Case Study of the CaSil Technology at Dieng, Indonesia; Successfully Eliminating Silica Scale

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ABSTRACT

The CaSil technology is a proprietary innovative new technology that eliminates silica deposition and scaling from geothermal brine, supersaturated in silica. The technology has been developed and successfully demonstrated at development plant scale operation over six years in four New Zealand geothermal fields.

This paper reports an initial study on the application of the CaSil technology to the silica supersaturated, hyper-saline brine from the Dieng geothermal field, Indonesia. Problematic dissolved silica is rapidly captured as a nanostructured calcium silicate material before silica deposition and scaling can occur. This yields a treated brine that can be cooled to unprecedented low temperatures without silica scaling, thereby enabling more heat energy to be accessed and electricity generated from the same brine flow than is currently possible.

Samples of brine from the Dieng-1 well that had been acidified after collection were provided by Geo Dipa Energi to CaSil Technologies for analyses and an initial assessment of the suitability of the CaSil technology to prevent silica scaling. Using atomic absorption and UV visible spectroscopies, electrochemistry, and titrations the main constituents of the brine were identified. Based on this, a simulated brine was generated and used to test and identify the potential of the proprietary CaSil technology to reduce silica levels and the Silica Saturation Index, SSI, of this high silica, hyper-saline brine accordingly.

Another intention of these trials was to explore effects from the borate buffer system due to the high boron content of the brine, on the CaSil technology and the reduction of the Silica Saturation Index (SSI) to levels where additional heat can be harnessed and electricity generated without inducing silica scaling. Autoclave reactions were used to simulate field specific high temperature and pressure reaction conditions.

The successful laboratory trials using the simulated brine were confirmed using the Dieng brine samples provided in further experiments. These show the pathway for possible field trials, which promise that by incorporating the CaSil technology, additional heat recovery and electricity generation from the Dieng resource can be achieved without silica scale formation, thereby unlocking the full energy potential and utilisation of this geothermal resource.

1. INTRODUCTION

Geothermal energy is an attractive natural renewable energy resource which can provide large quantities of heat energy for electricity generation and/or direct heating applications. In water dominated high enthalpy fields, the geothermal water (brine) in the subsurface reservoir that is typically about 200-300 ˚C, dissolves rock and sediment minerals in the reservoir rocks releasing silica mainly as the $H_3SiO_4^-$ ion, alkali and alkaline earth metal cations, and anions such as chloride and carbonate into the hot brine.

The superheated brine is piped to the surface where through the steam/water flashing process, about 1/3 of the mass flow is flashed into steam that is used to drive a turbine and generate electricity. The residual 2/3 of the mass flow of the now cooler brine can be used for binary cycle electricity generation or direct heating. The resulting cooling and concentration of the brine leads to silica supersaturation where the solubility of dissolved silica is exceeded, leading to silica polymerisation and problematic silica scaling. The scale undesirably blocks pipes, valves, heat exchangers, other process equipment and reinjection wells. (Borrmann et al 2009, Brown 2011).

Silica scaling severely limits the extent to which the separated brine can be cooled in the binary heat exchangers which in turn limits the amount of electricity generated from the resource. This is a major impediment to the efficient utilisation of the geothermal resource. Much of the heat energy contained in the separated brine is wastefully reinjected to the reservoir.

Current methods to address silica scaling include acid dosing to lower the pH which slows the silica polymerisation reaction, and the use of sequestering agents to bind the dissolved silica entities. However, both these approaches are not particularly effective and silica scaling still persists. Frequent cleaning of heat exchangers and the periodic cleaning of existing reinjection wells or drilling new wells is a common practice (Gunnarsson and Arnórsson 2005).

For higher enthalpy geothermal resources where the brine is heated to higher temperatures in the reservoir, the levels of dissolved silica in the brine are similarly higher. The problem of silica scaling is further increased, and the amount of electricity generated by the binary plant is decreased accordingly. This is particularly the case for the Dieng resource.

1.1 The CaSil Technology

The proprietary CaSil technology, developed by the authors Johnston, Borrmann Schweig and Fraser and owned by CaSil Technologies Ltd, eliminates the world-wide problem of

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silica scaling and unlocks the full energy potential of a geothermal resource. This is achieved by rapidly capturing the problematic silica species dissolved at supersaturated levels in the separated brine, as a unique proprietary nanostructured calcium silicate (CaSil) product, before silica polymerisation and scaling can occur. The Silica Saturation Index is reduced substantially. The CaSil product is separated continuously from the treated brine and used in various environmentally beneficial applications.

