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Application Results of Silica Extraction Technology at Kakkonda Geothermal Area and Evaluation of Extending the Life of the Reinjection Well

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ABSTRACT

Silica extraction technology has been developed in order to reduce the operating risks caused by silica scale deposition in injection wells and ground facilities, which is one of the big problems in geothermal power plants. The technology will enable an increase in the production of power using binary power generation through heat recovery from injection brine. Field tests were conducted by the demonstration unit at Kakkonda Geothermal Field using injection brine with silica concentrations of approximately 500 ppm and 1000 ppm. As a result, colloidal silica was successfully recovered from brine, and the silica concentration in the injection brine after applying the technology was only about 230 ppm. This indicates a lowering of the risk of silica scaling. We have conducted a scaling test using original brine and silica extracted brine. As a result, silica scaling was confirmed in the column using original brine. In case of using silica extracted brine, the amount of scale is about only 20 wt% of that in original brine. This indicated that this silica extraction technology will be able to extend the lifetimes of ground facilities and injection wells. This paper is based on results obtained from a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

1. INTRODUCTION

As it has been desirable to introduce renewable energy since the Great East Japan Earthquake of 2011, geothermal power generation that can be used as a base power source has attracted much attention in Japan. The goal is to conduct innovative technology development that contributes to the expansion of geothermal power generation as an effort to promote geothermal development.

The problem of silica scale due to high concentration of silica contained in geothermal water causes reduction in the reinjection capacity of reinjection wells in a geothermal power plant, and reduction in heat exchange efficiency when a binary power generation facility is introduced. These are among the causes of the decline in the utilization rate of geothermal power plants, but no drastic solution has yet been implemented. The purpose of this research and development is to actively recover silica contained in geothermal water as "colloidal silica" and to make it into a quality product that can be sold. In the future, by recovering lithium, which is a rare metal, from geothermal water, we aim to give new added value to the geothermal power generation business.

This R&D project is a project implemented by Geothermal Energy Research and Development Co., Ltd., Kitakyushu City University, and JGC Corporation as a commissioned project of the New Energy and Industrial Technology Development Organization (NEDO).

2. OUTLINE OF SILICA EXTRACTION METHOD

Silica scale adhering to surface piping, reinjection wells and reservoirs is one of the major problems in operating a geothermal power plant, because it causes narrowing of the piping and reduction in permeability of the reservoirs. As mitigative measures, the pH adjustment method, high temperature reduction method, dilution method, retention tank method, etc. have been studied. The silica extraction method, which has been tested in this research and development, is based on the technology which is under patent application by Geo40 of New Zealand. This method is a further development of the conventional retention tank method, wherein polymerized colloidal silica is concentrated and separated by the method of ultrafiltration. In addition, a refinement process is added to this method in order to manufacture colloidal silica.

2.1 Process of silica extraction method

An outline of the colloidal silica extraction process is shown in Figure 1. The temperature of injection brine is usually a high temperature of 100 °C or more. Therefore, the injection brine should be cooled by a heat exchanger before being introduced into the silica extraction facility.

The pH-adjust to injection brine promotes polymerization and the growth of colloidal silica. It is then concentrated to about 4wt% in the first stage ultrafiltration unit (UF1). Meanwhile, the concentration of silica in the filtrate is about 200 to 300 ppm, which reduces the risk of scale adhesion to piping and reduction wells. The colloidal silica solution concentrated by UF1 is sent to the second stage ultrafiltration apparatus (UF2), which will concentrate the colloidal silica solution to about 10wt%.

Thereafter, colloidal silica is grown to a target particle size using the principle of the Ostwald method. When it is achieved to glow the desired particle size, it is transferred to a third stage ultrafiltration unit (UF3), and it is finally concentrated to approximately 30wt%.

