UNIVERSITY OF YAMANASHI

Ultrafine Bubble Diffuser for Enhancing Hydrogenotrophic Denitrification of Groundwater Treatment

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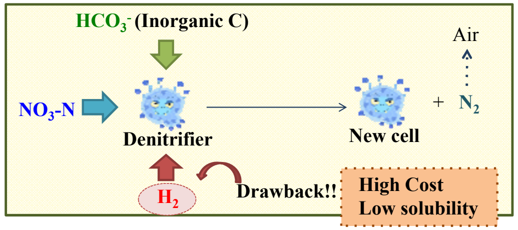
Introduction

Hydrogenotrophic Denitrification-(Biological treatment)

Biological reduction of nitrate to nitrogen gas under anaerobic conditions by direct immobilization of autohydrogenotrophic bacteria.

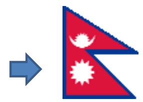


Key of this research focusing on H_2 supply

How to??

Increase H_2 effectiveness under simple system

Save H_2 supply (lowest H_2 with high efficiency)



(Nepal)

Introduction

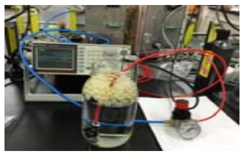
H_2 $\xrightarrow{\text{Dissolve in water}}$ Gas bubble → Bubbling generator

↑

Bubble distribution
Surface area
Solubility
Energy consumption

Ultrafine bubble diffuser ("MiBoS")

(Tsukasa ITO, Environmental Engineering Lab at University of Gunmu, Japan)



Arbitrary Function Generator

Pressure controller

MiBos

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.

Methodology

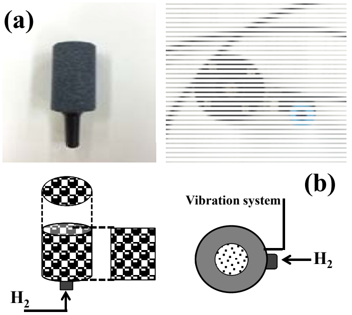


Fig1.Bubbling diffusers: a)Air stone b) Ultrafine bubble diffuser (MiBoS)

Physical characteristic

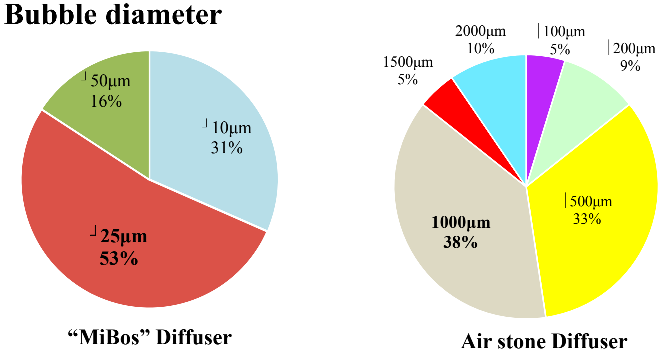
- Bubble diameter
- volumetric mass transfer coefficient (K_La)
- Dissolved hydrogen concentration (DH)
- Decay rate and time of DH maintained in the reactor)

Biological characteristic

- Specific H_2 consumption
- Long-term operation
- Microbial community

Results-Physical characteristic

Bubble diameter



- Average bubble were 25 µm for ultrafine bubble diffuser
- Average bubble was 1000 µm for Air stone diffuser

40 times

Results-Physical characteristic

Volumetric mass transfer coefficient

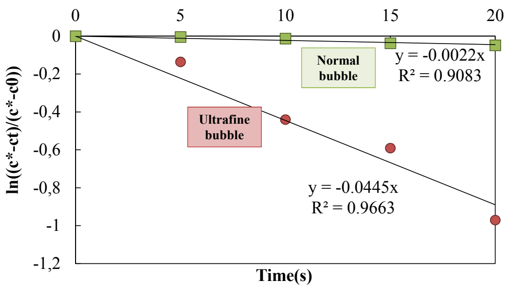


Fig 2. Profile of logarithm function of DH and time

Calculation

$$\ln\left(\frac{C^* - C_L}{C^* - C_s}\right) = -k_L a(t - t_s)$$

where; C^* is saturated DH concentration
C_s is DH concentration at initial point; t_s
C_L is DH concentration at time; t

