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Development of a Commercial Plant for Arsenic Removal from Geothermal Hot Water at Hatchobaru Power Plant

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ABSTRACT

This paper presents the arsenic removal plant and treated water supply system to hot spring resorts, developed by Kyushu Electric Power Co., Inc. (KEPCO)

In 1991, we started a research project and installed the pilot plant with the treatment capacity of 15 t/h at Hatchobaru Power Plant and have accumulated our basic technology.

In 2000, the Ministry of Economy, Trade and Industry of Japan completed the plant with a treatment capacity of 100 t/h for treated water supply system at Hatchobaru, and then, operated for three years with success. In this plant, arsenic concentration was reduced from 3-4mg/L down to the value less than 0.01mg/L that is the upper limit of environmental regulation for treated water in Japan.

The plant has been transferred from the government to KEPCO after three years experiments. Three organizations which are local community (Sujiyu District), local government (Kokonoe Town) and KEPCO to ensure effective utilization of treated water. We are now providing treated water to hot spring resorts through this system.

1. INTRODUCTION

Most geothermal power plants are located on the periphery of hot spring areas in Japan. Geothermal water has a high temperature after produced fluids and contains various chemical components, which can be utilized as hot spring water. The multi-purpose use of geothermal water is important issues in terms of effective use of energy as well as mutual profits both local community and power plants, and promote development geothermal. There are some places where hot water is effectively utilized through heat exchange with river water, but direct use of the water is uncommon, because of the arsenic in the water.

Under such circumstances, removal of arsenic below the environmental regulation will permit the direct utilization of the water. This could lead to economic benefits both to power plant and local community. A reduction of water to be injected well moderated the upload of reinjection well. Therefore, a project to develop a plant for removing arsenic contained in geothermal has been carried out at Hatchobaru.

2. GENERAL DESCRIPTION OF HATCHOBARU POWER PLANT

There are six geothermal power plants in Kyushu with an install capacity of 208 MW that account for about 40% of the total output in Japan. They consist of the Otake and Hatchobaru Power Plants, which undertake a continuous process from steam production to power generation, and the Yamagawa, Ogiri, and Takigami Power Plants which are jointly-developed power plants (Fig.1).

Hatchobaru Power Plant, which is located in Kokonoe Town, Oita Pref., is the largest geothermal power plant with a total output of 110 MW (55 MW x 2 units) in Japan and the first double-flush system in the world (Fig.2).

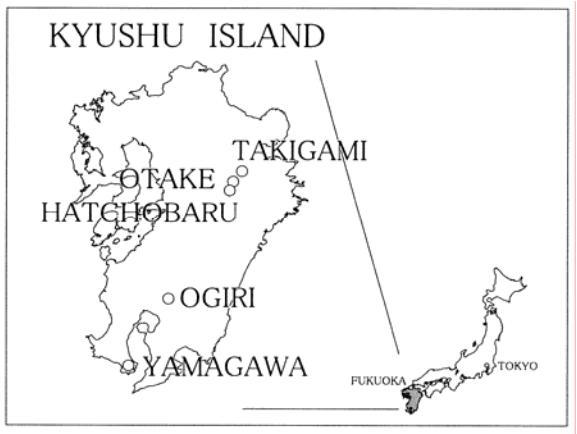

Figure 1: Our geothermal power plants



Figure 2: Hatchobaru Power Plant

The geothermal fluid from the production wells is separated into steam and water by steam separators. The gross quantity of hot water generated is about 1,500 t/h and have been totally re-injected into the underground for the purpose of environmental measures so far. Chemical characteristic of geothermal water of the unit 1 and unit 2 are shown Table 1.