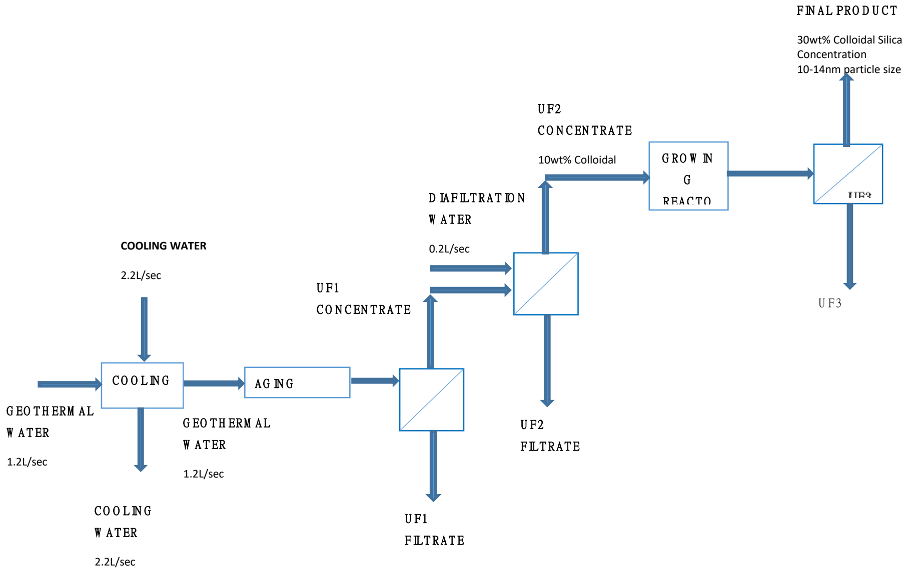


Figure 1: 100 ton/day silica extraction pilot plant.

3. DEMONSTRATION TEST FOR SILICA EXTRACTION PILOT PLANT

A demonstration test of the silica extraction process was carried out using the injection brine from the steam production base of the Kakkonda geothermal power plant. The demonstration test was conducted using two types of injection brine having different silica concentrations. Here, we report the results of a demonstration test for injection brine containing about 1,000 ppm of silica.

3.1 Outline of pilot plant

In the case of Japan's geothermal power plant, the test equipment was compactly arranged because there may not be a large place to install the test equipment. In addition, the test facilities were easily moved by storing the test facilities in multiple 20 ft containers. When carrying out the test, 20 ft containers were placed, and the necessary piping and other assembly work was carried out. The outline of the pilot plant is shown in Figure 2. Table 1 shows the specifications of the fluid which is used for the demonstration test using the pilot plant (processing amount of injection brine: 100 t/day).

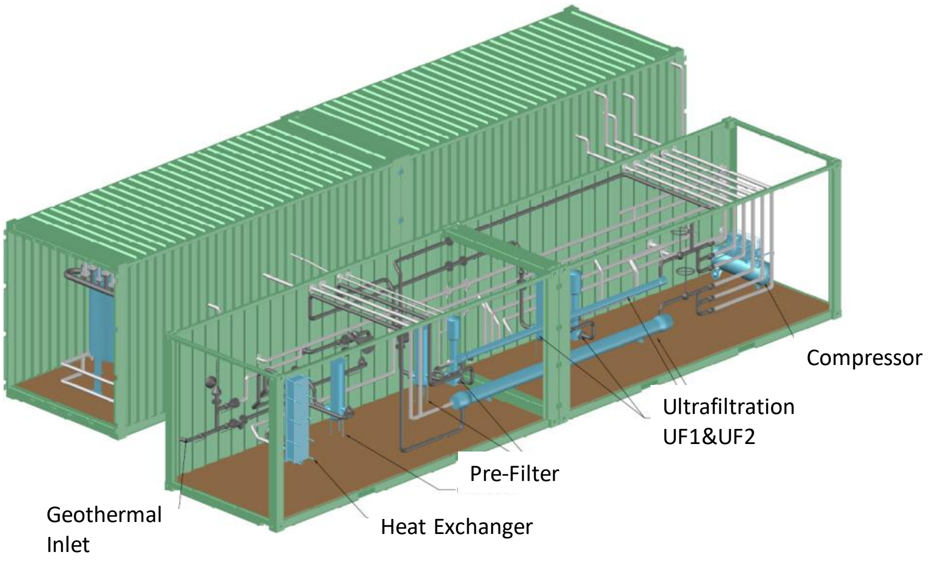


Figure 2: Conceptual design of pilot plant.

Table 1: Specifications of the fluid.

Fluid	Specification	Design Flow Rate
Injection Brine	From Injection Pipeline	72 L/min
		(103.7t/day)
Cooling Water	From Creek water	142 L/min
		(204.5t/day)
Water for Cleaning	Purification of river water using a water purifier	Max 15 m3/day
Acid solution	HCl	Circulation
Alkaline solution	NaOH	Circulation

3.2 Summary of the test results

The silica extraction demonstration test for high concentration silica was conducted from June 14, 2017 to October 2, 2017. The silica extraction cycle using the UF1 was conducted a total of 20 times. The injection brine had a silica concentration of 1,100 ppm to 1,200 ppm and a pH of 6.2 to 6.5, and the chemical properties of the injection brine were stable during the testing.