The temperature of the treated brine with this significantly reduced Silica Saturation Index, can be lowered much further than is currently possible with existing practices. This enables significantly more heat energy to be recovered for direct heating applications and more electricity to be generated by the binary cycle process accordingly. In addition, the necessity for cleaning silica scale and associated maintenance requirements is similarly reduced considerably, as is the need for drilling new reinjection wells.

The technology has been developed and successfully demonstrated at pilot plant scale operation over six years in four New Zealand geothermal fields, Wairakei, Kawerau, Mokai and Tauhara, each with different brine compositions and temperatures. This clearly demonstrated the robustness and the wide scale applicability of the technology to different geothermal resources (Johnston et al 2006, Johnston and Borrmann 2017, Schweig et al 2023, 2024)

The CaSil technology is therefore ideally suited for application at the Dieng geothermal resource, Indonesia, where the temperature of the separated brine can currently only be lowered to about 182 ˚C before silica scaling takes place. The CaSil technology reduces the SSI considerably and offers the ability to cool the treated brine to substantially lower temperatures and to enable more electricity to be generated accordingly. This is not possible by the use of acid dosing or sequestering agents.

This paper presents the results of an initial laboratory study on the application of the CaSil technology to prevent silica scaling in the Dieng geothermal brines, using a simulated brine with a composition typical of the high silica, hyper-saline geothermal brine from the Dieng geothermal resource. Also a sample of Dieng-1 brine is included. This work opens up the opportunity for a much wider and in depth field study, using actual Dieng brines.

1.2 The Dieng Geothermal Field

The Dieng geothermal field is one of the most prospected geothermal fields in the Central Java Province, Indonesia, located about 120 km from the province capital Semarang. The area of 63 km^2 in size is located along the Java Trench of the Indo-Australian Plate below the South-East Asian Plate in the volcanic arc, corresponding to the active andesitic volcanism related to the plate subduction. The Dieng area has an estimated field development potential of 400 MWe (Ministry of Energy and Mineral Resources, 2017). It is a high-temperature, hyper-saline field with surface manifestations such as fumaroles, hot springs, and acidic mud pools. These are distributed in the areas of Sileri, Sikidang and Pakuwaja. Sileri is located to the northwest with fluid temperatures around 300 ˚C and acid-sulphate-chloride type hot springs. In the central Sikidang area, fluids at depth are around 300 °C hot and contain high amounts of non-condensable gases (NCGs), mostly CO_2. Sileri and Sikidang are craters that consist of old Dieng volcanic rocks. The upflow areas of the hydrothermal systems are believed to be around Sileri and Sikidang where the fluid flows northeast, and southwest along faults. These faults are the drilling targets for future production wells.

Since 1975, 52 wells have been drilled in Dieng, 27 wells by Pertamina, 20 wells by Himpurna California Energy (HCE) and 5 slim holes for coring. 5 production wells and 4 injection wells are operating for power plant Unit 1. Samples discussed in this article relate to wells HCE 7 and HCE 30. The installed capacity of Unit 1 is 60 MWe and current production is around 55 MWe. In July 1998, this power plant was commissioned by Himpurna California Energy Limited. After the project was shelved for a while, in 2002, Geo Dipa Energi, a joint venture between PT Perusahaan Listrik Negara (PT PLN) and PT Pertamina, took over the ownership of the Dieng geothermal field. Since 2011, Geo Dipa Energi is a designated state-owned enterprise by Government Regulation no. 62/201.

At Dieng-1, Geo Dipa Energi operates one unit of a single-flash cycle with a capacity of 60 MWe (Ministry of Energy and Mineral Resources, 2017; Kamila et al., 2020). The resource of Dieng-1 is characterized by a water-dominated hyper-saline reservoir with temperatures ranging from 240 to 333 °C (Ministry of Energy and Mineral Resources, 2017; Sudarman and Hochstein, 2017; Nasruddin et al., 2016; Mohammadzadeh et al., 2018). Special attention is paid to the highly problematic issue of silica scaling in the production systems, turbines, and the reinjection system. Deposition of silica scale has been identified widely in Fluid Collection and Reinjection Systems (FCRS), such as in two-phase flow lines, i.e., the separator and the brine line to the reinjection site. These significant scaling problems limit the extent of cooling and the amount of electricity generated, and also adversely affect the operational cost of the Dieng Unit 1 plant. Therefore, a more effective and reliable scaling prevention method is required to ensure future operation, increased resource utilisation efficiency, the and future development of the Dieng geothermal field.

