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An Evaluation on the Applicability of Infrared Thermography in Identifying Silica Deposition in Geothermal Brine Lines

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ABSTRACT

Silica deposition in the surface pipe lines of geothermal fields operated by the Energy Development Corporation is due to supersaturation of the fluids with respect to amorphous silica and its subsequent precipitation. These scales and other transported debris deposits may build up and could cause flow restrictions in pipes and capacity decline of reinjection wells. Silica de-scaling operation is a major activity that requires shutting off the affected lines where severe deposition is suspected. In this report, a methodology of using infrared thermography for identifying locations and predicting thicknesses of silica scales in brine lines in the Mahanagdong sector of Leyte Geothermal Production Field is evaluated. Determination of the locations and thicknesses of silica deposits using pipe surface temperatures is based on the principle that silica scales inside pipes decrease the effective thermal conductivity of the pipe (Lite et al., 2006). Thus, portions of the pipelines with thick silica deposits will have lower surface temperatures compared with clean and scale-free portions. Pipe surface temperatures in this study were measured using a digital surface probe thermometer and an infrared thermography camera. Infrared thermography, together with temperature and pressure profiling, along the Mahanagdong sector has been proven to be a potential tool for identifying locations where significant scaling occurs. However, prediction of the scale thickness using the derived formula by Villena and de Lara (2006) yielded calculated thicknesses that did not approximate actual thicknesses based on actual pipe inspections. The possible reasons for very wide ranges of calculated thickness are: (1) the theoretical value of thermal conductivity of amorphous silica used in the formula is not applicable for silica deposits along geothermal brine lines; and (2) non-ideal or different conditions along the brine lines such as bare pipes or damaged insulations.

1. INTRODUCTION

Silica scale deposition in surface geothermal facilities is a common and recurrent problem encountered in geothermal fields of the Energy Development Corporation (EDC). This is commonly due to the inherent supersaturation of the separated brine fluids with respect to amorphous silica, or supersaturation brought about by poor pipe configuration and insulation. Silica scales and other transported debris may build up and cause restrictions in pipe and capacity decline of reinjection wells. Silica de-scaling operation is a major activity that requires shutting off the affected brine lines, or eventually cutting off the pipe portions where severe deposition has occurred. One methodology that has been identified to determine the locations of blockages, possibly silica scales, is infrared thermography. Hence, the objectives of this paper are:

(1) To determine the possible locations of silica scales in the Mahanagdong main reinjection line (MRIL) based on the results of infrared thermography;

(2) To correlate and verify predictions of locations of silica deposits and thickness calculations based on thermal data with actual field inspection results during pipe opening; and,

(3) To evaluate the applicability of infrared thermography in predicting scaled portions of the pipeline.

The determination of the locations and thicknesses of silica deposits using pipe surface temperatures is based on the principle that silica scales inside pipes decrease the effective thermal conductivity of the pipe (Lite et al., 2006). Thus, the portions of the pipelines with thick silica deposits will have lower surface temperatures compared with clear portions. Pipe surface temperatures may be measured by instruments such as a digital surface probe thermometer or an infrared thermography camera. A surface probe thermometer will give the temperature at particular spots on the brine line. An infrared thermography camera will produce two-dimensional images of invisible infrared or "heat" radiation and will provide non-contact surface temperature measurements.

An equation for the calculation of the thickness of silica scales inside pipe walls derived by Villena and de Lara (2006) was used in this study. Steady-state conditions were assumed where heat flow through the silica and pipe layers equals the heat flow from the pipe surface to the ambient. The derived equation to compute for the thickness of silica deposit “t” in brine lines is,

$$t = r_i \left[1 - \frac{\left(\frac{r_o}{r_i}\right)^{\left(\frac{k_{sil}}{r_{pipe}}\right)}}{e^{\left(\frac{k_{sil}}{r_o h}\right)\left(\frac{T_1 - T_2}{T_2 - T_{air}}\right)}} \right] \tag{1}$$

where t, r_i, r_o, k_{pipe}, k_{sil}, h, T_2, T_1, T_{air} are thickness of silica, inside radius of pipe (without silica), outside radius of pipe, thermal conductivity of pipe, thermal conductivity of silica, convection coefficient, temperature of inside surface of silica, temperature of outside surface of pipe, and ambient temperature of air, respectively.'