3.2.1 Colloidal silica extraction from reduced hot water containing high concentration silica

The silica extraction rate from the injection brine was analyzed. The recovery rate of silica is calculated from the ratio of the silica concentration in permeate and concentrate from the filtration processes of UF1, UF2 and UF3. Analysis of the recovery rate in each filtration stage from UF1 to UF3 shows that the recovery rate of silica from the injection brine was 69.7-76.9%. And the recovery rates of UF2 and UF3 were 97.6% and 98.9% respectively (Table 2). UF2 and UF3 are purification process. It means that the recovered silica by UF1 was recovered and formed as colloidal silica without waste.

As a result of this demonstration test, the recovery rate of silica by the UF1 cycle is 72.2-79.7%. The original silica concentration in the injection brine is about 1,200 ppm, therefore, the residual silica concentration after adopted this process is about 243-333 ppm. Saturation temperature of amorphous silica of the concentration is about 75°-80°C. This result is expected to greatly reduce the risk of silica scaling to injection pipes and wells (Figure 3).

Table 2: Colloidal silica extraction ratio from injection brine.

Batch	Recovery Rate			
	UF1 (%)	UF2 (%)	UF3 (%)	Total (%)
11	79.7	97.6	-	76.9[*1]
12	72.2	-	98.9	69.7[*2]

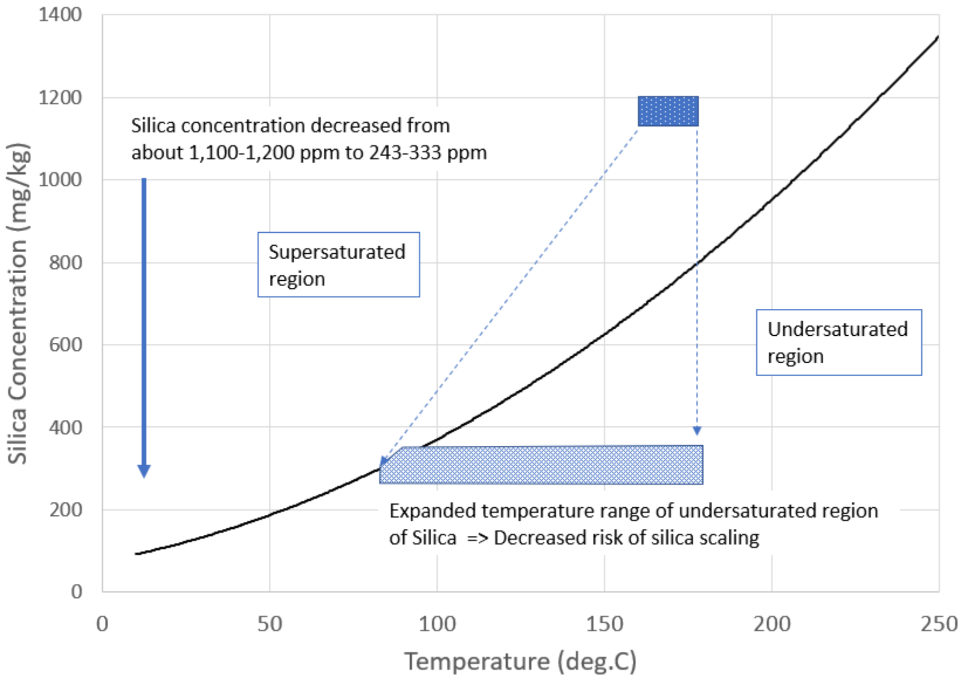
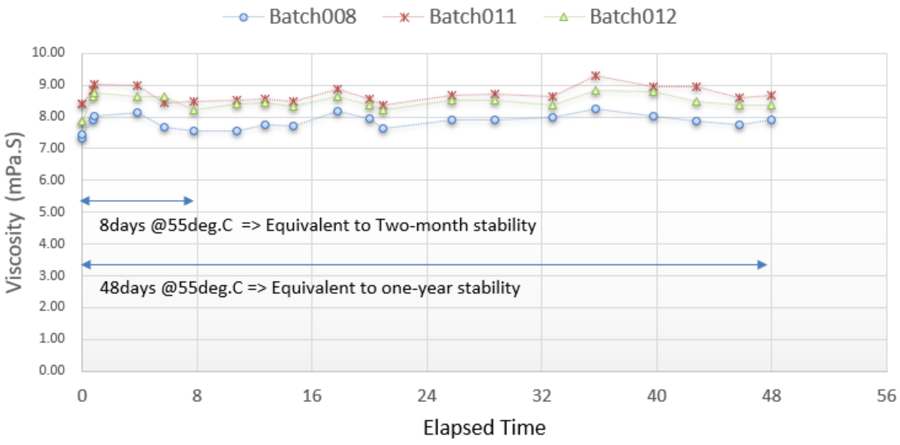


Figure 3: Reduction of silica scale risk by applying silica extraction method.

