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Design of photovoltaic systems to power aerators for natural purification of acid mine drainage

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ABSTRACT

This paper presents a case study of photovoltaic (PV) system design at Hwangji Youchang facility in Korea, to power an electrical aerator for natural purification of acid mine drainage. The aerator was designed as 13 units with air flow capacity of 60 L/min at the oxidation pond by considering the characteristics of incoming drainage. Site evaluation was conducted to identify a suitable location. The resulting PV system capacity was designed as 30.1 kW by considering monthly power consumption (342.39 kWh/month), safety factor of 5, and winter solar irradiance. Electricity production from the PV system was simulated via SAM software. The simulation results indicate that the PV system can generate at least 3016 kWh/month, which is sufficient to operate the 13 units of the aerator. The procedure has broad relevance for designing off-grid PV applications, particularly mining facilities that are often situated in remote locations.

1. Introduction

Natural purification of acid mine drainage can be achieved via two methods. The options for active treatment include ion exchange, electrochemistry purification, and physico-chemical treatment, whereas passive treatments include ALD (Anoxic Limestone Drain) and SAPS (Successive Alkalinity Producing System). Passive treatment is commonly applied at abandoned mines, as it has advantages of purification price for operation and maintenance. In Korea, following the completion of natural purification of mine drainage at Hotan-taback in 1996, more than 20 such facilities have been installed and operated [1].

Recently, some natural purification facilities have injected air (oxygen) into the oxidation pond to improve the efficiency of Fe removal [2]. This method uses an aerator to catalyze the reaction with iron sulfide and oxygen. The literature shows that this method improves the removal efficiency of Fe at an experimental scale [3–5]. However, it is difficult to power the aerator from the electricity power grid, since the treatment facilities are often on remote locations. Even when the location allows a facility to be connected to the electricity grid, the cost of purchasing conventionally produced electricity can be detrimental to operational and maintenance costs. Therefore, it is necessary to evaluate the use of renewable energy technologies as a means of powering the aerator.

Recent studies have investigated the use of off-grid renewable energy systems to supply electricity to remote areas. Kanase-Patil et al. [6] proposed a scenario for off-grid electricity supply and compared a variety of renewable energy scenarios for a remote area. Qoaider and Steinbrecht [7] investigated the economic feasibility of photovoltaic technology to supply the entire energy demands of off-grid communities practicing irrigated farming in arid regions. Ma et al. [8] reported on a real remote solar photovoltaic project on an island in Hong Kong using an off-grid system. Campana et al. [9] combined various models of water demand to develop a dynamic modeling tool for the design of a photovoltaic water pumping system. Even though the literature includes many studies of off-grid installations and comparisons of power output, relatively little attention has been paid to the photovoltaic system design problem for natural purification treatment facilities.

This paper presents a case study of a photovoltaic system designed to supply electricity for an aerator to remediate acid mine drainage at the Hwangji natural purification treatment facility in Korea. The methodology comprises the following five stages: design of aerator, solar site assessment, design of the photovoltaic system, simulation of system operation, and evaluation.

2. Aerator power supply using photovoltaic system

An aerator is a device for mixing air with another substance; the air is compressed and then injected at high or low pressure according to the application. Aeration applications include interior

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landscaping, the oxygenation of aquarium water, medical devices, whirlpool bathtub, and purification facilities. In the case of Korea, the majority of the market is in purification facilities. The available types of aerator differ in their operating principles: pumping, diaphragm, piston, etc.

Fig. 1 illustrates a typical aerator available on the market. The air capacity, power consumption, and operating pressure differ between models of aerator. Therefore, an aerator should be chosen according to air capacity.

A schematic of power supply methods by photovoltaic systems is presented in Fig. 2. The total system is composed of an oxidation pond, aerators, and the photovoltaic system. To supply power to one or many aerators, conservative design conditions should be applied: The photovoltaic system should be designed to ensure that energy output exceeds daily power consumption even under winter conditions, when irradiance (and therefore the system's energy output) is lowest. Furthermore, the system design should incorporate a safety factor, considering the number of sunless days and loss of system efficiency. An inverter is not required if the aerator operates on a direct current (DC) system. However, if the aerator operates on an alternating current (AC) system, an inverter should be considered for converting AC to DC. In this case, the electricity loss associated with the inverter should be considered in the design capacity of the photovoltaic system.

