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Modelling head losses in granular bed anaerobic baffled reactors at high flows during start-up

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ABSTRACT

Anaerobic treatment of low strength, high flow wastewaters can only be effective if the technology employed can meet key hydrodynamic requirements: maximising the contact surface area and contact period between the influent substrate and the biomass solids, minimising solid washout from the reactor and minimising the backpressure across the system. Backpressure or head loss is an important hydrodynamic property of gravity-flow packed bed reactors, where the flow is the resultant of frictional forces between the incoming fluid and the solid packing material through which the wastewater percolates. Excessive backpressure caused by high influent flow-rates can reduce the contact surface area and increase the influent head on the upstream side of the biomass bed leading to overflow spills, unstable performance and process failure. This study investigates the factors affecting backpressure across a Granular bed baffled reactor (GRABBR) with variable baffle positions. Experimental results were used to develop a mathematical model to quantify backpressure based on physical characteristics of the seed biomass, fluid-flow conditions and reactor geometry. Results have shown that for a constant flow rate the anaerobic baffled reactor exhibits the least backpressure characteristics when both the upflow and downflow areas are roughly 50% of the total compartmental width.

1. Introduction

The granular bed baffled reactor (GRABBR) is one of the high rate, gravity-flow systems for anaerobic treatment of wastewaters. It combines the advantages of the anaerobic baffled reactor (ABR) and the upflow anaerobic sludge blanket (UASB) by utilising granular biomass and anaerobic phase separation characteristics. The performance characteristics of the GRABBR have already been well documented (Baloch and Akunna, 2003b; Shanmugam and Akunna, 2008). Comparative studies have shown the GRABBR to possess superior process stability than the UASB at very high hydraulic loading rates (Shanmugam and Akunna, 2008). Anaerobic treatment of low strength and high flow wastewaters such as domestic sewage is a potential important area of application for the GRABBR.

High wastewater flow rate can bring about poor process performance for most biological wastewater treatment systems. The resulting high velocity can cause fluidisation within the reactor, disturbing the settling time of biomass which can lead to extensive biomass washout. It may also cause influent short-circuiting and channelling within the

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biomass bed forming dead-spaces that can further decrease the contact rate (Baloch and Akunna, 2003b).

Effective treatment under high flow conditions can be accomplished by retaining sufficient amount of biomass within the reactor and prolonging the contact time between the influent wastewater and the biomass in the reactor vessel (Bhatti et al., 1994; Langenhoff et al., 2000; Baloch and Akunna, 2003a). Thus, the reactor must be capable of achieving high solids retention time (SRT) relative to the hydraulic retention time (HRT) of the wastewater flow (Barber and Stuckey, 1999; Nachaiyasit and Stuckey, 1995). Hence, the study of the hydrodynamic properties of any treatment system is necessary in order to ensure optimal performance of the system.

Backpressure is an important hydrodynamic property of high rate gravity-flow reactors that can disrupt the influent flow pattern and reduce the contact period between the wastewater and the seed biomass. Backpressure refers to the flow resistance arising out of friction between the influent and the solid media through which the influent percolates (McCabe et al., 1993). This phenomenon is common in gravity filters and causes a pressure difference across the media that the flow has to overcome in order to percolate through the system. In gravity-flow systems this pressure difference causes an increase in the upstream influent level until sufficient pressure-head builds up to counteract this backpressure. Excessive backpressure can cause overflows, leakages or flow-reversal that can result in shutdown and lengthy recovery periods.

Biogas production within the anaerobic reactor can increase bed porosity and mixing (Grobicki and Stuckey, 1992; Gopala Krishna et al., 2008) causing a reduction in backpressure. However, stable biogas formation requires successful reactor start-up that is possible only with adequate surface contact between the seed biomass and the influent substrate. Backpressure at start-up can cause flow channelling restricting biogas formation by limiting the contact surface area.

Backpressure is an important design criterion when using any gravity-flow system containing high density and high settling biomass, such as the GRABBR, which minimises biomass washout. This research work investigates the role of variables such as biomass bed sizes and internal flow velocities on the occurrence and magnitude of backpressure during start-up when gas production is generally low or negligible. Variations in internal flow velocities were obtained by changing the baffle positions and influent HRT within the GRABBR compartments. The results were then used to develop a mathematical model for simulation of backpressure at various influent velocities and biomass bed heights.

Table 1 – Variation of compartment sections with baffle position.

Baffle position	Downflow area	Upflow area
1st	12%	88%
2nd	33%	67%
3rd	55%	45%

2. Materials and methods

2.1. GRABBR

The laboratory scale reactor used in this experimental study was constructed using Perspex (Fig. 1) with external dimensions of 61.7 cm × 18 cm × 33.7 cm for length, width and depth respectively. It consisted of five symmetric compartments and the total working volume was 10 L or 2 L for each compartment. Each compartment comprised of an influent inlet port and exit port separated by a hanging baffle that divides the compartment into downflow and upflow sections. The baffle could be placed within three different slots grooved within each compartment. The GRABBR was said to be in 1st baffle position when the hanging baffle was placed in the 1st slot in all the compartments. Similarly 2nd and 3rd baffle positions were obtained by fixing the baffles into their corresponding slots. There were three sampling ports per compartment. The relative proportions of downflow and upflow sections of each compartment for various baffle positions are indicated in Table 1.

A water jacket enclosed the GRABBR on three sides for temperature control and the fourth side was left open for observation and sampling purposes. Sampling ports were provided for collecting biogas, effluent and biomass from all the compartments.

2.2. Seed sludge

Granular seed sludge was obtained from a 1600 m^3 UASB plant from Davidsons Paper Mill in Aberdeen, UK. The reactor has been in operation for more than 10 years at mesophilic temperature (35 °C). The sampling point for the granular sludge was 2 m above the sludge bed.

2.3. Experimental procedure

Each compartment of the reactor was initially seeded with 200 ml of granular sludge (i.e. 10% capacity) and configured to

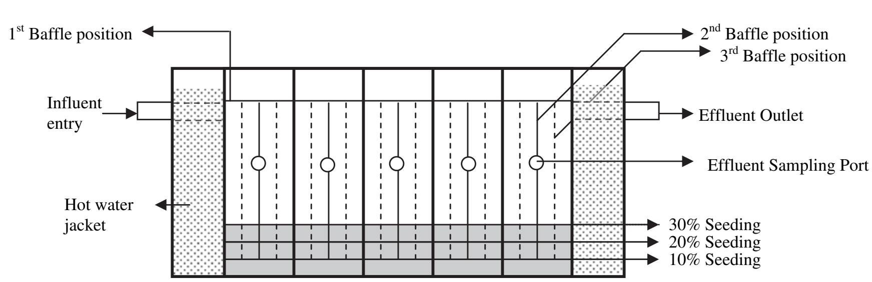

Fig. 1 – The granular bed baffled reactor (GRABBR).