3.2.2 Stability evaluation of colloidal silica

In this demonstration test, we have obtained 30 wt% colloidal silica solution with a particle size of 12nm. In order to evaluate the stability of the final product, the viscosity of the sample was measured. The time-dependent change of the viscosity of the colloidal silica sample was monitored under measurement conditions (equivalent to stability for 1 year) of 48 days at 50 °C. The measurement results are shown in Figure 4. We did not find a tendency of increasing viscosity, which would be seen as a prelude to gelling. It is estimated that at least one year of stability can be expected. In addition, it has actually been confirmed that the purified colloidal silica sample maintains its quality without gelation even after 1 year or more.



Measuring instrument: Brookfield Digital Viscometer Model DV1M

Figure 4: Colloidal silica viscosity measurement result (12 nm, concentration 30% sample).

3.3 Verification of extension of lifetime for geothermal Injection well by applying silica extraction method

An experiment was conducted to quantitatively evaluate the reduction of the risk of silica scaling to the injection pipes and wells by applying the silica extraction method. The test produced two test devices equipped with a column packed with zirconia beads. Injection Brine and UF1 filtrate were passed through each column, and the evaluation was performed by comparing the difference in weight before and after water flow (scale adhesion amount) (Fukuda, 2000).

3.3.1 Experiment device for Silica adhesion test

The manufactured silica adhesion test apparatus is composed of two systems (column 1 and column 2). Column 1 was used to pass injection brine, and column 2 was used to pass UF 1 filtrate. A conceptual view of the silica adhesion test equipment is shown in

Figure 5. The test brine was sent by a pump to the test apparatus at a flow rate of 1.3 L/min, retained in the retention tank for about 1 hour, and then passed to the column. This simulates the time lag after power generation until the brine is injected to the ground.

The column consists of a total of 11 sections, the sections being separated by meshed packing. During the test, the pressure of each section was monitored, and at the end of the test, zirconia beads were collected and weighed for each section to measure the difference in weight before and after the test.

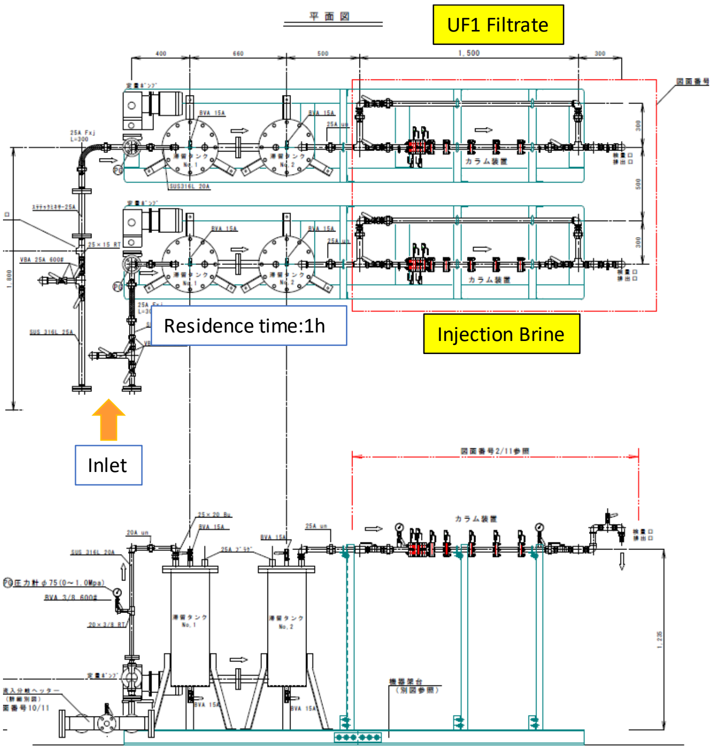


Figure 5: **Schematic design of silica adhesion test equipment.**

3.3.2 Result of the Experiment

Test condition results are summarized in Table 3. On the injection brine side, the brine remains at about 80-90 °C and pH 6.2-6.9. The UF1 permeated water side temperature decreased to about 72°-90°C and pH increased to 8.3 to 8.8. The pH on the UF1 permeated water side is higher than that on the reduced hot water side because the pH is adjusted when forming colloidal silica in the silica extraction test. As for the temperature on the UF1 permeated water side, at the beginning of the test, it took time to adjust the flow rate with the heat exchanger, but thereafter, it shifted at about 90°C.

Table 3: Record of silica adhesion test conditions.