3. Designing photovoltaic system to power aerators

This paper suggests five steps in designing the system (Fig. 3), as follows: 1. Calculate the required aerator capacity, considering acid drainage inflow rate and Fe^{2+} concentration, etc. 2. Analyze the causes of shadowing and other geographical parameters that reduce the efficiency of solar power systems, and conduct site evaluation to identify an appropriate location for the solar panels. 3. Design the system elements after determining the system power capacity, considering the power consumption of the aerators. 4. Evaluate the energy output of the photovoltaic system, through the use of simulation software with hourly irradiance data. 5. Review the simulated energy output to determine whether the designed system can provide stable energy supply to the air diffuser throughout the year. If the designed system is predicted to be unstable throughout the year, the system design should be revised from step 3.

3.1. Design of the aerator

The volume of air injected into the aeration pond is an important design consideration. It is necessary to install an aerator with sufficient discharge performance to ensure aeration of the pond. Fe^{2+} loading (L, kg[Fe^{2+}]/min) is calculated according to inflow of mine drainage per day (Q, m^3/day) and Fe^{2+} concentration (P, mg/L), as shown in Eq. (1).

$$L = \frac{Q \times P \times 10^{-3}}{24 \times 60} \tag{1}$$

Theoretically, the oxidation of Fe^{2+} associated with the oxygen supply is given as: 6.98 kg[Fe^{2+}]/kg[O_2] [10]. Therefore, the required input of oxygen necessary to treat the given Fe^{2+} loading (R, kg[O_2]/min) is calculated according to Eq. (2).

$$\mathrm{R} = \frac{L}{6.98} \tag{2}$$

If it is assumed that oxygen occupies 21% of the air by volume; therefore, the amount of air (S, kg[air]/min) required for the treatment of Fe^{2+} loading amount (L) is given by Eq. (3). The injection volume of air (K, L[air]/min) is further refined by Eq. (4) by using the air density (D, kg[air]/L[air]) at the pressure and temperature conditions of the oxidation scenario. This paper uses 0.0012 kg/L at 1 atm and air density at 20 °C.

$$\mathrm{S} = \frac{R}{0.21} \tag{3}$$

$$\mathrm{K} = \frac{S}{D} \tag{4}$$

The minimum volume of air required for the aerator (R, L/min) can be calculated as in Eq. (5), applying the injection volume of air (K), safety factor (α) and the solubility of air (H, mL/L) at the temperature and pressure conditions of the oxidation pond. In this paper, the safety factor and the solubility of air were assumed to be 1.1, 18.7 ml/L at 1 atm and 20 °C.

$$\mathrm{R} = \frac{K \times \alpha}{H \times 10^{-3}} \tag{5}$$

3.2. Solar site assessment

Site analysis is required prior to installation of the photovoltaic system, because it is necessary to analyze the shadowing conditions of the installation site, in combination with latitude, longitude, light interception, and obstructions of the PV array [11]. In this paper, a SunEye 210 fisheye-lens camera was used to measure solar access (SA, %) for quantitative measurement of photovoltaic system installation sites (Fig. 4).

$$\mathrm{SA}(\%) = \frac{Insolation(without\ shade)}{Insolation(total)} \times 100 \tag{6}$$

Solar access (%) is the ratio of solar insolation, which is not affected by the shadow of the solar radiation that may be incidental to the solar panel. The images produced with the fisheye-lens are

Technical Data

Model	V-60	Output	60 L/min
Power	35 W	Noise	< 45 dB
Voltage	110−115/220−240 V	Weight	5.6 kg
Frequency	50/60 Hz	Size	270x242x210 mm
Pressure	> 0.03 Mpa		

Fig. 1. Characteristics of an aerator. (Image source: http://www.hailea.com/e-hailea/product3/V-60.htm).