CONTROL OF SILICA SCALES AT MOMOTOMBO NICARAGUA

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ABSTRACT

The brine produced by a two phase steam separator in a water dominated geothermal reservoir can often form tenacious metal silicate and amorphous silica scales which will with time completely obstruct the pipelines taking the brine from the separator pad to a binary plant, a bottoming cycle plant or simply a reinjection well or discharge point. The geothermal fluid from Separators was initially discharged into local lakes, streams, or rivers. However, for both reasons of reservoir management and concern for the environment these fluids are now almost universally reinjected back into the reservoir. Furthermore, with the improvement and experience in production and operation of binary plants, it is becoming more and more common to extract the last kilojoule of energy and latent heat from the brine via these types of facilities. The need therefore to keep the pipelines, heat exchangers and pumps as scale free and deposit free as possible has increased significantly compared to the past. Another advance in operations and technology has been the development of equipment that can use the latent energy in the concentrated brine to provide direct heat via heat exchangers for facilities such as paper mills, green houses, and the production sites for the drying of meats and fruits. The scaling tendency of the concentrated brine can then become an even more problematic issue as the negatives associated with the scaling expand beyond periodic replacement of the liquid brine pipe to one of a constant loss of electrical production capacity in a binary unit or the loss of heat in a building. Removal of scale from the heat exchangers of the binary power plant in order to restore electrical generation capacity can lead over time to damage of the equipment, permanent lost capacity, and a reduction in reliability of the unit. In plants with high saturation levels of metal silicates and amorphous silica, the geothermal industry has developed solutions for control of the problem which are based on pH control, scheduled and periodic maintenance programs, the use of scale inhibitors, and a combination of all three methodologies. The use of strong acids for pH control has been used successfully in the industry for many decades. However, the use of strong acids has also led to major equipment failures, damaged heat exchangers, negative impacts on the reservoir and harmful environmental consequences. US trade patented ideas have also been developed and implemented to utilize the naturally occurring carbon dioxide present in the geothermal steam to produce a weaker carbonic acid to assist in the prevention of silica and metal silicate depositions (Weres, 2012). Periodic and Preventative maintenance programs vary from bi-annual to annual shutdowns in which heat exchangers and piping can be cleaned with high pressure water cleaning systems to the use of hydrofluoric (HF) and hydrochloric (HCL) acid descale recirculation programs. To reduce the impact of the use of the acid options and to extend out the periods of maintenance and the level of complexity involved with each maintenance outage, the development and use of silicate and silica inhibitors has been maturing substantially over the past 15 years. The development of the silica inhibitor has now been proven, in various geothermal fields over the past 10 years, to allow for the elimination for the need of strong acids, either in the role of pH modification or in the application as a descale chemistry.

This paper will examine the silica scaling issues that have occurred over the decades at one geothermal field in Momotombo, Nicaragua. The Momotombo Power Corporation (MPC) currently operates a geothermal plant in which silica deposition problems presented themselves on a) the brine line coming off a single flash Separator at the Momotombo Power Station and b) in the binary power plant which was constructed in 2002 to utilize the latent energy remaining in the flashed brine. After a historical review of the scaling problems at Momotombo, this paper will then document the progress made in reducing silica scale formation by the use of scale inhibitors.

1. INTRODUCTION

1.1 Momotombo Power Station

The Momotombo Power Station is located to the northwest of Lake Managua (aka Lake Xolotlan in the indigenous language). It is on the slope of the active Momotombo volcano and is in the Momotombo Volcano Nature Preserve. The plant resource is the Momotombo Geothermal field which is a water dominated field. The Momotombo Power Station began operation in 1983 with a 35 MW flash steam turbine. This was expanded in 1989 with a second 35 MW steam flash unit. However, over- exploitation of the reservoir field quickly prevented full capacity operation of either turbine. Well pressure decline, carbonate scale formation in production wells, and cool water intrusion into the reservoir led to a low point of electrical production in 1999 of just 8 MW. From 1999 to 2013 Ormat Technologies operated the plant and field after winning an international bid to operate the plant and field with a commitment to attempt to restore a significant percentage of the electrical capacity of the plant. In 2002, as part of this concession, Ormat Technologies installed a 7.2 MW Ormat Energy Converter (OEC) based on a closed Organic Rankine Cycle Process. In 2013, a new concession was granted to MPC, who currently owns and operates the facility.