Item	Injection Brine	UF1 Permeate
Test Term	July 27th,2017 18:00 ～ August 8th, 2017 7:50	July 27th,2017 18:00 ～ August 8th, 2017 8:15
Flow Rate	1.30 L/min	1.30 L/min
Temperature	82 - 91 ℃	72 - 92 ℃
pH	6.24 - 6.92	8.34 - 8.80

The pressure transition in column 1 (inlet side) at the time of the water flow test is shown in Figure 6. An increase in pressure indicates that the pressure loss increased due to the adhesion of scale to the beads. As a result of this test, it can be seen that the effect of scale adhesion is greater on the injection brine side. It is showed the amount of scale which is adhered on 1g of Zr beads in each column. When comparing the amount of scale after the test, it was observed that the injection brine side had five times amounts as compared with the UF1 permeate.

The scale on the surface of Zr beads was analyzed by a stereomicroscope and SEM-EDX. As a result of observation with a stereomicroscope, the scale from injection brine was white, and was adhered to the surface in the form of powder. In the observation by SEM, the scale samples were consisted of particles of 5 µm or less, and most of the particles were spherical. And we also observed plate-like particles. Observation of the spherical particles in more detail (5000x SEM image) shows that particles of several hundred nm are gathered. As a result of EDX analysis, the main components of both the spherical particles and the plate-like particles were O and Si, and they also contained several atomic percent to several tens of atomic percent of C, and trace amounts of Al and Na.

Analysis of beads samples for UF1 permeate was carried out by a stereomicroscope and SEM-EDX. Observation with a stereomicroscope showed that the deposits from UF1 permeate were yellowish brown to brown, and some dark brown deposits were also observed. Observation by SEM showed that the deposit on the bead surface was flat, and a compact substrate portion and a square self-shaped crystal portion were observed, and the appearance was different from that on the injection brine side. As a result of EDX analysis, the main components of the substrate portion were C, O, and Si, and the sample also contained several atomic percent of Al and a trace amount of Fe. The main components of the automorphic crystals were Na and Cl.

The results of this test show that the silica concentration in the injection brine could be significantly reduced by applying the silica extraction technology. The fact that the amount of scale adhesion is about 1⁄5 suggests that the injection wells may be able to prolong their lifetimes by a factor of about 5 times.

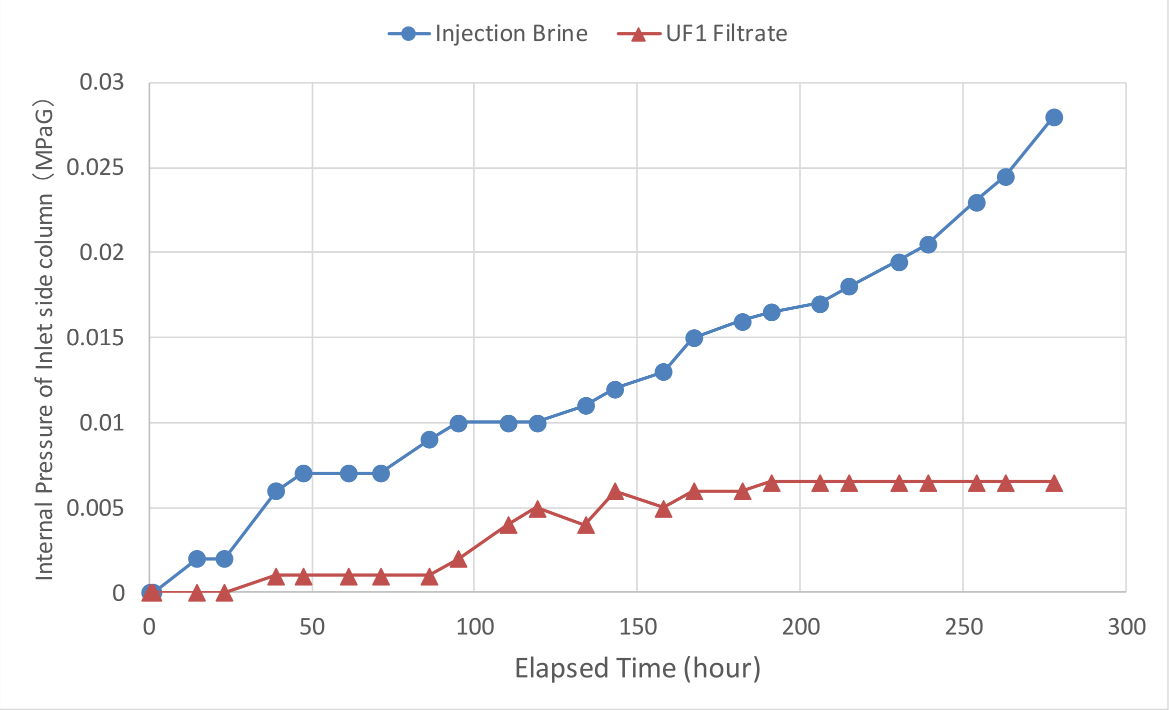


Figure 6: Internal pressure at inlet side of the column.

