Full-scale Demonstration Tests of Passive Treatment System by JOGMEC in Japan

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Abstract

Full-scale demonstration tests (flow rate: 100 L/min) of biological passive treatment system, which is environmentally-friendly and energy saving, was started at an abandoned mine site in Japan. AMD containing iron and zinc was treated in two vertical-flow bioreactors, aerobic reactor and anaerobic reactor utilizing iron oxidizing bacteria and sulfate reducing bacteria (SRB), respectively. In the aerobic reactor, AMD containing 35 mg/L of Fe was treated to below the wastewater standards by using a water transfer method such as a cascade. In the anaerobic process, applicability of a process using ethanol or rice bran as organic resources of SRB was studied.

Keywords: AMD, Passive Treatment, Sulfate Reducing Bacteria, Iron Oxidizing Bacteria

Introduction

In Japan and many other countries, level areas available for mine drainage treatment are limited due to geographic conditions. Therefore, it is necessary to introduce a compact passive treatment system with a short hydraulic retention time (HRT). Japan Oil, Gas and Metals National Corporation (JOGMEC) investigates compact biological passive treatment system with a vertical flow aerobic and anaerobic process. Iron oxidizing bacteria were utilised in the aerobic process for iron oxidation and removal to treat high iron content in the AMD. The anaerobic process was subsequently set utilizing sulfate reducing bacteria (SRB) with agricultural wastes, rice husk and rice bran as the organic resource for SRB. Pilot-scale test of this compact process has been carried out at an abandoned mine site in Japan since 2016. In this test, continuous removal of metal ions over a year was confirmed with hydraulic retention time (HRT) of 25 hours even at the ambient temperatures dropped to around -15°C in winter. As a next step, the full-scale demonstration tests for AMD containing iron, zinc, copper, and cadmium ions were started since November 2019.

Methods

The full-scale demonstration test was carried out at an abandoned mine site in Japan. In these tests, the AMD (Table 1 shows the concentrations of each metal ion) was treated with two-step passive treatment systems (Fig.1).

The first step was the iron oxidation process (reactor size of 36 m^2) in order to oxidize ferrous ions in the AMD to ferric ions utilizing the function of iron oxidizing bacteria and to remove as schwertmannite. This reactor was filled with crushed stone (d = 20 to 40 mm) which is for (1) a carrier of

Table 1 *Mine Water Quality.*

pH [-]	T-Fe [mg/L]	Zn [mg/L]	Cu [mg/L]	Cd [mg/L]	SO_4^{2-} [mg/L]
3.5 ~ 3.8	35 ~ 40	15 ~ 20	1 ~ 10	0.03 ~ 0.08	250 ~ 350

Figure 1 Full-scale demonstration test.

bacteria, (2) reaction field of Fe precipitation and (3) its capturing. The layer thickness of crushed stone was 0.5 m, a sampling pipe was vertically set to collect a water sample at a depth of 0.25 m. AMD was introduced into this reactor at a flow rate of 100 L/min, and the HRT was 1.2 hours.

The second step was anaerobic process. In these reactors, various metal ions were targeted to immobilize as sulfides resulting from the reaction with hydrosulfide ion generated by SRB. Two reactors were placed in parallel, and output water from iron oxidation reactor was introduced to each reactor with a flow rate of 50 L/min (25 hours of HRT). These reactors (W 5 m × D 16 m × H 3.5 m) made of concrete were buried in the semi-underground. At the bottom of reactors, water collection pipes were installed and limestone was filled to protect the pipes from clogging. Two series of rice husk mixture were filled over the limestone layer: The lower layer (1.0 m) consists of 9 ton of rice husk and 36 ton of limestone, and the upper (0.5 m) consists of 3.5 tons of rice husk and 28 ton of limestone.

One of the reactors is for tests using rice bran as an organic matter source for SRB. In this reactor, a layer of rice bran was placed on top of the rice husk layer. The other reactor is for tests adding ethanol as an organic source for SRB, as a semi-passive process.