The plant at present has 11 active production wells, 23 closed production wells, and 7 reinjection wells. Wells range in depth from 550 meters to 2,500 meters. Temperatures in the production wells range from 178 C to 226C.

Scaling is an issue with virtually all geothermal power plants and direct use applications of geothermal brines that come from water dominated reservoirs. The Momotombo station is no different and it’s initial encounter with scaling problems was related to calcite formation in the production wells. As electrical production reached it's nadir in 1999, Ormat, as a new owner of the plant and field began a program to restore the capacity of the plant. Actions taken included reworking the production wells, applying a calcite scale inhibitor to the reworked wells, reinjection of spent brine, and the installation of the bottoming binary cycle plant in 2002 / 2003. Reinjection has stabilized the pressure in the reservoir. However there has been a drop in temperature in many of the production wells over the past 14 years. (Kaspereit, 2016).

(Courtesty of Mountain Stamp Maps)

Figure 1: Location of Momotombo Power Station in the Republic of Nicaragua.

1.2 Chemistry of Brine

The Binary Plant is supplied brine from ~~10~~ 11 wells. Wells MT- 41 and MT-43 are especially high with respect to silica at 890 ppm and 1396 ppm. The impact of these high levels of silica can be modelled and the scale and deposition is what modelling has predicted (Weres, 2015).

A recent analysis of the chemical composition of the flashed brines from wells MT-41, MT-43, and the total brine flow (approximately 1,004 tons per hour) is indicated in Figure 2. This flashed brine supplies energy to the OEC binary bottoming unit.

Certificate of Analysis
March 10, 2017

Laboratory No.	17–03–13–58
Company	MOMOTOMBO
Address	MOMOTOMBO, NI
Engineer	NELSON DELGADO
Sample Date	March 7, 2017
Sample Class	Waters

Analysis	MT36/43	OEC	MT41	MT43
pH	7.46	6.25	7.90	7.73
Conductivity, µmho	10198	8547	10104	13532
"M"–Alkalinity, as $CaCO_3$, mg/L	52	54	56	264
Calcium Hardness, as $CaCO_3$, mg/L	96	156	73	56
Magnesium Hardness, as $CaCO_3$, mg/L	0.17	0.31	0.10	0.20
Iron, as Fe, mg/L	2.4	<0.10	0.12	0.41
Copper, as Cu, mg/L	<0.10	<0.10	<0.10	<0.10
Zinc, as Zn, mg/L	<0.10	13	13	<0.10
Sodium, as Na, mg/L	2041	1545	1942	2599
Potassium, as K, mg/L	381	242	364	719
Chloride, as Cl, mg/L	3651	2638	3414	4896
Sulfate, as SO_4, mg/L	35	88	21	4.6
Nitrate, as NO_3, mg/L	<1.0	<1.0	<1.0	<1.0
Ortho–Phosphate, as PO_4, mg/L	1.0	0.50	0.50	0.50
Silica, as SiO_2, mg/L	783	488	890	1396
Phosphonate, as PO_4, mg/L	8.6	3.1	2.5	8.1
Aluminum, as Al, mg/L	<0.50	<0.50	0.53	<0.50
Manganese, as Mn, mg/L	0.18	<0.10	<0.10	<0.10

Figure 2: Analysis of brine from MPC.

Of particular interest is the slightly alkaline pH of the higher silica bearing brines and the presence of aluminum. Very low levels of aluminum, as present in these waters, are sufficient to begin a precipitation of aluminum silicate that serves as a seeding mechanism for amorphous silica. The presence of the aluminosilicate drives the polymerization speed of the amorphous silica at a much faster rate than if there was no precipitant present in the brine.

1.3 Scaling of Pipelines

Wells MT-43 and MT-36 share a common Separator as seen below:

(Photo courtesy of Jose Guido, MPC)

Figure 3: Well MT-36 and the combined Separator for brine flow from MT-36 / MT-43

The saturation levels for metal silicates are above 1.0 and as a consequence both in the two phase line from the well and more dramatically in the flashed brine line coming off the separator, there has been severe scaling.

