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Performance of inorganic coagulants in treatment of backwash waters from a brackish aquaculture recirculation system and digestibility of salty sludge

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ABSTRACT

In this work two inorganic coagulants, $FeCl_3$ and polymeric aluminum sulfate (PAS) were tested for treating backwash waters from a drumfilter of a brackish RAS with a salinity level of 17.0 g/L. Their performances in terms of removal of total suspended solids (TSS), turbidity, total organic carbon (TOC), total phosphorus (TP) and reactive phosphorus (RP) were investigated. The results show that the removal efficiencies of total suspended solids (TSS), turbidity, total phosphorus (TP) and reactive phosphorus (RP) at the brackish conditions are higher than these in fresh condition with the same dosage of $FeCl_3$ reported in literature. Moreover, dosing PAS caused a 9% decrease in biochemical oxygen demand (BOD_5) of backwash waters, compared to that of the control group without adding PAS. The effects of $FeCl_3$ and PAS as well as the effect of compatible solutes on biomethane potential (BMP) of the sludge from the RAS were examined. The results of BMP tests show that addition of glycine betaine (GB) 0.50 g/L, trehalose (T) 0.50 g/L and the combination 0.25 gGB/L plus 0.25 gT/L enhanced BMP of the sludge by 9.0%, 11.6% and 10.3%, respectively, compared with that of the control group without addition of compatible solutes. However, inorganic coagulants, $FeCl_3$ and PAS, reduced BMP of the sludges from the sieve of the brackish RAS by 5.3% and 15.1%, respectively. Particularly, PAS (2.4 gAl/L) significantly lessened BMP. Therefore, PAS may not be a proper coagulant for concentrating sludges if anaerobic digestion is going to be adopted as a sludge post treatment approach to achieve sludge reduction and energy recovery. However, $FeCl_3$ may be a potential coagulant to further coagulate and flocculate backwash waters from marine RAS without substantially affecting the anaerobic digestibility of sludge produced by addition of $FeCl_3$.

1. Introduction

The demand of seafood has been significantly increased worldwide since 1970s due to the increasing population and the improved personal living conditions, particularly in developing countries (Naylor and Burke, 2005). However, the fish – and seafood stock in oceans is exhaustible and in some regions already overexploitations have occurred (Naylor and Burke, 2005). Meanwhile, regulations become more and more stringent, making waste discharge to external facilities nearly not possible for some RAS (van Rijn, 2013). Hence, aquaculture, particularly the recirculation aquaculture system (RAS), seems to be a feasible and very promising approach to satisfy the increasing demand for seafood (Timmons and Ebeling, 2007; Martins et al., 2010). Intensive RAS produces fish and seafood in a much more environmentally friendly way and is characterized by a much higher production efficiency and less land-use, compared to conventional aquaculture systems (Timmons and Ebeling, 2007; Tal et al., 2009). The latter have often been reported with problems such as contamination of the local environment, loss of gene pool of fish via interbreeding and epidemics of parasites between farmed stocks and wild stocks. In contrast, RAS emit less wastewater and wastes since they consist of not only culture units, but also wastewater treatment units (Timmons and Ebeling, 2007).

Nonetheless excess concentrated streams from RAS threaten the sustainability of RAS (Zhang et al., 2013b). Particularly sludges

Abbreviations: RASs, recirculation aquaculture systems; PAS, polymeric aluminum sulfate; TSS, total suspended solids; VSS, volatile suspended solids; TS, total solids; VS, volatile solids; TP, total phosphorus; TOC, total organic carbon; RP, reactive phosphorus; BOD_5, 5 days biochemical oxygen demand; BMP, biomethane potential; GB, glycine betaine.

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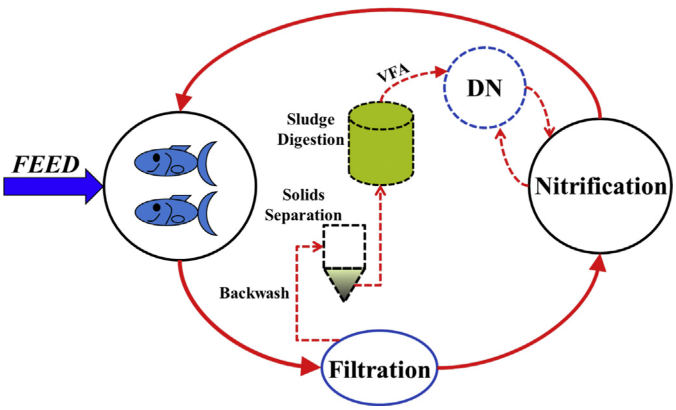

Fig. 1. Scheme of the brackish aquaculture recirculation system.

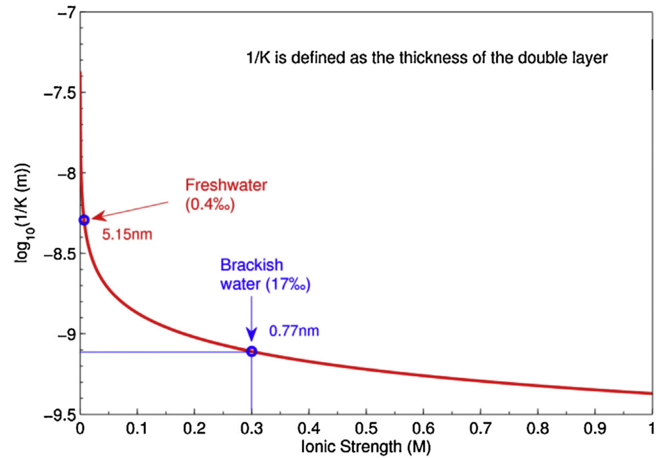

Fig. 2. Impact of ionic strength on thickness of a double layer of particle in NaCl solution).

from marine/brackish RAS are of concern, since they contain high contents of salts that may negatively impact fields or groundwater if the sludges are used as fertilizer and, therefore, need to be treated in another way. Thus, proper approaches to treat the sludges are urgently needed to be investigated in order to achieve less emission or even "zero-emission" from marine/brackish RAS (Zhang et al., 2013b).