The AMD before and after treatment were periodically sampled and analyzed. Items for monitoring were temperature, pH, Oxidation-Reduction Potential (ORP), concentrations of metals (iron, copper, zinc, cadmium, etc.) and sulfate ion, and chemical oxygen demand (COD). Total sulfide ion concentration was analyzed with a spectrophotometric method using methylene blue.

Results and Discussion

(1) Iron oxidation reactor

The iron oxidation reactor was tested since April 2019. At the beginning of the test, ferrous ion (Fe^{2+}) concentration decreased to approximately 6 mg/L and total iron (T-Fe) concentration decreased to 15 mg/L, which exceeds the wastewater standards (T-Fe: 10 mg/L) in Japan. In the pilot scale test, T-Fe concentration decreased to below 10 mg/L, when DO at the surface layer increased over 6 mg/L. On the other hand, DO in the full-scale test was around 5 mg/L. Therefore, a small box was put at the inflow point of raw water for water introduction like a cascade, and the test was restarted at July 2019, resulting that DO in the surface layer increased to 6 mg/L. Fig.2 shows comparison of iron concentration before and after changing the water introduction method.

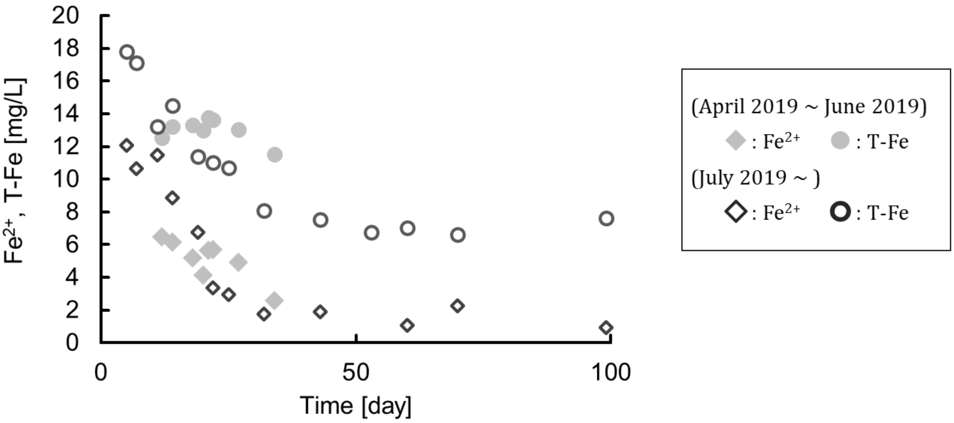

Figure 2 *Changes in iron concentration of treated water.*

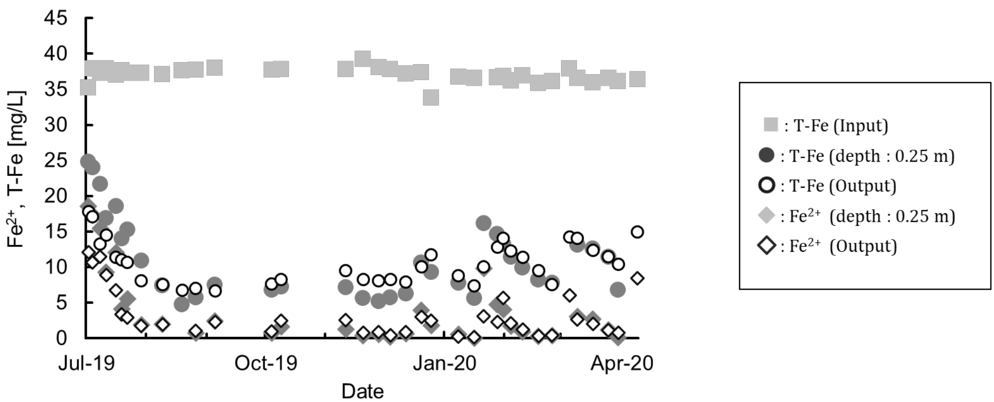

Figure 3 *Annual processing performance of iron oxidation.*

Fe^{2+} concentration of output decreased to 2- 3 mg/L, indicating that relatively high activity of iron oxidizing bacteria. In addition, T-Fe concentration was less than 10 mg/L, and met the wastewater standards.