2. HISTORICAL BACKGROUND OF THE MAHANAGDONG MAIN REINJECTION LINE, OR MRIL

The Mahanagdong geothermal sector is part of the Leyte Geothermal Field located in the island of Leyte, Philippines (Fig. 1). Mahanagdong was developed into two sub-sectors namely Mahanagdong-A (MG-A) and Mahanagdong-B (MG-B) with plant capacity of 120 MWe and 60 MWe, respectively. The main Mahanagdong reinjection line was installed in 1998, and has undergone manual cleaning in 2004 and 2006, and mechanized cleaning in 2005. The mixed brine flowing through the main reinjection line (MRIL) right after the separator vessels has a silica saturation index (SSI) range of 0.93 – 1.12. The silica saturation index (SSI) further down the MRIL prior to injection into wells ranges from 0.99 – 1.05. Despite the fluids' only near saturation condition with respect to amorphous silica at which massive scaling is not expected, excessive temporary dumping of brine into thermal pond has occurred. Suspected reduced pipe capacity within the MRIL led to the investigation of possible blockages.

Pressure profiling along the MRIL in August 2008 (Fig. 2) revealed higher measured pressures at the tapping points along the MRIL compared to the designed pressures. Pressure differences were observed to be significant at the upstream sections, along Low Point 1 (~2 kscg) and Low Point 2 (~3.5 kscg), and some portions downstream towards the injection wells.

Figure 1: Geothermal production fields (GPF) operated by Energy Development Corporation (EDC) and their installed capacities. The Mahanagdong geothermal sector is part of the Leyte Geothermal Production Field located in the island of Leyte, Philippines.

3. RESULTS OF THERMAL SCANNING IN THE MAHANAGDONG REINJECTION LINE (LITE ET AL., 2010)

Infrared thermography along the brine line was conducted in November 2009. Based on the temperature profiles obtained from thermal images of the whole stretch of the MRIL, six (6) locations (Table 1 and Figs. 3 and 4) are characterized by lower temperatures. These locations are: (1) Near Manhole 00, (2) Between Manhole 2.1 and Spool B, (3) Spool B (Low point 1), (4) Near Manhole 4, (5) Near Manhole 6.7, and (6) Injection pad. The minimum temperatures in these six locations range from 61-98°C, while the maximum temperatures in the identified areas range from 144-157°C. The six areas along the MRIL where significant silica scaling is predicted are indicated by red arrows in Figure 5.

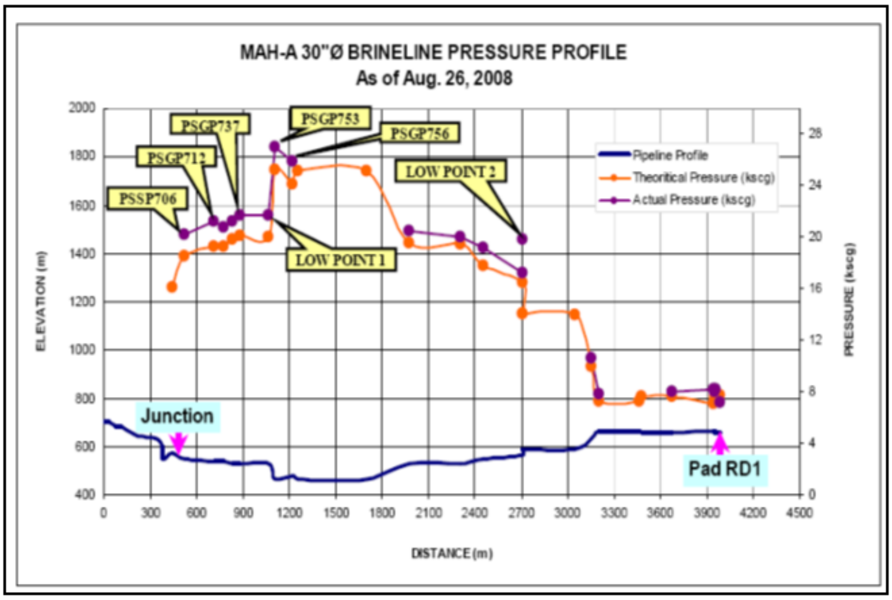
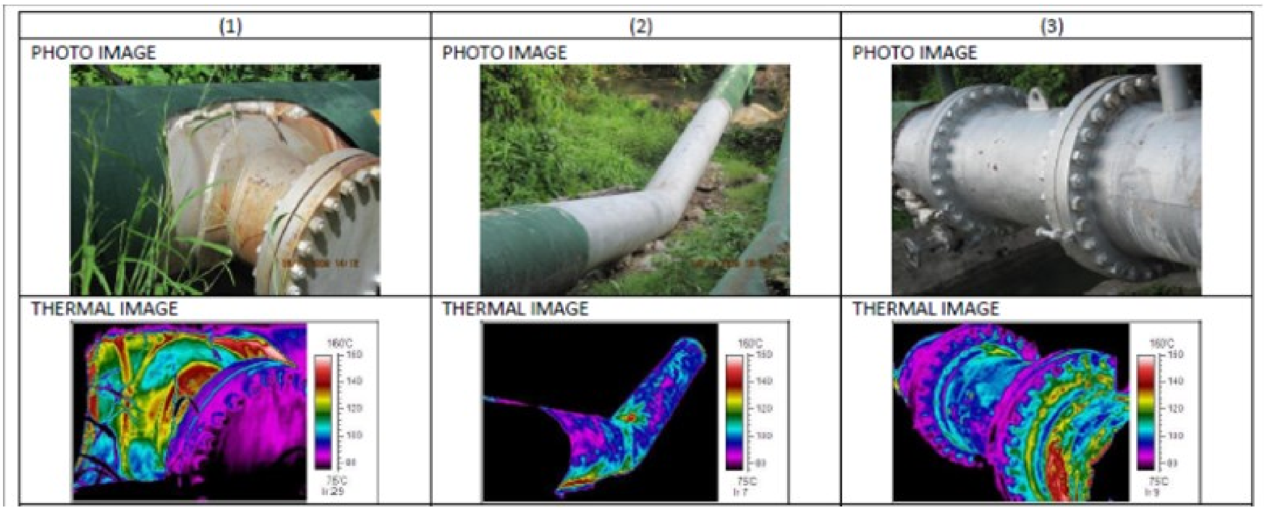


