

Studies on the expansion characteristics of the granular bed present in EGSB bioreactors

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Abstract

In this study, the expansion characteristics of an anaerobic granular bed in EGSB reactors based on terminal settling velocity study of the granules and the Richardson-Zaki equation (1954) have been investigated. The settling velocity study shows that the mean settling velocity of the granules is in accordance with the Allen formula because the settling process falls within the intermediate flow regime range ($1 < Re_t < 110$) rather than in the laminar flow regime range; the bed expansion study based on the above conclusion is found to be similar to that suggested by the Richardson-Zaki equation. The validity of the settling velocity model is verified by using the operating parameters of several full-scale anaerobic reactors with an average relative error of 3.77%, and the bed expansion data obtained from two laboratory-scale reactors are used to test the correlation with an average relative error of 2.64% and 4.57% respectively. Moreover, it could be a theoretical method to propose a suitable value of V_{up} during different operation periods of an EGSB system.

Keywords: UASB, EGSB, granular bed expansion, mean settling velocity, modelling, Richardson-Zaki equation

Notation

d_p	granule diameter by wet sieving (m)
g	gravitational acceleration ($m \cdot s^{-2}$)
H	bed-expansion height (m)
H_0	initial bed height (m)
n	expansion index
Re_t	Reynolds number at terminal velocity
u_t	mean settling velocity of the granules (m/h)
V_{up}	upward liquid velocity (m/h)
μ	the viscosity of wastewater (Pa.s)
ε_0	preliminary bed voidage
E	bed voidage
η	bed expansion
ρ	the density of wastewater ($kg \cdot m^{-3}$)
ρ_p	the density of the granules ($kg \cdot m^{-3}$)

Introduction

The expanded granular sludge bed (EGSB) reactor, a novel variation on the upflow anaerobic sludge blanket reactor (UASB) concept in combination with the anaerobic fluidised-bed reactor (AFBR), has recently experienced tremendous growth. Although UASB is still the predominant technology in use, EGSB-type processes are now gaining more popularity driven by economics (Frankin, 2001).

Similar to UASB technology, the EGSB reactor relies on the self-immobilisation properties of micro-organisms and the

development within the reactor of a granular biomass with good settling properties. Compared with conventional UASB reactors (0.5 to 2 m/h), the advantage of the EGSB system (> 4 m/h) is the significantly better contact between sludge and wastewater. So it is widely believed to be a potentially high-rate anaerobic reactor by experts from different countries (Seghezzi et al., 1998; Hulshoff et al., 2004).

The knowledge of the bed expansion plays an important role in the design and operation of an EGSB reactor, because it is the key point to reach a compromise between bed expansion and sludge washout, and the stability and performance of the EGSB system would be sensitive to the degree of expansion (Liu et al., 2002). Therefore, quantitative research on bed expansion in EGSB reactors is necessary, although few reports are found in the literature.

In fact, the bed expansion is closely related to the settling characteristics of the sludge, hence the settling characteristics of the granules have to be discussed first.

The mean settling velocity is generally used to evaluate the settling characteristics of the granules. Almost all previous work published suggests that the mean settling velocity of the granules is in accordance with Stokes' law because the settling process is in the laminar flow range (Hulshoff, 1989; Hu, 2003; Field, 2005), whilst others suggest that it is in accordance with the Allen formula because the settling process falls within the intermediate flow range (Wang, 2002). However, the settling characteristics of the granules have scarcely been discussed theoretically by the above workers.

To the best of our knowledge, there has been no report yet on the quantitative relationship of the bed expansion in EGSB reactors, partly due to the lack of an approved method to determine the settling velocity and Re_t of the granules.

The objective of this study is to focus on the bed expansion characteristics of EGSB reactors on the basis of settling velocity study of the granules.

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