ARTICLE IN PRESS

Chemical Engineering & Processing: Process Intensification xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Chemical Engineering & Processing: Process Intensification

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

Effective biodegradation of organic matter and biogas reuse in a novel integrated modular anaerobic system for rural wastewater treatment: A pilot case study

Haoran Pang[a,*], Ping Wu[b], Lingfang Li[a], Zhenjiang Yu[a], Zhenjia Zhang[a]

[a] *School of Environmental Science and Engineering, Shanghai Jiaotong University, Shanghai 200240, China*
[b] *Zoeller (Shanghai) Environmental Engineering Co., Ltd., Shanghai 201103, China*

A R T I C L E I N F O

Keywords:
Rural wastewater
Decentralized
Anaerobic digestion
Ultrafiltration membrane
Biogas

A B S T R A C T

To meet the various requirements of rural/decentralized wastewater treatment in China, a novel integrated anaerobic system was developed, in the combination of anaerobic digestion and membrane filtration processes. In this study, a pilot-scale system, consisting of an anaerobic chamber, an equalization chamber and an anaerobic membrane chamber was investigated, in terms of the organic matter removal, nutrients removal, biogas production and power consumption. Pilot trials reflected that at both maximum design flowrate of 3 m^3/d and shock flowrate of 5 m^3/d, Chemical Oxygen Demand (COD) concentration in the influent was generally greater than 300 mg/L; its removal efficiency exceeded 80%. The removal efficiencies of total nitrogen (TN) and total phosphorous (TP) was of 33 ± 14% and 25 ± 6%, respectively; whereas minor increase of ammonia and phosphate in the permeate effluent. Daily produced biogas increased from 40 to 170 L/d during the trials, and the estimated mean biogas yield coefficient was 0.14 ± 0.04 m^3biogas/kgCOD$_{removed}$ (35 ± 3 °C). Promising power consumption was expected to be lower than 0.5 kW h per ton of water production when operated below the maximum design flowrate. This integrated system provides a good alternative for rural wastewater treatment, which has the potential to become a sustainable and green process.

1. Introduction

Wastewater treatment in rural areas is essential to prevent the pollution of aquatic environments as well as sanitation [1], especially for those people living in less developed areas of developing countries with no/less access to wastewater collection and treatment facilities. Reusing or directly discharging untreated/insufficiently treated decentralized wastewater poses serious risks to environment and public health, which has aroused the concern for both researchers and government officials. However, current centralized wastewater treatment systems involve large capital investments and operating costs. Such systems are therefore not applicable for decentralized wastewater treatment [2]. Simple and energy-saving treatment systems, such as septic tanks, constructed wetlands and sand filter systems are widely applied in decentralized wastewater treatment due to low costs and less maintenance; however, these systems fail sometimes in long-term sustainable operation, in particular at shock loads.

Among these processes engaged in the rural wastewater treatment, the anaerobic process is now considered to be the best method [3]. Since the escalating energy prices during the 1970s and improvement in environmental education, the anaerobic treatment process has gained momentum, and more stable and efficient high-rate anaerobic systems have been developed [4], including Anaerobic Filter (AF) [5,6], Upflow Anaerobic Sludge Blanket reactor (UASB) [7] and Fluidized Bed Reactor (FBR) [8,9]. Treatment of wastewater by the anaerobic process is now considered sustainable [10] and appropriate for on-site wastewater treatment [11], because of its simplicity, cost effectiveness, small footprint, low sludge production, low energy and nutrients demand and fewer requirements of professional management. Furthermore, the process can provide methane gas, a high-calorie fuel gas [12–14]. Many researchers have reported the performance of different types of pilot or lab scale multi-stages anaerobic membrane systems [15–17] in treating low-strength but complex wastewater; or otherwise, treating high-strength/high-load wastewater [18–20]. Nevertheless, to the best of our knowledge, few attempts have been made of combining anaerobic digestion and anaerobic membrane separation processes into an integrated hybrid system to treat such low-strength wastewater. Since after the pre-treatment of raw wastewater by anaerobic digestion, the organic strength could be reduced for the succedent membrane filtration process and mitigate the membrane fouling. Besides, the produced

* Corresponding author.
E-mail address: jacksmith1121@126.com (H. Pang).

http://dx.doi.org/10.1016/j.cep.2017.04.006
Received 25 August 2016; Received in revised form 6 April 2017; Accepted 9 April 2017

Please cite this article as: Haoran, P., Chemical Engineering & Processing: Process Intensification (2017), http://dx.doi.org/10.1016/j.cep.2017.04.006

