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OPTIMISATION OF BIOLOGICAL NITROGEN REMOVAL PROCESSES TO TREAT REJECT WATER FROM ANAEROBIC DIGESTION OF SEWAGE SLUDGE

Doctoral Thesis directed by Joan Mata Álvarez

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CERTIFICA:

Que el present treball d'investigació titulat "*Optimisation of Biological Nitrogen Removal Processes to treat Reject Water from Anaerobic Digestion of Sewage Sludge*", constitueix la memòria que presenta l'Enginyer Químic **Alexandre Galí Serra** per a aspirar al grau de Doctor per la Universitat de Barcelona i que ha estat realitzada dins del programa de Doctorat "Enginyeria del Medi Ambient i del Producte", bienni 2002-2004, en el Departament d'Enginyeria Química de la Universitat de Barcelona sota la meva direcció.

I perquè així consti, firmo el present certificat, a vint-i-sis de Juny de dos mil sis.

Dr. Joan Mata Álvarez

SUMMARY

Treating the supernatant (reject water) from anaerobic sludge digestion (usually around 800-1200 mg NH_4^+-N L^{-1}) may be a good solution for meeting local requirements regarding N discharges. As reject water represents 0.5-2 % of the total wastewater influent flow and contains 15-25% of the total nitrogen, it is recirculated to the head plant.

In the present work, the study of real reject water treatment is presented from the operational, kinetic and economical point of view. The study began with a lab-scale start up of biological nitrification/denitrification process to treat reject water (800-900 NH_4^+-N mg L^{-1}) from a mesophilic (35 ºC) anaerobic sludge digester of a Spanish Municipal Wastewater Treatment Plant (WWTP). Sludge acclimation to denitrification process was quite fast (6-7 days), whereas in nitrification it was slower (20 days). The use of a sequencing batch reactor (SBR) to treat reject water produced a complete biological nitrogen removal working with solid retention time (SRT) of 15 days, hydraulic retention time (HRT) of 1.3 days, temperature of 28ºC, pH between 7-8.5 and biomass concentration around 3500 mg VSS L^{-1}.

The process was then further optimised with two lab-scale SBR with control of temperature using methanol for denitrification due to the lack of a readily biodegradable carbon source. Process kinetics were compared through the specific Ammonium Uptake Rate (sAUR) finding the appropriate operational sequence at 32ºC with an 8 hour cycle length. Every operational cycle was carried out with a SRT of 11 days, HRT 1 day and 2500 mg VSS L^{-1}. In order to avoid nitrate formation, and thus to save costs, the oxygen concentration was maintained below 1 mg L^{-1} during the aerobic periods and pH remained within an optimal range (7.5-8.5) alternating different aerobic/anoxic sub-cycles inside the operational cycle. With this strategy, the range of alkalinity could be controlled avoiding the addition of external chemicals and nitrite accumulation was prevented. Therefore, the sAUR was 22 mg NH_4^+-N g^{-1} VSS h^{-1} and the specific Nitrite Uptake Rate (sNUR) 47 mg NO_2^--N g^{-1} VSS h^{-1} with a total nitrogen removal of 0.8-0.9 kg N day^{-1} m^{-3}.

In order to make the process more economical, the use of internal organic carbon sources from the WWTP to develop the denitrification steps in the SBR was studied. Several internal flow-rates from the WWTP were tested finding that the primary hidrolysate would be the only one feasible for denitrification. When using the primary sludge, the reactor worked with an average biomass concentration of 2700 mg VSS L^{-1}, obtaining an sAUR of 17 mg NH_4^+-N g^{-1} VSS h^{-1}, an sNUR of

38 mg NO_2^--N g^{-1} VSS h^{-1} and a total nitrogen removal of 0.7 kg N day^{-1} m^{-3}. The use of that internal organic carbon source would lead to a cost reduction of 0.2-0.3 € kg $^{-1}$ N removed.

The next step was to compare the SBR technology to obtain the nitrite route with the continuous technology using a chemostat reactor. In that way, a SBR and a chemostat SHARON (Single-reactor High activity Ammonia Removal Over Nitrite) continuous reactor were operated to develop the biological nitrogen removal via nitrite to treat real reject water at lab-scale. Methanol was added for denitrification in both reactors. An 8 hour SBR cycle was operated with the conditions explained above in a 3 L tank. SHARON process was operated in a 4 L chemostat reactor at 33 ºC where it was combined with denitrification in the same chemostat with a total HRT of 2 days using intermittent nitrification/denitrification periods of 1 hour. Both systems were compared from the operational, kinetic, design and economical point of view. As a conclusion, the SBR would be a slightly cheaper process (1.01 versus 1.28 € kg $^{-1}$ N) due to the higher volumetric reaction rates. On the other hand, the SHARON/denitrification reactor would be a more stable and regular process in the presence of fluctuations and changes in the system.

The same reactors can also be used to produce an influent ready for the Anaerobic Ammonium Oxidation process (Anammox) to save costs in terms of oxygen supply (nitrification) and methanol dosage (denitrification). Therefore, a comparative study to produce the correct influent for an Anammox reactor from reject water was carried out. The influent for the Anammox process needs to be composed of NH_4^+-N and NO_2^--N in a ratio roughly 1:1. The modification of temperature, ammonium concentration, pH and SRT allows the achievement of partial nitrification with a final effluent only composed with NH_4^+-N and NO_2^--N at the right stoichiometric ratio. The equal of NH_4^+/HCO_3^- ratio in reject water results in a pH decrease when approximately 50% of NH_4^+ is oxidised giving a natural control of the NH_4^+/NO_2^- ratio in the effluent. A SBR and a SHARON chemostat type of reactor were studied at lab-scale for their suitability to obtain the required Anammox influent. At stationary state, both systems had an sAUR of 40 mg NH_4^+-N g^{-1} VSS h^{-1}, but in terms of absolute nitrogen removal the SBR removal was 1.1 kg N day^{-1} m^{-3}, whereas in the SHARON process was 0.35 kg N day^{-1} m^{-3} due to the different HRT used.

Finally, the WWTP under study was modelled with Activated Sludge Model No1 (ASM1) in order to see if the effluent pollutants can be well predicted. After the simulation the model fitted correctly in winter periods, but predicted more nitrification than the obtained in summer periods. Moreover, the enlargement of the WWTP with an N removal step was simulated concluding that the treatment of reject water combined with an addition of organic carbon to denitrify the main line would be needed in order to achieve the law nitrogen requirements (Directive 91/271/EEC).

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