Figure 4: Scale in pipeline of Separator Brine Line

Figure 5: Another section of piping from area MT 36/ 43

1.4 Bottoming Unit

In October 2002 an ORMAT bottom cycle binary plant was put into service. Within one year the unit was facing severe silica scaling problems which would lead to a continual reduction in electrical production. The initial solution to the problem was to program a maintenance cleaning program which utilized hydrofluoric acid (HF). Between 2004 and 2007 the unit had to be cleaned 6 times with HF (Porras, 2008). By the 6^{th} acid cleaning, tube wall testing of the vaporizer and pre-heaters indicated that severe metal loss had occurred in the isopentane and brine heat exchangers. It was determined that continued future acid cleaning with HF would jeopardize the integrity of the binary unit and risk a loss of isopentane.

The level of deposits from the Separator lines, was a good indicator the danger of scaling in the OEC, given that silica scales are temperature dependent – lower temperature will translate to faster and more scaling. Amorphous silica is also time dependent with respect to precipitation as well as being dependent on the presence of seeding particles. (Weres, 2015).

The OEC is located over one kilometer from the MT 36 / MT 43 Separator and this distance provides a sufficient residence time for more silica to precipitate out of solution. The reaction rates increases as temperature drops, specifically at the outlet of the OEC, in the preheater sections.

Figure 6: Ormat OEC bottoming unit, placed into service in October of 2002.

1.5 General Lay-Out of Well Field

Eleven wells supply steam to the flash unit and the flashed brine is piped to the Ormat Energy Converter (OEC). Six of the wells are treated with an inhibitor for calcite deposition control. The feed of the inhibitor for these wells is in the well bore before the flash zone. Four other wells do not have calcite scaling issues, but they have high levels of silica which when added to the total brine flow cause major deposition problems at the OEC. The silica levels in these wells are also such that they cause deposits in the separator brine pipelines.

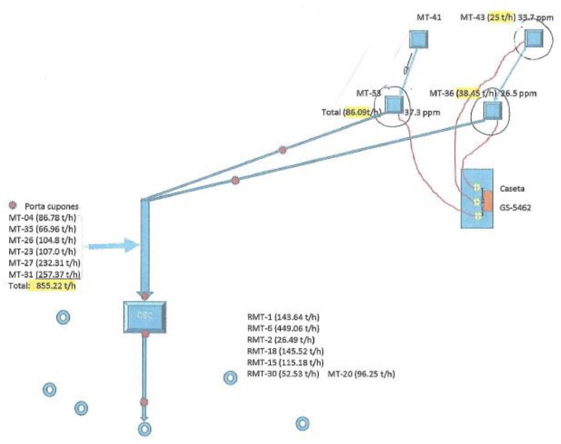

Figure 7: Layout of wells, flows, and OEC at MPC

2. DEVELOPING AN INHIBITOR PROGRAM

2.1 First Stage

Controlling the deposits became critical after the limitation on future HF acid cleanings. The first response was simply to feed an inhibitor prior to the OEC. This provided a major improvement to the operating ability of the plant, and from 2008 to 2017 no acid cleanings have been utilized. Annual maintenance allowed for a now much softer deposit to be mechanically removed. Just as importantly the drop off in electrical production due to scaling on the vaporizer was significantly slowed. (Porras, 2008). Despite the dramatic improvement, concerns still remained for plant operations. First, the brine pipelines continued to suffer from heavy deposition, which eventually led to reduced brine flow. Second, even with the improvement in reduced scale formation, the binary plant was still having a gradual drop off in electrical production through the course of the year. After the annual mechanical cleaning the plant would see a significant boost in electrical production which would then slowly diminish over time. Finally, the plant had concerns that the reinjection wells would begin to also lose permeability due to deposition if silica scale was not more thoroughly controlled. The photograph of scale coupons in Figure 8, shows that despite decent results, especially when compared to having no inhibitor, there was still room for improvement in the scale inhibitor control program.

Figure 8: Scale coupons at inlet and outlet of OEC after 5 months.

2.2 Modelling of the Brine

Given the concerns and room for improvement, in 2015 the brines going to the OEC were modelled by Dr. Oleh Weres using his proprietary software program STF (Silica Temperature and Flash) in conjunction with data from Geochemists Workbench v.9.09.