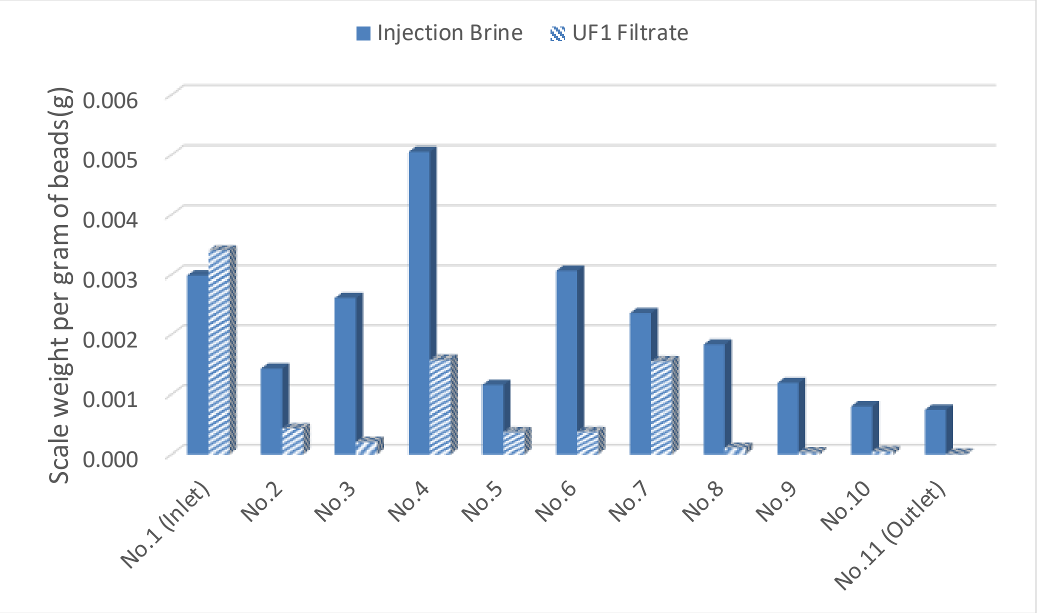


Figure 7: Scale weight adhered at the end of the test (weight per gram of beads).

4. PERFORMANCE ANALYSIS OF RECOVERED COLLOIDAL SILICA

Performance analysis of the recovered colloidal silica was carried out for applications as soil stabilizer and precision casting binder.

4.1 Performance Analysis for Soil Stabilizer

A special silica solution was prepared by combining the recovered colloidal silica and water glass in a specific combination. A strength test was conducted using the test body (sand gel) which made silica gel. In an unconfined compression strength test, a specimen of φ5 cm × 10 cm (height) was produced by a mixing method using the prepared chemical solution and Toyoura sand. The relative density of the specimen was 50, and curing was performed at 20°C so as not to dry the specimen, and the compressive strength was measured with an unconfined compression strength test. The measurement was performed at a stroke speed of 0.5 mm/min. As a result of the test, at 7 days of material age, the chemical solution using the geothermal recovery colloidal silica was slightly weaker than the comparative chemical solution, but it became almost the same strength after 14 to 28 days, when it was repeated. The measurement results of the unconfined compression strength test of 28 days of material age are shown in Figure 8. The specimen using the geothermal recovery colloidal silica was found to have the same performance as the existing specimen, so it was found that sufficient strength for use in liquefaction prevention could be obtained.

