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OPTIMIZATION OF UPFLOW SLUDGE-BLANKET REACTOR FOR DENITRIFICATION OF GROUNDWATER WITH LOW HARDNESS

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Introduction

Retention of biomass is an important factor in anaerobic biological unit processes including denitrifying upflow sludge-blanket (USB) reactors which rely on autoaglomeration as a catalyst for formation of biomass granules [1,2]. The dynamic process of sludge growth in conjunction with mineral precipitation (mainly $CaCO_3$) results in a heavier sludge with improved retention characteristics. Others have shown that USB reactors fed with waters having hardness levels ranging from 200 to 250 mg $CaCO_3$ ℓ^{-1} encountered difficulties due to floating sludge and wash-out; with hard waters (260 to 400 mg $CaCO_3$ ℓ^{-1}), improved performances were realized due to development of denser granules [1,2]. In this work, denitrifying granular sludge maintenance was investigated with a focus on minimizing chemical additions to a soft water. It should be possible with pH adjustments at a moderate alkalinity to attain sufficiently high mineral precipitation with soft to marginally hard waters. USB operation without the high hardness levels hereto considered necessary would result in significant savings where soft source waters are of concern.

Materials and Methods

The USB reactor used in this research (Fig. 1) was made of glass and had a 1.7 ℓ working volume with a 7.0 cm diameter and was operated at 25°C. A mechanical stirrer with a bent wire shaft (no blades) rotated at 20 rpm was routinely used to enhance sludge-gas separation. Influent consisted of groundwater with varying concentrations of $NaNO_3$ and $CaCl_2$. Ethanol was adjusted to maintain a C:N ratio of 1.9. Alkalinity was fed at about 180 mg $CaCO_3$ ℓ^{-1}. Precipitation potential (PP) was determined by a graphic method [3] and is, basically, $CaCO_3$ in solution beyond its theoretical solubility limit. Sludge biomass was estimated as volatile suspended solids (VSS).

Results and Discussion

By adjustments in pH, calcium, and flow rate, variations in PP and loading rates were effectuated. Bed volume (reaction zone) was about 2/3 of the hydraulic volume. Sludge mineral content and VSS are correlated with PP and nitrogenous volumetric loading rate (VLR) in Fig. 2. From the highest VLR plateau proceeding downward, flow rates were 5.0, 4.0, 3.0, and briefly 2.0 ℓ hr^{-1} corresponding to hydraulic retention times (HRT) of 20, 26, 34, and 51 minutes. At the highest flow rate used, the vertical flow velocity (or overflow rate) was 2.2 cm min^{-1} which did not resulted in bed fluidization. Sludge granule settling velocities were over an order of magnitude higher at 67 (SD = 25, n = 13) cm min^{-1}.

With influent calcium reduced to about 45 mg $CaCO_3$ ℓ^{-1} and pH at 7.9 (effluent pH, ca. 8.4), reactor PP was set to about +5 mg $CaCO_3$ ℓ^{-1} and granule mineral content responded with a steady decrease (following day 8, Fig. 2). With mineral content approaching 20 %, reactor PP was boosted to +20 mg $CaCO_3$ ℓ^{-1} (day 45) by an adjustment in pH and a calcium increase to 90 mg $CaCO_3$ ℓ^{-1} (total hardness, 120 mg $CaCO_3$ ℓ^{-1}). After about one week, an increasing trend in mineral content and bed biomass (VSS) began. A considerable drop in VLR was also initiated at this time which would not be conducive to an increase in biomass as observed. The increase in PP employed here is thus demonstrated to be a significant factor in retention of biomass.

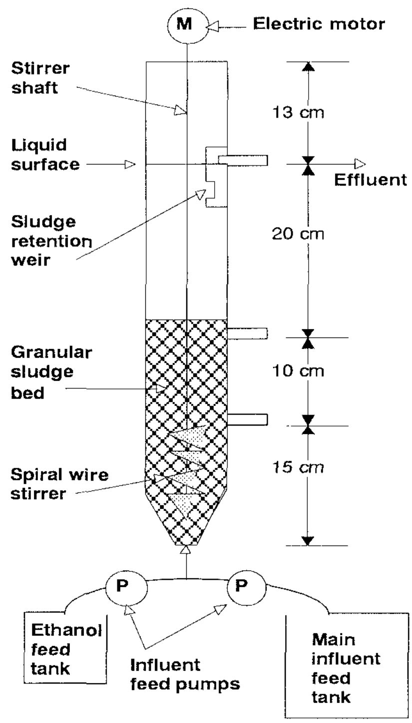

Figure 1. Upflow sludge-blanket reactor used in this research (liquid volume, 1.7 ℓ).

