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Novel bioevaporation process for the zero-discharge treatment of highly concentrated organic wastewater

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ARTICLE INFO

Article history:
Received 24 February 2013
Received in revised form
13 June 2013
Accepted 24 June 2013
Available online 3 July 2013

Keywords:
Bioevaperation
Highly concentrated organic wastewater
Metabolic heat
Biodegradable volatile solids

ABSTRACT

A novel process termed as bioevaporation was established to completely evaporate wastewater by metabolic heat released from the aerobic microbial degradation of the organic matters contained in the highly concentrated organic wastewater itself. By adding the glucose solution and ground food waste (FW) into the biodried sludge bed, the activity of the microorganisms in the biodried sludge was stimulated and the water in the glucose solution and FW was evaporated. As the biodegradable volatile solids (BVS) concentration in wastewater increased, more heat was produced and the water removal ratio increased. When the volatile solids (VS) concentrations of both glucose and ground FW were 120 g L^{-1}, 101.7% and 104.3% of the added water was removed, respectively, by completely consuming the glucose and FW BVS. Therefore, the complete removal of water and biodegradable organic contents was achieved simultaneously in the bioevaporation process, which accomplished zero-discharge treatment of highly concentrated organic wastewater.

1. Introduction

Wastewater discharged from food, leather, chemical and paper industries often contain highly concentrated organic matters. Commonly, activated sludge process and anaerobic digestion can be considered for treating this type of wastewater. However, the traditional and modified activated sludge processes are known to treat wastewater containing a relatively low concentration of organic compounds (Lin et al., 1996). On the contrary, anaerobic digestion is widely applied to treat the highly concentrated organic wastewater. However, anaerobic digestion leaves effluent that needed to be further treated since BOD (biochemical oxygen demand) concentration is usually high in the effluent. It also generates sludge, albeit, less than aerobic processes (Wang et al., 2010).

Instead of biologically removing contaminants dissolved in the wastewater, production of purified water through filtration can be considered. Membrane processes such as micro- and ultra-filtration and reverse osmosis separate contaminants from water based on the pore size of the

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http://dx.doi.org/10.1016/j.watres.2013.06.044

