of the eight process data tested, only four showed a relationship to chloride levels of the primary scrubber: steamwash rate, separator pressure, separator level and brine rate out to the injection wells. Below is the table showing the upper and lower limits of these parameters

Table 1: Upper and lower limits of factors for the Phase II experiment.

Process parameter	Lower limit	Upper limit
Steamwash rate, kph	19	25
Separator level, inches	38	44
Separator pressure, psig	137	147
Brine rate, kph	580	620

3. PHASE II

3.1 Experimental Phase

The next phase was an experiment where combinations of the high and low levels of the relevant factors were tested to confirm interaction or independence of the various factors in terms of the effect on the chloride content of the steam. The parameters identified in phase I were steamwash rate, separator level, separator pressure and brine rate. Separator level and brine exit rates are inversely related and either one can be included in the experiment to reduce the variables to be tested. Below is the experimental design for Phase II.

Table 2: Factor combinations for Phase II experiments on SS-4.

Factor Combinations	Steam Wash Rate a	Separator Pressure b	Separator Level c	Response
1	19	137	39	y1
a	25	137	47	y2
b	19	147	47	y3
c	19	137	47	y4
bc	19	147	47	y5
ac	25	137	39	y6
ab	25	147	39	y7
abc	25	147	39	y8

The combinations define the levels of the three parameters, which will result in a particular chloride data. The operators set the levels for each parameter in each combination, allow for the system to stabilize and acquire at least three data points for each combination before setting up the next combination. The corresponding chloride data were also collected. The power plant load was maintained constant at 50 MW during the experiment.

3.2 Results

The results were plotted against time (Figure 1). Figure 1c shows the chloride levels out of the primary scrubber and its relationship to the steam wash rate. In the early part of the experiment, the lower limit of 19 kph appears to be the critically low rate because at this rate, any fluctuation in the other factors (Figure 1a and 1b), result to variable chloride levels greater than 50 ppm. When steamwash rate was maintained at 25 kph chloride levels did not vary as greatly or as frequently, suggesting that the fluctuations in the other factors were not significant enough to negate the effect of the high steamwash rate.

In the last part of the experiment where steamwash is again 19 kph (Figure 1c) chloride levels did not fluctuate as much compared to the first part. Figure 1a and 1b show that the levels of the other two factors were not the same in this part of the experiment compared to the first part. These observations suggest that there is interaction between these process factors and the levels of these factors and this interaction determine the chloride levels out of the primary scrubber.

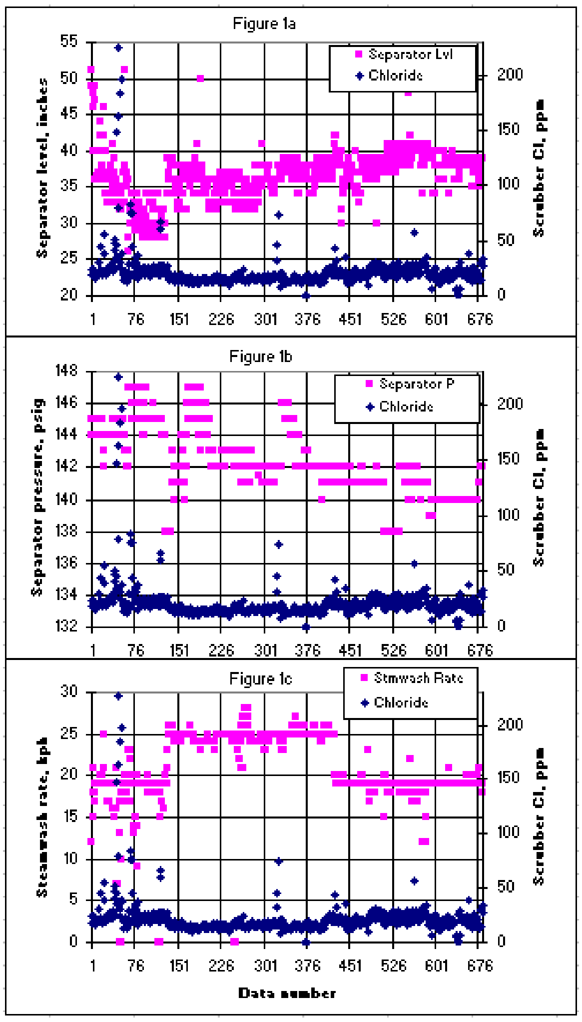

Figure 1: Phase II primary scrubber chloride levels of SS-4 plotted against separator level (1a), separator pressue (1b) and steamwash rates (1c).

To find out how these factors and their levels affect chloride levels, the factor combinations found in the data were sorted. Table 3 shows the high and low levels used for the factors in the design of experiments (Miller and Miller, 1993; Massart, et al, 1988).

Table 3. Factor combinations found in Phase I data analysis.

	Separator Pressure (psig)	Separator Level (inches)	Steamwash Rate (kph)
High	144-147	44-47 or higher	23-25 or higher
Low	137-140	<39-42	<19-21

Chloride levels of these high-low combinations were compared and presented in Table 4. The combination of factor levels that result in the lowest chloride level out of the primary scrubber is one with high steamwash rate, high separator pressure and low separator level.

