APPLICABILITY OF SCALE PREVENTION SYSTEM USING BIOREACTOR IN NEW ZEALAND GEOTHERMAL FIELD

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ABSTRACT

Applicability of scale prevention system using bioreactor in New Zealand geothermal field was investigated. It confirmed that Sulfolobus sp. Strain7 could not grow in New Zealand geothermal water and had to be used with heat exchanger like as original system. 20 bacteria were isolated from New Zealand geothermal water. 8 out of 20 bacteria had higher sulfur oxidizing abilities than Sulfolobus sp. Strain7. The size of bioreactor was estimated in the case of applying to Ohaaki geothermal power station. It was confirmed that only a part of H2S from discharged gas was enough for scale prevention. Excess H_2SO_4 was produced if all the H_2S discharged from Ohaaki geothermal power station was treated.

1. INTRODUCTION

Geothermal energy is one of the most promising alternate of fossil energy from the viewpoint of low CO_2 emission and technical maturity for electricity generation. In geothermal power stations, silica scale deposition is one of the most serious problems. Silica deposition causes plugging troubles in surface facilities such as the hot water transportation lines and a reduction of reinjection capacity. In the cases of binary system and direct use of hot water, the silica scale problem is more severe. On the other hand, direct emission of H_2S from geothermal power station is also a matter of great concern from the environmental point of view. Geothermal fluid generally contains around 1% of non-condensable gas. The main content of the gas is CO_2 and small amount of H_2S is included. Several countries, such as US and Philippines, have already been put under obligation to equip H_2S abatement system and caused an increase in the costs.

From these backgrounds, we are developing a new process that can achieve scale prevention and H_2S abatement simultaneously.

It is known that pH modification of geothermal brine is effective on scale prevention. Some kind of sulfur oxidizing bacteria can oxidize H_2S to H_2SO_4. In our process, H_2S is removed from the non-condensable gas as H_2SO_4 using bioreactor. H_2SO_4 is used for pH modification of geothermal brine. Fujioka et.al, (1995) confirmed applicability of *Sulfolobus* sp. *Strain7* for oxidizing H_2S from geothermal field. Hirowatari et. al. (1997,1998) carried the field experiment out at Otake geothermal power plant using bubbling tower type of bioreactor. The results showed that the system could be operated stably for over 2,700 hours and was applicable for geothermal power plant, but mass transfer of H_2S at gas-liquid interface limited H_2SO_4 production rate. Takeuchi et.al.(2000) improved the H_2S removal and H2S04 production reaction using advanced bioreactor. Packing tower type of bioreactor could be operated over 3000 hours at Otake geothermal power plant and make H_2SO_4 production rate 3~6 times larger than bubbling tower type.
In this paper, we investigate applicability of our system to foreign geothermal field in New Zealand.

3. OBJECTIVES

3.1. Applicability of thermo-acidphilic bacteria

In our present system, we use fresh water for the desulfurization solution using in the bioreactor with the heat exchanger, because *Sulfolobus* sp. *Strain7* can not grow in geothermal hot water from the Hachobaru area. If we use the geothermal hot water for the desulfurization solution, the system becomes much simpler. We try to confirm the growth of *Sulfolobus* sp. *Strain7* in various geothermal waters from other fields. If thermo-acidphilic bacteria exist in a geothermal area, they could grow in geothermal water. We try to acquire thermo-acidophilic bacteria that suit our system by screening bacteria sampled from appropriate geothermal feature.

3.2. Estimation of bioreactor size

In Ohaaki geothermal power station in New Zealand, only limit of gas discharge is on amount and it should be under 40t/h. There is no limit on H_2S emission now. To prevent scale deposition, high temperature injection is adopted to Ohaaki geothermal station. If scale can be prevented using our technology, more energy was acquired. We investigate the system for scale prevention in the case that our system is applied to Ohaaki geothermal power station.

4. METHODS

4.1. Growth in geothermal water

The bacterial strain used in the process was isolated from the acidic spa in Beppu Hot Springs, Japan by Oshima and originally designated *Sulfolobus acidocaldarius Strain7.* (Inatomi. 1983). Due to a small difference in 16 S rRNA nucleotide sequences of *strain 7* and *S. acidocaldarius* type strain DSM639, it was redesignated tentatively as *Sulfolobus* sp. *Strain7* recently. The chemical composition of the growth medium is shown in **Table-1**. The cells were harvested after a week cultivation in medium 1 and inoculated to medium 1 prepared using geothermal water instead of distilled water. After inoculation, media were placed in an incubator keeping the temperature at 70 deg C. The optical density of the media was measured using a Taitec miniphoto 80 as an indicator of cell density.