The CaSil Technology is ideally suited to prevent silica scaling in the FCRS to protect the current Geo Dipa Energi assets, enable significantly more electricity to be generated by the binary cycle technology and provide a useful CaSil product for environmentally beneficial applications. This will allow more efficient energy utilisation of the resource and its further expansion.

The chemistry of brines is very field and well specific. The CaSil technology has been shown to prevent silica scaling in four different New Zealand geothermal resources. Building on this success, some preliminary laboratory scale trials using simulated geothermal brines with a composition typical of the Dieng geothermal resource, together with samples of the Dieng brine, have been carried out. The results are presented here.

2. RESULTS AND DISCUSSION

Four acidified samples of brine from the Dieng-1 field were provided by Geo Dipa Energi, Indonesia. These were analysed using the facilities at Victoria University of Wellington, New Zealand (VUW), and also at GNS Science, Taupo, New Zealand for confirmation. The main components (>10 ppm) detected in the brine samples were

silica, boron, calcium, arsenic, sodium, potassium, lithium, and chloride. Minor (1 to 10 ppm) elements were manganese, iron, and aluminium. Traces of magnesium, strontium, indium, and germanium were also detected. The samples of brine contained flakes of solid material, which upon digestion released further potassium, silica, and sodium into the brine. These were likely to be mineral fragments from the reservoir rocks. Historically, the brine of the Dieng geothermal field is known to also contain sulfur (measured as sulfate), hydrogen carbonate (bicarbonate), and ammonia. Due to the acidification of the samples, these species were not detected. The acidification step is necessary to reduce the extent to which silica polymerisation takes place following sampling and cooling of the brine, and transportation.

2.1 Analysis of Brine and Preparation of Simulated Brine

Table 1 provides an overview of the range of the major constituents from the historical data, the actual levels measured in the Dieng-1 brine at Victoria University of Wellington, and in the two samples of the simulated brine, Sim 1 and Sim 2.

Table 1: Major constituents of brine collected from the Dieng geothermal field.

		Historical data	VUW	Sim 1	Sim 2
Silica	ppm	650 to 950	1175	1000	1200
Na	ppm	7k to 11k	9000	8000	8000
K	ppm	2k to 3k	2542	2500	2500
Cl	ppm	16k to 20k	18k	18k	18k
B	ppm	450 to 700	352	450	450
Ca	ppm	600 to 900	624	600	600
HCO_3^-	ppm	25 to 45	n/a	40	40
Li	ppm	35 to 65	45	45	

For the following study and the preparation of a simulated brine from Dieng, only the major constituents were considered. Sim 1 and Sim 2 differ in their silica and lithium contents.

Particulates of solid material were also present in the acidified samples from the Dieng field. These were analysed and found to contain silica, borate, potassium, and chloride and were omitted from the simulation. Ammonia, and sulfide were not considered due to their volatile and noxious nature but will be included in future studies.

The brine simulation faced several challenges: At high pH (>9.5) borate species can precipitate out, and silica and calcium can react to form calcium silicates. Furthermore, at the pH value chosen, silica is supersaturated and will form silica gel. As discussed below, these challenges were successfully overcome, and stable simulated brines were prepared using the constituents in table 2.

Table 2: Stock solutions as source of various elements/species.