Table 1 Chemical components in geothermal water at Hatchobaru Power Plant

Item	Unit	Hatchobaru Unit1	Hatchobaru Unit2
pH	—	6.1～7.8	7.9～8.7
Cl	mg/l	2,260～2,300	2,950～3,030
As	mg/l	2.88～3.18	3.69～4.13
T-SiO_2	mg/l	731～771	878～909

Analyzed in March, June, September, and December 2003

Table 2 Treated water quality

Item	Unit	Treated water	Environmental regulation
As	mg/l	≦0.01	≦0.01
pH	—	6.8	6.5～8.5
SS	mg/l	0.3	≦25
Temperature	℃	76	—

3. FIRST STAGE EXPERIMENTS

This experiment was performed in order to confirm that the concentration of arsenic in geothermal water can be reduced down to less than the environmental regulation value, and to develop a system that permits multi-purpose utilization of treated water.

The pilot plant was installed within the Hatchobaru Power Plant premises in November 1991, with a treatment

capacity of 15 t/h geothermal water. The quality of treated water is shown in Table 2. With respect to the arsenic removal capacity, it has been confirmed that the concentration of arsenic in treated water can be reduced down to less than 0.01 mg/L; the target value (environmental regulation), and stable operation of the plant was realized (Umeno J. et. al., 1998)

4. SECOND STAGE EXPERIMENT

4.1 General Description

Over the period from 1995 to 2003, New Energy Foundation (NEF, Kumagae I. et. al., 2003), under the contract with the government, conducted a plant scale experiments on treatment geothermal water from Hatchobaru Power Plant. Treatment capacity of the plant was desined to be 100 t/h and an arsenic concentration in treated water was reduced to less than 0.01 mg/L under condition of practical operation.

In June 2003, the plant was transferred from the central government to KEPCO and more experiments were conducted with a view of implementing a hot water supply system using treated water.

4.2 OUTLINE OF THE PLANT

The plant was constructed and operated at Hatchobaru between 1996 and 1999. The outline of the plant and the schematic flow diagram are shown Fig.3 and 4, respectively. The specification and install design value of the plant are summarized in Table 3 and 4, respectively. The plant is broadly classified into 1) a main treatment facility comprising a reaction tank, flocculation tank, sand filters (7 lines with two towers in series), a neutralization tank, a treated water tank, 2) sludge treatment facility comprising a thickener, a sludge tank, and filter presses.

The process comprises basically of a chemical treatment process, a filtration process, and a dehydration process. In addition, heated water that is heat-exchanged with river water (hereinafter called “heated water”) is sent to this plant for diluting the treated water to ensure to prevent scale deposition and to make the stable operation of the plant.