Well	Location		P (barg)	T (°C)	Calcite Log_{10} S	Amorphous SiO_2 Log_{10} S	Amorphous SiO_2 S
MT-41	Reservoir		–	251.4	–0.49	–0.43	< 1
	Wellhead	(a)	7.5	172.6	+0.05	–0.15	< 1
	Leaving HX		–	65	–1.50	+0.38	2.4
MT-43	Reservoir		–	262.6	–0.74	–0.41	< 1
	Wellhead	(b)	7.5	172.5	–0.28	–0.09	< 1
	Leaving HX		–	65	–1.87	+0.43	2.7
MT-4	Reservoir		–	200.9	+0.11	–0.41	< 1
	Wellhead	(b)	5.0	158.9	+0.69	–0.26	< 1
	Leaving HX		–	65	–0.02	+0.22	1.6
MT-42	Reservoir		–	231.0	+0.21	–0.35	< 1
	Wellhead		5.9	164.5	+0.05	–0.11	< 1
	Separator		4.4	154.9	–0.05	–0.06	< 1
	Leaving HX		–	65	–0.74	+0.39	2.5
36 & 43	Separator	(c)	4.8	157.1	–0.02	+0.08	1.2
	Leaving HX		–	65	–1.19	+0.56	3.6
53 & 41	Separator	(c)	4.5	155.2	–0.08	+0.07	1.2
	Leaving HX		–	65	–1.11	0.53	3.4

Figure 9: Saturation levels for the different brines and reconstruction of estimated condition prior to flash at Separator.

2.3 Selection of new inhibitor and feed point

Based on the saturation data two changes were implemented in December 2016 with the scale inhibitor program. Change one, was in the chemical composition of the inhibitor. The original product consisted of two active ingredients. The product selected for the current trial (Dec 2016 until the present) is composed of 4 different active ingredients. The second change was to move the feed point from a single injection quill directly before the OEC to multiple injection points at the well heads of the highest silica containing wells. Injection would now be prior to the Separators.

2.4 Start of the new inhibitor program

In mid-December 2016 the new program with the new feed points was started. Coupons were installed at the inlet to the OEC and at the outlet of the preheater. The outlet of the preheater is the last section of equipment in the OEC exposed to the brine, and the brine is at the lowest temperature and most scale forming condition.

Figure 10: Scale coupons three weeks into the new program

The trial is now into the 10th month and scale formation is extremely light and controlled. As can be seen below, these are the same coupons that were installed at the commencement of the trial back in Dec 2016. They have not been cleaned over the last 10 months. Coupons are removed for inspection, weighing, and photography and then placed back into the brine flow.

Figure 11: Scale coupons 10 months into the new program

2.5 Scale formation in the Pipeline

In mid-July 2017 maintenance was performed on wells MT-36 and MT-43. This provided an opportunity to look into the pipeline. The old scale was as expected still present. However, the amount of new scale that had formed, just as with the coupons located at the OEC, was extremely negligible.

Figure 12: Old scale deposit with newer deposit having coated on top. Old deposit is dark grey material almost ½ inch thick. New white deposit was only 1/64" thick.

2.6 Plant Operation Data

Plant operational data from Dec 2016 to the present shows constant temperatures and electrical production. Indicating that scale is not precipitating on the unit heat exchangers even as heat is removed from the brine and the scaling propensity for silica increases.

3. CONCLUSION

Silica scale that initially presented itself during the first years of plant operation was bothersome but not a critical problem to plant operations at the Momotombo Power Station. This condition changed when a bottoming cycle binary plant was installed in late 2002. The silica scales which had been noted previously began to impact electrical production of the OEC within one year. The initial response of programmed outages to conduct HF acid cleanings was successful for the first 4 years until the accumulated corrosive impact of the acid placed the unit in jeopardy of failure. The HF cleaning could not therefore be continued. Indeed, the evaporator or vaporizer section of an OEC at a geothermal plant in a neighbouring country had to be replaced in 2016 after over 200 of the heat exchanger tubes had to be sealed off due to isopentane leaks that developed precisely because of repeated HF acid cleanings. The binary plant that suffered these tube failures used sulfuric acid for pH control to slow the rate of silica deposition during the course of the year. Nonetheless, at the end of each year, sufficient tenacious silica deposits would form in the binary plant heat exchangers that a HF cleaning had to be conducted to restore the plant to rated electrical production.

The first use of silica inhibitor at MPC was to feed a rather simple product directly in front of the OEC. This provided good results, especially when compared to the condition of the HX when no inhibitor was used. However, after 8 years, and concerns for brine pipelines and the desire for even better control of deposition in the OEC and injection wells a new program was developed in 2015. The first step was to model the brines, the second step was to develop a new chemistry program, and the final action was to establish new feed points that could better protect not only the OEC but the brine pipelines. The new program began in Dec 2016 and results have been extremely positive to date.

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