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

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

Results-Physical characteristic

Dissolve hydrogen and decay rate

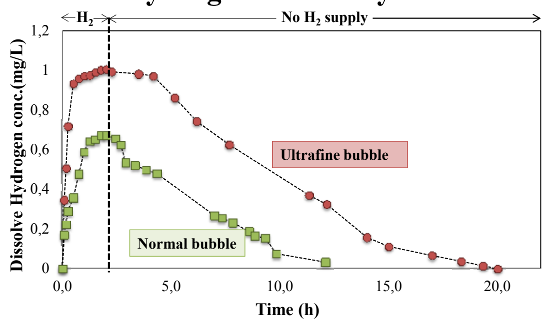
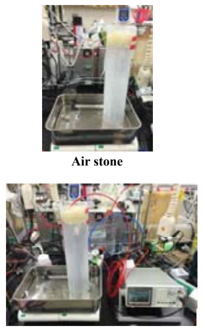


Fig 3. Profile of dissolved hydrogen (DH) concentrations



Air stone

Ultrafine bubble

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

Results-Biological characteristic

❑ Specific hydrogen gas consumption

$NO_3^- + 3.03\ H_2 + H^+ + 0.229\ HCO_3^- \longrightarrow 0.477\ N_2 + 3.6\ H_2O + 0.0458\ C_5H_7O_2N$

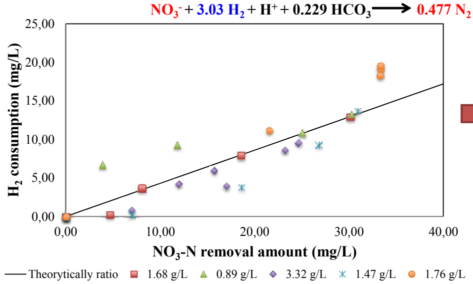


Fig.4 Correlation of H_2 consumption and nitrate removal at various biomass concentrations

- **Minimum 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)
- **Nitrite to nitrogen gas consumed:** 0.29±0.09 mgH_2/mg N (0.21-0.26)
- **Nitrate removal rate:** 3.55±0.92 mg/gMLSS·h
- **Hydrogen consumption rate:** 1.61±0.61 mg/gMLSS·h

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Methodology

❑ Lab-scale HD reactor

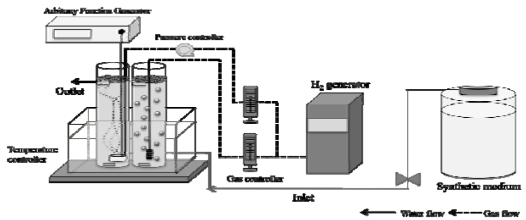
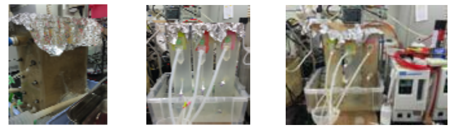


Fig 5 . Layout of lab-scale hydrogenotrophic denitrification reactors



- **Synthetic groundwater (Kathmandu, Nepal)**
  48.5 $NaNO_3$, 0.5 $NaHCO_3$, 0.3 $MgSO_4\cdot7H_2O$, 0.03 KH_2PO_4, 0.18 $CaCl_2\cdot2H_2O$, and trace elements I and II
- **Nitrogen source**
  NO_3-N conc. = 40 mg N/L
- **Operating condition**
  Biomass conc. = 0.3g/L
  Reactor volume = 2 L
  HRT = 12 h
  Temp. = 32 C
- **Design H_2 flow rate**
  -Minimum H_2 consumption 0.45 mg N/mgH_2
  Air stone = 1 mL/min
  MiBoS = 1 mL/min

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Results-Biological characteristic

❑ Performance of HD reactor

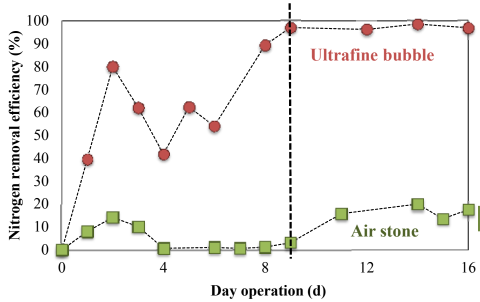
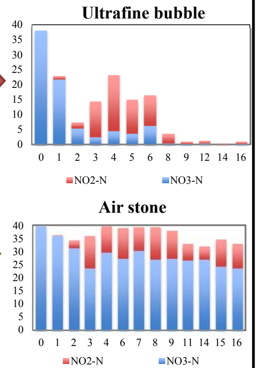


Fig 6. Performance of reactors using ultrafine bubble and air stone diffuser



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

WHO standard
NO_3-N (10 mg N/L)
NO_2-N (0.9 mg N/L)