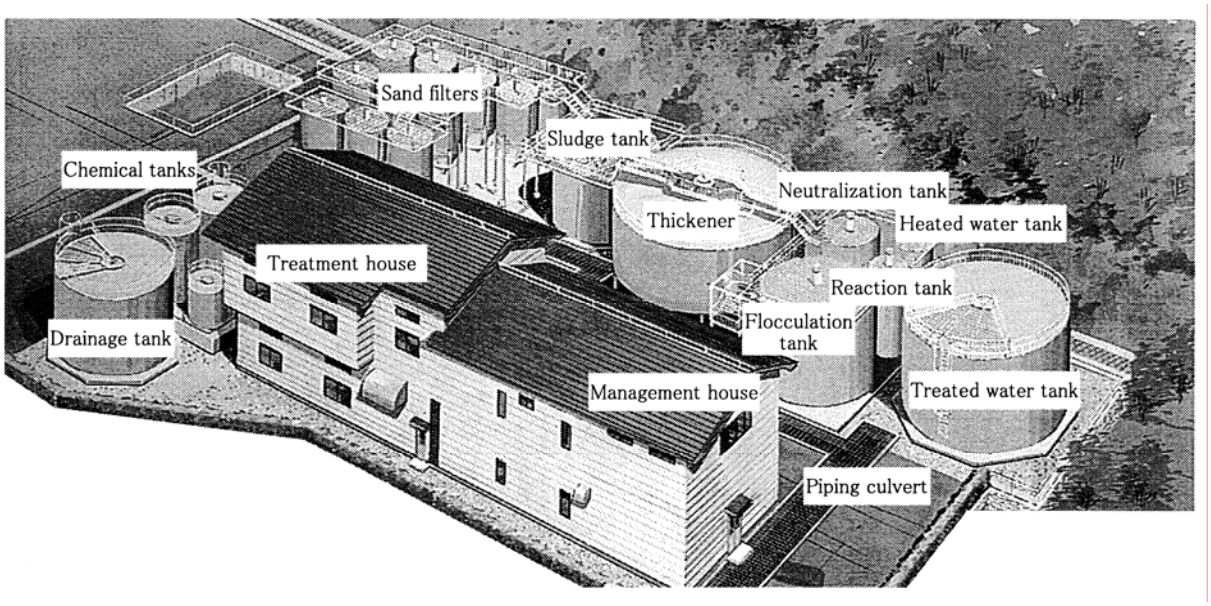

Figure 3: Outline of the plant

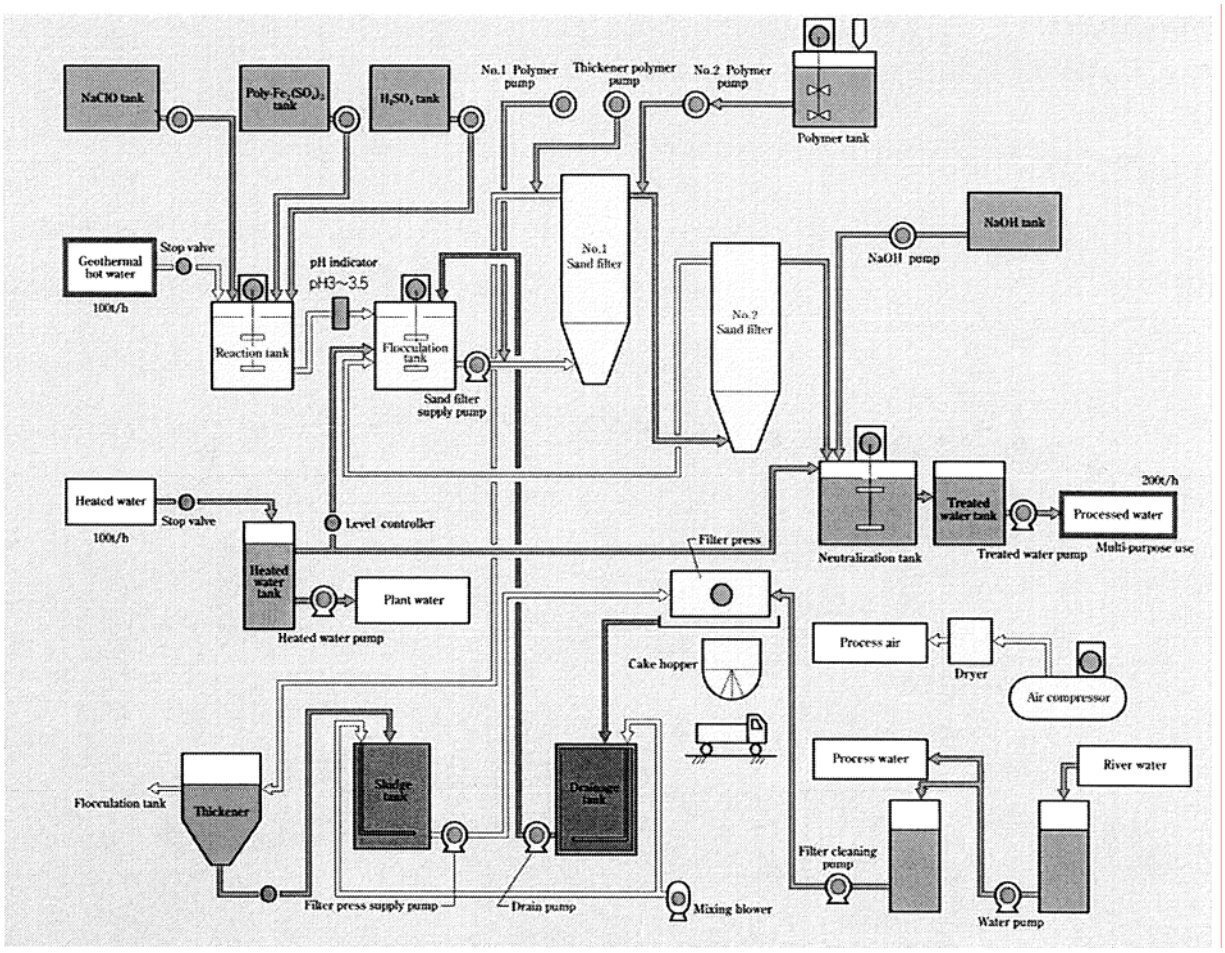

Figure 4: Schematic flow at the plant

Table 3 Design conditions

Quantity of water planned	・Hot water 100 t/h (2,400 t/day) ・Heated water 100 t/h (2,400 t/day) ・Treated water 200 t/h (4,800 t/day)		
Operation time	①Chemical reaction/filtration process	24-hour continuous operation	
	②Dehydration process	24-hour continuous operation	
Hot water properties	Temperature 90 ° C, pH 5.8-8.0, arsenic < 4.5 mg/l Silica < 750 mg/l, SS 0.9 mg/l approx.		
Heated water properties	Temperature 78 ° C, pH 6.5-8.8, arsenic < 0.005 mg/l Silica 25 mg/l, SS 0.4 mg/l		
Treated water	Target value	Temperature 70-74 ° C, pH 5.8-8.6 Arsenic < 0.01 mg/l, SS < 2.0 mg/l Prime Minister's Office Order provisions for environmental standard values for the Water Pollution Control Law and thereafter	
Dehydrated cake	Target value	Moisture content < 55%	Controlled industrial waste disposal

The above volumes are calculated assuming the liquid specific gravity to be 1 and t to be roughly equal to m3 (t≒m3).

Table 4 Basic requirements for design

	Item	Unit	Design conditions	Remarks
Chemical Treatment process	Reaction pH	—	3	
	Fe/As ratio	—	29	
	Polymerized Ferric sulfate addition concentration	mg/L	1,186	Fe11%
	Sodium hypochlorite addition concentration		180	
	Sulfuric acid addition concentration		0	
	Reaction tank caustic soda addition concentration (reacted)		135	100%-equivalent
	(neutralized)		65	100%-equivalent
