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YANAIZU-NISHIYAMA GEOTHERMAL POWER STATION H_2S ABATEMENT SYSTEM

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ABSTRACT

Tohoku Electric Power Co., Inc.'s Yanaizu-Nishiyama Geothermal Power Station (Fukushima Prefecture, Japan) started commercial operation in May 1995. At 65 MW it has the largest geothermal power output from a single unit in Japan.

Since the start of test operations in December 1994, some people have complained about an odor in the air. To evaluate this, Tohoku Electric Power measured and analyzed the possible sources of the odor using air sampling bags and continuous hydrogen sulfide (H_2S) monitoring equipment. The source of the odor was identified as the H_2S that was released from our geothermal station at a very low concentration range of 6-60 ppb.

Based on the results of an odor survey, we decided, from various anti-odor countermeasure options, to install an H_2S abatement system as the most effective way to resolve the odor problem. An H_2S abatement system had not been installed in Japan before, but we selected this method with environmental protection as the primary goal. The system is a dry-type that oxidizes H_2S gas with a catalyst and generates by-product molten sulfur. It is the world's first application with this type of system in a geothermal power station. The H_2S abatement efficiency is high (over 90%) and the system is easy to operate. The system was completed in July 1998 and is now operating satisfactorily.

1. YANAIZU-NISHIYAMA GEOTHERMAL POWER STATION

Yanaizu-Nishiyama Geothermal Power Station features:

- The largest single unit geothermal power output (65 MW) in Japan.
- The area at the site is designated as "Class IV" under Japanese "Noise Control Law". Noisy equipment is in a building and a sound-proof wall surrounds the cooling tower. The cooling tower fans and the main transformer are low-noise types.
- Since the amount of non-condensable gas in the main steam is high (about 6 wt%), the gas extraction system uses both a steam ejector and a vacuum compressor.
- The cooling tower is an aggregate octagonal shape and this effectively diffuses the exhausted gas and lessens topographical influence on emission.
- Hot water and steam condensed water are returned underground.

2. ODOR FIELD SURVEY

2.1. The odor

Odor was scattered over a wide area around our plant, and detectable up to 15 km away from our the plant. The odor was noticeable several times a month. The duration of the odor during an incident ranged from 10 min to several hours .

2.2. Source of the odor

The only odorous substance exhausted from our station is hydrogen sulfide (H_2S). H_2S is a colorless gas and even at very low concentrations it has an odor. The recognition threshold for humans is 0.006 ppm.

Assuming that H_2S was the cause of the odor, the air around our plant was sampled and analyzed using sampling bags, from September 1995 to August 1996. A continuous H_2S analyzer has been used since December 1995 at four points around the plant.

It was confirmed that the H_2S concentration detected in the air was sometimes over its recognition threshold. The H_2S level ranged from "very weak but identifiable (0.006 ppm)" to "easily perceptible (0.06 ppm)" as defined in Japan's "Offensive Odor Control Law". These levels do not affect human health or the natural environment. The Japanese "Industrial Safety and Health Law" standard for the working environment is below 10 ppm (Offensive Odor Law Research Association, 1995).

At Yanaizu-Nishiyama, H_2S sources are the geothermal power station and natural fumaroles around the station. The former exceeds the latter in quantity. To identify the location of the source of the odor, a power output control test was conducted from July 1 to October 3, 1996. In this test, output was reduced from 65 MW to 34 MW and H_2S emission reduced from 500 m^3/h to 340 m^3/h. Over the duration of the test, the frequency of H_2S detection showed a decreasing trend compared to before the power output control test, although differing meteorological conditions made strict comparisons difficult.

The results confirmed that the source of the H_2S odor was mainly the geothermal power station. .

2.3. Odor occurrence mechanism

Quantity of H_2S
The quantity of non-condensable gases and H_2S concentration in the steam produced were about 30 t/h and 0.7 t/h. These values are about 10 times higher than those of other geothermal power stations in our service area.

Meteorological conditions
At the rated output of the Yanaizu-Nishiyama power plant, the cooling tower emits about 500 m^3/h of H_2S at a concentration of 33 ppm. Under most meteorological conditions, it would be rare for this exhausted gas to cause an odor.