Nomenclature

A	Surface area of reactor wall (m^2)
A_{top}	Surface area of radiating body (m^2)
a, b, c	Empirical constants in the Antoine expression, with values of −2,238, 8.896 and 273, respectively (Mason, 2009)
BVS	Biodegradable volatile solids
C_{dryair}	Specific heat of dry air (1.004 kJ kg^{-1} °C^{-1}) (Haug, 1993)
C_{solid}	Specific heat of dried sewage sludge (1.046 kJ kg^{-1} °C^{-1}) (Haug, 1993)
C_{water}	Specific heat of water (4.184 kJ kg^{-1} °C^{-1}) (Haug, 1993)
C_{watvap}	Specific heat of water vapor (1.841 kJ kg^{-1} °C^{-1}) (Haug, 1993)
conc.	Concentration
F_a	A configuration factor to account for the relative position and geometry of the objects (0.5, dimensionless) (Ahn et al., 2007)
F_e	The emissivity factor to account for non-black body radiation (0.85, dimensionless) (Ahn et al., 2007)
FW	Food waste
H_{BVS}	Heat of combustion of sludge BVS (21.0 MJ kg^{-1} BVS) (Zhao et al., 2010)
H_{glu}	Heat of combustion of glucose (15.644 MJ kg^{-1} glucose) (Atkinson and Mavituna, 1991)
L_{latwat}	Latent heat of water evaporation (kJ kg^{-1})
M_{air}	Molar mass of air (g mol^{-1})
M_{glu}	Molar mass of glucose (g mol^{-1})
M_{H_2O}	Molar mass of water (g mol^{-1})
MC	Moisture content (wt%)
MC_{final}	Moisture content of the sludge bed after bioevaporation (wt%)
$MC_{initial}$	Moisture content of the sludge bed before bioevaporation (wt%)
m_{air}	Mass of dry air (kg)
m_{eva}	Mass of evaporated water (kg)
m_{final}	Mass of sludge bed after bioevaporation (kg)
m_{glu}	Mass of glucose (246 g)
m_{H_2O}	Mass of actually-measured evaporated water (kg)
$m_{H_2O\text{-}bio}$	Mass of theoretically-calculated evaporated water (kg)
$m_{H_2O\text{-}BVS}$	Mass of metabolic water from sludge BVS (kg)
$m_{H_2O\text{-}glu}$	Mass of metabolic water from glucose (kg)
$m_{initial}$	Mass of sludge bed before bioevaporation (kg)
m_{solid}	Mass of dry solid in sludge bed (kg)
m_{water}	Mass of water in sludge bed (kg)
n_{BVS}	Molar number of sludge biodegradable volatile solids (mol)
n_{CO_2}	Molar number of CO_2 (mol)
$n_{CO_2\text{-}BVS}$	Molar number of CO_2 from biodegradable volatile solids of sludge (mol)
$n_{CO_2\text{-}gas}$	Molar number of CO_2 measured by a gas analyzer (mol)
$n_{CO_2\text{-}glu}$	Molar number of CO_2 produced from glucose degradation (mol)
n_{glu}	Molar number of glucose (mol)
P	Atmospheric pressure (mm Hg)
p_{vs}	Saturated vapor pressure of water (mm Hg)
p_v	Vapor pressure of water (mm Hg)
p_{vi}, p_{vo}	Water vapor pressure of inlet and outlet air (mm Hg)
Q_{bio}	Biologically generated heat (kJ)
Q_{BVS}	Heat generated from biodegradable volatile solids of sludge (kJ)
Q_{condu}	Heat loss by conduction (kJ)
Q_{dryair}	Consumed sensible heat by inlet dry air (kJ)
Q_{evapo}	Consumed latent heat by removed water (kJ)
Q_{glu}	Heat generated from glucose (kJ)
Q_{radi}	Heat loss by radiation (kJ)
Q_{solid}	Consumed sensible heat by dry solid (kJ)
Q_{water}	Consumed sensible heat by water (kJ)
Q_{watvap}	Consumed sensible heat by water vapor (kJ)
RH	Relative humidity
T_a	Ambient temperature (°C)
T_m	Temperature of the sludge bed (°C)
T_t	Temperature of the top surface of the reactor (°C)
TS	Total solids
t	Bioevaporation time (min)
U	The coefficient of heat transmittance (0.5×10^{-4} kJ d^{-1} m^{-2} °C^{-1}) of the reactor wall (Zhao et al., 2010)
V_{air}	Volume of air (L)
V_{CO_2}	Volume of CO_2 (L)
VS	Volatile solids
ν	Airflow rate (2.04 L min^{-1})
ω	The weight of water vapor on a dry air basis (kg H_2O kg^{-1} dry air)
σ	Stefane Boltzmann constant (5.67×10^{-11} kJ $s^{-1}m^{-2}$ K^{-4}) (Ahn et al., 2007)

membrane. In this case, concentrated wastewater is generated as a byproduct. For highly concentrated wastewater, however, it is very difficult, even if it is technically possible, to obtain absolutely clean water because too much energy and materials are needed.

In order to overcome these obstacles, it is possible to consider evaporating wastewater rather than obtaining clean water. For wet waste, the method of thermal drying is frequently used. Heat produced by burning fuel is supplied to the waste to evaporate the liquid water by which wet waste is dried to the designated moisture content (MC) (Vaxelaire et al., 1999). For wastewater, it is practically impossible to evaporate all the water due to economic infeasibility given by fuel consumption. However, it would be ideal if both water and organic matters can be removed from highly concentrated wastewater with minimal consumption of energy.

It is well known that microbial metabolism leads to the production of metabolic heat (Madigan et al., 2012). As the substrate concentration increases, the amount of heat