Research article

Energy footprint and carbon emission reduction using off-the-grid solar-powered mixing for lagoon treatment

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Abstract

Mixing is the driver for the energy footprint of water resource recovery in lagoons. With the availability of solar-powered equipment, one potential measure to decrease the environmental impacts of treatment is to transition to an off-the-grid treatment. We studied the comparative scenarios of an existing grid-powered mixer and a solar-powered mixer. Testing was conducted to monitor the water quality, and to guarantee that the effluent concentrations were maintained equally between the two scenarios. Meanwhile, the energy consumption was recorded with the electrical energy monitor by the wastewater treatment utility, and the carbon emission changes were calculated using the emission intensity of the power utility. The results show that after the replacement, both energy usage and energy costs were significantly reduced, with the energy usage having decreased by 70% and its cost by 47%. Additionally, carbon-equivalent emission from electricity importation dropped by 64%, with an effect on the overall carbon emissions (i.e., including all other contributions from the process) decreasing from 3.8% to 1.5%.

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1. Introduction

In rural areas and/or small communities, affordable and reliable water resource recovery (formerly referred to as wastewater treatment) can be a challenge, especially in developing countries (Massoud et al., 2009). To cope with this problem, there are two strategies: one is centralized and fully built water resource recovery facilities (WRRF), typically with aerated biological processes; the other is decentralized treatment infrastructure typically involving natural treatment systems (Fig. 1), such as facultative lagoons (Bdour et al., 2009). The limitations and problems of installing fully built facilities in rural areas and/or small communities are increasingly obvious over time. With low population and household density, constructing a fully built WRRF becomes costly with respect to both capital and operating costs (Crites et al., 2006).

In a fully built WRRF, the diffused aeration system and activated sludge process are energy-intensive and are responsible for a large portion of the treatment's energy- and carbon-footprints (Reardon, 1995), while the primary sedimentation performs the bulk of the separation with minimal energy input (Gori et al., 2011, 2013). However, solar power is becoming one of the most promising renewable energy sources, and solar cells can be used as an auxiliary or supplemental power source for water resource recovery facilities to help reduce energy importation and its associated carbon emissions (US EPA, 2013). For the second strategy, embedded natural systems in decentralized plants are increasingly sought after in rural and/or isolated areas. Even though the land requirement is larger than it is for the conventional fully built wastewater treatment plants, these treatment systems are less resource-intensive and may be more ecologically sustainable (Muga and Mihelcic, 2008; Anagnostopoulos and Vavatsikos, 2012; Ghirardini et al., 2012). However, for lagoons the energy recovery potential from biogas production is traded for their ease of operation (Rosso and Stenstrom, 2008). In areas where labour and energy costs are a constraint, natural treatment systems serve as even more attractive alternatives. Among the natural treatment systems, lagoon treatment has long been recognized as the most inexpensive method (per unit load removed) of treating domestic
wastewater in rural areas and/or small communities (Gloyna, 1971; Bringolf and Summerfelt, 2003).

For facultative water resource recovery lagoons, the driver for the process energy consumption is usually mixing. Mixing provides both re-suspension of the settled solids and oxygenation at the surface of wastewater in contact with atmospheric air (Agunwamba, 1992). There are two general categories for lagoon aeration systems to conduct mixing. One is surface aeration, characterized by mechanical mixers floating on the surface of the water to shear the surface of the lagoon in small droplets, and the other is a subsurface impeller that shears air being drafted from above the water surface (Aberley et al., 1974; Boyd, 1998; Salter et al., 2000). There are existing lagoons equipped with bubble diffusers, however these are in the minority since they require a degree of engineering comparable to fully built WRRFs (Metcalf and Eddy, 2014).

Traditionally, lagoon mixers are on-grid units that consume electricity intensively (Rich, 1980). In recent years, with the decrease in cost of photovoltaic units, solar-powered mixers began to emerge on the market. These units are typically equipped with low power (and low rpm) motors. Therefore, the solar-powered mixers became suitable for lagoons and other installations where gentle mixing was appropriate. Given their reliance on solar power, and given that the majority of power is generated employing fossil fuels, these off-grid mixers could be both an energy and carbon-emission conservation option.

Several are the tools for modelling greenhouse gas (GHG) emissions (Mannina et al., 2016). A generally accepted classification of carbon emissions can be found in the Local Government Operations Protocol (LGO, 2008), where GHG emissions are discriminated into three scopes:

- Scope I refers to emissions that come directly from sources within the treatment plant, such as the CO₂, CH₄ and N₂O emissions from wastewater treatment processes, mostly from biological treatment processes.
- Scope II refers only to indirect emissions associated with the consumption of electricity, steam, heating, or cooling. Physically, Scope II emissions are produced at the facilities where electricity is generated; one example would be emissions that occur at a power plant as a result of electricity used by the wastewater treatment plant.
- Scope III emissions include all other indirect emissions that are not covered in Scope II. In WWTPs, Scope III usually includes the emission from fossil fuel combustion during the biosolids transportation, and fugitive CH₄ and N₂O emissions from biosolids generated by landfill or land application.

The goal of this project was to evaluate the performance of a facultative lagoon equipped with both on-grid and photovoltaic mixers. This research focused on the comparison of mixing equipment due to the power demand events occurring at peak periods that not only burden the treatment cost but also contribute to the utility’s carbon footprint (Scope II emissions). The water quality targets from treatment were considered a constraint to the evaluation, while the target analysis focused on the energy and carbon footprint of the treatment process. We quantified a substantial reduction in the indirect emissions from power generation after the adoption of photovoltaic mixing, while maintaining the desired treatment performance in terms of effluent water quality. However, the direct emission from the lagoon highly compensate the decrease in energy-related emissions, indicating that for a substantial reduction of the total carbon footprint of lagoon treatment the abatement or treatment of the direct emissions should be the focus of reduction measures.

2. Materials and methods

2.1. Testing site

Our tests were conducted at the lagoon owned and operated by the Inyokern Community Services District (ICSD), located in Inyokern, CA. This location is the town with the highest degree of insolation (>7000 Wh m⁻² d⁻¹; Simons and McCabe, 2005) in the United States, exceeding 350 days of sunlight per year. ICSD receives sewage from 310 urban connections and the treatment facility has lined lagoons for biological oxidation and evaporation. It serves approximately 1000 persons, with an influent flow of approximately 190 m³/d (50,000 gal/d). After manually cleaned screens, the sewage is routed to a facultative lagoon for biological
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