This area is meteorologically calm with weak winds in all seasons. From meteorological observations taken over a one-year period from May 1990 to April 1991 prior to constructing the geothermal power station, annual mean wind speed was 0.5 m/s and the calmness rate (wind speed below 0.4 m/s) was 63%.

We checked the correlation between the wind speed and day and night temperature differences based on meteorological data from the rooftop of the station building. The occurrence of the odor is not clearly related to wind direction, but the odor was evident when the wind speed is comparatively weak and the difference between day and night temperatures is large.

These meteorological conditions can produce temperature inversion layers and, in our case, the temperature inversion layer was somewhat related to the occurrence of the odor. Although the air diffusion phenomenon when there is a temperature inversion layer has not been sufficiently explained either theoretically or experimentally, it can be assumed that under the conditions shown in Fig.1, the temperature of the gases exhausted from the cooling tower equals the air temperature at a certain altitude. At this altitude, the gases from the cooling tower lose buoyancy and trail horizontally.

Photos 1 and 2 were taken during a well flow test. In Photo 1, well flow steam ascends and diffuses normally. In Photo 2, well flow steam begins to trail at a certain altitude and this is where the temperature inversion layer is deemed to be.

When there is an inversion layer and the gases trail horizontally, diffusion does not progress smoothly. With a local wind, the air containing such gases can go down to the surface and the result is the odor.

With this kind of mechanism, the landing points for the odor are considered to be scattered over a wide area and the duration of the odor is short. These characteristics agree with the odor survey results.

2.4. Summary

Summarizing the above, the odor was produced because of specific, very weak wind conditions and the high H_2S content in the exhausted gases at the Yanaizu-Nishiyama Geothermal Power Station.

3. ODOR COUNTERMEASURES

3.1. Comparison of odor countermeasures

This was our first experience with an odor originating from H_2S, and no other example was found in other geothermal power stations in Japan. To deal with the problem, countermeasures were pursued from various perspectives.

Output control

As described above, an output control test was conducted to confirm the source of the odor and to suppress the suspected source of the odor. By reducing the output to half, the odor was scarcely detected at Showa-mura and Kaneyama-machi which are located more than 10 km from our plant, but at Mishima-machi and Yanaizu-machi, within 5 km of the station, the occurrences of odors decreased to some extent but did not disappear completely.

Masking and deodorizing

Masking the odor with an aromatic fragrance and deodorizing with activated carbon were examined. Using the aromatic fragrance in a large quantity as a masking reagent tends to lead toward secondary occurrences of the odor of the fragrance and the method is not feasible. Deodorizing with activated carbon is also not feasible because of the large amount of H_2S.

Underground re-injection

Underground re-injection methods include direct re-injection method injecting H_2S with re-injection water through re-injection wells, and absorption injection method injecting a magnesium hydroxide solution that absorbs the H_2S through re-injection wells.

Direct injection method is used at the Coso Geothermal Power Station in the USA (Y.Esaki, et al., 1996; Y.Hibara et al., 1995) and other places. If this was applied to our station then based on the total amount of injection water at as little as 220 t/h, the non-condensable gas that could be injected would be below 2%.

The absorption injection method has examples with equipment used at small-scale thermal power stations. H_2S is absorbed by magnesium hydroxide producing magnesium sulfate (non-poisonous and a constituent of sea water) that is discharged to the sea. Because our plant produces high H_2S concentration steam, about 130 tons of magnesium hydroxide would be needed per day. Transporting and stockpiling the large quantity of the reagent makes this method physically and economically unfeasible.

The H_2S abatement system

There are various types of H_2S abatement systems. They are represented by the Amine-Claus method used for petroleum refining and the Limestone-gypsum method used at thermal power stations. Both methods have large-scale equipment requirements. Securing sufficient space to install the system at the power plant located in a mountainous area, technological limitations in the complex system preventing unmanned operation, and economic considerations led us to determine that any of these systems would be difficult to adopt.

Some geothermal power stations outside Japan have wet-type H_2S abatement systems installed, including the LO-CAT and Stretford methods.

In case of adopting the LO-CAT method at our geothermal power plant, catalyst consumption would be great because of the large amount of exhausted H_2S and the operational costs would be high.

