Introduction and Operation of Advanced Environmental Systems: Geothermal Heat Collection System and New Wastewater Treatment System

● Yasushi Yazawa ● Yuichi Mori ● Masato Takizawa ● Masahiro Yazawa
● Masaaki Hashizume

Dissemination of advanced, highly efficient technologies to reduce environmental impact at production and development sites, including natural energy and resource recycling, is a corporate social responsibility. However, there are many constraints in adopting these new technologies depending on the features, such as the site environment and corporate structure, and the effect of reducing environmental impact and cost-effectiveness greatly differ. In particular, it is an absolute requirement for site operation to construct a system for stable operation both at use points (production and development processes, etc.) and discharge points (wastewater treatment and waste, etc.) of printed circuit board manufacturing such as at Fujitsu Nagano Plant. Fujitsu Facilities Ltd., which operates plant facilities under such stringent conditions, has considered these challenges, and adopted the following technologies, the first in Japan to do so as a production site: a geothermal heat collection system, where underground heat can be directly used as an energy source for production lines; and a new wastewater treatment system, where the copper-based materials in the copper waste liquid discharged from production lines can be recovered and recycled with high efficiency by using a method that differs from the conventional one. This paper introduces the performance of these two new technologies, and also the points we have improved to obtain the maximum capability of the systems according to the features of the Fujitsu Nagano Plant, throughout the introduction process of technology selection, basic designs and trial operations. This paper also describes our know-how to overcome challenges.

1. Introduction

The Fujitsu Group has been working on reducing environmental impact in a systematic manner: It has established the Environmental Policy and Environmental Action Plan, put in place a system to visualize the actual results of reducing peak power and CO_2 emissions of the respective sites such as laboratories, plants and offices by energy management, and set specific targets to be achieved. In addition, it is striving to reduce chemical usage by reconsidering the method of wastewater treatment. Promoting the use of natural energy is also listed in the targets and the respective sites are implementing their own activities such as introducing a photovoltaic power generation system. The construction of environmental systems at the respective sites may vary depending on the purposes and conditions of the facilities.

This paper presents a geothermal heat collection system and a new wastewater treatment system installed at Fujitsu Nagano Plant, which is a printed circuit board manufacturing site that combines a use point for manufacturing and development processes and such like and a discharge point for wastewater treatment and waste, etc.

2. Geothermal heat collection system

Air conditioning systems that make use of geothermal heat have been adopted mainly in hospitals and schools. The installation of these systems at the Nagano Plant was the first attempt in Japan by a plant directly linked to product manufacturing. This section describes the installation of a geothermal heat collection system and results of its operation.

2.1 Background of installation

1) Challenges in the Nagano Plant and selection of natural energy

The Nagano Plant is a community-based facility surrounded by quiet residential areas. It is a Type 1 designated energy management factory as stipulated in the Energy Conservation Law of Japan, which means it is a factory that consumes 3000 kL or more of energy as measured in crude oil equivalent.

Challenges faced by the plant include:

- Reduction of energy consumption (reduction of CO_2 emissions and costs)
- Harmonious coexistence with residents living in the vicinity (environmental consideration including noise control)
- Stable energy supply (quality maintenance and business continuity)
- Shortage of space for installation of equipment

To solve these by making use of natural energy, we have made a comparison as shown in **Table 1**.

Both widely used photovoltaic power generation and wind power generation, which are the mainstream, have insufficient stability and require large installation areas. They therefore do not adequately solve the challenges. Accordingly, we focused on geothermal heat utilization. This is not intended to be used to generate power but to utilize the heat for air conditioning. It is a promising way to reduce energy consumption. In addition, the underground temperature is constant throughout the year and apparently can be stably used. Furthermore, the equipment is mostly buried in the ground and so does not cause problems such as noise. In this way, use of geothermal heat was judged to be a way to solve many challenges and we investigated it specifically.

2) Geological survey of the plant

When applying geothermal heat, the existence of groundwater heavily affects the performance of the system. This is because water acts as a medium for heat transfer, allowing us to utilize a larger amount of the heat. As a result of examining the geological data in the initial phase of the plant's construction, we found that groundwater strata storing (aquifers) were located at a shallow depth of 3 m to 23 m and decided that the geological conditions were suitable as well.