	SS quantity generated		255	
Filtration process	No.1 sand filter			
	LV	m/h	<9.6	
	Inflow SS	mg/L	<90	
	Treated water SS	mg/L	<2.4	
	Backwash ratio	%	30	
	Polymer addition concentration	mg/L	3	
	No.2 sand filter			
	LV	m/h	<6.9	
	Inflow SS	mg/L	<2.4	
	Treated water SS	mg/L	<1.4	
	Backwash ratio	%	42	
	Polymer addition concentration	mg/L	0	
Dehydration process	Thickener			
	Water area load	$m^3/m^2 \cdot day$	<25	
	Retention time	h	3	
	SS recovery factor	%	>95	
	Sludge SS	mg/L	6,000	
	Polymer addition concentration		1	
	Dehydrator (Filter Press)			
	Raw water SS	mg/L	6,000	
	Dehydrated cake moisture content		<55	
	SS recovery factor	%	>99	
	Filtration capacity	$kg\text{-}SS/m^2$	3	
	Stock solution temperature	℃	<80	

4.2.1 Chemical Treatment Process

Trivalent form of arsenic (arsenite, Ballantyne J.M. et. al., 1988) in separated water is oxidized to pentavalent form of arsenic (arsenate) by dosing oxidizers (sodium hypochlorite) and the arsenate is co-precipitated with coagulants (polymerized ferric sulfate) to produce iron arsenate flocks. The reaction formula in the reaction and flocculation tanks is as follows:

AsO_3^{3-}+NaClO -> AsO_4^{3-}+NaCl

AsO_4^{3-}+Fe^{3+} -> $FeAsO_4$

4.2.2 Filtration Process

This process is positioned as the filtration of the flock flowed from flocculation tank. The sand filtration system with the continuous upward flow was adopted to remove the flock. The suspended substance (SS) in treated water was reduced to less than 2.0 mg/L with two sets of the sand filter.