With the Stretford method, the initial cost for the system and the operational costs are comparatively low, although the low purity of the sulfur reduces its usefulness.

There are eight examples of a dry-type H_2S abatement systems in the USA. This method handles low concentration H_2S at small natural gas plants and features direct oxidation of H_2S using a catalyst.

The lack of examples for geothermal power stations and the comparatively high initial costs for the equipment are disadvantages of the dry-type H_2S abatement method. Easy handling because the H_2S gas is oxidized directly, long catalyst life (alumina and silica-based catalysts can be used for 2-5 years), and size of abatement system equipment that permits installation of the system in mountainous areas are advantages.

3.2. Discussion

From the options available to us, a dry-type H_2S abatement system was selected. Our selection was based on selecting the best method with primary consideration to environmental protection. In our case, there is a high H_2S content. We were considering selling the sulfur by-product, which requires high purity (more than 99.9%). This led us to judge this system as more superior.

The cost for the facility and equipment is high, but the size of the system is suitable for our geothermal power plant. It is easy to operate and maintain. The catalyst has a long life and the operating costs are not expensive compared to other systems.

Since there was no experience with this type of system and it was the first application in a geothermal power plant, performance tests were conducted to confirm H_2S abatement ability using the catalyst in a real system.

4. DRY-TYPE H_2S ABATEMENT SYSTEM

4.1. Fundamental concept

As shown in the layout (Fig.2), the system was installed on the premises of an existing geothermal power plant. The diagram shows that the subject gases are derived from the gas extraction line that brings non-condensable gases from the condenser to the cooling tower. After the H_2S is removed, the scrubbed gases are returned downstream into the same line.

Operating the system does not cause any new environmental problems such as noise emission or other air pollution.

Since the dry-type H_2S abatement system operates in tandem with the geothermal power plant, it conforms to the geothermal power station master plan. Individual consideration was given to system location, the amount of cooling water from the existing power generating system, etc. to match the two systems with respect to connections and operation.

As with the existing geothermal power station, normal operation is done remotely.

4.2. Operating principles

Basic configuration

The main system has a process gas line where the H_2S in the non-condensable gases is oxidized to sulfur (gas), a thermal oil line where pre-heating takes place for catalytic oxidation and the sulfur vapor produced is cooled to a molten state, and a nitrogen line that is used to purge the process-gas line during system start-up and shut-down (Fig. 3, Photo 3).

Principles

In the process-gas line, H_2S is firstly oxidized with the Selectox catalyst (aluminum oxide and silicon dioxide based) into SO_2 in the first reactor. Then, in the same reactor, the SO_2 and the H_2S which has not reacted yet, undergo an immediate oxidation reaction (Claus reaction) to produce sulfur vapor. After passing through the first reactor the process gas is cooled and the sulfur vapor produced is removed in a molten state.

The process gas, with the sulfur vapor removed, is led to the second reactor. The H_2S and SO_2 produced in the first stage undergo oxidation with a Claus catalyst (aluminum oxide based) to produce sulfur vapor in a Claus reaction. After passing through the second reactor, the process gas is cooled again and sulfur is released in a molten state. In this second-stage reaction, most of the H_2S contained in the steam is removed from the process gas in a molten state.

After passing through the second reactor, the process gas is sent to the third reactor where the slight amount of sulfur vapor and H_2S remaining are oxidized into SO_2 with the Selectox catalyst to prevent the line from clogging. Thus, at each stage in the process gas line, H_2S is removed and the process gas is exhausted from the cooling tower.

The apparent, total reaction is given by:
$2H_2S + O_2 \rightarrow 2S + 2H_2O$

Thermal oil line

To make the above H_2S catalytic reaction progress smoothly, it is necessary to pre-heat the H_2S gas to the temperature required for oxidation and then cool the produced sulfur vapor for the conversion to molten sulfur. The H_2S gas is pre-heated to about 190ºC before the first and second reactors and about 260ºC before the third reactor. These temperatures are higher than the temperature of geothermal steam (166ºC), so geothermal steam cannot be used for pre-heating. Also, high quality cooling water is not easy to obtain and for these reasons it was decided to use thermal oil to combine cooling the sulfur vapor and pre-heating the process gas.