Figure 2: Comparison of designed pressures with actual pressure profile along MG-A MRIL (Lacambra, 2008)

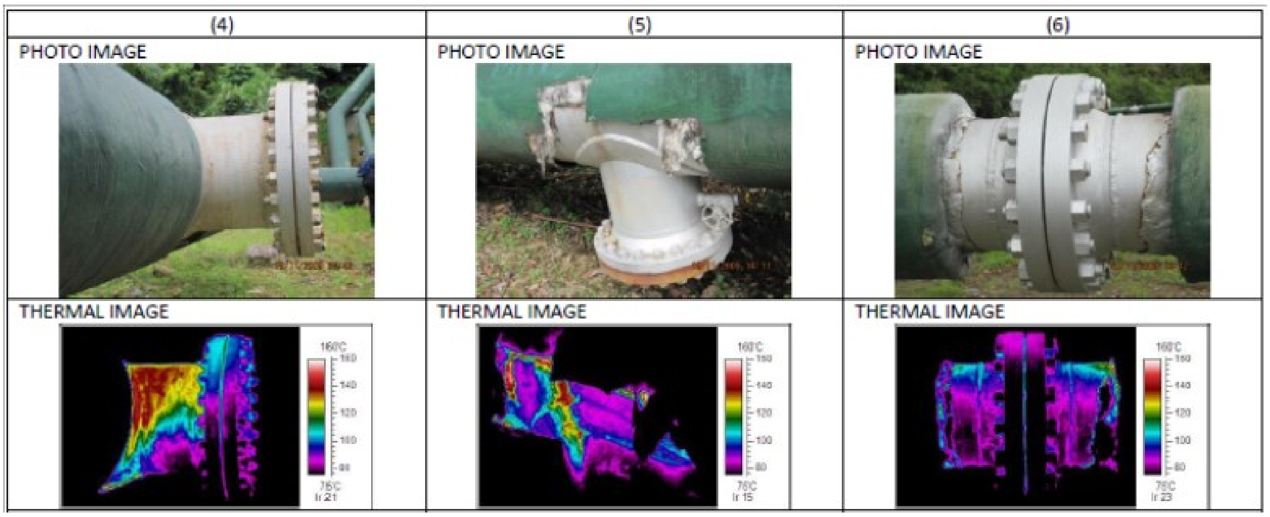
Table 1: Locations inside the Mahanagdong MRIL where significant scaling is identified based on temperature data obtained from thermal images. The minimum and maximum calculated scale thicknesses from the derived formula are given in millimeters.

