Chemical Engineering Journal 243 (2014) 265–271

Contents lists available at ScienceDirect

Chemical Engineering Journal

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

High-throughput nitritation of reject water with a novel ammonium control loop: Stable effluent generation for anammox or heterotrophic denitritation

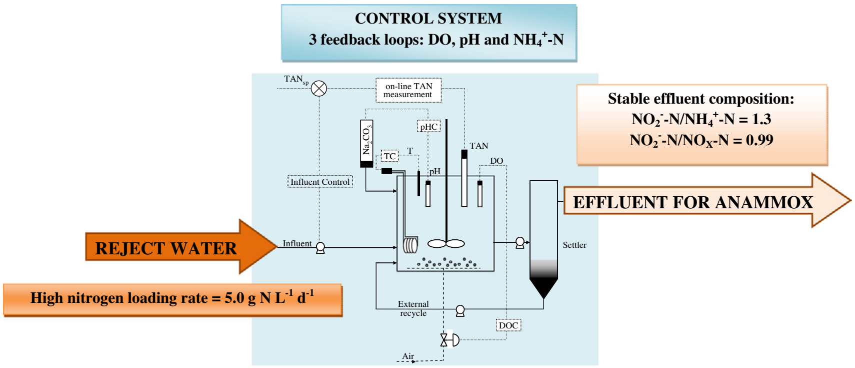
Josep A. Torà [a], Javier Lafuente [a,b], Carme Garcia-Belinchón [c], Lynne Bouchy [c], Julián Carrera [a], Juan A. Baeza [a,*]

[a] *Departament d'Enginyeria Química, Escola d'Enginyeria, Universitat Autònoma de Barcelona, 08193 Bellaterra (Barcelona), Spain*
[b] *MATGAS Research Centre, Campus Universitat Autònoma de Barcelona, 08193 Bellaterra (Barcelona), Spain*
[c] *CETaqua, Water Technology Center, Carretera d'Esplugues, 75 08940 Cornellà de Llobregat, Spain*

HIGHLIGHTS

- High nitrogen loading rate in a controlled activated sludge for partial nitritation.
- Nitrogen loading rate of 5.0 or 9.3 g N L^{-1} d^{-1} for reject or synthetic water.
- The new control system allows a suitable and stable effluent for anammox treatment.
- Effluent with total nitritation was achieved only modifying the ammonium setpoint.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 19 July 2013
Received in revised form 11 November 2013
Accepted 24 November 2013
Available online 28 November 2013

Keywords:
Anammox
AOB
Control
Partial nitrification
Nitritation
TAN

ABSTRACT

This work presents a new control system for the nitritation of high-strength ammonium wastewater as reject water from sludge dewatering. It is based on three independent feedback control loops: (i) DO control by manipulating the aeration flow-rate, (ii) pH control with the addition of solid Na_2CO_3 and (iii) control of NH_4^+—N concentration in the reactor using the influent flow-rate as the manipulated variable. Its application in an activated sludge configuration with one reactor and a settler, demonstrated: (i) capability to achieve stable effluent composition with proper NO_2^-—N/NH_4^+—N ratio for anammox treatment and ii) possibility to obtain an effluent with full nitritation suitable for heterotrophic denitrification only modifying the ammonium setpoint. A nitrogen loading rate (NLR) up to 5.0 ± 1.0 gN L^{-1} d^{-1} was stably treated using real reject water ($T = 30$ °C, pH = 7.5) with a NO_2^-—N/(NO_2^-—N + NO_3^-—N) ratio of 99%. NLR reached up to 9.3 ± 0.5 gN L^{-1} d^{-1} with synthetic wastewater.

1. Introduction

Reject water is a high-strength ammonium wastewater produced in the sludge dewatering process in wastewater treatment plants (WWTP). This effluent is usually mixed with the influent of the WWTP to be treated in the conventional water line.

---

* Corresponding author. Tel.: +34 935811587; fax: +34 935812013.
E-mail addresses: javier.lafuente@uab.cat (J. Lafuente), cgarciab@cetaqua.com (C. Garcia-Belinchón), LBouchy@aqualogyuk.com (L. Bouchy), julian.carrera@uab.cat (J. Carrera), juanantonio.baeza@uab.cat (J.A. Baeza).