	Target	Also adds
NaCl	Na	Cl
KCl	K	Cl
LiCl	Li	Cl
As_2O_3 in NaOH	As	Na
CaCl2	Ca	Cl
$Na_2B_4O_{17}•10H_2O$	B	Na
"Na_2SiO_3"	Silica	Na
$NaHCO_3$	HCO_3^-	Na

Hydrochloric acid was used to adjust the pH, which also adds chloride ions to the solutions thereby assisting in establishing the intended chloride concentrations. Sodium silicate is basic and provided the starting point of the simulated brines. With silica being the main target species of this study, greater care was taken in matching the intended silica levels. The other components were added rapidly to enable speedy processing of the brine due to its tendency to form silica gel. The alkali chlorides, arsenic, and bicarbonate solutions and water were added to the sodium silicate solution first. Then the pH was adjusted to below 9. The borax solution was added, and the pH adjusted to about 6.8. The calcium chloride solution required slight acidification to stabilize it. This slightly acidic solution was added last, and the pH of the final solution adjusted to 6.5 to represent that of Dieng-1 brine. In total, 8 simulated brines were prepared. These synthetic brines were analysed to determine the closeness of them to the actual Dieng-1 brine composition.

An overview of how closely the composition of these brines adhered to the planned two simulations is shown in Figure 1. Brines 1 to 3, 7 and 8 were following the Sim 1 composition and brines 4 to 6 of Sim 2. All brines prepared could be used to prepare 2 to 4 samples that were used in the CaSil technology application experiments in parallel, before deposits started to form, with the rest of the brine needing to be discarded. The compositions achieved were mostly within 10 percent of the desired values with some deviating about 20 percent. Lithium was only added to 1 brine, due to limited availability of the source material. Overall, the brines were representative of the compositions targeted and the Dieng-1 brines. Hence, application of the CaSil technology under different operating conditions was attempted for all these brines.

Samples of these prepared brines were taken rapidly and the CaSil agent added. The resulting slurry was stirred for another minute as the CaSil reaction is very rapid, allowed to settle for 2 minutes, and filtered under vacuum. The filtrate was recovered for analysis. The filter cakes were dried at 120 ˚C overnight and weighed to establish yields. Treatments were carried out at room temperature and 70 ˚C at a litre scale, and at 150 and 180 ˚C in a scaled down approach (250 mL) in an autoclave. The autoclaved samples were cooled

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down rapidly and quenched to obtain temperature dependent data.

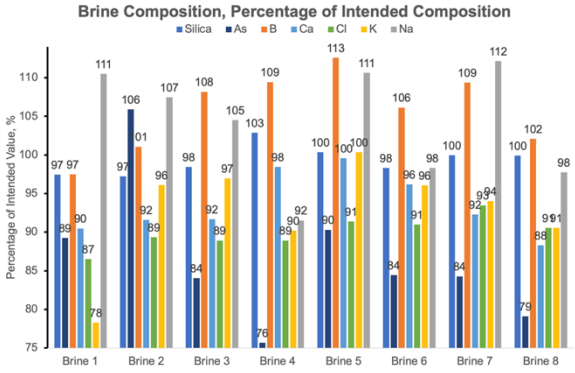

Figure 1: The deviation in the respective compositions of simulated brines from their intended values.

As stated above, the CaSil treatment substantially lowers the Silica Saturation Index (SSI) of geothermal waters by removing silica as a unique nanostructured calcium silicate (CaSil) material. Thereby the CaSil technology enables use of geothermal waters at lower temperatures than currently possible. This laboratory scale work was carried out to ascertain if the CaSil treatment is applicable to the high silica, hyper-saline brines from the Dieng geothermal resource, and any adverse effects of the high levels of borate in the brine. The results presented in Figure 2 show that the residual silica concentration in the treated brine is lowered from the respective initial values of 1000 and 1200 ppm silica to about 150 ppm at room temperature and to about 350 to 450 ppm at 180˚C. The increase in residual silica content with increasing temperature is consistent with the temperature dependent solubility of silica. In all cases the SSI is substantially reduced, allowing the brine to be cooled to much lower temperatures that is currently possible. This desirably confirms the applicability of the CaSil technology to prevent silica scaling at Dieng and thereby enable more electricity to be generated from the existing brine flow (Figure 3).

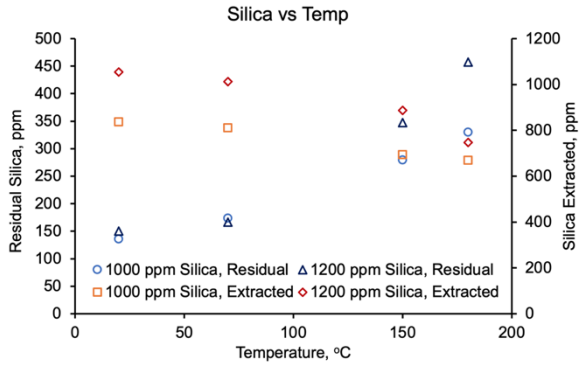

Figure 2: Residual and extracted silica at different temperatures by the CaSil technology.