No.	Location	Min. Temp (°C)	Max. Temp (°C)	Minimum Scale Thickness, mm	Maximum Scale Thickness, mm
1	Near Manhole (MH) 00	84.91	156.17	3.30	152.15
2	Between MH 2.1 & Spool B	98.48	150.76	8.38	103.89
3	Spool B (Low point 1)	94.97	152.34	6.86	115.06
4	Near MH 4	76.92	146.77	12.70	188.47
5	Near MH 6.7	61.27	157.15	2.29	277.37
6	Injection pad	75.97	144.11	15.75	193.04



Max. Temp: 156.17°C	Max. Temp: 150.76°C	Max. Temp: 152.34°C
Min. Temp: 84.91°C	Min. Temp: 98.48°C	Min. Temp: 94.97°C
Max. Deposit: 152.15 mm	Max. Deposit: 103.89 mm	Max. Deposit: 115.06 mm
Min. Deposit: 3.30 mm	Min. Deposit: 8.38 mm	Min. Deposit: 6.86 mm

Figure 3: Results of infrared thermography along the MRIL including photo and thermal images, temperatures and calculated minimum and maximum scale thicknesses at locations 1, 2 and 3 (Modified from Lite et al., 2010)



Max. Temp: 146.77°C	Max. Temp: 157.15°C	Max. Temp: 144.11°C
Min. Temp: 76.92°C	Min. Temp: 61.27°C	Min. Temp: 75.97°C
Max. Deposit: 188.47 mm	Max. Deposit: 277.37 mm	Max. Deposit: 193.04 mm
Min. Deposit: 12.70 mm	Min. Deposit: 2.29 mm	Min. Deposit: 15.75 mm

Figure 4: Results of infrared thermography along the MRIL including photo and thermal images, temperatures and calculated minimum and maximum scale thicknesses at locations 4, 5 and 6 (Modified from Lite et al., 2010)

