Treatment of high-strength wastewater using anaerobic-aerobic granular bioreactor

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INTRODUCTION

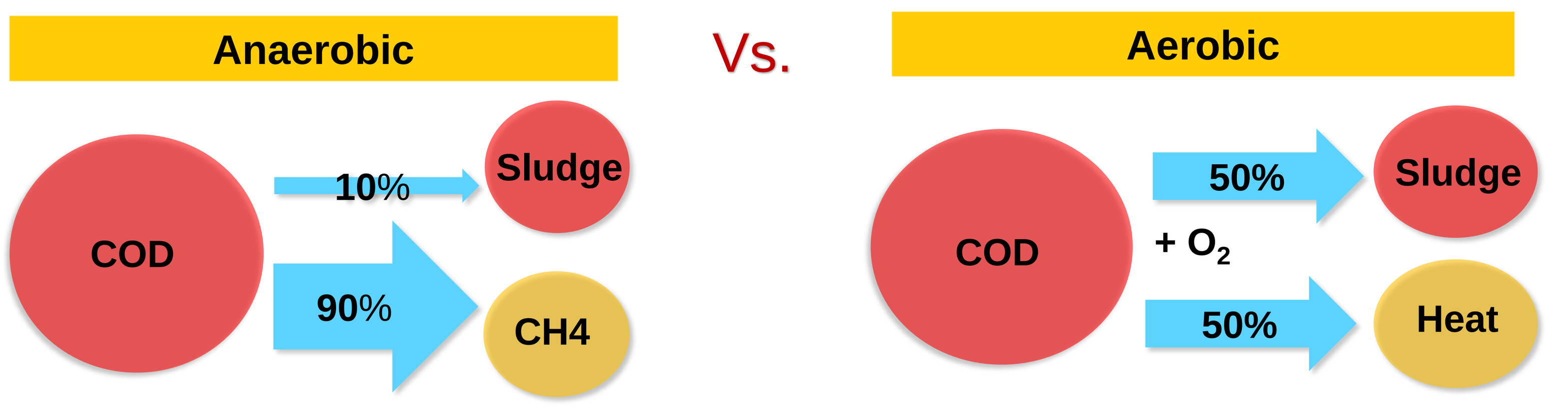
Background. Industrial wastewater is a major source of water pollution due to its elevated organic content. High-strength wastewaters are typically defined as those with organic concentrations in the range of 1,000 - 200,000 mg COD/L [1]. Examples of these industries include: breweries & beverages, food, distilleries & fermentation, pulp & paper, chemical & petrochemicals, textile, and landfill leachates.

Biological wastewater treatment provides excellent economic advantages over other treatment processes not only in terms of capital investment and operating cost, but also the opportunity it provides towards the conversion of waste into renewable energy source [2,3]. In addition, unlike other physico-chemical treatment processes, biological treatments can efficiently degrade industrial compounds without generating toxic by-products [4].

However, conventional biological treatment processes fail to stabilize high-strength wastewater to regulatory limits. Aerobic treatment processes are not economically feasible for the treatment of high-strength wastewater. Anaerobic processes suffer from low growth rate of the microorganisms, high sensitivity to toxic loadings, fluctuations in environmental conditions, and require post treatment to bring the water quality within regulations [5,6].

Objective. This work aims at developing an integrated anaerobic-aerobic granular bioreactor (IA^2GBR) combining the benefit of anaerobic digestion (i.e., biogas production) with the benefit of aerobic treatment (i.e., better removal of organics). The combined system will overcome the limitations of both anaerobic and aerobic systems, such as long treatment duration and low stability due to rapid bacterial growth, respectively.

In this project, biogranulation, formed by the self-immobilization of microorganisms, would be employed as a novel technology in an up-flow semi-pilot-scale bioreactor. These granules are dense microbial communities packed with different bacterial species, and typically contain millions of organisms per gram biomass. Individually, they are not capable of completely degrading wastewaters. However, interactions within the resident species can achieve rapid treatment for high volumes of wastewater in a smaller footprint when compared to conventional biomass [7,8].