As the Dieng brines contain high levels of borate, the effect of the borate buffer system on the CaSil technology was investigated. For the simulated Dieng brines, the pH values increased to between 7.7 and 9. It was considered that the presence of the borate in the brine governed this increase in pH, as borate is commonly used in buffer systems (Dubin, 1984). The work here shows that this level of pH increase in the simulated Dieng brines does not affect the CaSil technology.

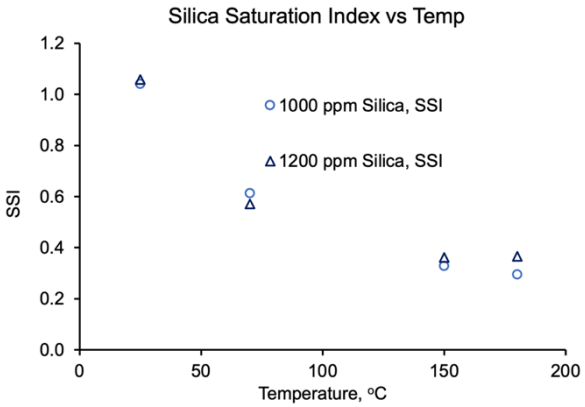

Figure 3: SSI vs temperature for treatment of simulated brines.

Using the values for the residual silica concentrations and the pH of the treated brines, the SSI was calculated using the formula published by Brown (2011). Due to the buffering of the pH value, the SSI at room temperature was about 1. However, with increasing temperature the SSI reduced considerably, and very desirably it was as low as 0.3 for the experiments carried out at 180 ˚C. The calculated values of the SSI for following CaSil treatment at different temperatures are shown in Figure 3. These low values of the SSI cannot be achieved by the other methods currently used to address silica scaling.

The effect of the borate in buffering the pH likely leads to the very low amount of calcium carbonate present in the CaSil product, despite the carbonate/bicarbonate species being present in the simulated brine (see XRD study below). The equilibrium between bicarbonate and carbonate is on the lower side of bicarbonate (pKa_2 = 10.33). Therefore, by keeping the pH lower, borate buffer effectively prevents the formation of carbonate ions. This is an interesting finding and invites further investigation.

The application of the CaSil technology in preventing silica scaling as demonstrated here, desirably provides a treated Dieng brine with a very low SSI, that can now be used in downstream recovery of other dissolved minerals including lithium. For these recoveries it needs to be established, if the CaSil technology interferes with any of these species for the Dieng brine. As expected, there was no significant change in the level of lithium before and after the CaSil treatment (less than 1% change which is within the experimental measurement uncertainty). Further work will be carried out in the future to confirm this on actual Dieng brines.

The X-ray diffraction patterns of the CaSil products formed in the process (Figure 4), show the presence of sodium and potassium chlorides (marked as salt, S, in the figure). These species could readily be removed from the CaSil products by washing the filter cakes with water, confirming that they originate from trapped pore water in the CaSil filter cakes.

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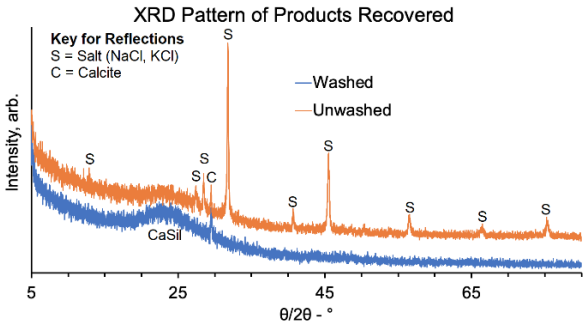

Figure 4: Evidence of salt trapped in the pore water of products.

The broad hump in the XRD pattern centered at about 23 °2θ is typical of CaSil, which is amorphous/polycrystalline in nature. Very minor amounts of calcium carbonate (C) in the form of calcite are shown by its main peak at about 30 °2θ. No other calcite peaks are observable. This is a common species that gets trapped in CaSil particulates and is removed with them accordingly. The bicarbonate added to the simulated brine formed this calcite. As, the amount of bicarbonate in the original brine and in the brine following CaSil treatment were very similar, as indicated by titration with acid, the amount of calcite formed was similarly very small. This is a consequence of the borate buffer system detailed above.