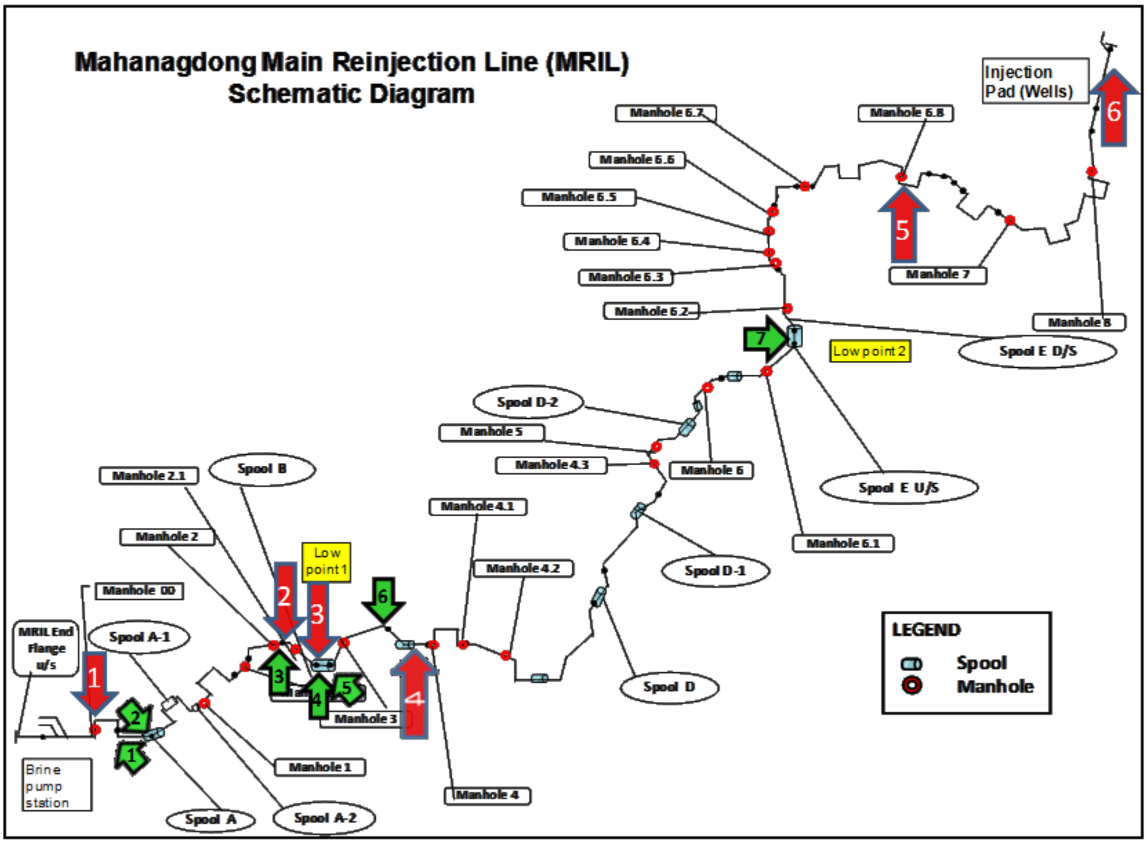


Figure 5: Predicted areas inside the MRIL (red arrows) with significant scaling based on infrared thermography and recommended priority locations (green arrows) for de-scaling during the PMS (Modified from Baltazar et al., 2010)

4. RECOMMENDED PRIORITY LOCATIONS FOR CLEANING AND DE-SCALING IN THE MRIL

Several factors were considered by a task force headed by A. D. Baltazar in determining priority locations for cleaning and de-scaling operations in the MRIL. These factors were: 1) results of the infrared thermography, pressure profiles, and the historical inspection results along the brine line. Knowledge of the surface facility configuration and historical scaling data along the line, as well as temperature and pressure data, were greatly considered in the selection of the priority locations. Based on these factors, the recommended locations to be prioritized for de-scaling during the preventive maintenance service (PMS) in January to February 2010 (green arrows in Fig. 5) were:

(a) Near Manhole 00
(b) Near Spool A
(c) Near Manhole 2
(d) Near Manhole 2.1
(e) Near Spool B
(f) Near Spool C
(g) Near Low Point 2 (spool)

5. MAHANAGDONG PMS INSPECTION AND DOCUMENTATION HIGHLIGHTS

The Mahanagdong power plant and surface facilities underwent preventive maintenance schedule (PMS) shutdown in January to February 2010. The PMS activities included inspection, cleaning and de-scaling operations of the ~2000-m recommended pipe length of the MRIL.

Of the 2000-m length recommended for de-scaling, only ~1757 was cleaned using high pressure water rotajet cleaning units. The rest of the brine line was cleaned manually. The highlights of the inspection and documentation are:

(1) Based on actual measured thicknesses in spools of the MRIL, amorphous silica scales were thicker at the upstream side of the brine line and thinner towards the downstream side (Table 2). Scale thickness in the upstream spools ranged from 10-34 mm, compared to 5-9 mm thick scales in spools on the downstream side.

Table 2: Measured scale thicknesses in spools along the MRIL (Baltazar et al., 2010)

Inspected Area of the MRIL	Measured Thickness, mm				Average Thickness, mm
	Top	Left	Right	Bottom	
End Flange	39.4	47.1	45.5	4.1	34.0
Spool A	9.7	3.6	14.0	10.5	9.4
Spool A-1	16.3	17.8	15.0	13.4	15.6
Spool A-2	27.0	26.2	24.9	5.7	20.9
Spool B	10.4	7.5	6.3	2.1	6.6
Spool D	11.0	8.7	11.1	5.0	8.9
Spool D-1	9.3	9.5	8.8	5.3	8.2
Spool D-2	8.1	12.5	9.2	7.7	9.4
Spool E U/S (Low point 2)	5.7	5.7	5.7	5.7	5.7
Spool E D/S (Low point 2)	4.5	7.6	6.5	3.5	5.5

(2) In manholes, thicker scales of >100-240 mm thickness range were found near the vicinity of Low Point 1 (upstream), Low Point 2 (midstream), and near the downstream side of the line, and MH 7 (Table 3). The other manholes had relatively thinner scales with thickness of generally < 70 mm.

(3) The samples collected inside the brine line are composed primarily of amorphous silica, minor amounts of corrosion products, and in some areas, smectite, altered rocks and minerals, and traces of cement (Table 4).

The locations with actual relatively thick scales in MRIL are shown as shaded cells in Tables 2 and 3, and shown as shaded green ovals in Figure 6. They are generally located at the upstream side of the brine line near Low Point 1 vicinity and midstream near Low Point 2. One location, Manhole 7, is near the downstream part of the brine line.