Anaerobic + **Aerobic**

Biogas production

- ✓ Less disposal of sludge
  - ✓ Nitrification and denitrification
- ✓ Biological phosphorus removal

Better removal of organics

- ✓ Excellent effluent quality
  - ✓ High overall treatment efficiency
- ✓ Reduction in operating costs

✓ Stabilization of high-strength wastewater

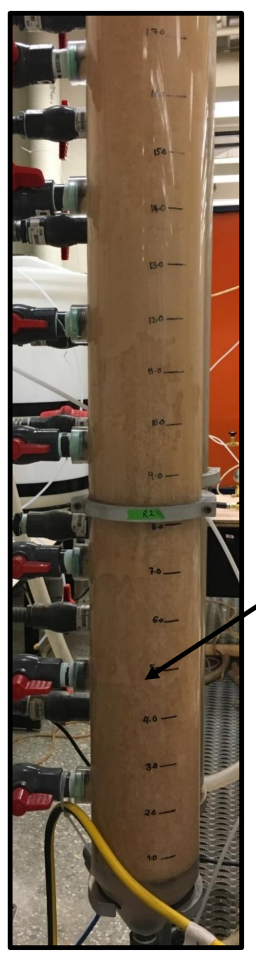
METHODS

Experimental setup

- Two cylindrical acrylic reactors with an internal diameter of 150 mm and a working volume of 20 L were used in a sequencing batch reactor (SBR) mode to cultivate the base aerobic granules.
- Aeration was provided by means of fine air bubbles diffusers located at the bottom of the reactor with an air flow rate of 28 L/min (superficial upflow air velocity of 2.8 cm/s).
- Influent was introduced through a port located at the bottom of the reactor while effluent was discharged through an outlet port placed at intermediate height of the reactor resulting in a volumetric exchange ratio of 60%.
- The reactor was operated initially at 3.4 h per cycle sequentially: 8 min of influent filling, 186 min of aeration, 8 min of settling, and 2 min of effluent withdrawal. The cycle was adjusted to 4 hours by extending the aeration period to 221 mins after 4 weeks of operation.
- After maturation, one of the reactors was converted to operate under anaerobic conditions (i.e., upflow anaerobic sludge blanket – UASB).

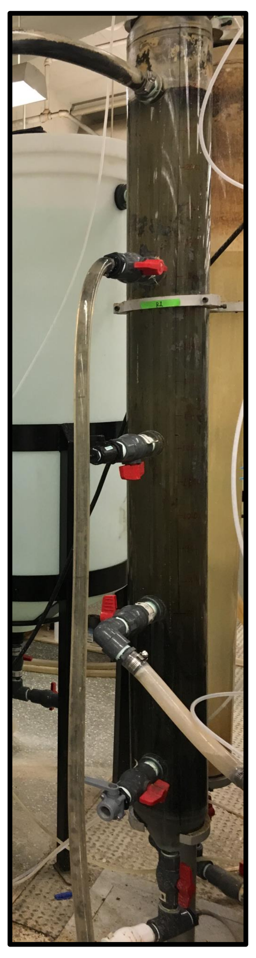
Medium composition

- Synthetic wastewater consisted of sodium acetate as sole carbon was used.
- Essential nutrients for biomass synthesis, namely nitrogen, N and phosphorus, P were supplemented in the form of NH_4Cl and a buffer solution of potassium phosphate (KH_2PO_4 and K_2HPO_4).



Granule cultivating SBR

Granular bed



UASB reactor

RESULTS

Granule formation and biomass characteristics

- Granulation started after 3 days of operation.
- The reactors were granule-dominated after 2 weeks (diameter 1-2 mm).
- Mature granules of diameter 2-3 mm were achieved after 30 days of operation.
- Mixed liquor suspended solids (MLSS) concertation continued to increase to reach 25 g/L (75-80% volatile).
- Sludge settleability improved drastically to reach sludge volume index (SVI) of less than 30 mL/g, with SV30/SVI5 > 0.9 (i.e., no compression settling).