2.2 Treating Actual Dieng-1 Brine

Table 3: Comparison of untreated and CaSil treated brine form Dieng-1 HCE 7c.

		Untreated	Treated	Change
Silica	ppm	1141	77	-1064
Na	ppm	9345	9528	183
K	ppm	2193	2117	76
Cl	ppm	8420	8200	220
B	ppm	304	305	-1
Ca	ppm	514	658	144
Li	ppm	42	43	-1
As	ppm	23	20	3
pH		6.5	8.83	2.33
SSI		9.75	0.6	-9.15

Encouraged by the findings from the study of simulated brine, a sample from Dieng-1, HCE 7c FA, was treated with the CaSil technology. Prior to treatment, the pH value of the brine sample had to be raised to levels (pH 6.5) comparable to untreated brine. This was accomplished by addition of sodium hydroxide. The supernatant and CaSil product from the treatment of HCE 7c were recovered and analysed. While the CaSil product from the simulated brine was white in color, the HCE 7c CaSil sample was cream colored, which is probably due to the presence of iron and manganese, as they were minor constituents and not incorporated into the simulated brine. Similar discolorations in the presence of iron and manganese have been observed in our previous work. The analysis of the untreated and treated brine from HCE 7c is presented in Table 3.

The most notable and very desirable feature is the substantial removal of silica from Dieng-1 brine, raising of the pH, and consequently substantially lowering the SSI from 9.75 to 0.6. This very clearly demonstrates the effectiveness of the CaSil technology in removing the problematic silica and reducing the SSI to below 1, thereby preventing silica scaling.

The values for arsenic, boron, chlorine, lithium, potassium, and sodium essentially remained unchanged within the margin of uncertainty. The amount of calcium increased, as is expected from to the CaSil treatment.

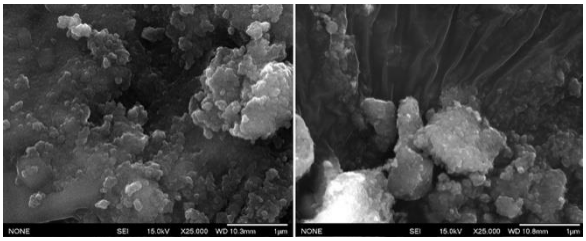

Figure 5: Scanning electron microscope images of simulated CaSil (left) and CaSil recovered from treated HCE 7c (right).

The scanning electron microscope images of the CaSil products generated from the simulated brine and the HCE 7c brine (Figure 5) show the products are very similar, and indeed comparable to CaSil products we have generated from many other brines (Borrmann 2009). This result further demonstrates the successful application of the CaSil technology to prevent silica scaling in Dieng brine and to provide a useful CaSil product.

3. CONCLUSIONS

Samples from Dieng-1 brine were provided by Geo Dipa Energi to CaSil Technologies to assess the applicability of the CaSil technology in preventing silica scaling from the brine. The samples and historical data provided by Geo Dipa Energi formed the basis of preparing a simulated brine that was used to carry out the preliminary study presented here. The results clearly show that the CaSil technology substantially reduces the silica content of the simulated brines and also the Dieng-1 brine, thereby lowering the SSI, which in turn prevents silica scaling.

The study also showed that borate present in the brine forms a buffer system that influences the pH change in a way that has not been observed prior to this study. As the Silica Saturation Index is also dependent on the pH, the effect of borate needs to be taken into account in implementing the CaSil technology. However overall, it does not adversely affect the CaSil technology. In the actual brine sample, the effect of borate on the pH was not as pronounced as in the simulated brine samples.

Very little carbonate was captured in the CaSil product despite this species being present in the simulated brine. This could also be due to the presence of the borate buffer. The equilibrium between bicarbonate and carbonate would be on

the side of bicarbonate ($pKa_2 = 10.33$). Therefore, by keeping the pH at levels lower than observed for other brines, the borate effectively prevents the formation of carbonate ions, which appears to be necessary to form the usual calcite impurity on the surface of CaSil particles. This is an interesting finding and invites further investigation.