3) Study of operational conditions

Air conditioning systems that utilize geothermal heat are generally used for cooling in summer and heating in winter and are often adopted in hospitals and schools as mentioned earlier. The plant uses cold water (at approximately 7°C) produced by a large refrigerator for cooling, and hot water (at approximately 44°C) produced by gas boilers for heating. We first considered installing a geothermal system for office air conditioning but a trial calculation of the effect did not give a favorable result. The reasons are:

- Short operating time of the air conditioning system
- Existing air condition systems are advantageous for cooling

In particular, the short operating time significantly reduces the effect. We therefore decided that it would be impossible to maximize the system's performance if installed. At the same time, however, the system was found to produce a great effect during heating as compared with the existing air conditioning system. Based on these results, we established the operational conditions:

- Air conditioners that are running for long hours
- Air conditioners operated for heating throughout the year

and selected targets for installation which meet these conditions.

4) Selection of targets for installation and investigation of the system

After conducting several investigations of the

Table 1
Natural energy comparison.

Type	Seasonal variation	Diurnal variation	Characteristics
Geothermal heat utilization	Stable	Stable	• Not power generation equipment but equipment that uses heat • Electric power required as a power source • Most of the equipment buried underground
Photovoltaic power generation	Variable	Variable	• High cost of power generation • Large installation area required for equipment
Wind power generation	Variable	Variable	• Regular maintenance and inspection essential • Fairly large installation area required • Noise and low-frequency oscillation generated

actual state of operation, heat load, etc. of air conditioners, the targets to which the system could be installed were narrowed down to air conditioners for cleanrooms, which require strict temperature and humidity control. To maintain the controlled humidity, these air conditioners use cold water to dehumidify the air. Hot water is used to raise the temperature of the dehumidified air to the specified value. The load of this process is especially significant in summer, when the outside air humidity is high. That is, heating is required throughout the year and the running time is continuous for 24 hours every day throughout the year.

Through these processes, we decided to build a geothermal heat collection system that produces hot water for heating and supplies it to air conditioners for cleanrooms throughout the year for the purpose of reducing the fuel consumed by the gas boilers.

2.2 System overview

1) System flow

The main pieces of equipment of a geothermal heat collection system include a heat pump and a geothermal heat exchanger. A heat pump is based on a technology for extracting heat from media such as water and air to use it as a heat source for cooling and heating. For example, a household air conditioner utilizes a kind of heat pump.

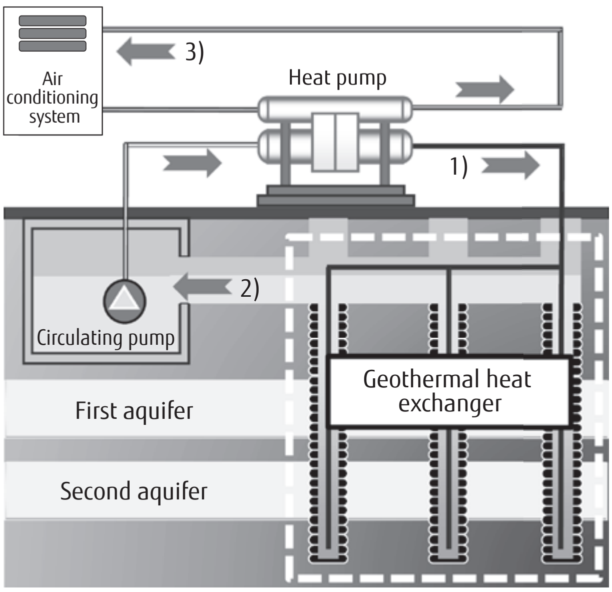


Figure 1
Outline of geothermal heat collection.

The water circulated by the pump installed underground (heat source water) is cooled to approximately 5°C as it passes through the heat pump [1) in **Figure 1**]. Then, it goes through the geothermal heat exchanger, when the geothermal heat is collected to increase the temperature to approximately 8°C [2) in Figure 1]. The hot water used in the air conditioning system is heated to approximately 44°C as it passes through the heat pump, which is then supplied to the air conditioner [3) in Figure 1]. Characteristically, the system does not pump up groundwater for use but only extracts the heat held in the ground to use for increasing the temperature of the heat source water.

2) Geothermal heat exchanger

The geothermal heat exchanger is composed of multiple heat extraction pipes for collecting geothermal heat. A total of 31 pipes are buried at a depth of 30 m in the ground beneath roads of the plant (**Figure 2**).