4.2.3 Dehydration Process

The flock separated by the sand filter is allowed to flow into a thickener for sedimentation. Then, sediments pass through a sludge tank to be dehydrated in filter presses for storage in cake hoppers before being carried and treated at the regulation area.

4.3 Test Run

The test run of the plant was performed from November 1999 to March 2000 to examine the conditions on arsenic removal performance and the properties of treated hot water at various operating loads. The arsenic concentration of the treated water mostly depends on the pH during the coagulation reaction and the quantity of polymerized ferric sulfate added, and thus their optimum reaction conditions were investigated. Their relationships to the arsenic concentration of treated water are shown in Fig.5.

4.4 Experiments

Separated waters from Hatchobaru Power Plant Units 1 and 2 were used to perform the experiments over three years, from April 2000 to March 2003. The central-control system was adopted to monitor the operating conditions of the plant by three-shift duty. The water quality at various points was checked once a day.

4.4.1 Performance

The water qualities are shown in Table 5. The treated water is diluted with heated water in the proportion of 1:1. The arsenic concentration in treated water was 0.01 mg/L and this concentration meets the environmental standard value (0.01 mg/L) to establish an arsenic removal technology.

Leaching test of the dehydrated cake showed the arsenic concentration in the elution being lower than 0.3mg/L that is the criterion for land reclamation in Japan.

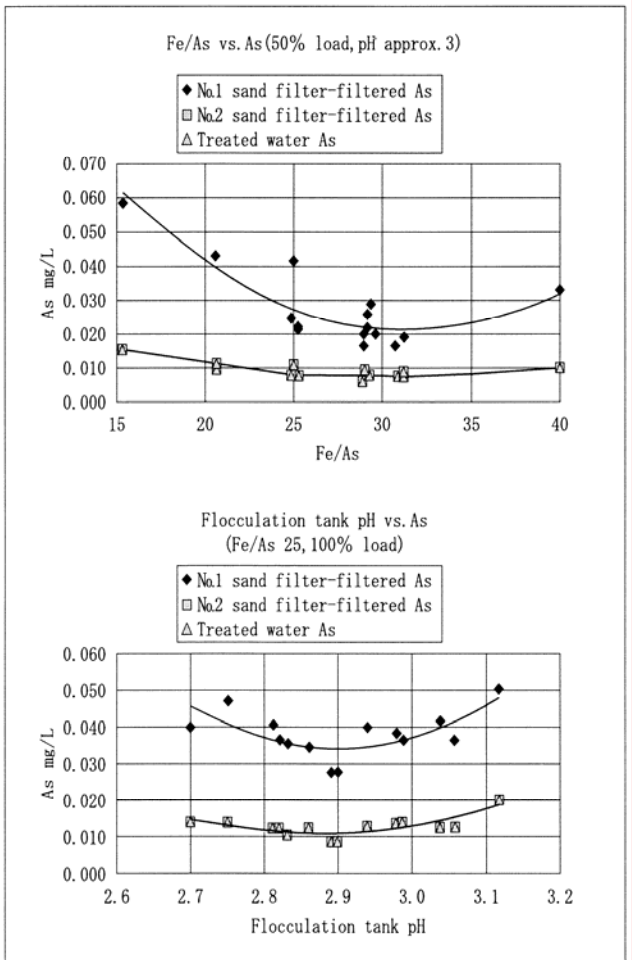

Figure 5: Relation of Fe/As ration and flocculation tank pH to arsenic concentration