The table also points to the major role played by steamwash rate in maintaining relatively low chloride levels out of the scrubber. A high steamwash rate alone reduced the chloride level to 17 ppm from a discharge chloride of about 3500 ppm. All the low chloride levels were a result of high steamwash rate combined with the other two process factors. All the high chloride levels resulted from a low steamwash rate combined with the other factor levels.

Table 4: Primary scrubber chloride levels as affected by the different factor combinations. (+) refers to the high value and (-) refers to the low value of the factor.

Factor Combination	Steamwash rate (kph)	Separator pressure (psig)	Separator level (inches)	1[0] Scrubber Cl level (ppm)
ab	+	+	-	14
abc	+	+	+	15.1
a	+	-	-	17
bc	-	+	+	20.5
1	-	-	-	22
c	-	-	+	24.5
b	-	+	-	39.2
ac	+	-	+	no data

During the test when steamwash was held at 25 kph, the average chloride concentration was 16 ppm. Given a discharge chloride of about 3500-ppm, the equivalent steam quality was 99.5% which seemed to be the limit of SS-4 in removing chloride from the steam going out of the primary scrubber. In contrast, the average chloride level from SS-4 during uncontrolled operation, without maintaining steamwash at a high level, was around 94 ppm (Figure 4). Notwithstanding, out of 173 data points for SS-4 chloride, only three resulted in generation loss due to steam purity problems (Mak-Ban Generation Losses Report, 2000). Therefore, the secondary scrubbing facilities are still able to clean up the steam before it reached the power plant. Nevertheless, the results of the experiment imply that by maintaining the optimum steamwash rates, separator level and separator pressure during the separation phase (i.e., separator and primary scrubber vessels combined), chloride levels of the steam going out from the secondary scrubber will have less than 1.0 ppm Cl going into the power plant (Figure 5). Figure 5a show high chloride incidents when steamwash was apparently lower than optimum but show no high chloride incidents when steamwash rates were controlled.

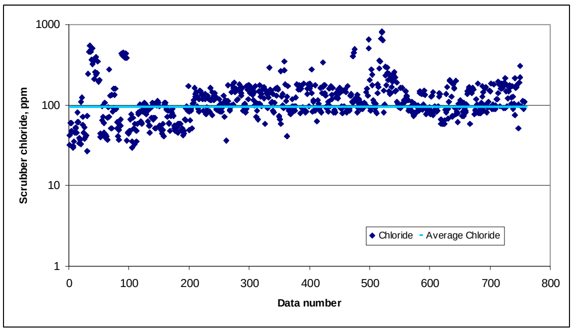

Figure 4: SS4 scrubber chloride from Phase I data-gathering conditions. Average Cl is 94 ppm.

4. CONCLUSIONS

There is untapped opportunity in applying statistical process control to monitor steam purity. This study was done to explore that opportunity but experts in the field of statistical process control may have better ways to achieve the desired results. Most application of process control is in the manufacturing industry but a shift in perspective can benefit an industry like geothermal because in effect, we produce our own raw materials and we can start applying process control right there.

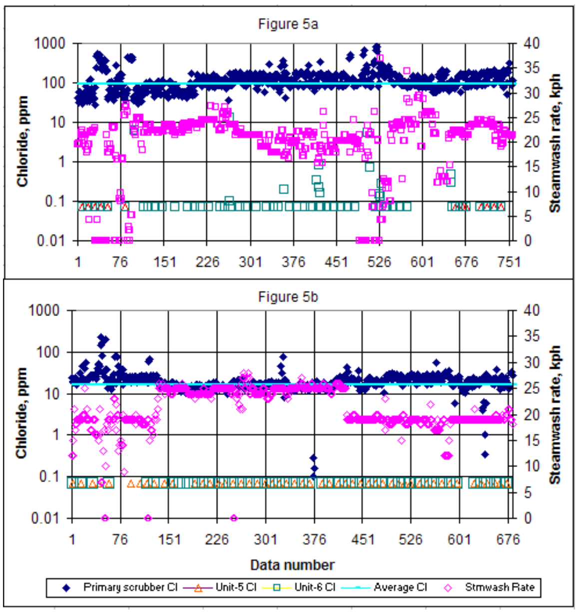

Figure 5: Power plant response to primary scrubber chloride: unoptimized conditions (5a) and optimized conditions (5b).

The study proved that determining the relationship between physical parameters in the separation phase and the steam quality ultimately delivered to the power plant can be the basis of a monitoring program. With further development, the time may come when condensate sampling can be eliminated and chemical monitoriing replaced with monitoring physical process parameters related to customer quality requirements. Appropriate control charts can be developed later on to help operators visualize the process and see what is happening to the system and maybe even anticipate and fix a potential upset before it develops into a problem.

4. ACKNOWLEDGEMENTS

The authors would like to thank CGPHI and NPC for giving us permission to publish this paper.

REFERENCES

Massart, D. L., Vandeginste, B. G. M., Demin, S. N., Michotte, Y. and Kaufman, L.. Chemometrics: a Textbook. Data Handling in Science and Technology, Vol 2. The Netherlands, Elsevier Science Publishers, (1988).

Mak-Ban Generation Losses Report, PGI / UNOCAL internal report, (2000).

Miller, J. C. and Miller , J. N.: Statistics for Analytical Chemistry, England, Ellis Horwood Limited, (1993).

NIST/SEMATECH e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/, (2006).

Qualpro: Statistical Quality Control, Qualpro's Eight Step Procedure, (1999)