Journal of Environmental Management 81 (2006) 1–18
Journal of Environmental Management
www.elsevier.com/locate/jenvman

Review

Modelling anaerobic biofilm reactors—A review

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Received 7 October 2004; received in revised form 4 October 2005; accepted 5 October 2005
Available online 6 March 2006

Abstract

Anaerobic treatment has become a technically as well as economically feasible option for treatment of liquid effluents after the development of reactors such as the upflow anaerobic sludge blanket (UASB) reactor, expanded granular sludge bed (EGSB) reactor, anaerobic biofilter and anaerobic fluidized bed reactor (AFBR). Considerable effort has gone into developing mathematical models for these reactors in order to optimize their design, design the process control systems used in their operation and enhance their operational efficiency. This article presents a critical review of the different mathematical models available for these reactors. The unified anaerobic digestion model (ADM1) and its application to anaerobic biofilm reactors are also outlined.

Keywords: Mathematical model; UASB; AFBR; EGSB; Biofilter; Biofilm; Anaerobic

Contents

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0301-4797/$ - see front matter
doi:10.1016/j.jenvman.2005.10.002

1. Introduction

The term "biofilm reactor" refers to that class of bioreactors where the biocatalyst exists in an anchored form, either on the surface of an inert "carrier" or attached to one another. The carrier could be the wall of the reactor, baffles provided for this purpose or particles of some inert material. Biocatalysts such as microorganisms could also grow attached to one another, giving rise to a "biogranule". The carrier or the biogranule could be stationary as in a packed-bed or expanded bed system or mobile as in the case of a fluidized bed system. Typically, in such reactors, the rate of substrate conversion is limited by the rate of transport of substrate into the biofilm. In an anaerobic biofilm reactor, the biocatalyst will include all the different bacterial species responsible for the break down of complex organic molecules to a final end product consisting of methane and carbon dioxide. The anaerobic treatment, as the main biological step in wastewater treatment systems, was scarce until the development of the upflow anaerobic sludge blanket (UASB) reactor in the early 1970s (Lettinga et al., 1980). UASB processes are based on the development of dense granules (1–4 mm) formed by the natural self-immobilization of the anaerobic bacteria. This kind of immobilization does not employ any support material such as Raschig rings or clay in the reactor (Nicolella et al., 2000). A schematic of a typical UASB reactor is shown in Fig. 1. Wastewater enters the bottom of the reactor through the inlet liquid distribution system and passes upward through the dense anaerobic sludge bed. Because of the high biomass concentration, it was demonstrated that volumetric organic loading rates as high as 50 kg chemical oxygen demand (COD) per m^3 per day could be employed (Hulshoff Pol, 1989). The liquid velocity inside the reactor is usually in the range of 0.5–1.0 m/h. This reactor consists of a sludge bed, a sludge blanket and a clarifier zone supplemented with a physical device called the gas–solid separator.

In anaerobic fluidized bed reactor (AFBR), the liquid to be treated is pumped through a bed of inert particles (typically sand with a particle size range of 0.2–0.8 mm) at a velocity sufficient enough (10–20 m/h) to cause fluidization (Nicolella et al., 2000). In the fluidized state, the media provides a large surface for attached biological growth and allows biomass concentrations to develop in the range of 10–40 kg/m^3 (Cooper and Sutton, 1983). A typical flow diagram of an AFBR is shown in Fig. 2. Compared to other high rate anaerobic reactors such as UASB, the fluidized bed system is claimed to have the following advantages: higher purification capacity, no clogging of the reactor (as in filters), no problem of sludge washout (as in UASB systems if granular sludge is not obtained), and small volume and land area requirements (Heijnen et al., 1989).

To study the sensitivity of the process to various operating parameters and to optimize the design of these reactors, it is necessary to have mathematical models which

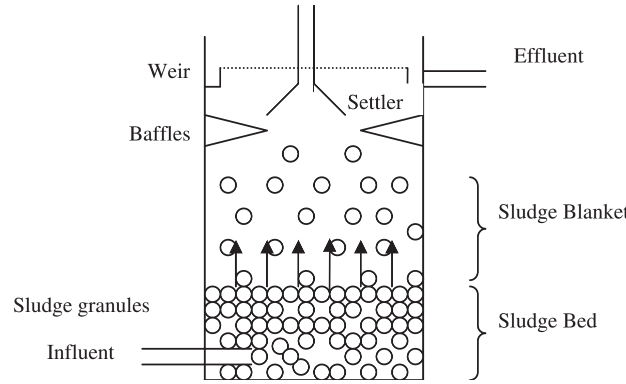

Fig. 1. Schematic diagram of UASB reactor.

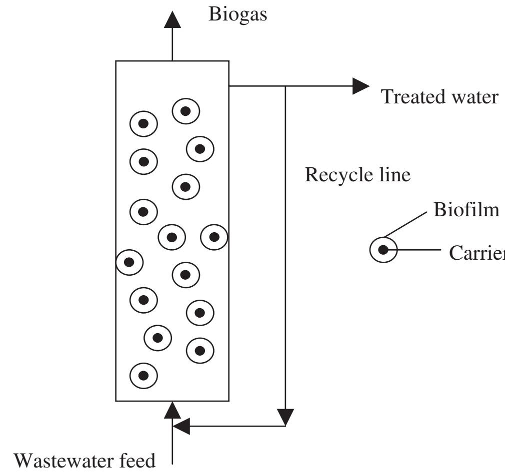

Fig. 2. Anaerobic fluidized bed reactor (AFBR).

are simple in concept and close to the physical situation existing in these reactors. During the past few decades there have been a number of studies on modelling of UASB and AFBR reactors. An effort is made in this article to present the gist of different approaches used in developing mathematical models for these reactors. This article also reviews different proposals available for modelling the structure of the biological granules and biofilm-covered particles in these reactors.

2. Models for UASB reactors

The formation of anaerobic granular sludge is considered to be a necessary condition for the successful operation of a UASB reactor. The efficiency of the reactor depends mainly on active biomass concentration and the influent flow rate. As the reactor reaches steady state, a dense bed composed of granulated sludge develops at the bottom. Immediately above the sludge bed, a zone consisting of finely suspended particles called the sludge blanket forms. A clear zone over this sludge blanket constitutes the settling zone. To keep the sludge granules in suspended condition inside the reactor, the inlet flow rate