6. DISCUSSIONS

6.1 Prediction of locations of significant scaling in the Mahanagdong Main Reinjection Line

In Figure 6, the red arrows, near the upstream side and two arrows near the downstream side of the brine line, point to locations where surface temperatures were lower, and hence concluded to be sites of significant silica deposits. These were generally proven by actual inspection results. Red arrows fall within the green ovals, locations where thicker deposits were actually measured. Based on this, infrared thermography along the MRIL has proven to be a potential tool for determining the locations where significant scaling (red arrows) are present as shown in Figure 6.

The priority locations for opening and cleaning recommended by the task force (shown by green arrows in Fig. 4), selected not only based on temperature and pressure data, but also historical scaling data and surface pipe configuration, generally fell within the two major areas of thick deposits based on actual inspection (vicinities of Low Point 1 and 2).

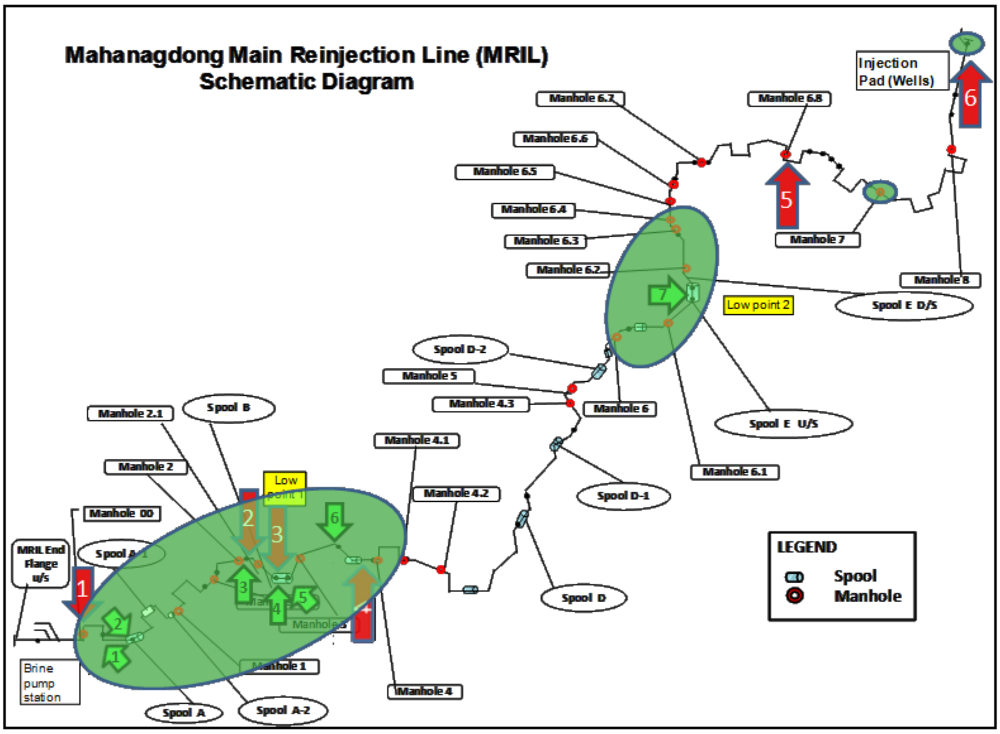


Figure 6: Recommended priority locations for de-scaling (green arrows), locations with possible significant scaling based on infrared thermography (red arrows), and areas with thicker scales based on actual measured scale thicknesses (green ovals) during the PMS of the MRIL (Modified after Baltazar et al., 2010)

Table 3: Measured scale thicknesses in manholes along the MRIL (Baltazar et al., 2010)

Site Inspected	Actual Thickness, mm				Maximum Thickness, mm	Orientation
	Top	Left	Right	Bottom		
Manhole 00	2.3	3.7	4.3	320.0	320.0	Side
Manhole 1	Full				101.6	Bottom
Manhole 1.1*	Minimal			5.0	5.0	Bottom
Manhole 2	13.8	13.2	7.6	127.0	127.0	Side
Manhole 2.1	Full				69.8	Bottom
Manhole 3	6.8	2.7	5.9	114.3	114.3	Side
Manhole 4	5.6	3.3	5.7	95.2	95.2	Side
Manhole 4.1	Full				101.6	Bottom
Manhole 4.2	4.6	4.1	4.1	209.6	209.6	Side
Manhole 4.3	1.3	1.7	6.8	90.0	90.0	Side
Manhole 6	Minimal			150.0	150.0	Side
Manhole 6.2	Minimal			56.9	56.9	Side
Manhole 6.3	Minimal			241.3	241.3	Side
Manhole 6.4	Minimal			241.3	241.3	Side
Manhole 6.5	Minimal			69.8	69.8	Side
Manhole 6.7	Full				69.8	Bottom
Manhole 6.8	Full				69.8	Tangential
Manhole 7	6.5	9.2	15.8	152.4	152.4	Side
Manhole 8	6.7	7.4	6.9	2.4	44.4	Side