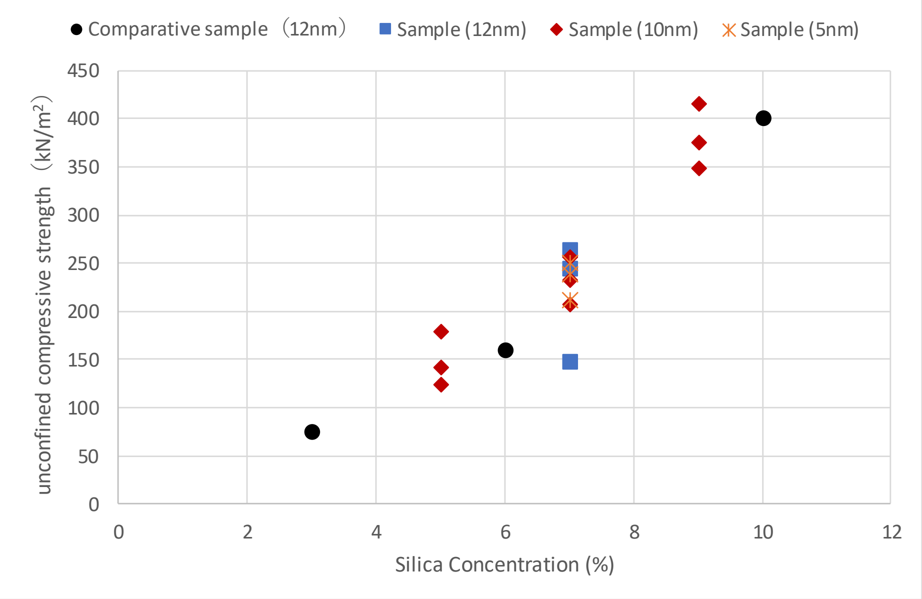


Figure 8: Relationship between unconfined compressive strength and silica concentration of specimen (material age: 28 days)

The volume shrinkage of the hydrogel was measured with reference to a method using a glass measuring flask. Although the volumetric shrinkage of the specimen using the geothermal recovery silica was about 10% or less in most samples, the shrinkage tends to be slightly larger than that of the conventional colloidal silica. Although it is difficult to make a judgment because there is no clear standard for the product shrinkage rate, increasing the blending ratio of colloidal silica on the high concentration side while comparing with the existing chemical solution is another issue.

4.2 Performance Analysis for Precision Casting Binders

A sand mold was prepared from the slurry and fired, and the sand mold was tested for strength and air permeability. In the sand mold strength test, the firing strength of the recovered colloidal silica from geothermal brine was the highest, exceeding that of the general-purpose grade (Figure 9). Although a minimum strength is required, there is a concern that if the strength is too high, the mold may have poor workability. The reason for the high strength is considered to be the mold having a great thickness and high density, because slurry viscosity is high and the stucco (sand) is attached well. The strength of the sand mold is considered to extend over a range that can be adjusted by changing the blending ratio of fireproof sand and the colloidal silica at the time of slurry preparation. Colloidal silica recovered from reduced hot water has been confirmed to have a quality that can withstand practical use by adjusting the silica blending ratio.

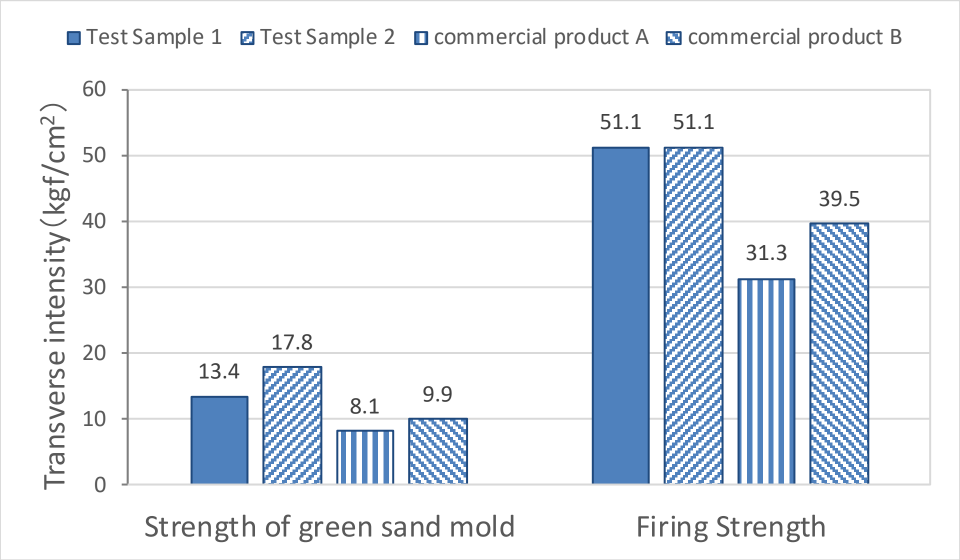


Figure 9: Results of sand mold strength test.

5. BUSINESS MODEL OF SILICA EXTRACTION METHOD

The business model is organized when applying the silica extraction method. The following two types can be considered as methods of silica extraction. The first case is "silica extraction for each injection well (brine flow rate: 1,000 t/day)" and the second is "silica extraction is performed for each injection base in the aggregation method (brine flow rate 5,000 t/day)". Next, the following two models can be considered for a silica extraction business. The first is a business model focusing on a countermeasure to silica scaling by the power generation operator (Countermeasure model of silica scaling), and the second is a business model focusing on silica extraction by colloidal silica manufacturers (silica extraction models). Figure 10 shows a combined business model. The following three cases can be considered as the effect of the Countermeasure model of silica scaling: (1) chemical cost reduction effect for pH adjustment method; (2) reduction effect of drilling or cleaning cost for injection well due to decrease in injectivity performance; and, (3) increase of electric power generation for binary and double-flush type power stations by setting the temperature of injection brine lower than the present temperature. In the silica extraction model, the following two models can be considered: (1) use the recovered colloidal silica as a product to obtain sales income; and, (2) recovery of rare metals such as lithium from geothermal brine after silica extraction, which is a technology that has been tested in this project, and obtain sales income.