4.2. Screening of thermo-acidphilic bacteria

To acquire specific species (*Sulfolobus* sp.), we selected the condition to collect the geothermal water as follows.

pH: under 4.0
Temperature: 60-85 deg C
Organic matter is supplied.

Table-2 shows sampling sites and conditions.

10 ml of each geothermal water was placed into a screw capped tube at the sampling site and brought back to the laboratory, keeping temperature high in thermos container. After adding nutrients, the tubes were incubated in an aluminum block bath at 70 deg C. The optical density of the media was measured in the same manner as previously mentioned. Samples that the growth of bacteria was confirmed in were used for experiment to estimate sulfur oxidation abilities. 1 ml of each sample was inoculated to 9ml of Medium 2. The pH was measured as an indicator of sulfur oxidation ability. 4 accumulated cultures for single colony isolation were selected considering with the results of growth and sulfur oxidation. Each culture was plated on gelrite plate and incubated at 70 deg C. 5 viable colonies were isolated from each plate. Sulfur oxidizing abilities of isolated bacteria were investigated by same way mentioned above.

4.2. Estimation of bioreactor size

Initial Condition

Initial condition of Ohaaki geothermal power station is as follows (Sueyoshi et. Al., 1997).

Full electric generation capacity	: 116.2 MW
Brine from separator	:1,800 ton/h
Noncondensable gas (NGC)	: 40 ton/h

Composition of NGC

Gas	(Wt%)
CO_2	97.25
H_2S	1.39
H_2	0.01
N_2	0.64
Hydrocarbon	0.71

The Rate of Load

In present day, the Ohaaki geothermal power station is operated under limited capacity. We estimate the bioreactor size for scale prevention with changing the load of Ohaaki geothermal power station. Case1, 2 and 3 are calculated under assumption that brine and gas are proportional to generation capacity.

Methods for Estimation

H_2SO_4 production rate was decided using the curve acquired from the result of field experiment. **(Figure-1)** Amount of produced H_2SO_4 was decided from initial brine condition. Essential concentration for scale prevention generally vary from 10 ppm to 100 ppm, we assumed it 40 ppm in this study.

5. RESULT AND DISCUSSION

5.1. Growth in geothermal water

Growth curves of *Sulfolobus* sp. *Strain7* in each geothermal water are shown in **Figure-2**. Growth curves of control (medium without geothermal water) and 10% of Otake geothermal water were almost same. Media contained 25 % of Otake geothermal water affected on growth rate and maximum yield of *Sulfolobus* sp. *Strain7*. Growth was completely inhibited at the condition of 50% and 75% of Otake geothermal water. In the case of Wairakei, growth rate and maximum yield were affected by 10 % of geothermal water. Media contained 25 % of Wairakei geothermal water completely inhibited the growth of *Sulfolobus* sp. *Strain7*. In the case of Ohaaki, 10 % and 25 % of geothermal water affected on growth rate and maximum yield. Media contained 50 % of Ohaaki geothermal water completely inhibited the growth of *Sulfolobus* sp. *Strain7*.

The relationship between relative growth after 2 days incubation and geothermal water concentration is shown in **Figure-3**. Relative growth was defined as follows.

$$\text{Relative growth}\,[\%] = \frac{\text{growth in geothemal water medium}}{\text{growth in fresh water medium}} \times 100$$

All relative growth of *Sulfolobus* sp. *Strain7* was under 10% at the condition whose geothermal water concentrations were over 50%. In this experiment, all essential nutrients to grow were added, so it was confirmed that all geothermal waters contained an inhibitor on the growth of *Sulfolobus* sp. *Strain7*. It was confirmed that we have to use *Sulfolobus* sp. *Strain7* with heat exchange if system was applied in New Zealand field.

5.2. Screening of the thermo-acidophilic bacteria

Table-3 shows a summary of the results. Growth was confirmed in 12 out of 15 samples, and the sulfur oxidizing ability was confirmed in 11 out of 12 grown samples. These results showed that thermo-acidophilic bacteria were not spatial in geothermal field. We could not confirm the growth in any samples collected from Rotokawa sinter area. It suggested that geothermal water of Rotokawa sinter area contained inhibitor for growth of *Sulfolobus* sp. *Strain7*. **Figure-4** showed pH of samples isolated from accumulated culture after 14 days incubation. 8 out of 20 samples indicated lower pH than cultured media of *Sulfolobus* sp. *Strain7*. It showed that these bacteria had higher sulfur oxidizing abilities than *Sulfolobus* sp. *Strain7*. To confirm applicability of these bacteria for actual plant, we have to consider total system and need more detail analysis, such as growth rate, yield, sulfur oxidizing rate, requirement of nutrient and so on.