1385-8947/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.cej.2013.11.056

Nomenclature

ACR	ammonia consumption rate
AOB	ammonia oxidizing bacteria
CLSM	confocal laser scanning microscopy
DO	dissolved oxygen
FA	free ammonia
FISH	fluorescence in situ hybridization
FNA	free nitrous acid
HRT	hydraulic residence time
NLR	nitrogen loading rate
NOB	nitrite oxidizing bacteria
OUR	oxygen uptake rate
PI	proportional-integral controller
PID	proportional-integral-derivative controller
PN	partial nitritation
SACR	specific ammonia consumption rate
SRT	sludge retention time
TAN	total ammonia nitrogen ($TAN = NH_4^+{-}N + NH_3{-}N$)
TAN_{SP}	TAN setpoint
TIC	total inorganic carbon
TNN	total nitrite nitrogen ($TNN = NO_2^-{-}N + HNO_2{-}N$)
TSS	total suspended solids
VSS	volatile suspended solids
WWTP	wastewater treatment plant
μ_{AOB}	specific growth rate of AOB
μ_{NOB}	specific growth rate of NOB
$\mu_{max,AOB}$	maximum specific growth rate of AOB
$\mu_{max,NOB}$	maximum specific growth rate of NOB
b_{AOB}	decay rate of AOB
b_{NOB}	decay rate of NOB
$b_{max,AOB}$	maximum decay rate of AOB
$b_{max,NOB}$	maximum decay rate of NOB
$K_{I,FA,AOB}$	FA inhibition constant of AOB
$K_{I,FA,NOB}$	FA inhibition constant of NOB
$K_{I,FNA,AOB}$	FNA inhibition constant of AOB
$K_{I,FNA,NOB}$	FNA inhibition constant of NOB
$K_{S,DO,AOB}$	DO affinity constant of AOB
$K_{S,DO,NOB}$	DO affinity constant of NOB
$K_{S,FA,AOB}$	FA affinity constant of AOB
$K_{S,FNA,NOB}$	FNA affinity constant of NOB

However, different studies have demonstrated that the specific and separated treatment of reject water is more convenient than its recycle [1]. Among the proposed treatments, biological processes are the most convenient from both economic and ecological points of view. Biological nitrogen removal of reject water can be -performed by (i) the classical nitrification–denitrification (full ammonium oxidation to nitrate followed by heterotrophic denitrification), (ii) nitritation–denitritation (oxidation of ammonium to nitrite followed by nitrite denitrification), which has some advantages compared to the conventional process [2,3] and (iii) partial nitritation (PN)–anammox which is the most novel process and ensures nitrogen removal through an autotrophic process [4,5]. As a pretreatment of the anammox reactor, the PN reactor has to achieve an effluent ratio of total nitrite nitrogen ($TNN = NO_2^-{-}N + HNO_2{-}N$)/total ammonia nitrogen ($TAN = NH_4^+{-}N + NH_3{-}N$) around 1.3, which is the stoichiometric ratio required by anammox:

$$NH_4^+ + 1.3NO_2^- + 0.066HCO_3^- + 0.13H^+ \\ \rightarrow 1.02N_2 + 0.26NO_3^- + 0.066CH_2O_{0.5}N_{0.15} + 2.03H_2O$$

One of the most common PN reactors for achieving the suitable influent for anammox is the SHARON process [4]. However, recent studies have shown that the actual bottleneck in the overall capacity of the autotrophic N-removal process is due to the limiting capacity of the first part of the treatment, that is, PN with the SHARON reactor [6]. This limitation is due to the low biomass concentration that can be achieved because it works without biomass retention to achieve and maintain PN [7]. Consequently, the development of robust technologies for PN at higher nitrogen loading rates (NLR) is required to improve the capacity of the autotrophic N-removal [8].

PN reactors for anammox systems are usually operated without advanced control loops, as only DO control is usually implemented. The effluent with the required TNN/TAN ratio for the anammox step is achieved thanks to the bicarbonate/TAN ratio of the reject water, which typically contains the stoichiometric alkalinity required to oxidize around 50% of the inlet ammonium [9]. However, the treatment of wastewaters without the proper bicarbonate/TAN ratio or some fluctuations of influent TAN and alkalinity concentrations could strongly affect the TNN/TAN ratio of the effluent and therefore it could disturb the anammox process [10,11].

Process control is widely recognized in the literature as essential to ensure successful reactor operation under different influent conditions in PN systems [12]. Main control options recommended consider flow adjustment, influent total inorganic carbon (TIC) control and base/bicarbonate dosing in the reactor. Flow adjustment is a feasible option because a large number of sludge dewatering systems in WWTP work only part of the day and hence reject water storage is already available. For example, centrifuges generally operate only during the working hours, and reject water is already stored with the objective of distributing its load during all the day. Many other industries as chemical, pharmaceutical or food industries also produce high-strength ammonium wastewaters discontinuously that must be stored and treated progressively.

In this scenario, the development of a new PN system with a specific control loop is a requirement to produce a proper effluent for anammox treatment from any high-strength ammonium wastewater, independently of its bicarbonate/TAN ratio. To this aim, a novel automatic control loop able to maintain a specific TAN concentration in the effluent was developed and applied to a single activated sludge nitrifying reactor under continuous operation. The TAN control loop manipulates the influent flow-rate to obtain a more reliable system able to treat reject water at high rates and obtaining an effluent suitable for a subsequent anammox reactor. Moreover, the versatility of the control system was studied for achieving an appropriate effluent for a subsequent heterotrophic denitritation by only decreasing the TAN setpoint (TAN_{SP}).

2. Materials and methods

2.1. Partial nitritation system setup

The experiments were performed in a continuous activated sludge system consisting of an aerobic mixed reactor with a working volume of 25 L followed by a 25 L settler (Fig. 1). The reactor was equipped with measurement systems for dissolved oxygen (DO) (WTW Oxi 340i CellOx 325), pH (Crison pH 52-03) and temperature (Pt-100). TAN was measured with an on-line ammonium ion selective electrode (NH4Dsc Ammonium sensor with a Cartrical cartridge and a SC100 controller, Hach Lange, Düsseldorf, Germany), which provided a stable measurement with low noise. The DO control was based on a proportional-integral derivative