Nomenclature

AF	Anaerobic Filter
AeMBR	Aerobic Membrane Bioreactor
ALK	alkalinity
AnMBR	Anaerobic Membrane Bioreactor
BAF	Biological Aerated Filter
COD	Chemical Oxygen Demand
DN	Nominal Diameter
FBR	Fluidized Bed Reactor
FMBR	Anoxic Membrane Bioreactor
HRT	Hydraulic Retention Time
LMH	membrane flux
MLSS	Mixed Liquor Suspended Solid
OLR	Organic Loading Rate
PLC	Programmable Logic Controller
PVC	Polyvinyl Chloride
SS	Suspended Solids
ST	septic tank
TMP	Trans-Membrane Pressure
TN	total nitrogen
TP	total phosphorous
UASB	Upflow Anaerobic Sludge Blanket reactor
VS	Volatile Solids
VFAs	Volatile Fatty Acids
WW	wastewater
Q_{inf}	influent flowrate
$Q_{eff.}$	effluent flowrate (refer to the membrane permeate flowrate)
S_{inf}	COD concentration in the influent
S_{eff}	COD concentration in the permeate
$V_{effective}$	effective volume of bioreactor
$A_{mem.}$	total membrane surface area
η_{COD}	COD removal efficiency
y_b	biogas yield coefficient
V_{biogas}	daily produced biogas volume
M_{COD}	removed COD mass by anaerobic digestion

biogas by anaerobic digestion can be reused for membrane scrubbing and gas-lift for energy-saving.

In this study, a pilot-scale integrated anaerobic system was assessed for rural analogous wastewater treatment application, in terms of the COD removal, nutrients removal, biogas production and membrane filtration performance. The system applied in this study was characterized by the combination of an anaerobic digestion module and an air-lift anaerobic membrane filtration module with gas sparging. It was operated at maximum design hydraulic loads and at shock loads, with also comparative studies of different sludge contents on membrane performance. Membrane fouling was assessed with respect to the Trans-Membrane Pressure (TMP) and membrane flux variation. Furthermore, in order to evaluate the marketing potential of this anaerobic system, power consumption per ton of produced water was also evaluated. The results in this study can shed light on the treatment performance and biogas reuse of the hybrid system for treating such low-strength wastewater into long-term stable operation.

2. Material and methods

2.1. Experimental setup

The schematic diagram of the integrated system, flowchart of wastewater treatment and on-site scene of the pilot are shown in

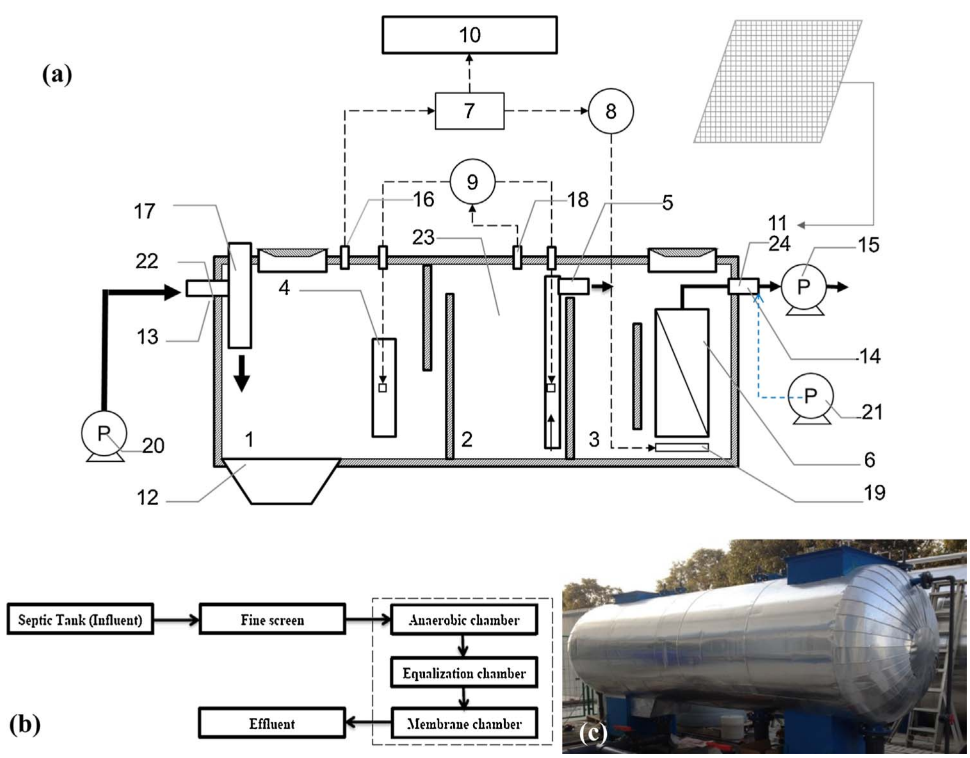

Fig. 1. (a) Schematic diagram of the integrated system: 1. Anaerobic chamber; 2. Equalization chamber; 3. Membrane chamber; 4. Gas agitation; 5. Gas lift; 6. Ultrafiltration membrane unit; 7. Biogas collection bag; 8. Gas pressure pump 1#; 9. Gas pressure pump 2#; 10. Biogas – power generator; 11. Solar panel and supplementary power; 12. Sand collector; 13. Influent; 14. Effluent; 15. Permeate pump; 16. Gas collection outlet; 17. Water – seal pipe; 18. Gas recirculation outlet; 19. Pluse-sparger; 20. Inlet submerged pump; 21. Backwash pump; 22. Influent sampling port; 23. Equalization chamber sampling port; 24. Permeate sampling port. (b) Flowchart of the anaerobic system for treating wastewater in this study; (c) on-site scene of the pilot.