Fig.3 shows the treatment performance of the iron oxidation reactor after changing inflow method to like cascade. A month after the test restarted, T-Fe concentration decreased to below 10 mg/L, and the treatment performance was maintained till January 2020. After that, the precipitated iron frequently caused clogging in the reactor, and the water level often rose. As a result, the aeration efficiency often decreased, and the treatment performance decreased with T-Fe concentration of 10 to 20 mg/L.

Further, since the iron concentration at the output and the water depth of 0.25 m were almost the same, it is speculated that Fe^{2+} ion oxidation reaction and Fe^{3+} ion precipitation reaction occurred in the upper half area of the reactor.

(2) Anaerobic reactor

Since June 2020, the semi-passive process adding ethanol was started in one of the anaerobic reactors. In many cases, the reactor is shaped like a pond covered with a waterproof sheet, but in this test, it was a rectangular parallelepiped reactor made of concrete, as a result of designing and estimating the construction cost for some shapes. Since the set flow rate and HRT for each series of anaerobic reactor were fixed, the required reactor volume can be calculated. As a result of designing based on the volume of this reactor, as shown in Fig. 4,

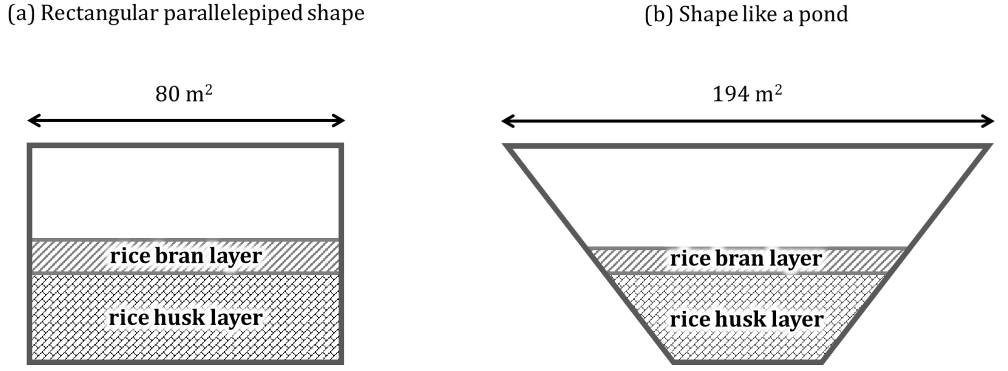

Figure 4 *Anaerobic reactor design results in two shapes.*

when the reactor was made into a rectangular parallelepiped (a), the area required for reactor installation was less than half that in the case where it is shaped like a pond (b). In this design, the reason for the empty space above the rice bran layer was that the drainage level of the previous process (iron oxidation reactor) was lower than the ground surface. Moreover, when the construction cost at this time was estimated, the case of the reactor made of concrete (a) was almost the same as the case of reactor with a waterproof sheet by digging (b). Therefore, a rectangular parallelepiped shape that requires a smaller area was adopted and an anaerobic reactor was placed in this test.

Conclusions

A full-scale passive verification test was started at the closed mine site in Japan since 2019. In this test, the treatment process consists of an aerobic iron oxidation process and an anaerobic process, with a flow rate of 100 L/min.

In the iron oxidation process, surface DO was maintained at around 6 mg/L, owing to the unique water introduction method, resulted in high microbial activity of the iron oxidizing bacteria. T-Fe concentrations was effectively treated (< 10 mg/L), and it was maintained for approximately six months, including the winter season when the microbial activity was lowered. On the other hand, clogging occurred in the reactor due to the precipitates of removed Fe. The precipitation was mainly observed in the upper half of the reactor, and clogging was temporarily solved by stirring the surface. However, since the maintenance interval was gradually shortened, the process improvement to reduce clogging is important.

Regarding the anaerobic treatment process, we designed two cases, a concrete rectangular parallelepiped reactor and a pond-shaped reactor using waterproof sheet. Althought their construction costs were the same level, the former requires small area. Therefore, we chosed and cnstructed a concrete rectangular parallelepiped reactor for the anaerobic process, and its test using ethanol and rice bran as an organic resource is ongoing.

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