Innovative radial to axial flow distribution in a low-cost anaerobic fluidized bed system for wastewater treatment

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Highlights:

- Assembly of a low-cost bench-scale anaerobic fluidized bed system.
- Potential of fluidization in biofilm reactors for sanitation.
- Assessment of operational conditions of the anaerobic fluidized bed reactor.

Keywords: Bioreactor; fluidization; biofilm.

INTRODUCTION

Over the years, the importance of wastewater treatment has become increasingly evident in reducing environmental damage. Efficient and effective wastewater treatment reduces pollution and allows water to be reused, thus promoting environmental conservation, sustainability and also generating energy (Dutta et al., 2023). Therefore, it is crucial to explore alternative solutions that can be implemented to optimize the efficiency of wastewater treatment plants (Paritosh and Kesharwani 2024).

Among the alternative processes used, fluidization has emerged as an effective method of wastewater treatment. Although typically used in industrial processes such as drying, granulation and combustion, it can also be applied to wastewater treatment using attached film bioreactors. In this specific case, the biofilm grows attached to a solid material kept moving in the medium under the fluidized regime. It is noteworthy that the assembly of low-cost bench-scale fluidized bed reactors assists in better understanding the process of wastewater treatment and encourages the use of these systems in the implementation of new wastewater treatment plants.

A low-cost fluidization unit was constructed to develop this research. The study assessed the treatment of organic wastewater under anaerobic conditions. Three modifications were performed to the fluidization process typically applied to carry out this research: (i) recirculation was performed from a feeding/stabilization/sedimentation tank; (ii) flow distribution was performed from the radius to the axis of the reactor instead of the classical upward flow distribution from the bottom of the reactor and (iii) the usage of a ratio of height to diameter (H/D) of approximately 2 for the reactor, much smaller than the typical values used that vary from 5 to 35 (Morais 2016). This flow distribution pattern, though demonstrated in a lab-scale reactor, could be upscaled by integrating custom distribution nozzles and enhanced recirculation mechanisms to accommodate larger reactors. Future studies may focus on these engineering adaptations for industrial applications.

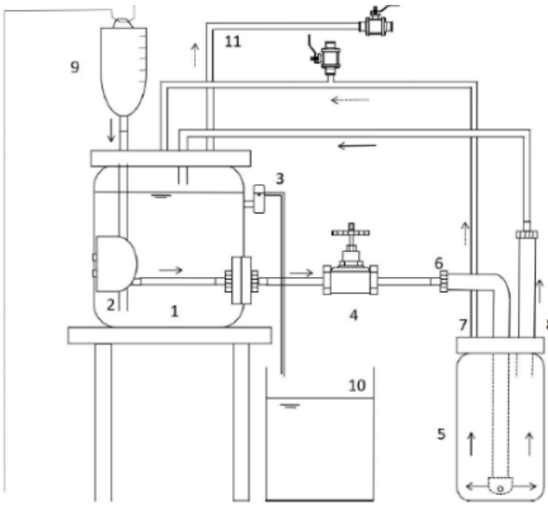
METHODOLOGY

The reactor design and operational conditions are grounded in well-established principles of fluidization and biofilm formation (Heijnen et al., 1989; Jaafari et al., 2014), with this study aiming to refine these parameters for improved wastewater treatment.

As shown in Figure 1, the anaerobic fluidized bed system (AnFBS) is composed of (1) settling/mixing tank, (2) a submerged recirculation mixing pump, (3) effluent outlet syphon, (4) globe valve, (5) anaerobic fluidized bed reactor (AnFBR), (6) feeding (inlet) tube, (7) gas outlet (vent), (8) effluent outlet, (9) feeding tank, (10) outlet tank, (11) system's gas outlet,. The dimensions of the AnFBR were: (i) total volume of approximately 1.9 L, (ii) height (H) of 22 cm and (iii) diameter (D) of 10.5 cm. A volume of 0.8 L of sand, used as a solid material for biofilm growth, was added to the reactor. Two sedimentation tank (ST) configurations with different H/D and total volume ratios were evaluated.

The minimum fluidization velocity was calculated based on the Ergun equation and adapted to the granular media used. The biofilm in this study developed on granular sand particles, simulating the attached-growth form necessary for fluidized systems.

Figure 1 – Bench-scale anaerobic fluidized bed system



Following the procedures tested by Morais (2016), the AnFBR was inoculated with a culture of anaerobic microorganisms acclimated in static bench-scale reactors for 80 days at a final volumetric organic load of 0.40 kg/m³.d. Landfill leachate with added glucose (50% of the chemical oxygen demand (COD) value of each source) was used as a substrate during acclimation. Initial tests to evaluate the performance of the fluidization system to remove organic matter were firstly carried out with the same substrate used during the acclimation, and subsequently with synthetic wastewater.

Two AnFBS were assembled, one used as control and the other for hydraulic testing. Flow distribution, response to temperature changes, fluidization, sedimentation and drag tests were carried out, similar to those performed by Morais et al., (2022). In addition, the start-up of the reactor at reduced COD concentrations was evaluated. Table 1 presents the conditions used to perform each test.

Table 1 – Operational characteristics of hydraulic tests applied to the fluidization system

	Drag test	Sedimentation test	Temperature test	Distribution test	Fluidization test
Goal	Identification of dragging of solid material	Evaluation of the behavior of the system resulting from the use of each sedimentation tank	Evaluation of the influence of temperature change on the system	Evaluation of the number and sizes of distribution holes	Evaluation of fluidization characteristics
Flow rate of the recirculation pump (m^3/h)	0.1 - 0.5	0.1 - 0.5	0.1-0,5	0.1-0.5	0.1-0.5
Diameter of sand (µm)	357 and 505	357	357	357	357 and 505
Amount of sand ($V_{MS}/V_{útil}$)	20% and 40%	40%	20% and 40%	40%	20% and 40%
Durantion of the tests	1 hour for each flow rate applied	During start-up and continuous operation of the reactors	Until the stabilization of temperature, as a result of the heating of the system	1 hour per flow rate applied, for each distributor	At least 30 minutes for each condition applied to the system
Method	Weighing of solid material in the sedimentation tank	Evaluation of biofilm formation, accumulation of solid material, intensity of mixing, hydraulic conditions at the inlet and outlet of the system	Measurement of temperature according to the time of system's operation	Evaluation of fluidization characteristics, formation of dead zones and flow distribution related to the flow distributor used	Determination of fluidization intensity as a function of operation time and flow rate applied

RESULTS AND CONCLUSIONS

As a result of the tests applied to the fluidization systems, it can be pointed out that:

- the minimal experimental fluidization velocity of 10.8 m/h±0.5 was higher than the calculated theoretical value, as observed by Morais et al., (2022);

- the flow distributor with four 4 mm holes was associated with the best flow distribution, with fewer dead zone formations and preferential flow paths. A higher number of holes resulted in clogging and a reduction in fluidization intensity;

- during the first 7 days of operation it was observed that approximately 50 g of solids were dragged from the system. However, during the remaining period of operation, during maintenance operations, an amount of dragged solids less than 1 g was observed;

- an increase in system temperature of approximately 10ºC was observed as a result of the use of a submersible pump;

- over a period of 70 days of operation, an increase in COD reduction efficiency from 46.7% to 64.9% was observed.

Future research should explore Computational Fluid Dynamics (CFD) simulations or intermediate-scale tests to assess deviations in flow distribution patterns when transitioning from bench-scale to larger systems, as done by D'Bastiani et al., (2021).

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