Understanding the criticality of granule integrity to resilience of anaerobic wastewater treatment

Yolanda Aguilera, Elise Cartmell, Ewan J. McAdam, John N. Lester
Elise Cartmell
Cranfield University, Cranfield, Bedfordshire, UK

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Introduction
The efficacy of an expanded granular sludge blanket reactor (EGSB) can be directly correlated to the well-being of the granular matrix as it is the granular matrix which enables both carbon reduction and methane production (Siggins et al., 2011). Equally important are the process hydrodynamics which maximise treatment performance by promoting mass transfer through fluid pumping and the turbulence induced by gas formation within the granules (J. Wu et al., 2006). However, the granule structure is a dynamic environment bound together in a polymeric structure which is prone to attrition over time. This effect is exacerbated when EGSB are operated in non-ideal conditions. An example of this is the adaptation of EGSB to the treatment of temperate domestic wastewater which has gained significant attention in recent years (J. Wu et al., 2006). The low temperatures and low substrate concentrations of these wastewaters in temperate regions coupled to the high half saturation kinetic values ($K_s$), reduce the rate of anaerobic organic biodegradation increasing the risk of anaerobic community instability and the subsequent loss of granule structure. In addition to treatment performance problems, structural failure of the granule will result in bacterial washout. This study therefore develops analytical test methods following adaptation from those proposed by Pereboom (1997) to understand the strength of granules in process systems and subsequently to identify the granules integrity following exposure to process perturbation.

Methods
An attrition test was designed with the purpose of assessing the granule strength in ex-situ conditions to provide a controlled shear environment. The test was carried out using eight columns of 40 mm diameter (Pereboom, 1997). Gas and liquid were recirculated. Gas shear rates ($\gamma$) up to 800 s$^{-1}$ were applied. Air was used to provide shear analogous to biogas bubbling to ensure controllability (Varma and Al-Dahhan, 2007). Gas flow rates ranged from 0.05 L min$^{-1}$ to 5 L min$^{-1}$ and liquid flow rates in the range of 0.08 L min$^{-1}$ to 0.5 L min$^{-1}$ to provide upflow velocities analogous to those encountered in typical range of EGSB (1 - 6 m h$^{-1}$).

Size distribution was carried out following the methodology described by Phung K. Le, (2011), the diameter and structural properties of the granules were measured by digital image analysis (Etterer and Wilderer, 2001), the density was determined using gradiated glycerol solutions and the settling velocity calculated according to Etterer and Wilderer (2001). The granular sludge was characterised before and after the attrition test to evaluate the robustness of the granule.
Results
Digital images proved granule diameter in addition to qualitative information on occlusions and ‘scarring’ (Fig. 2).

![Image of anaerobic granules](image)

Fig. 2. Digital image of anaerobic granules. Image taken by light microscope (Model + magnification).

Settling velocity was correlated to granule diameter (Fig. 3). A linear trend was established between granule diameter and settling velocity, with a maximum velocity of 5.06 cm s\(^{-1}\) recorded for a granule of diameter 2.8 mm.

![Graph of settling velocity vs. diameter](image)

Fig. 3. Settle velocity (cm s\(^{-1}\)) correlated to granule diameter. Granule diameters tested 1 mm to 3.35 mm.

Discussion and Conclusions
In the seed population, granules are characterised by a uni-modal population illustrative of a robust granule. Grotenhuis (1991) related size distribution to the growth or disintegration of the granules and the substrate concentrations. However the stability was supported by a lack of granule ‘scarring’ on the surface of the granules (Fig. 2). Importantly, within this size population, granules exhibit high settling velocities since diameter (d) governs settling rate (Eq. 1):

\[
V_s = \frac{g(d - d_c)d^2}{18\mu}
\]

On the basis of this work, for the nominal conditions operated within an EGSB for temperate domestic wastewater, the critical granule diameter is not exceeded, thus ensuring settling velocity does not exceed the superficial \(V_L\) of 1.3 m h\(^{-1}\) (0.036 cm s\(^{-1}\)) fixed within the reactor. Critically, shear produces an increased population of fine which can be characterised by lower particle diameters and low settling velocities. Results from shear tests will be illustrated and compared to granule samples extracted from an EGSB at 3 months, 6 months and 12 months operation on real domestic wastewater in temperate (unheated) conditions with a remit to optimise hydrodynamics and extend the life of granular systems operated on extreme conditions.

References


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