Nitrogen line

Nitrogen gas is used to purge the process gas line when starting and shutting down the system and to raise the temperature of the process gas line when starting up.

4.3. System outline

The system is shown in Fig.3 and Photo 3. It is designed to accept the changes in the amount of non-condensable gases and H_2S contained in the steam. These changes are estimated based on short-term variation, pulsed variation recognized in several-day intervals or several-ten-day intervals, and long-term natural attenuation.

Amount of gases to be treated	about 36 t/h (Base Load)
Amount of H_2S	about 0.65 t/h (Base Load, Max: 0.8 t/h)
Rate of H_2S removal	above 90%
Molten sulfur by-product	about 12 t/day (Base Load)

4.4. Main specifications

The main specification of H_2S abatement system equipment is as follows

Reactor and catalyst	
1st reactor	Selectox catalyst
2nd reactor	Claus catalyst
3rd reactor	Selectox catalyst
Thermal oil capacity	
Amount of thermal oil	about 70 m^3
Sulfur recovery	
Sulfur pit	1 unit
Sulfur shipping equipment	1 unit

4.5. Supervisory control

Supervisory control of the system is through continuous monitoring using the distributed control system (DCS). When starting up and shutting down, supervisory control is done in the control room near the system. During normal operation, supervisory control is done in the remote control room. During normal operation, all controls, including system inlet gas pressure control, reaction airflow control and thermal oil temperature control, as the main controls, are automatic.

4.6. Construction period

The construction of H_2S abatement system equipment started in June 1997 and completed in July 1998. It is now operating satisfyingly.

ACKNOWLEDGEMENTS

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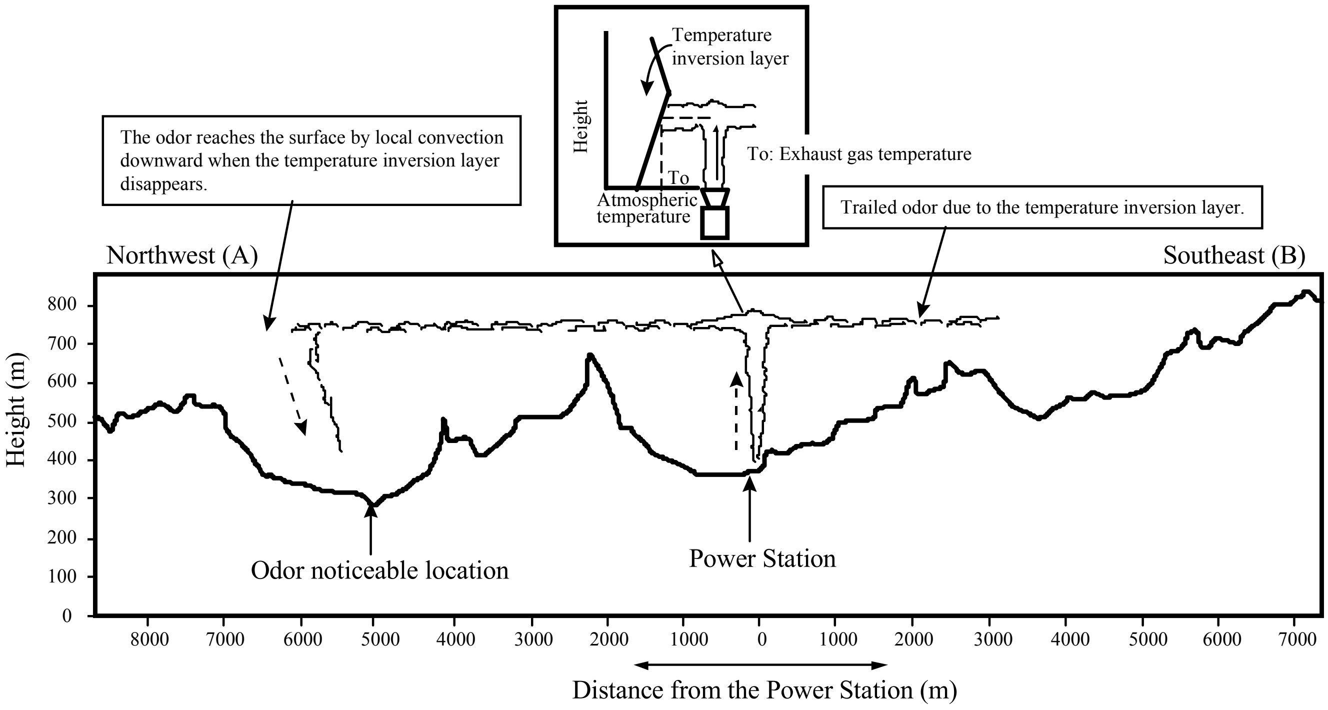