Most RAS (Fig. 1) contain units for nitrogen removal such as biofilters, but lack efficient phosphorus removal units (Martins et al., 2010). Phosphorus and suspended solids can be effectively removed by coagulation/flocculation, which is e.g. widely applied in drinking water and industrial wastewater treatment (Ebeling et al., 2006). With regard to RAS, publications are limited to lab-scale studies on coagulation/flocculation for the removal of TSS, turbidity, TP and RP of wastewaters from fresh-water RAS (Ebeling et al., 2003, 2005, 2006; Ebeling and Ogden, 2004; Rishel and Ebeling, 2006; Sharrer et al., 2009). Thus far, only a few studies on coagulation/flocculation in saline wastewater have been reported (Suzuki and Maruyama, 2002; Velasquez and Monje-Ramirez, 2006). To date, no reports are available on performance of inorganic and/or organic coagulants/flocculants in treatment of wastewaters from brackish/marine RAS, and application on pilot scale and full scale is lacking. Hence, investigation on the application of coagulants/flocculants for the treatment of marine/brackish RAS wastewater is of great significance. On the other hand, research has shown that inorganic coagulants may decrease the degradability of macromolecules, like proteins, during anaerobic sludge digestion (Dentel and Gossett, 1982; Chen et al., 2008). However, to our knowledge, no evaluation has been done on the anaerobic digestibility of sludges produced if coagulation is applied to concentrate the waste stream from marine/brackish RAS. The high salinity of brackish/marine RAS sludge may limit their digestibility. Nevertheless, compatible solutes such as trehalose, and glycine betaine have been reported to improve the BMP of saline organic streams (Rubenhagen et al., 2001; Oh et al., 2008; Vyrides et al., 2010). Moreover, Zhang et al. (2014) showed that compatible solutes, trehalose and glycine betaine, improved specific methanogenic activity and also acid phosphatase activity of anaerobic sludge fed with the salty sludge from a brackish RAS. Since uptake of compatible solutes from the media is more favorable for the microorganisms than biosynthesis (van der Heide et al., 2001), compatible solutes addition represents an interesting strategy to respond to the osmotic stress in saline digesters.

As aforementioned above that there is no literature report on performance of inorganic coagulants in treating wastewaters with high ionic strength from brackish/marine RAS. A high ionic strength in solutions causes a compression of the electrical double layer of a particle in solutions, as is illustrated in Fig. 2 (Ito et al., 2004; Gan and Liu, 2008), which can also be specified by the parameter $1/k$, shown in Eq. (1) and defined in the Debye–Huckel theory. Based on the impacts of ionic strength on thickness of a double layer, we could expect that the dosage of coagulants needed in saline conditions for removing particles might be lower compared to fresh-water conditions.

$$k = \left(\frac{e^2 I}{\varepsilon_0 \varepsilon_r k T} \right)^{0.5} \quad (1)$$

where e is the fundamental unit of electricity 1.6×10^{-19} C, ε_0 represents the permittivity constant of free space, 8.85×10^{-12}, ε_r is the relative permittivity of the medium (water), 78.94, k denotes Boltzmann constant, 1.3807×10^{-23} J K, and I is the ionic strength of the solution (mol m^{-3}), which is defined as $I = 1/2 \sum N_A n_i z_i^2$, where N_A is the Avogadro number, 6.023×10^{23} (mol^{-1}), n_i is the moles of the ith ions (moles/m^{-3}) and z_i is the magnitude of the charge for the ith ion. Moreover, high ionic strength also reduces the solubility products of $Fe(OH)_3$ and $Al(OH)_3$ (Gayer and Woontner, 1956; Gayer et al., 1958; Millero and Liu, 1999). This may also be conducive in reducing optimal dosage of inorganic coagulants.

The main objectives of this study are 3-fold: First, to evaluate performance of coagulants in treatment of backwash water from a brackish RAS under high ionic strength condition; Second, to examine the effect of inorganic coagulants on biodegradability of the salty sludge; Third, to investigate whether addition of compatible solutes could enhance methane production rates from the salty sludge. Therefore, in this work we investigated the performances of two inorganic coagulants, $FeCl_3$ and polymeric aluminum sulfate (PAS) in removal of TSS, turbidity, TOC, TP and RP of backwash waters from a drumfilter of a brackish fish farm. The results are compared to the performances of $FeCl_3$ and $AlCl_3$ in coagulation and flocculation of wastewater from fresh water RAS in an investigation conducted by Ebeling et al. (2003). Moreover, BOD_5 and BMP were assessed to determine the potential impacts of additions of inorganic coagulants on aerobic and anaerobic digestibility of the brackish sludge. Additions of compatible solutes, trehalose and GB, to concentrated sludges from a sieve screening the backwash water from the drumfilter of the brackish RAS were conducted to assess the potential improvement on BMP of the sludges and the performance of trehalose, GB and the combination of the two.