5.3. Estimation of bioreactor size

Table-4 shows the results of estimation for Ohaaki geothermal power plant. Case 1 discharges large amount of brine, so size of bioreactor for scale was large. From the results of Case 3, the present plant needed 55 m^3 of bioreactor for scale prevention. If the dimensions of bioreactor were about 7m height (4m height of packing bed) and 3m diameter, 2 of bioreactors for scale prevention is needed. In all case, the system uses only a part of discharged gas. If all H_2S from discharged gas were converted H_2SO_4 and injected in reduction well, excess amount of H_2SO_4 was large and pH becomes too low. If we apply our system for Ohaaki geothermal power station as H_2S abatement system, excess H_2SO_4 is to be treated.

6. CONCLUSION

To investigate the applicability of scale prevention system using bioreactor in New Zealand geothermal field, biological experiment and scale estimation were carried out.

From the bacterial growth experiment, it confirmed that *Sulfolobus* sp. *Strain7* could not grow in New Zealand geothermal water and had to be used with heat exchanger like as original system.

From the bacterial screening experiment, 20 bacteria were isolated from New Zealand geothermal water. 8 out of 20 bacteria had higher sulfur oxidizing abilities than *Sulfolobus* sp. *Strain7*.

The size of bioreactor was estimated in the case of applying to Ohaaki geothermal power station. It was confirmed that excess H_2SO_4 was produced if all the H_2S discharged from Ohaaki geothermal power station was treated.

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Table-1
The chemical composition of the media

	medium1	medium2
$(NH_4)_2SO_4$	1.3	0.4
NaCl	0.2	
KCl		0.2
K_2HPO_4		0.2
KH_2PO_4	0.3	
$MgSO_4 \cdot 7H_2O$	0.25	0.4
Na_2MoO_4		0.0003
$FeSO_4 \cdot 7H_2O$		0.3
$CaCl_2 \cdot 2H_2O$	0.05	
Yeast extract	1.0	0.2
Glucose	1.0	
Casamino acid	1.0	

(g/L-distilled water,pH is adjusted using 1N H_2SO_4)

Table-2
Sampling site and condition

No.	pH	Temp.	Field	Place	Water
1	3.6	80	Wairakei	pool by claret	orange
2	2.7	60	Wairakei	The claret	deep orange
3	2	82	Wairakei	217	grey
4	2.7	60	Rotokawa	Black mud pool by	black
5	2.7	80	Rotokawa	Sinter	yellow
6	2.9	82	Rotokawa	Sinter	black
7	2.7	82	Rotokawa	Sinter	black
8	3.6	65	Waio-Tap	Mud	grey
9	2.6	67	Te-Copia	Kaolinite	beige
10	2.9	73	Te-Copia	Kaolinite	beige
11	2.6	71	Te-Copia	Southern	orange
12	4	80	Kuirau	Beside	mud
13	2.1	70	Tikitir	Devil	black
14	2.6	80	Tikitir	Small	clear
15	2	82	Tikitir	Pool opposite pool	clear

Table-3
Summary of screening results

Sample			Growth using organic matter				Sulfur oxidation
No.	pH	Temp.	initial	1st	2nd	3rd	
1	3.6	80	++	++	+	+	-
2	2.7	60	+	++	+	+	+
3	2	82	++	++	++	++	++
4	2.7	60	+	+	+	+	+
5	2.7	80	-	-	-	-	-
6	2.9	82	-	-	-	-	-
7	2.7	82	-	-	-	-	-
8	3.6	65	+	+	+	++	++
9	2.6	67	+	+	+	+	++
10	2.9	73	+	+	++	++	++
11	2.6	71	+	++	++	++	+
12	4	80	+	+	+	+	++

Table-4
The results of scale estimation

				Case1	Case2	Case3
Geothermal Field						
	Full Capacity		MW	116	116	116
	Rate of load		-	1	0.7	0.
	Capacity		MW	116	81	46
Initial condition (Noncondensable Gas)						
	Flow rate		t/h	40	28	16
	Density		kg/m³	1.92	1.92	1.9
	H_2S					
		concentration	v%	1.76	1.76	1.7
			w%	1.39	1.39	1.3
		Flow rate	kg/h	556	389	222
			kmol/h	16.4	11.4	6.
Geothermal Brine						
	Flow rate		t/h	1800	1260	504
	Scale prevention					
			ppm	40	40	40