3) Heat extraction pipe and heat collecting method

The heat extraction pipes have a double-pipe structure. After passing through the inner pipe, the heat source water turns back at the end and flows back through the gap with the outer pipe to extract heat in the ground (**Figure 3**). The outer pipe is corrugated to make more effective use of geothermal heat. This allows us to collect a larger amount of heat than that of the conventional method. Therefore, the installation depth can be reduced, offering a benefit of reduced digging cost. **Table 2** shows a comparison with the

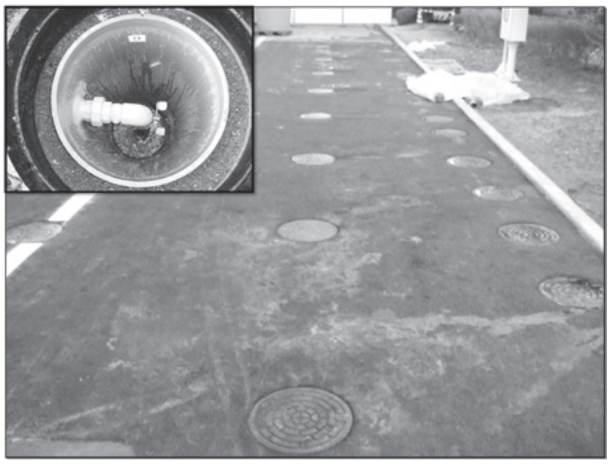
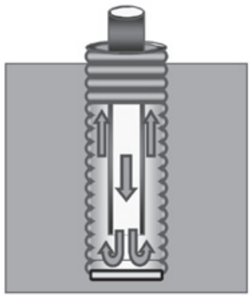
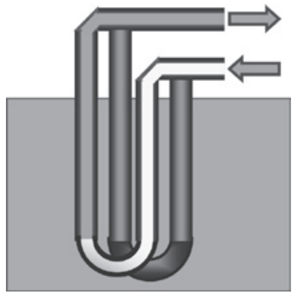


Figure 2
Installation site of geothermal heat exchanger (road on premises) and inside of manhole (upper left).

Table 2
Comparison with conventional method.

Method	New method	Conventional method
Elevation view	 Increasing heat transfer area to improve amount of extracted heat	 Commonly used method
Material	Outer pipe: FEP / Inner pipe: polyethylene	Polyethylene
Installation depth	About 5–25 m	About 100–150 m
Amount of extracted heat	100–180 W/m	25–50 W/m
Characteristics	Low digging cost because of shallow installation depth Seismic resistance achieved by high flexibility	High digging cost because of deep installation depth Refilling with filler required after digging

FEP: Fluorinated ethylene propylene

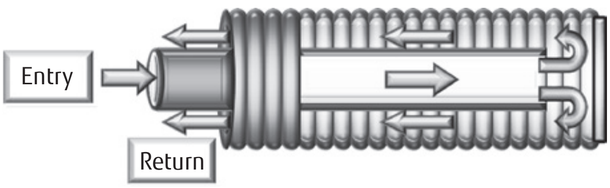


Figure 3
Structure of heat extraction pipe.

conventional method.

2.3 Improvement measure for operation and its effect

1) Improvement of heat collection

The flow rate of the heat source water was calculated based on an estimate that the new heat collection method would extract heat of 155 W/m. However, analysis of the trial operation data showed that only about 30% of the designed amount of extracted heat was achieved. As a result of various investigations and verifications conducted including those on the failure of equipment, it was found that the originally calculated flow rate of heat source water was not sufficient. We increased the flow rate and achieved an improved amount of extracted heat.

2) Effect of the system operation

Based on the actual result of operation, the system was proved to reduce the annual fuel usage by approximately 28 kL (crude oil equivalent) and CO_2 emissions by approximately 73 tons. Because most of the system is buried underground, it did not form a dead space.

2.4 Future challenges

For the installation of the heat extraction pipes, we used data obtained in the initial phase of the plant construction for information about geological features and designed the amount of extracted heat by referring to the data from a case in which the same method had been adopted. However, the amount of extracted heat may be smaller than the estimate, as described above. Accordingly, a thermal response test[note)] must be conducted in advance to take into account the impact of underground temperature on the actual amount of extracted heat and installation spacing to design the system.

3. New wastewater treatment system

The Nagano Plant is a manufacturing site that produces high-density multilayer printed circuit boards

note) Analyses of thermal conductivity of strata and thermal resistance of the geothermal heat exchanger by circulating water after embedding the heat extraction pipes.

and has a 24-hour continuous-operation system. For this reason, very large amounts of water, chemicals, electric energy and gases are used, which makes it one of the most environmentally impacting manufacturing sites among the entire group companies.

The copper plating wastewater discharged from the production lines is chemically treated by the wastewater treatment facilities in the plant to be separated into detoxified wastewater and solid copper sludge (solid-liquid separation). In this way, approximately 4000 m^3/day of wastewater is treated. While the treated wastewater is discharged into a river under strict around-the-clock surveillance, the separated copper sludge is dehydrated with a dehydrator and subsequently sold as a valuable resource. The system to detoxify wastewater and give value to copper sludge had been established. However, the cost of chemicals used in the treatment process had been increasing and the copper sludge was dealt with at low prices due to the large amounts of chemical components contained. In reality, the system failed to make significant contributions to cost reduction.

