Introduction

Hydrogenotrophic Denitrification-(Biological treatment)
Biological reduction of nitrate to nitrogen gas under anaerobic conditions by direct immobilization of autohydrogenotrophic bacteria.

Key of this research focusing on H\textsubscript{2} supply
How to??
- Increase H\textsubscript{2} effectiveness under simple system
- Save H\textsubscript{2} supply (lowest H\textsubscript{2} with high efficiency)

Objective

- To comparative the physical characteristic and biological activity between ultrafine bubble system and common bubble system with suspended growth reactor
- To determine the specific hydrogen gas consumption and the effectiveness of hydrogen gas supply from both systems
- To investigated the microbial community present in the system.

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Methodology

Physical characteristic
- Bubble diameter
- Volumetric mass transfer coefficient ($K_{La}$)
- Dissolved hydrogen concentration (DH)
- Decay rate and time of DH maintained in the reactor

Biological characteristic
- Specific $H_2$ consumption
- Long-term operation
- Microbial community

Fig1. Bubbling diffusers: a) Air stone b) Ultrafine bubble diffuser (MiBoS)

Results-Physical characteristic

Bubble diameter

- Average bubble were $25 \mu m$ for ultrafine bubble diffuser
- Average bubble was $1000 \mu m$ for Air stone diffuser

Volumetric mass transfer coefficient

- $K_{La}$ (Volumetric mass transfer) : Ultrafine bubble ($0.045 s^{-1}$) > air stone ($0.002 s^{-1}$)

Dissolved hydrogen and decay rate

- Ultrafine bubble shows greater solubility in water faster that air stone bubble

“MiBoS” Diffuser

Air stone Diffuser

- Average bubble were $25 \mu m$ for ultrafine bubble diffuser
- Average bubble was $1000 \mu m$ for Air stone diffuser

- 40 times

Calculation

$$\ln\left(\frac{C_i - C}{C_i - C_0}\right) = -K_{La}(t - t_s)$$

where: $C_i$ is saturated DH concentration
$C_0$ is DH concentration at initial point, $t_s$ is DH concentration at time; $t$

Results-Physical characteristic

No $H_2$ supply

- Saturation conc. : Ultrafine bubble (1 mg/L) > Air stone (0.67 mg/L)
- DH existent in reactor: Ultrafine bubble (18 h) > Air stone (10 h)
Results-Biological characteristic

Specific hydrogen gas consumption

\[ \text{NO}_3^- + 3.03 \text{H}_2 + 1.47 \text{HCO}_3^- + 0.229 \text{HCO}_3^- \rightarrow 0.477 \text{N}_2 + 3.6 \text{H}_2\text{O} + 0.0458 \text{C}_5\text{H}_7\text{O}_2\text{N} \]

- Minimum \( \text{H}_2 \) consumption: 0.45 ± 0.06 mg H\(_2\)/mg N (0.35-0.43)
- Nitrate to nitrite consumed: 0.16 ± 0.04 mg H\(_2\)/mg N (0.14-0.17)
- Nitrate removal rate: 3.55 ± 0.92 mg/gMLSS·h
- Hydrogen consumption rate: 1.61 ± 0.61 mg/gMLSS·h

Fig. 4 Correlation of \( \text{H}_2 \) consumption and nitrate removal at various biomass concentrations

Fig. 5. Layout of lab-scale hydrogenotrophic denitrification reactors

Synthetic groundwater (Kathmandu, Nepal):
- 48.5 NaNO\(_3\), 0.5 NaHCO\(_3\), 0.3 MgSO\(_4\)·7H\(_2\)O, 0.03 KH\(_2\)PO\(_4\), 0.18 CaCl\(_2\)·2H\(_2\)O, and trace elements I and II
- Nitrogen source: NO\(_3\)-N conc. = 40 mg N/L
- Operating condition: Biomass conc. = 40 mg N/L
  - Reactor volume = 2 L
  - HRT = 12 h
  - Temp. = 32°C
  - Design \( \text{H}_2 \) flow rate
  - Minimum \( \text{H}_2 \) consumption 0.45 mg N/mgH\(_2\)
  - Air stone = 1 mL/min

Methodology

Lab-scale HD reactor

- Design \( \text{H}_2 \) flow rate
- MiniBoS flow rate

Results-Biological characteristic

Performance of HD reactor

- Ultrafine bubble: Removal efficiency: 99% within 9 day operation
- Air stone: Removal efficiency: 20%

Fig. 6. Performance of reactors using ultrafine bubble and air stone diffuser

\[ \text{H}_2 \text{H} \text{used by HD} = \frac{[\text{NRR(g/m}^3\text{·d)} x \text{V x Minimum } \text{H}_2 \text{ consumption (mgH}_2\text{/mg N)}]}{\text{Total } \text{H}_2 \text{ supply (g/d)}} \times 100 \]

\[ \text{H}_2 \text{ released (%)} = 100 - \text{H}_2 \text{ used by HD} \]

\[ \text{H}_2 \text{ effectiveness} = \frac{\text{Nitrogen removal rate (g/m}^3\text{·d)}}{\text{Total } \text{H}_2 \text{ supply (g/d)}} \times 100 \]

Calculation

- \( \text{H}_2 \) used by HD (%) = \( \frac{[\text{NRR(g/m}^3\text{·d)} x \text{V x Minimum } \text{H}_2 \text{ consumption (mgH}_2\text{/mg N)}]}{\text{Total } \text{H}_2 \text{ supply (g/d)}} \times 100 \)
- \( \text{H}_2 \) released (%) = 100 - \( \text{H}_2 \) used by HD
- \( \text{H}_2 \) effectiveness = \( \frac{\text{Nitrogen removal rate (g/m}^3\text{·d)}}{\text{Total } \text{H}_2 \text{ supply (g/d)}} \times 100 \)
Results-Biological characteristic

Total bacterial community

Next Generation Sequencing method (Illumina MiSeq)

- **Total bacterial community**
  - Air stone
  - Ultrafine Bubble

- **Fig8. Relative abundance of microbial community in the phylum and class levels under air stone and ultrafine bubble systems**

Conclusion

Ultrafine bubble supply system has efficiency and **H₂** utilization higher than normal bubble supply system in both physical part and biological part:

- High solubility (dissolve hydrogen concentration) and long retention time
- High volumetric mass transfer (0.045 s⁻¹) >> 20 times
- High system performance (99% of N removal) with less **H₂** supply (1 mL/min)
- High **H₂** effectiveness (1206.15 mgN/gH₂) under simple design, which was comparative with other research
- Save **H₂** (low **H₂** supply but high system performance)

The use of an **ultrafine bubble** diffuser is an option for enhancing the performance of a hydrogenotrophic denitrification reactor.
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Thank you for your kind attention