Key Words: denitrification, granular sludge, upflow sludge blanket, precipitation potential.
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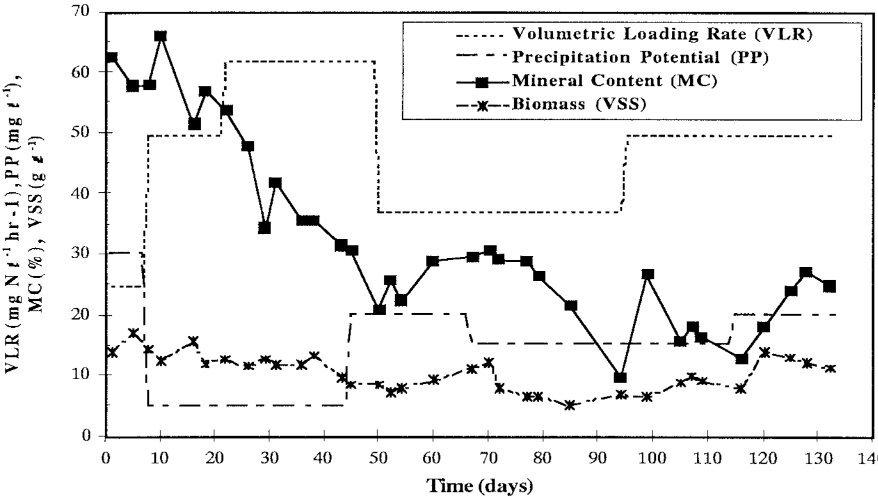

Figure 2. Time course of nitrogenous VLR, PP, granule mineral content, and biomass (as VSS).

A subsequent decrease in reactor PP to +15 mg $CaCO_3$ ℓ^{-1} (day 67, Fig. 2) via a pH adjustment had no immediate effect on granule characteristics. Within one week, though, bed biomass concentration (VSS) dropped and mineral content began a gradual decline. In a further effort to assess potential effects of substrate loading, VLR was increased (day 94). In contrast to a similar event on day 20, biomass started a gradual increasing trend and mineral content stopped decreasing. The added potential energy from the increase in substrate loading thus appears to have had some benefit in combination with the higher calcium (90 mg $CaCO_3$ ℓ^{-1}) and PP (+15 mg $CaCO_3$ ℓ^{-1}). In an effort to boost granule mineral content, influent pH was increased to 8.5 (effluent pH ca. 8.8) with a resulting reactor PP of about +20 mg $CaCO_3$ ℓ^{-1} (day 104). Within one week, mineral content and biomass concentration demonstrated an increase, climbing to about 24 % and 12 g VSS ℓ^{-1}, respectively.

Subsequent assays were conducted to further characterize effects of VLR by varying influent nitrate (12 to 38 mg N ℓ^{-1}) at a fixed flow rate (4.0 ℓ hr^{-1}). As shown in Fig. 3, increases in VLR resulted in a nearly linear increase in alkalinity production rate. Hardness reduction rate (as calcium precipitation), however, was curvilinear with little effect below a VLR of about 50 mg N ℓ^{-1} hr^{-1}. These results are corroborative of the apparent benefit realized when VLR was increased (day 94, Fig. 2) in conjunction with a modest PP of +15 mg $CaCO_3$ ℓ^{-1}.

Conclusion

Even at a relatively low influent hardness level (120 mg $CaCO_3$ ℓ^{-1}), PP was demonstrated to be an effective tool for manipulating sludge characteristics. Coupled with an adequate PP, an increase in VLR also resulted in a gradual increase in biomass concentration. Operation at even lower hardness levels may be possible within the range of pH values used here with influent alkalinity and VLR adjustments.

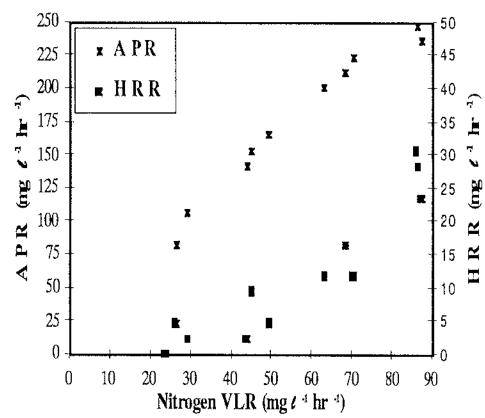

Figure 3. Volumetric alkalinity production rate (APR) and hardness reduction rate (HRR) versus nitrogenous VLR.

References:

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