The silica extraction method is effective in reducing the cost of countermeasures in the operation of a geothermal power plant using silica scale and increasing the amount of power generation using a larger temperature difference. In addition, it has become possible to commercialize silica scale, which has been ignored until now, as colloidal silica. In this way, efforts to actively convert the silica scale problem into a source of income are expected to improve the profitability of the geothermal power generation business.

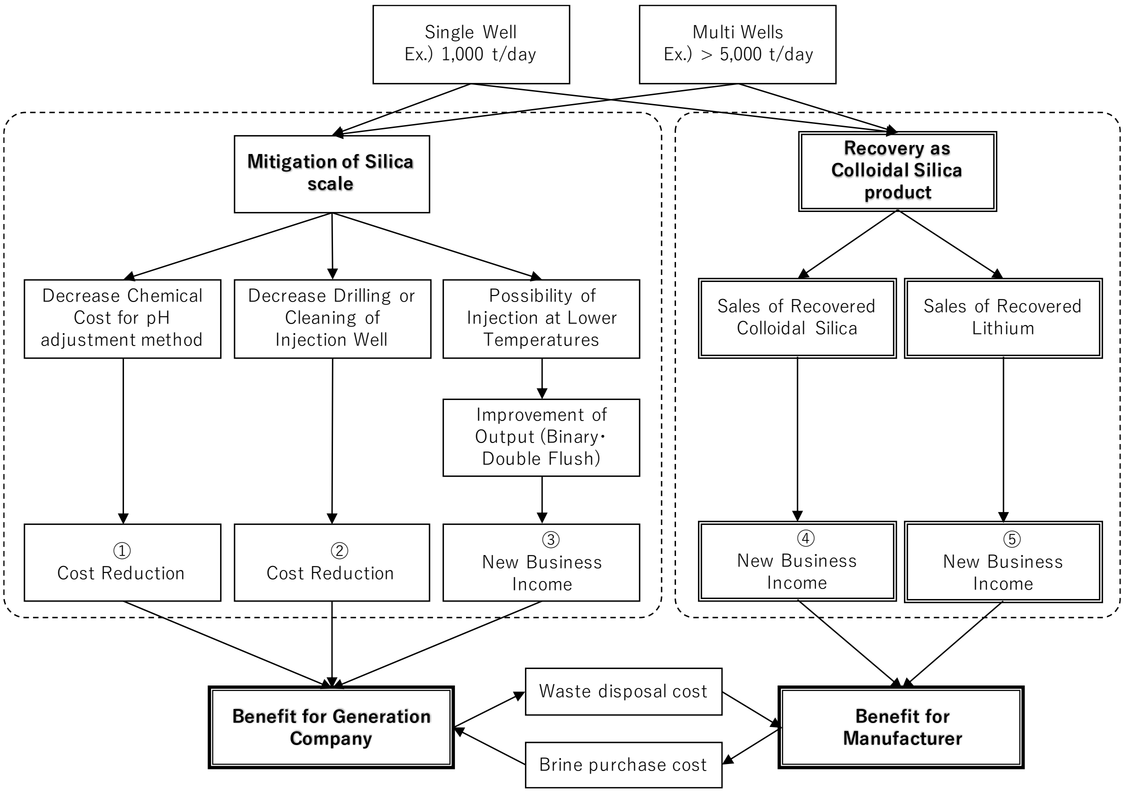


Figure 10: Concept of business model using silica extraction method.

6. CONCLUSION

As a result of the demonstration test carried out in this research and development, we succeeded in extracting silica at a recovery rate of about 70 to 77% from injection brine including about 1,000 ppm Silica. The extracted silica was purified as colloidal silica with a concentration of about 30wt%, and it was confirmed that the recovered silica had a quality enabling use as a soil stabilizer or a binder for precision casting.

By applying the silica extraction method, it is possible to inject the brine to the ground in a state of being undersaturated with silica, so it is expected to reduce the risk of silica scaling and prolong the life of the injection well. At the same time, purification of high market value colloidal silica is a new added value. In the future, we hope that this technology will help improve the utilization rate of the geothermal power plant and the business feasibility by introducing the silica extraction method.

As future goals, we plan to further improve the quality of the produced colloidal silica, reduce the size of the silica extraction plant, and reduce power consumption by optimizing the process of the lithium recovery plant.

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