6.2 Calculation of scale thickness using the derived formula by Villena and de Lara (2006)

Thickness calculations based on the derived formula gave very wide ranges (Table 5). The calculated thickness range was actually based on the temperature range captured in a thermal image of the particular area along the MRIL. The minimum calculated thickness is based on the highest temperature, while the maximum calculated thickness is based on the lowest temperature captured in a particular image. The wide ranges of calculated silica scale thicknesses effectively encompass most of the actual silica scale thickness measured in the field, and thus prediction of the scale/deposit thickness based on temperature data is not yet achieved at the present time. Moreover, some of the actual thickness measurements do not even fall within the wide range of predicted thickness like in MH 00, Spool 2, MH 4. The possible reasons why inaccurate thicknesses were calculated are: (1) the theoretical value of thermal conductivity of amorphous silica that was used is not applicable for silica deposits along geothermal brine lines; and (2) non-ideal or different conditions along the brine lines (bare pipe, damaged insulations, etc.).

Table 4: MRIL scale composition and description (Rosell, 2010)

Site Inspected	Scale Composition	Description
Spool # 1	~100% amorphous silica	White – dark gray Hard, compact, glassy scales
Manhole # 00	~100% amorphous silica	Light – dark gray Hard, banded, angular scales
Manhole # 2	~100% amorphous silica	Light – dark gray Hard, porous, compact, wavy banded scales
Manhole # 2.1	~100% amorphous silica (trace cement)	Gray Loose scale deposits of medium-coarse sands
Spool B	~100% amorphous silica	Colorless – gray
Manhole # 4	~70% amorphous silica ~30% debris (scales, corrosion products, altered rocks & minerals)	Light-dark gray Hard, angular fragments
Manhole # 6.2	~55% amorphous silica ~35% smectite ~ 10% corrosion products	Light – dark gray Loose, coarse sand to pebble fragments

Table 5: Comparison of measured and calculated thicknesses of deposits in the MRIL.

Predicted Sites of Significant Scaling based on Thermal Scanning	Some Inspection Sites during 2010 PMS	Actual Measured Thickness (mm)	Calculated Thickness Range (mm)
1	Manhole 00	2.3 - 320.0	3.3 - 152.2
2	Manhole 2.1	69.9	8.4 - 103.9
3	Spool B	2.1 - 10.4	6.9 - 115.1
4	Manhole 4	3.3 - 95.3	12.7 - 188.5
5	Manhole 6.7	69.9	2.3 - 277.4
6	---	---	15.8 - 193.0

7. CONCLUSIONS

Infrared thermography along the Mahanagdong main reinjection brine, or MRIL, has proven that it is an applicable tool for identifying locations where significant silica scaling occurs. Four identified sites, located at the upstream side of the brine line, were indeed characterized by thicker scales of > 100 mm compared to other sites based on actual inspection results. Another predicted location is the reinjection pad which also proved to be a site of very thick deposits as documented during the PMS. Only one recommended location in Manhole 6.7, out of the total six, was characterized by relatively thin deposits.

Based on the experience in Mahanagdong, using historical scaling and inspection data and pipe configuration in addition to temperature and pressure data would give higher confidence and accuracy in determining sites of thick scaling (Fig. 4).

Prediction of the scale thickness using the derived formula by Villena and de Lara (2006) is not yet achieved at the present time. The possible reasons for very wide calculated thickness ranges are: (1) the theoretical value of thermal conductivity of amorphous silica used in the formula is not applicable for silica deposits along geothermal brine lines; and (2) non-ideal or different conditions along the brine lines (bare pipe, damaged insulations, etc.).

Future work for this study will be back calculation of the thermal conductivity of amorphous silica to be able to accurately predict scale thickness. In addition, thorough analysis and description of scales and deposits in brine lines will be done to be able to characterize them with respect to composition and textures. The data that will be obtained may be used later in determining the appropriate thermal conductivity for the type of silica or other deposits present in geothermal brine lines.

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