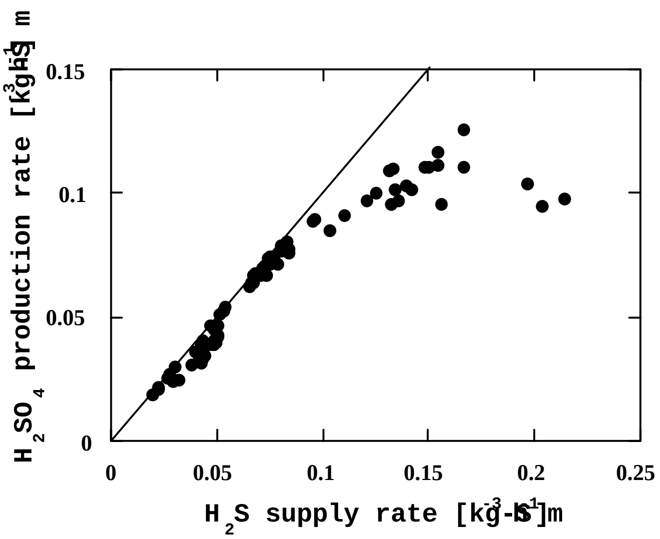

Figure-1
Relation between H_2SO_4 production rate and H_2S supply rate

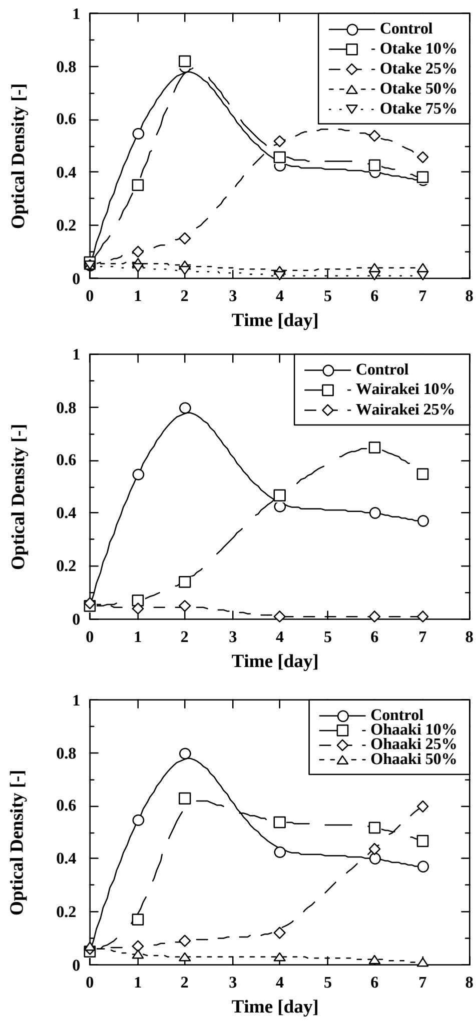

Figure-2
Growth curves of *Sulfolobus* sp. *Strain7* in various geothermal waters

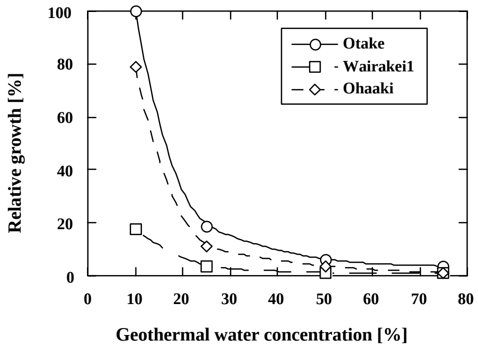

Figure-3
Relative Growth of *Sulfolobus* sp. *Strain7* in various geothermal waters

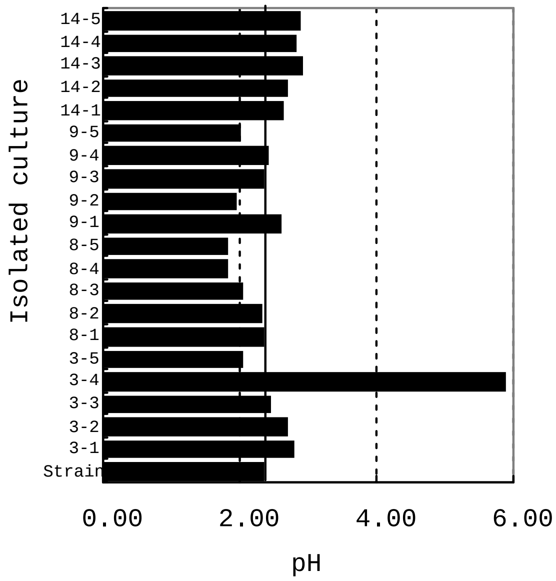

Figure-4
Sulfur oxidizing abilities of isolated culture