Fig.1 The odor occurrence mechanism (Northwest-Southwest[A-B]terrain pofile)

This shows the terrain profile from northwest to southwest around the Power Station. It is estimated that the odor from the Power Station trails in midair due to the temperature inversion and the odor reaches the surface by local convection downward.

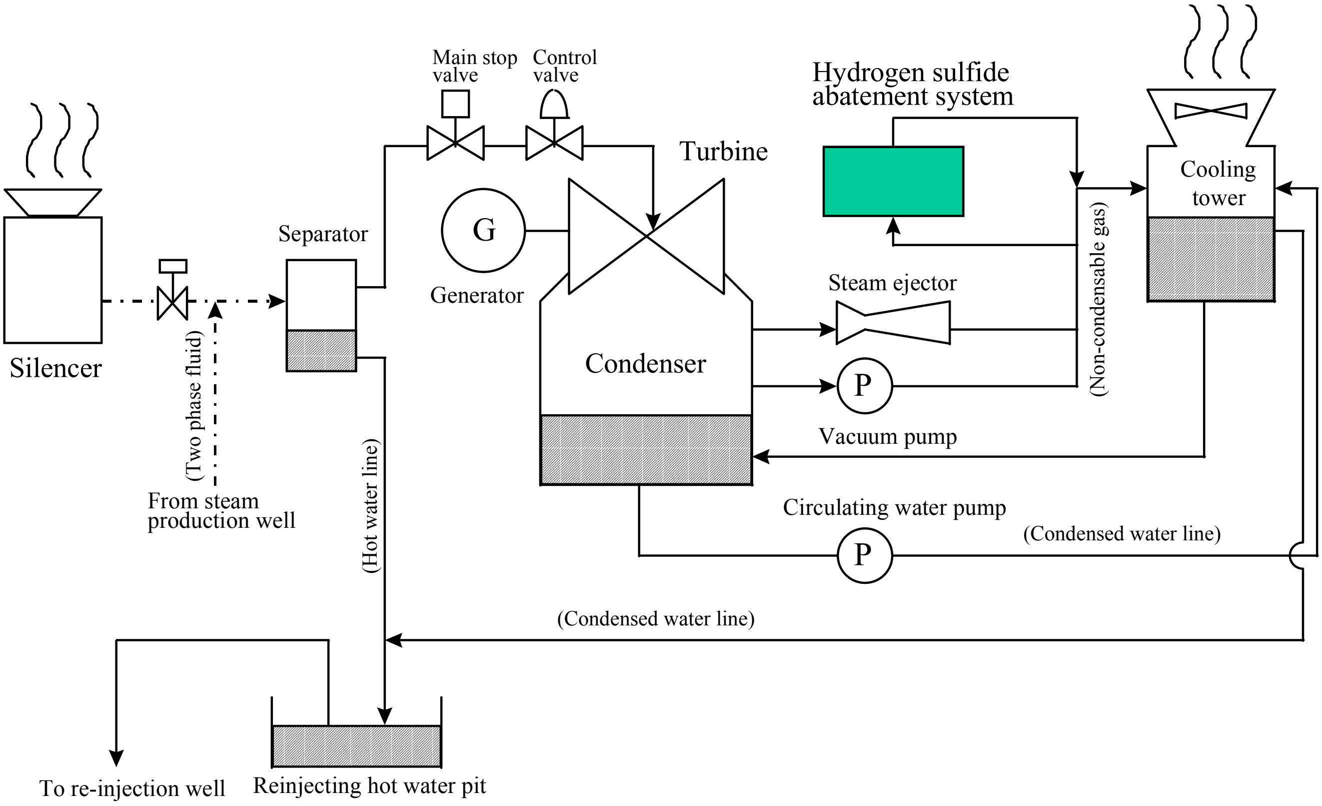

Fig.2 Yanaizu-Nishiyama Geothermal Power Station system
(Hydrogen sulfide abatement system is installed in the existing gas extractor exhaust line.)