This section describes a case of introducing a new wastewater treatment system that has succeeded for the first time in Japan in recovering copper at a higher density without using chemicals.

3.1 Background of introduction

The existing solid–liquid separation system had problems because it required large amounts of chemicals. We therefore attempted to reduce those amounts by conducting beaker tests under all conditions. However, we could not obtain favorable results in terms of the quality of wastewater, which was the most important point. Then, we widened our view to investigate without regard for the existing treatment methods or fields and found an unprecedented technology, although not yet practical, to use iron powder for separating impurities contained in oil for reuse, and we focused our attention on this.

To study the possibility of applying this method to a copper recovery system, we first built a mini-plant and conducted various experiments and operational tests through trial and error. Good results were obtained in terms of both the water and sludge quality and we found out the method was practical.

To realize the system, we combined the operational know-how that the Fujitsu Group has with regards to wastewater treatment.

3.2 System overview

1) Common wastewater treatment method

For treatment of copper plating wastewater discharged from the plant, a solid–liquid separation system (**Figure 4**) is generally used. The water treatment method involves adding a flocculant of polyferric sulfate ($[Fe_2(OH)_n(SO_4)_{3-n/2}]_m$) to combine the ionized copper components, which have been neutralized by calcium hydroxide ($Ca(OH)_2$)/sodium hydroxide (NaOH), with the copper sludge and the mixture is then efficiently precipitated by using polymer flocculant for separation.

2) Method for new wastewater treatment system

The method used for the new system is capable of treating about 10% of the entire currently treated amount and allows recovery of highly concentrated copper sludge without using chemicals other than those for neutralization (**Figure 5**).

The characteristics of the process flow are as follows:

- Mixing of copper slurry and iron powder in the filtration apparatus and discharging treated water only [1] in Figure 5]
- Separation of the copper slurry and the iron powder [2) in Figure 5]

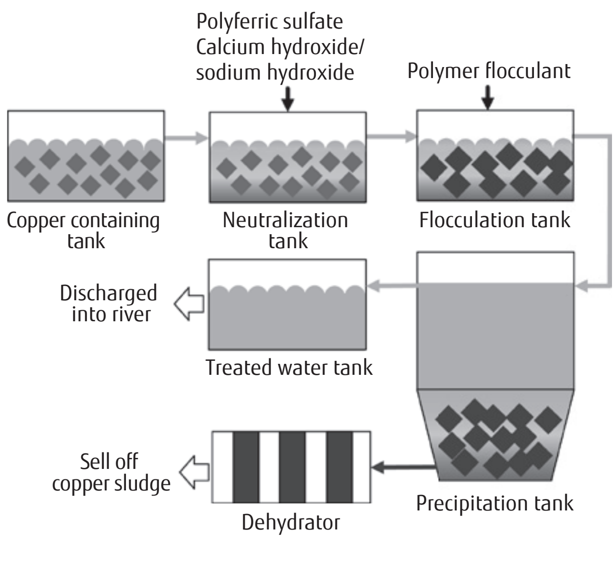


Figure 4
Outline of solid-liquid separation system.

- Selling of only copper slurry separated from iron powder [3) in Figure 5]

3.3 Improvement measures for trial operation

During trial operation, the filtration apparatus clogged up with iron powder, so that the operation was stopped. Upon investigation of the cause, the iron powder was confirmed to be in a more viscous state than usual. Analysis of the iron powder showed that silicone materials were attached. The silicone materials are components contained in the defoamer used for defoaming the wastewater. A beaker test was conducted under the same conditions as the system to verify what actually happened, and as a result we were able to reproduce the attachment of the silicone materials to the iron powder (**Figure 6**).

To solve this problem, we changed the operation procedure from collection of all wastewater into this system for treatment to division between the existing equipment and the new system for treatment in accordance with the existence of the defoamer. In this way, we successfully solved the problem and acquired operational know-how.

