Journal of Cleaner Production 122 (2016) 287–307

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Review

Wastewater treatment in microbial fuel cells – an overview

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ARTICLE INFO

Article history:
Received 28 August 2015
Received in revised form
5 February 2016
Accepted 5 February 2016
Available online 12 February 2016

Keywords:
Microbial fuel cell
Bioelectrochemical systems
Wastewater
Bioenergy
Algae
Source separation

ABSTRACT

Environmental issues associated with water sanitation are not confined to developing countries alone but are the most basic human and environmental necessities all over the world. Wastewater sources are major causes for environmental pollution in surface and ground water bodies. Current wastewater treatment technologies are not sustainable to meet the ever growing water sanitation needs due to rapid industrialization and population growth, simply because they are energy- and cost-intensive leaving latitude for development of technologies that are energy-conservative or energy-yielding. For the present and future context, microbial fuel cells technology may present a sustainable and an environmentally friendly route to meet the water sanitation needs. Microbial fuel cell based wastewater systems employ bioelectrochemical catalytic activity of microbes to produce electricity from the oxidation of organic, and in some cases inorganic, substrates present in urban sewage, agricultural, dairy, food and industrial wastewaters. This article presents the potential for energy generation and comprehensive wastewater treatment in microbial fuel cells. The article provides an overview of recent literature with two specific aims. First, it provides an overview of current energy needs for wastewater treatment and potential energy recovery options followed by a comprehensive review of the principles of wastewater treatment, substrate utilization (organic removal), recent process developments, nutrient and metal removal capacities in microbial fuel cells. Several issues related to process performance, organic removal capacities and potential environmental impacts were discussed in detail. From the economic and life cycle assessment point of view, although recent developments in power production are encouraging, important discoveries in electrode materials, innovative and integrated process configurations along with experience in pilot scale studies are urgently required to determine the real potential of the microbial fuel cell technology to provide sustainable and energy-positive wastewater treatment.

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http://dx.doi.org/10.1016/j.jclepro.2016.02.022
0959-6526/

1. Introduction

Wastewater treatment is not only a concern for developing countries but it continues to be the most basic sanitation need to protect the environment and the water bodies that serve as drinking water sources around the world. Wastewater treatment accounts for about 3–4% of the United States' electrical energy load, which is approximately 110 TWh/year, or equivalent to 9.6 million households' annual electricity use (McCarty et al., 2011). In UK, wastewater treatment requires approximately 6.34 GWh of electricity, almost 1% of the average daily electricity consumption of England and Wales (DTI, 2005). Wastewater treatment requires about 0.5–2 kWh/m^3 which depends on the process and wastewater composition and interestingly, it contains about 3–10 times the energy required to treat it (Gude, 2015a). The energy locked in wastewater is mainly present in three forms: 1 – organic matter (~1.79 kWh/m^3); 2 – nutritional elements such as nitrogen, phosphorous (~0.7 kWh/m^3); and 3 – thermal energy (~7 kWh/m^3) (McCarty et al., 2011). Energy available in domestic wastewater source can be classified as chemical and thermal energy. Chemical energy (~26%) is available in the forms of carbon (measured as chemical oxygen demand, COD) and nutrient compounds (nitrogen, N and phosphorous, P). Thermal energy holds a major portion of this energy potential (74%). Chemical energy can be efficiently harvested while thermal energy may not be extracted except by use of a heat pump and subject to wastewater source temperature. By extracting this hidden chemical energy, wastewater treatment can be turned into an energy-yielding or energy-independent process rather than an energy consuming process while eliminating environmental pollution (Gude et al., 2013).

Direct disposal of wastewater generating from various sources such as domestic, agricultural and industrial facilities is the major cause for various environmental impacts including eutrophication of surface waters, hypoxia, and algal blooms impairing potential drinking water sources. Current wastewater treatment processes are energy- and chemical-intensive and require large investments without any revenue generation. Wastewater treatment processes have an energy demand of 0.5–2 kWh/m^3 of the wastewater treated for carbon and partial nitrogen removal. During the treatment a considerable amount of greenhouse gases (GHGs), such as carbon dioxide (CO_2) and nitrous oxide (N_2O), and other volatile substances are released into the atmosphere, and in the meantime excess sludge is produced which needs further disposal. For example, each kWh of electricity production involves release of 0.9 kg CO_2 emissions and for every 1000 tons of wastewater treated, 1500 tons of greenhouse gases are released (EIA, 2009; Wang et al., 2010). Emissions associated with the energy demand of wastewater treatment systems in

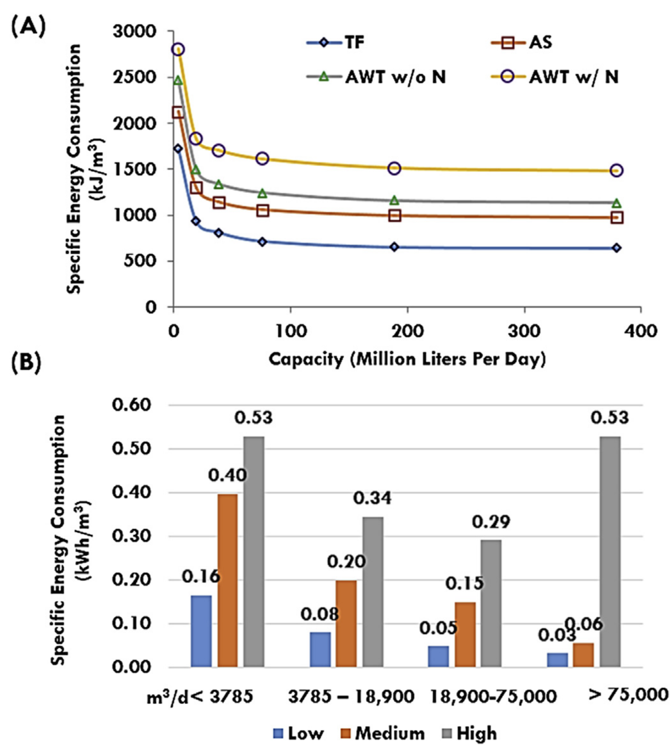

Fig. 1. (A) Energy required for carbon and nitrogen removal in activated sludge (AS); trickling filters (TF); advanced wastewater treatment without nitrogen removal (AWT w/o N) and advanced wastewater treatment with nitrogen removal (AWT w/N); (B) Low, median and high values for energy consumption at different wastewater treatment capacities.