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Biofluid mechanical investigations in sequencing batch reactor (SBR)

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Abstract

In the present contribution experimental and numerical investigations of multiphase flow in a sequencing batch reactor (SBR) are presented. In the bioreactor the formation and growth of granular activated sludge (GAS) with diameter up to 5 mm occurs. In order to experimentally analyse multiphase flow patterns in a mixture of water, air and granules in the SBR, optical in situ techniques are applied. Particle image velocimetry (PIV) and particle tracking velocimetry (PTV) are employed to observe the velocity fields of fluid and granules. For the three-dimensional numerical simulation of the flow problem the Euler–Euler approach is used. The comparison of experimental and numerical results shows a lot of similarities. The characteristic flow patterns can be observed in three zones of the SBR. It can be shown that effect of normal strain rate up to $\dot{\varepsilon} = 15\,s^{-1}$ and shear strain rate up to $\dot{\gamma} = 15\,s^{-1}$, besides biochemical activities have a major influence on the formation, shape and size of the granules in the SBR under aerobic conditions.

Keywords: Multiphase reactors; Fluid mechanics; Simulation; Visualilsation; Particle image velocimetry (PIV); Particle tracking velocimetry (PTV)

1. Introduction

The sequencing batch reactor (SBR) cycle is used for biological purification of wastewater. It is a suspended growth process in which all major steps occur in the same tank in sequential order (Liu and Tay, 2004). In comparison to conventional activated sludge (CAS) the granules are characterised by a higher density, a compact shape, high biomass retention, a characteristic diameter up to 5 mm and a good settling ability (Etterer and Wilderer, 2001; Tay et al., 2001).

Granulation is a complex process, in which many factors affect the structure and the composition of granules. According to Dolfing et al. (1987), Lettinga et al. (1980), Van der Hoek (1987), Van Loosdrecht et al. (2005), Etterer and Wilderer (2001), the substrate type and its composition have a significant influence on the formation of granules. The fastest granulation is obtained with glucose and peptone as a carbon source. Furthermore, high feast–famine regime with pulse feeding is necessary for compacted granules formation (McSwain et al., 2004).

The superficial gas velocity (SGV) is one of the most important parameters for granules formation and structure. It is estimated as a ratio of air flow rate $\overset{\circ}{V}$ and cross-sectional area A of bioreactor. According to investigations carried out by De Kreuk et al. (2005), granules reach a maximal diameter if SGV $= 2\,cm/s$. The significant role of SGV in the granulation process is confirmed also by Tay et al. (2001). They investigate the operation of three bioreactors with the same geometrical configuration (800 mm height and 60 mm in diameter) and working volume of 2.0 l. Granulation process is compared for different SGV of 0.3, 1.2, and 2.4 cm/s, that is equivalent to a flow rate of 0.5, 2 and 4 l/ min, respectively. During these experiments no granulation is observed for the case with the lowest flow rate. In contrast, formation of aerobic granules can be stated at higher velocities. In that condition, they have a more regular and rounded shape. Additionally, SGV generates substantial hydrodynamically induced mechanical stress (Tay et al., 2001). This stress can be classified as shear stress due to relative motion between particle and fluid (Henzler, 2000), normal stress due to pressure (gradients) and velocity gradient and turbulent stress due to rapid velocity fluctuations. Trinet et al. (1991), Oashi and Harada (1994) and Tay et al. (2001) report

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that high hydrodynamic stresses can stimulate the production of extracellular polymeric substances (EPS). EPS act as a kind of glue substance between the microorganisms of an aggregate (Liu and Tay, 2001, 2002). According to Tay et al. (2001) this substance also plays an important role in the formation and maintenance of aerobic granules.

Although many research groups try to explain the mechanism of granules formation, the effect is not completely understood at present. The scientific investigations concentrate more on the study of microbiological, chemical, biological and physical aspects. In contrast, the granulation is not studied in details from the fluid mechanics point of view. At present, only few information concerning the influence of shear and normal stress on granulation is available (Esterl et al., 2002; Hartmann and Delgado, 2003; Díez et al., 2007). As mentioned above, it is supposed that the hydrodynamic effects have a key influence on the formation and structure of granules in SBR. Therefore, a better understanding of the role of fluid mechanics in this process is required.