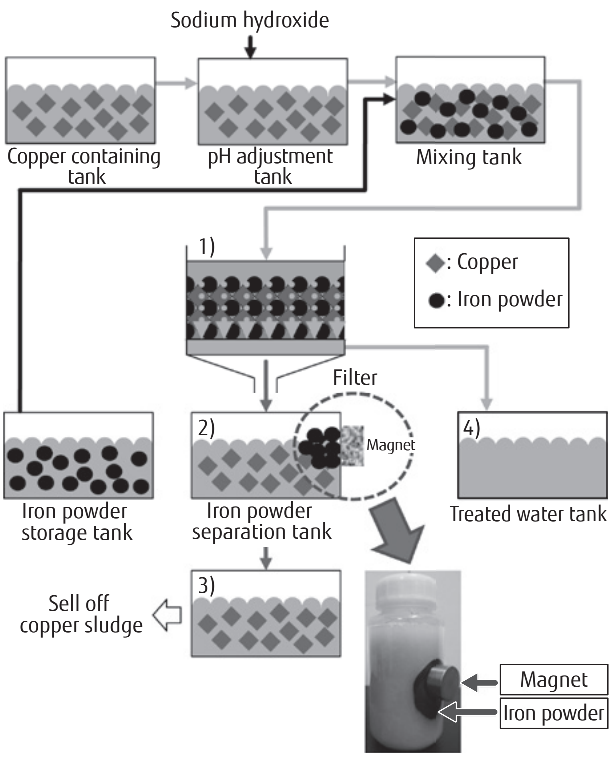


Figure 5
New wastewater treatment system.

3.4 Effect of new system operation (comparison with conventional method)

As shown in **Table 3**, the effect includes reducing the environmental impact accompanying the reduction in the usage of chemicals, which has in turn brought about a cost reduction and improved profit on copper sludge sale. The ratio of the copper content concentration of the sludge has increased by about sixfold as compared with the conventional method because chemicals and other impurities were eliminated.

4. Conclusion

This paper has presented a geothermal heat collection system that makes use of natural energy and a new wastewater treatment system to recover copper resources, which are in place at Fujitsu Nagano Plant. We intend to continue expanding the systems to promote further reductions of environmental impact.

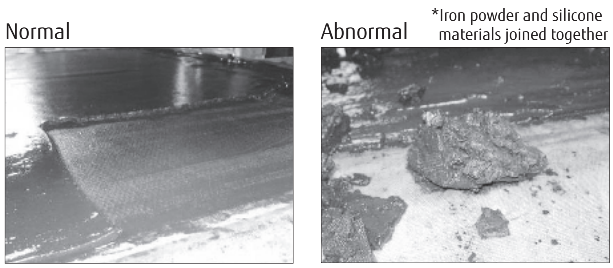


Figure 6
State of iron powder in filtration apparatus.

Table 3
Effect of new system operation.

Reduction of environmental load	Reduced cost/increased profit on sale	Treatment (time/space)	Copper content concentration rate of sludge
• Number of chemicals reduced from 4 to 1	• Reduced chemical purchase cost • Improved profit on selling copper sludge	• Reduced from 2 hours to 1 hour • Reduced by approx. 50%	• Improved about sixfold as compared with conventional method

The technologies employed for these two systems are very versatile. Geothermal heat can be applied to city centers, densely populated areas, datacenters and office buildings regardless of groundwater intake regulations or existence of space in which to bury the geothermal heat exchanger, and use for agriculture (including plastic greenhouses) is under consideration. The new wastewater treatment system is capable of significantly reducing chemical use and risks related to the location in which it is installed and makes it possible to recover precious metals other than copper resources (such as silver and palladium). Fujitsu Facilities Ltd. is committed to providing these technologies including the provision of know-how for group sites in Japan and overseas and their promotion with a view to rolling out business to general customers.

Yasushi Yazawa
Fujitsu Facilities Ltd.
Mr. Yazawa is currently engaged in basic design, operation, maintenance and management of plant facilities (air conditioning and electric equipment) and in charge of introduction of geothermal heat collection system.

Masahiro Yazawa
Fujitsu Facilities Ltd.
Mr. Yazawa is currently engaged in basic design, operation, maintenance and management of plant facilities (wastewater treatment equipment) and in charge of introduction of new wastewater treatment system.

Yuichi Mori
Fujitsu Facilities Ltd.
Mr. Mori is currently engaged in basic design, operation, maintenance and management of plant facilities (air conditioning and electric equipment) and in charge of introduction of geothermal heat collection system.

Masaaki Hashizume
Fujitsu Facilities Ltd.
Mr. Hashizume is currently engaged in basic design, operation, maintenance and management of plant facilities (wastewater treatment equipment) and in charge of introduction of new wastewater treatment system.

Masato Takizawa
Fujitsu Facilities Ltd.
Mr. Takizawa is currently engaged in basic design, operation, maintenance and management of plant facilities (air conditioning and electric equipment) and in charge of introduction of geothermal heat collection system.