Spatial mass transfer properties of upflow anaerobic reactors with a pilot UASB as case study

Zohaib Ur Rehman Afridi[1], Jing Wu[1]*, Zhong Hua Li[1], Raseduzzman Akand[1], Souhila Poncin[2], Huai Zhi Li[2]

[1]*State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084 P.R. China*

[2]*Laboratory of Reactions and Process Engineering, Université de Lorraine, CNRS, 1, rue Grandville, BP 20451, 54001 Nancy cedex, France*

**Corresponding author: wu_jing@mail.tsinghua.edu.cn*

Highlights

- Spatial mass transfer conditions in upflow anaerobic reactor was studied at first time.
- Main degradation was in bottom zone due to high mass transfer.
- Mass transfer in UASB increased with increase in granule size

1. Introduction

Upflow anaerobic reactors including upflow anaerobic sludge blanket (UASB), internal circulation (IC) and expanded granular sludge blanket (EGSB) reactors are the most high efficiency anaerobic reactors in the world. But mass transfer inside them is still not clear and remains like a black box. This study for the first time break down the black box of the mass transfer in upflow reactor with a pilot UASB reactor as case study in the views of granules. Anaerobic granules were taken from different zones of the reactor and their mass transfer rates were analyzed under organic loading rate (OLR) of 4.32-8.30 kg COD/(m^3.d).

2. Methods

Anaerobic granules were taken from a pilot-scale mesophilic UASB reactor. The height of the reactor was 4.9 m with reaction zone of 3.5 m, and its internal diameter was 0.5 m. The working volume of the pilot reactor was 0.92 m^3. Granules were collected from five distinct ports in reaction zone as Port 1 at height 0.25 m, Port 2 at height 0.9 m, Port 3 at height 1.65 m, Port 4 at height 2.4 m and Port5 at height 3.15 m along the height of the reactor respectively. Convective and molecular mass transfer rate was calculated according to our previous study[1]. Mass transfer was evaluated by studying the characteristics of the granular sludge (size, porosity, pore length, density, fluid collection efficiency).

3. Results and discussion

Figure 1 shows the changes in mass transfer condition along the height of the reactor. A decline in mass transfer rate was observed as the height increased. The convective and molecular diffusion rate decreased as granules shifted from 0.25 m to 1.65 m and 3.15 m respectively. The convective diffusion rates (F_{CD}) of granules at 0.25 m, 0.9 m and 3.15 m at respective OLRs were 1.22, 0.6 and 0.012 mg/s at OLR 4.32 kg COD/(m^3.d), 2.96, 0.87 and 0.023 mg/s at OLR 5.70, 2.73, 1.56 and 0.23 mg/s at OLR 6.92 and 3.06, 1.35 and 0.26 mg/s at OLR 8.30 kg COD/(m^3.d) respectively.

On the other hand, molecular diffusion rates (F_{MD}) were $1.20E^{-07}$, $1.02E^{-07}$ and $1.90E^{-08}$ mg/s at OLR 4.32 kg COD/(m^3.d). At OLR 5.70 kg COD/(m^3.d) the values were $2.07E^{-07}$, 1.78E-07 and 3.98E-08 mg/s. At OLR 6.92, the values were $3.13E^{-07}$, $2.27E^{-07}$ and $9.11E^{-08}$ mg/s and $3.97E^{-07}$, $3.04E^{-07}$ and $1.50E^{-07}$ mg/s at OLR 8.30 kg COD/(m^3.d) respectively. The results show that bottom zone of the reactor is high mass transfer zone where most of the degradation takes place.

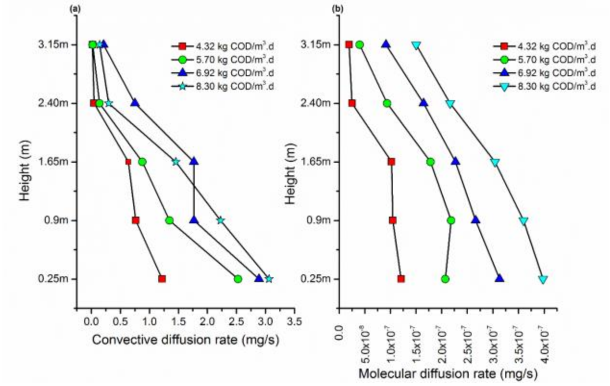

Figure 1 Spatial mass transfer rate: (a) Convective and (b) molecular diffusion rate of granule in reactor

Another important result is that mass transfer is highly dependent on size of the granule. Mass transfer rates for granules from each port under respective COD concentration were calculated as shown in Figure 2. It was observed that molecular and convective diffusion rates increased exponentially as the size increased from 0.5 to 2.5 mm. Thus it can be inferred that large granules may enhance the mass transfer process.

Based on the mass transfer rate for granules ranging from 0.5-2.5 mm under COD 3000-9000 mg/L, an empirical Eq. 1 and 2 for convective and molecular diffusion rates is presented.

$$FCD = 0.006e^{2.775d} \qquad R^2 = 0.942 \qquad (1)$$

where F_{CD} is convective diffusion in mg/s, d is diameter of the granule (cm)

$$FMD = 1E\text{-}08e^{1.4342d} \qquad R^2 = 0.950 \qquad (2)$$

where F_{MD} is molecular diffusion in mg/s, d is size of the granule (cm).

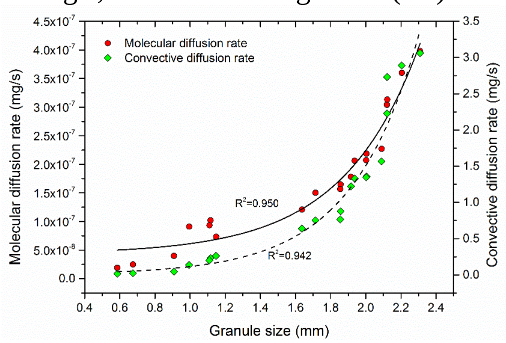

Figure 2: Convective and molecular diffusion rates of different sized granules

4. Conclusions

Both convective and molecular mass transfer existed inside the reactor but had inverse relationship with the height of the reactor. Granules at the bottom of the reactor were most efficient. The study would be helpful for the improvement of full-scale reactors.

Acknowledgments

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References .

[1] Z. Afridi, J. Wu, ZP. Cao, Z.L Zhang, HZ Li, S. Poncin, Z.H Li. Biochem. Eng. J.(2017), 154-160.

[1] Keywords

Anaerobic granule, Convective diffusion; Molecular diffusion; Mass transfer; Upflow anaerobic reactor