Consequently, the fluid dynamic investigations of multiphase flow in a SBR are considered in the present paper. In order to observe the velocity distribution, experimental in situ techniques with particle image velocimetry (PIV), particle tracking velocimetry (PTV) as well as numerical simulations are carried out. The experimental and numerical results are compared herein. Furthermore, an estimation of the shear and normal stress acting on granules are presented.

2. Methods

2.1. Experimental setup

Granular sludge is grown in a laboratory scale SBR. Our SBR bioreactor model is based on this used by McSwain et al. (2004). The cylindrical bioreactor is constructed as a plexiglas tube of 90 mm diameter and 1000 mm height. It is filled with 4 l of fluid. SBR is fed with a synthetic wastewater with a composition suggested by McSwain et al. (2004). The reactor is inoculated with granules from the Mc Swain's bioreactor, which are grown from a municipal wastewater treatment plant (initial mixed liquor suspended solids 2.5 g/l) in Garching (Germany). SBR is operated with a total cycle length of 6 h that gives four cycles per day. Every cycle consists of five steps (fill, react, settle, draw and idle). The react phase (the longest part of the cycle) is the most important for our experimental and numerical studies. At this stage, interactions between granules, air and fluid appear and here investigations are carried out. Bioreactor is aerated by sandy, cylindrical disperser (height—50 mm, diameter—30 mm) which is placed on the bottom of the SBR. Based on the experimental results of McSwain et al. (2004), air flow rate of 4 l/ min provides good granulation conditions. The schematic SBR process with its cycle timing is shown in Fig. 1. The cycle is controlled automatically.

Biofilm growth in bioreactor is discarded every day (McSwain et al., 2004). The wasted volume $V_{w/\mathrm{day}}$ is calculated using

$$V_{w/\mathrm{day}} = \frac{V_r}{t}, \qquad (1)$$

where V_r indicates reactor volume (4000 ml) and t is sludge residence time (SRT—40 days). After 40 days of bioreactor operation 100 ml granules per day are wasted.

2.2. In situ techniques

For the experimental analysis of the multiphase flow pattern in the bioreactor, optical in situ techniques are employed. The circular cross-sectional shape of the bioreactor is appropriate for practical purposes in waste water cleaning but inconvenient for optical investigation due to light refraction effects. In order to avoid these effects the tubular bioreactor is immersed in a rectangular plexiglas basin which is filled with water. Such a configuration leads to a significantly improved optical accessibility of the SBR interior. The scheme of the experimental setup is depicted in Fig. 2.

He–Ne laser and video lamp are used as two independent light sources applied for two different measurements techniques. The plane of the He–Ne laser light sheet is arranged perpendicular to the camera optical axis. Because of a large granule concentration the laser plane is placed close to the bioreactor wall. The principal idea of measurements with He–Ne laser is shown in Fig. 3.

The video lamp is situated ahead of the bioreactor. Images are acquired by a high-speed CCD camera (MIKROTRON GmbH) with a macro-zoom objective allowing a maximum speed of 520 frames/s. In current case the images of flow patterns with a size of 860 × 1024 pixels are taken with two different speeds,

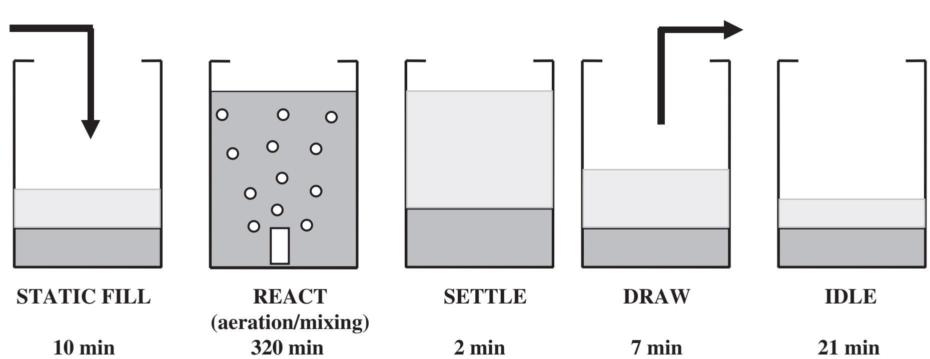

Fig. 1. Scheme of the sequencing batch reactor (SBR) cycle.