Dimensioning of aerated submerged fixed bed biofilm reactors based on a mathematical biofilm model applied to petrochemical wastewater – the link between theory and practice

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ABSTRACT

The description of a biofilm mathematical model application for dimensioning an aerated fixed bed biofilm reactor (ASFBBR) for petrochemical wastewater polishing is presented. A simple one-dimensional model of biofilm, developed by P Harremöes, was chosen for this purpose. The model was calibrated and verified under conditions of oil-refinery effluent. The results of ASFBBR dimensioning on the basis of the biofilm model were compared with the bioreactor dimensions determined by application of load-based design rules for these systems (ATV standards). The differences resulting from two different approaches to ASFBBR design are analysed and discussed. The efficiency of the ASFBBR bioreactors, designed in two different ways, are then compared during dynamic simulation utilising the most advanced one-dimensional biofilm model developed by Wanner and Reichert (1996).

Keywords: Biofilm modelling; petrochemical wastewater; biofilm reactors

INTRODUCTION

Currently, applied aerated submerged fixed bed biofilm reactor (ASFBBR) design criteria are of an empirical nature. The design criteria have been developed on the basis of observations of many ASFBBR systems working under a variety of surface organic loading rates (SOL) and total Kjeldhal nitrogen loading rates (TKN-load). The results of these studies enabled the determination of the relationship between SOL or TKN-load and efficiency of organic contaminant removal or nitrification in ASFBBR reactors (Schlegel and Koeser, 2007; Chapanova et al., 2007; DWA/ATV-DVWK, 2002; DWA/ATV, 1997; DWA/ATV, 1991; Grady et al., 1999). In parallel, different types of mathematical models have been developed, taking into account their complexity and modelling objective (Mann and Stevenson, 1997; Henze et al., 2000; Morgenroth, 2000; Vanhooren, 2002; Wanner et al., 2006; Takacs at al., 2007). Authors such as Wilderer (2003), Harremöes (2003) and Rittmann (2007) emphasize the need to link theory with practice, for the transition from the design and operation of fixed bed biofilm reactors based on engineering pragmatism to the application of well-developed scientific theories. These authors indicate that this is a condition for the further development of biofilm technology and for meeting the future challenges of emerging contaminant removal from wastewater (Wuertz et al., 2003; Wanner et al., 2006; Rittmann, 2007).

Model-based ASFBBR system design is conducted by the calculation of organic matter or nitrogen removal rate per unit area of the reactor's bed, under the assumed technological conditions of the wastewater treatment process. The kinetics of contaminant removal is expressed in biofilm models in a mechanistic way, as a set of correlated mathematical equations, which describe basic (fundamental) processes and their relationships. Because of that, it might be assumed that this method of bioreactor dimensioning could be more accurate, precise and flexible in comparison to reactor design based solely on empirical criteria. Takacs et al. (2007) presented a new mathematical model of biofilm, developed for engineering purposes. In his publication, the results of simulations conducted with a calibrated model and data derived from other researchers' experiments on MBBR (moving bed bioreactors) and IFAS (integrated fixed film activated sludge) systems for municipal wastewater treatment were described. The results demonstrated that the model predicts the performance of these systems (nitrification) correctly. There is a lack of information in the available literature on model-based biofilm reactor dimensioning for industrial/petrochemical wastewater. The information presented in this paper concentrates on the application of a mathematical biofilm model to determine the minimum required area of bed media/minimum required bed media volume (the aim of biofilm reactor dimensioning) of an ASFBBR reactor for the final treatment of oil-refinery wastewater. Therefore, the process of organic carbon removal in ASFBBR was within the scope of all studies and simulations reported herein.

The aim of this article was to demonstrate how existing mathematical models of biofilm could be applied in engineering practice to ASFBBR reactor dimensioning. A simple, one-dimensional, mathematical model of biofilm (Harremöes, 1978) was chosen for this purpose, calibrated and verified under conditions of oil-refinery wastewater effluent. The assumed set of technological parameters utilised during reactor design was also derived from experimental studies on the full-scale wastewater treatment system of an oil-refinery. The results of ASFBBR dimensioning on the basis of the biofilms model were compared with the bioreactor dimensions determined by application of load-based design rules of these systems. Efficiency of the ASFBBR bioreactors, designed in two different ways, was

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