Renewable and Sustainable Energy Reviews 54 (2016) 235–246

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Review on hybrid energy systems for wastewater treatment and bio-energy production

Pei Fang Tee [a], Mohammad Omar Abdullah [a,*], Ivy Ai Wei Tan [a], Nur Khairunnisa Abdul Rashid [b], Mohamed Afizal Mohamed Amin [a], Cirilo Nolasco-Hipolito [c], Kopli Bujang [c]

[a] Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), 94300 Kota Samarahan, Sarawak, Malaysia
[b] Sarwak Energy Berhad (SEB), Wisma Sesco, Jalan Bako, 93050 Petra Jaya Kuching, Malaysia
[c] Faculty of Resource Science & Technology, Universiti Malaysia Sarawak (UNIMAS), 94300 Kota Samarahan, Sarawak, Malaysia

ARTICLE INFO

Article history:
Received 5 August 2015
Received in revised form
25 September 2015
Accepted 10 October 2015
Available online 11 November 2015

Keywords:
Bioenergy
Hybrid energy
Wastewater treatment

ABSTRACT

Access to clean water has been a great challenge around the globe due to the high pollutant contents in the water. Therefore, there is a high demand of freshwater resources or a dire need of clean recycle wastewater as a new source of water supply. In order to accomplish this, new concept or engineering systems need to be developed where hybrid wastewater treatment system can be an effective pollutants removal. Wastewater contains energy in the form of biodegradable organic matter. The concept of accomplishing wastewater treatment and generate energy simultaneously has been a trend recently and can be done with hybrid wastewater treatment system. Energy gained from such hybrid system is therefore both sustainable and environmental friendly which may be good source of bio-energy to compliment the power of a treatment plant. In this paper, we classify hybrid wastewater systems typically include physical–biological hybrid, physical–chemical hybrid, chemical–biological hybrid and physical–chemical–biological hybrid system. From the detailed literature gathered thus far, hybrid systems demonstrated some potential advantages compared to stand-alone systems such as: more stable and sustainable in the voltage generated, better overall treatment efficiency and energy savings.

Contents

1. Introduction

Water becomes the scarcest thing in some parts of the world as the availability is becoming limited due to the increasing

* Corresponding author. Tel.: +60 82583280 (direct line); fax: +60 82 583409.
E-mail addresses: amomar13@gmail.com, amomar@feng.unimas.my, amomar@unimas.my (M.O. Abdullah).

http://dx.doi.org/10.1016/j.rser.2015.10.011
1364-0321/

Nomenclature or Abbreviation

AD	anaerobic digester
AEF	acid-extractable fraction
AEM	anion exchange membrane
AFBMFC	anaerobic fluidized bed with MFC
ANa	mmonia nitrogen (NH_3–N)
AnHMBR	anaerobic hybrid membrane bioreactors
ANR	autotrophic nitrogen removal
AOBF	anaerobic-oxic-anoxic biofilm filtration
AOC	assimilable organic carbon
AOP	advanced oxidation process
AS	activated sludge
BDOC	biodegradable dissolved organic carbon
BOD	biochemical oxygen demand
CEM	cation exchange membrane
COD	chemical oxygen demand
DAF	dissolved air flotation
DOC	dissolved organic carbon
$FeCl_3$	ferric chloride
HAAFP	haloacetic acids formation potential
MABR	membrane-aerated biofilm reactor
MCABR	membrane coagulation adsorption bioreactor
MFC	mircrobial fuel cell
MBBR	moving bed biofilm reactors
MBR	membrane bioreactor
MEC	microbial electrolysis
MRC	Microbial reverse electrodialysis cell
MF	microfiltration
MLR	mixed liquor recirculation
NA	naphthenic acid
O_3	ozone
PAC	powdered activated carbon
PACl	polyaluminium chloride
PBBR	packed-bed biofilm reactor
RED	reverse electrodialysis
RO	reverse osmosis
SBR	sequencing batch reactor
SS	suspended solids
TDS	total dissolved solids
TF	trickling filter
THMFP	trihalomethanes formation potential
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
TSS	total suspended solids
UASB	upflow anaerobic sludge blanket
UF	ultrafiltration
UV	ultraviolet
VFCW	vertical flow constructed wetlands

contamination and environmental activities around the globe [1,2]. There are 1.2 billion people living on this earth today with no access to safe drinking water; typically two million people die annually of diarrhoea and about one third of the world's population lack satisfactory sanitation [3]. The high demand of freshwater resources and growing environmental awareness give rise to the use of reclaimed wastewater as a new source of water supply [4].

Wastewaters are commonly categorized as domestic wastewater or industrial wastewater. Domestic wastewater refers to wastewater generated from "non-manufacturing activities" occurring in residential homes which includes sewage (from toilets) and grey water (from bathrooms and kitchens). There are many types of industrial wastewater based on the different industries and contaminants; each sector produces its own particular combination of pollutants. Wastewaters are typically contaminated with physical, chemical and biological composition which has tremendous negative impact on environment, where it has the ability to destroy many animal habitats, and cause irreparable damage to many ecosystems. Wastewater treatment processes are designed to achieve improvements of the wastewater quality. The two main reasons for collecting and treating wastewater are to prevent water-borne transmission of disease and to preserve the aquatic environment [5]. Physical composition in wastewater such as suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment. On the other hand, constituents such as biodegradable organics can lead to depletion of natural oxygen resources and to the development of septic conditions. Nutrients such as nitrogen and phosphorus, when discharged to the aquatic environment can lead to the growth of undesirable aquatic life and cause groundwater pollution when discharged in excess. Many compounds found in wastewater have characteristics of carcinogenic, mutagenic, tetratogenic or have high acute of toxicity [5].

Therefore, an advance treatment method such as hybrid wastewater treatment system has gained much attention in recent years for a more effective removal of pollutants from wastewater [6]. The concept of microbial fuel cell (MFC) in accomplishing wastewater treatment and to generate bioenergy simultaneously has also been a trend where much effort has been put in to maximize the power generation [7,8]. Wastewaters contain energy, in the form of biodegradable organic matter, that we expend energy to remove rather than trying to recover it [9]. Besides, there is a continuous global concern on environments and shortage of energy from fossil fuels like pollution and global warming with the exponential growth of population [10,11]. This trend has triggered global movement towards the generation of renewable energy by developing new technology and engineering systems which are not only sustainable but clean and environmental-friendly. There are some hybrid technologies which are promising and yet completely different approach to wastewater treatment as the treatment process can become a method of capturing energy in the form of electricity or hydrogen gas, rather than a drain on electrical energy.

Even though the energy generated from hybrid wastewater treatment system is not significant to support the energy demand of a city, it is however sufficient to run a treatment plant [9]. With advances, capturing this power could achieve energy sustainability of the water infrastructure.

This paper is not a review on MFC alone but on the hybrid of wastewater treatment systems. MFC is just one of them which is categorized under chemical–biological hybrid system; therefore this review paper is geared towards this method of classification i.e. based on "hybrid" schemes. We have classified all the possible hybrid wastewater treatment systems which can be applied in the treatment process. Furthermore, the advantages and disadvantages of the hybrid system are discussed in detail. The notable advantages of the hybrid wastewater treatment system are more stable and sustainable voltage generated, better overall efficiency and energy saving. Nevertheless, some hybrid system