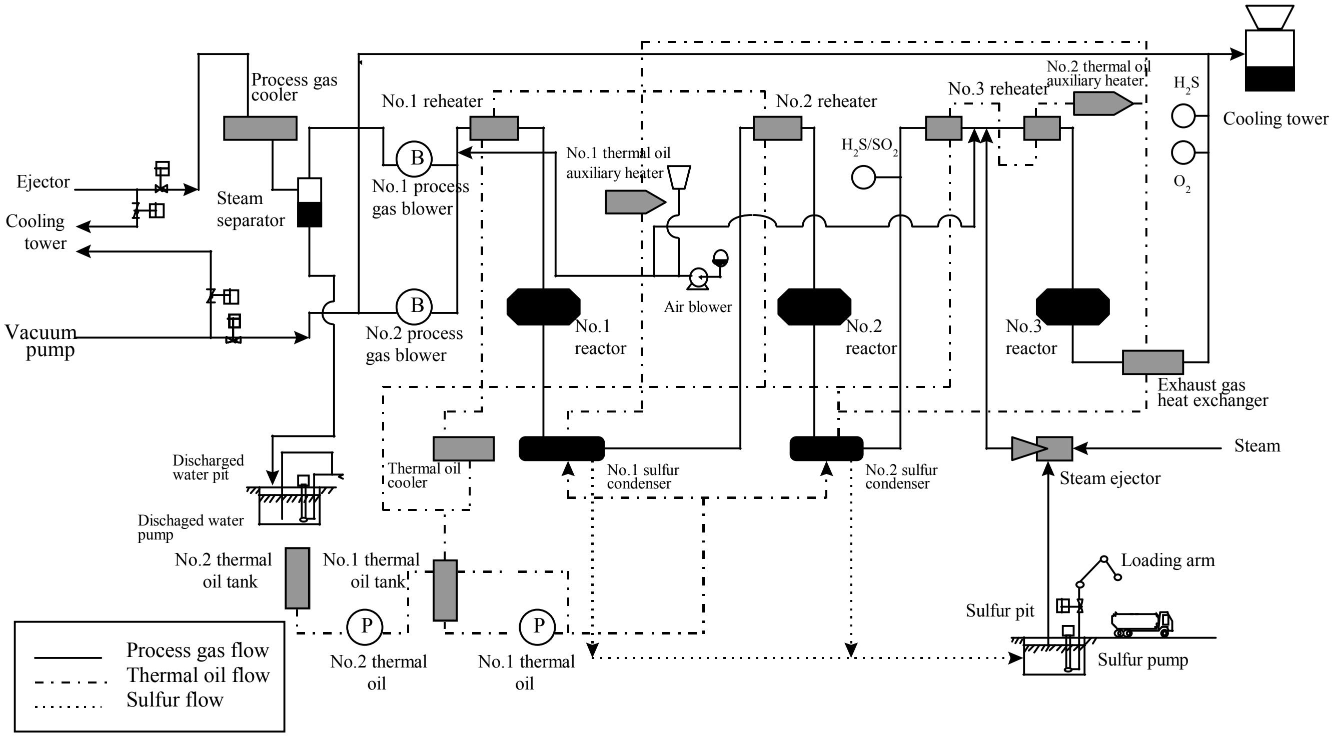

Fig.3 Dry-type Hydrogen sulfide abatement system flow at the Yanaizu-Geothermal Power

Photo 1
Well flow test at Yanaizu-Nishiyama Geothermal Power Station.
Well flow steam normally diffuses upward.

Photo 2
Well flow test at Yanaizu-Nishiyama Geothermal Power Station.
Well flow steam stops rising at a certain height and trails horizontally, caused by temperature inversion that blocks diffusion upward.

Photo 3
Dry-type hydrogen sulfide abatement system