Mature aerobic granules (after 3 weeks of cultivation)

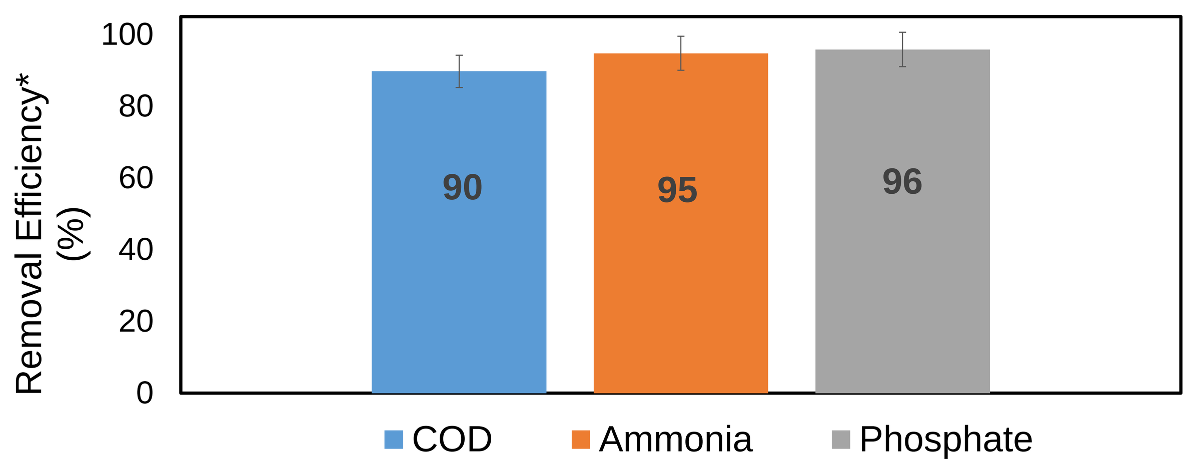
5-min settling

Granules vs. activated sludge characteristics

Parameter	Acetate-fed Granule	Activated Sludge
Average diameter (mm)	2 – 3	0.15
SVI (mL/g)	30 – 50	150 – 250
Biomass concentration in reactor (g/L)	17 ± 5	3 – 5

System performance: organics and nutrients removal efficiencies

- In an 105 days experiment, the average COD, ammonia, and phosphate removal efficiencies were 90%, 95%, and 96%, respectively.
- Effluent ammonia and phosphate concentrations were below detection levels (0.01 mg/L)



*Influent wastewater characteristics

COD (mg/L)	NH_3-N (mg/L)	PO_4 (mg/L)	OLR (g/L.day)
2500 – 8000	80 – 200	20 – 70	10 – 35

CONCLUSIONS AND FUTURE WORK

This work presented the first attempt on the treatment of high-strength wastewater using anaerobic-aerobic granular bioreactors.

- Aerobic granules were successfully cultivated using acetate based substrate in 3 days only in a 20 L column type upflow reactor.
- Treatment of high-strength wastewater at COD concentrations up to 8,000 mg COD/L and at organic loading rate (OLR) up to 30 kg COD/m^3.day was successfully achieved.
- Experimental results of over 100 days showed stable aerobic granules, providing COD treatment efficiency exceeding 90% with effluent quality meeting discharge standards.
- Aerobic granular sludge was successfully converted to anaerobic granules, offering the advantage of granule formation in a much shorter time (7 – 10 days), compared to 2 – 8 months for anaerobic granules.
- Future work will investigate the treatment efficiencies of a sequential anaerobic-aerobic granular systems for target COD concentrations up to 25,000 mg/L.

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