Based on the success of the work using the simulated brines, one of the samples studied in the analysis of Dieng-1 brine was treated by the CaSil technology. This similarly showed the treatment was successful and a CaSil product was produced. The residual silica concentration and pH value meant that the Silica Saturation Index was desirably lowered to 0.6. This low SSI value and the extent of removal of problematic silica from the geothermal brine cannot be achieved by any of the practices currently used to address silica scaling. The distinct advantages of the CaSil technology in preventing silica scaling are clearly demonstrated here.

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REFERENCES

Borrmann, T., Johnston, J.H., and McBrearty, R.: Nano-Structured Calcium Silicate - A Solution to the Formation of Silica Scale in Geothermal Water, *GRC Transactions*, **33**, (2009), 695-698. https://www.geothermal-library.org/index.php?mode=pubs&action=view&record=1028544

Brown K.: Thermodynamics and kinetics of silica scaling, *Proceedings*, International Workshop on Mineral Scaling, Manila, Philippines, (2011).

Dubin, L.: Silica inhibition: prevention of silica deposition by boric acid/orthorborate ion, *United States Patent*, 4584104, (1984).

Gunnarsson, I. and Arnórsson, S.: Treatment of Geothermal Waste Water to Prevent Silica Scaling. *Proceedings*, World Geothermal Congress 2005. Antalya, Turkey, 24-29 April 2005. International Geothermal Association. (2005). https://www.geothermal-library.org/index.php?mode=pubs&action=view&record=8001229.

Harper, R.T., Thain, I.A., and Johnston, J.H.: Towards the Efficient Utilization of Geothermal Resources, *Geothermics*, **21**, (5/6), (1992), 641-651. https://doi.org/10.1016/0375-6505(92)90017-4.

Johnston, J.H., Borrmann, T., and McFarlane, A.J.: Nano-structured Calcium Silicate, Functionalised Forms Thereof, Preparation and Uses. *NZ Patent Specification* No. 537747, (2006).

Johnston, J.H. and Borrmann, T.: Nanostructured Calcium Silicate Hydrate – A Potential Solution to Problematic Silica Deposition from Geothermal Brine and a Useful Product. *New Zealand Geothermal Workshop, Rotorua*, 22-24, (2017).

Kamila, Z., Kaya, E., and Zarrouk, S.J.: Reinjection in geothermal fields: An updated worldwide review 2020, *Geothermics*, **89**, (2020), 101970. https://doi.org/10.1016/j.geothermics.2020.101970.

Ministry of Energy and Mineral Resources: Potensi Panas Bumi Indonesia Jilid 1. Kementerian Energi dan Sumber Daya Mineral, Ministry of Energy and Mineral Resources, Jakarta, Indonesia (2017).

Mohammadzadeh, S., Jalilinasrabady, S., Fujii, H., and Pambudi, N.A.: Classification of geothermal resources in Indonesia by applying exergy concept, *Renew. Sustain. Energy Rev.*, **93**, (2018), 499–506. https://doi.org/10.1016/j.rser.2018.05.018.

Nasruddin, N., Alhamid, M.I., Daud, Y., Surachman, A., and Sugiyono, A.: Potential of geothermal energy for electricity generation in Indonesia: A review, *Renew. Sustain. Energy Rev.* **53**, (2016), 733–740. https://doi.org/10.1016/j.rser.2015.09.032.

Schweig, M., Johnston, J.H., Borrmann, T., and Fraser, Update, H.P.: On the CaSil Technology: Economically Solving the Worldwide Problem of Silica Scaling and Enabling Unprecedented Low Temperature Direct-Heat Extraction and Electricity Generation Utilisation. *GRC Transactions*, Vol. 47, (2023) 2733-2744.

Schweig, M., Johnston, J.H., Borrmann, T., and Fraser, Update, H.P.: Unlocking Geothermal Potential: The CaSil Technology. *Proceedings: The 10th Indonesia International Geothermal Convention & Exhibition*, Indonesia, (2024).

Sudarman, S., and Hochstein, M.P.: History of Geothermal Exploration in Indonesia (1970-2010), *Proceedings 36th New Zealand Geothermal Workshop 24 - 26 November 2014*, Auckland, New Zealand (2014).