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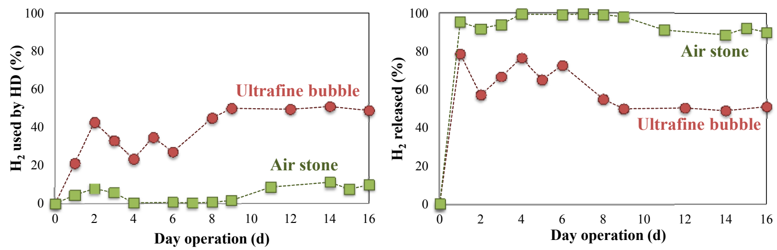
Results-Biological characteristic

❑ H_2 Balance (H_2 used & H_2 Release)



- **H_2 used by bacteria** : 51%
- **H_2 release** : 49%
- **H_2 Effectiveness** : 1206.15 mg N/H_2

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- **H_2 used by bacteria** : 9.88%
- **H_2 release** : 98.22%
- **H_2 Effectiveness** : 196.92 mg N/H_2

Calculation

H_2 used by HD (%) = {[NRR(g/m³.d) x V x Minimum H_2 consumption (mgH_2/mg N)] / [Total H_2 supply (g/d)]} X 100

H_2 released (%) = 100 – H_2 used by HD

H_2 effectiveness = [Nitrogen removal rate (g/m³.d) x Volume (m³)] / Total H_2 supply (g/d)

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ults-Biological characteristic

Performance of HD systems in the literature

	Diffuser Type	Media for microorganisms attachment	Influent NO_3-N (mg/L)	HRT (h)	H_2 supply (g/d)	Removal efficiency (%)	H_2 effectiveness (mgN/mg H_2)	Reference
g tor	Bubble stone	No	1000	480	2.14	100	116.82	Mousavi, Ibrahim, & Aroua (2013)
g tor	Commercial bubble stone	No	20	3	1.34	100	12.38	Ghafari et al. (2009)
actor	Air stone	Yes	20	2.5	9.00	96	58.88	Khanitchaidecha et al. (2012)
d	Fixed nozzles	Yes	340	1.0	11.57	82	347.20	Vasiliadou et al. (2009)
d	Aquarium diffusing stone	Yes	20	2.0	12.86	80	41.38	Lee et al. (2010)
d actor	Pressurized gas tank	Yes	150	16.0	0.64	100	316.41	Park et al. (2005)
d actor	Air stone	No	40	12.0	0.13	16	196.92	This study
d actor	Ultrafine bubble	No	40	12.0	0.13	98	1206.15	This study

Results-Biological characteristic

❑ Total bacterial community

Next Generation Sequencing method (illumina MiSeq)

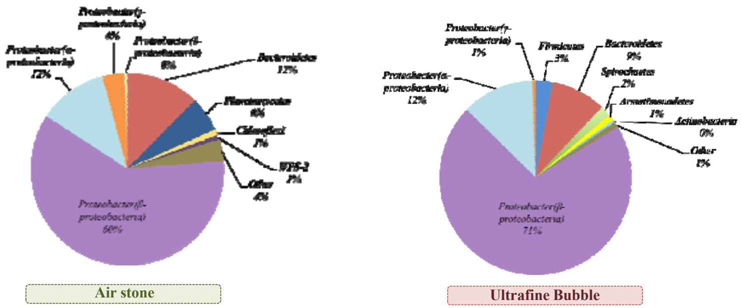
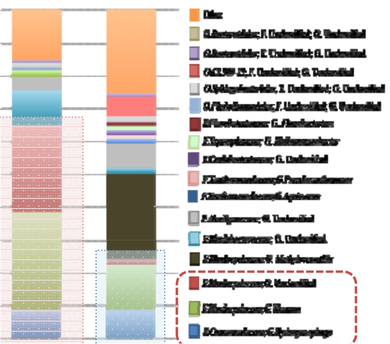


Fig8. Relative abundance of microbial community in the phylum and class levels under air stone and ultrafine bubble systems

ults-Biological characteristic

otal bacterial community



- ❖ ***Hydrogenophaga sp.*****,** ***Thauera sp*****. and unclassified genus in** ***Rhodocyclaceae*** might be responsible for HD process and the excellent performance on nitrogen removal.
- ❖ ***Thauera sp.*** was the predominant genus at ultrafine bubble
- ❖ ***Methyloversatilis sp*****.** was the predominant genus at normal

Conclusion

Ultrafine bubble supply system has efficiency and H_2 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 H_2 supply (1 mL/min)
- High H_2 effectiveness (1206.15 mgN/gH_2) under simple design, which was comparative with other research
- Save H_2 (low H_2 supply but high system performance)

The use of an **ultrafine bubble** diffuser is an option for enhancing the performance of a hydrogenotrophic denitrification reactor

knowledgements

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SATREPS
Science and Technology Research Partnership for Sustainable Development Program

Thank you for your kind attention

Generation Sequencing method (illumina MiSeq)