Table 5 Water qualities during experiment

	December 2001			
Operating conditions	No.1 hot water			
	Fe/As ratio 25			
	Hot water 40 t/h, Heated water 40 t/h			
	Arsenic	SS	T-SiO2	T-Fe
Hot water	0.018	0.8	737	0.32
Heated water	0.003	0.6	5	0.14
Treated water	0.001	0.0	347	0.49

4.4.2 Experiments for Improvement of Operational Cost

- Improvement of sand filter

The sand filter installed in the plant comprises 7 units with two towers connected in series. The sand in the filter tower needs to be kept fluidized in order to prevent sticking. A portion of water in the outlet of the second filter sent back to the flocculation tank to keep the water level constant. Then the mass flow rate in the tower was kept at constant even in the treatment being low. Therefore, the number of the filter for optimum operation can be controlled depending on the amount of demand in the treated water. This leads to a reduction of operating cost, which include less power required for re-circulation, and less frequent exchange of sand in the tower. It has been confirmed that the arsenic concentration in treated water remains the regulation value even on operation under a reduced number of units.

- Unattended operation test at night

When any problem occurred with the plant, the system was kept left for 2 hours to check the items of the stability and safety on the plant. The results showed that treated water could be supplied to the local community without fixing problem or controls for 2 hours. After this period, action was taken under the supervision of operators with respect to problems occurred during operations. The nighttime unattended operation has been confirmed to be feasible from the observation that the treated water was continuously supplied for about 2 hours. Continuous supply of the water was judged from the water quality monitoring during the plant shutdown due to alarms and problems, and from the capacity of the treated water tank (280 m^3).

4.5 Chemicals and Power Consumption

The required quantity of chemicals such as polymerized ferric sulfate, sodium hypochlorite, and caustic soda used will increase in proportion to the amount of geothermal water treated. With respect to the sulfuric acid, less amount will be used when the Fe/As ratio of the water is the water higher and, inversely, more amount will be required when the Fe/As ratio is lower. This is because adding polymerized ferric sulfate will reduce of the water pH of the coagulation tank down to the specified pH value.

Power consumption is generally constant since the only equipment that fluctuates in response to the quantity of hot water treated is the injection pump for chemicals. Any seasonal variation in power consumption is due to the effect of the air-conditioning in the operation room.

5. TEST RUN

A test was performed from July 2003 to confirm a system to treated water to the local community. Since boron was newly added to the regulated items (upper limit discharge water regulation: 10 mg/L) as a result of the amendment of the Water Pollution Control Law in July 2001, we performed an operation of diluting the geothermal water containing a high boron concentration (33.0-41.5 mg/L) with heated water (0.37-0.60 mg/L). The plant was operated and unattended at night on the based of the successful achievement of the previous test.

The water quality of treated water during test is shown in Table 6. As shown in the Table, harmful element such as arsenic and boron in the treated

water satisfies the regulations. Thus, the treated water can be used as hot spring water. The water is of “sodium - chloride type.”

6. OUTLINE OF HOT WATER SUPPLY SYSTEM

From the viewpoint of effective use of unused geothermal energy, the treated water will be supplied by establishing a hot water supply system operated by the organization consisting of local community (Sujiyu District), local government (Kokonoe Town), and KEPCO. The overall supply flow is shown in Fig. 6.

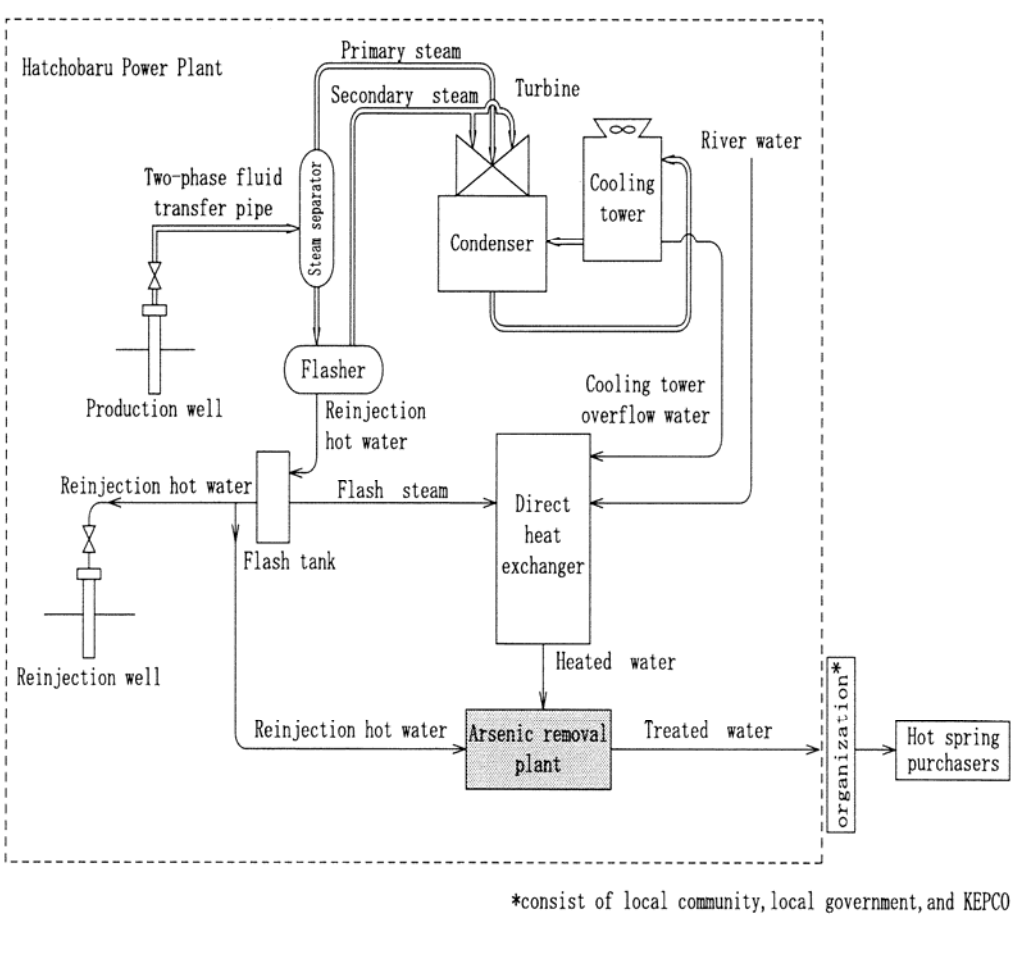

Figure 6: How water supply flow at Hatchobaru Power Plant

Table 6 Water qualities during test run

	March 2004				
Operating conditions	No.1 hot water Fe/As ratio 25 Hot water 30 t/h, Heated water 110 t/h				
	Arsenic	SS	T-SiO2	T-Fe	B
Hot water	3.3	0.9	759	—	34.3
Heated water	0.003	0.3	—	—	0.7
Treated water	0.005	0	174	0.12	8.4
Environmental regulation	≦0.01	≦25	—	—	10*

* Discharge water regulation

7. CONCLUSIONS

Development of the technology to remove arsenic from geothermal water allows extensive utilization of the water that has been used in a limited purpose. In this study, a plant to extract arsenic contains in the geothermal water was developed with a coagulation method. The treated water was confirmed that the concentration of arsenic was lowered below the environmental regulation, and the treatment capacity of the plant was 100t/h of the water at maximum. The plant is also free from a silica scaling problems as the water is treated in low pH range. The treated water will be supplied to the local community through a newly formed organization consisting of local community (Sujiyu District), local government (Kokonoe Town), and Kyushu Electric Power CO., Inc.

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