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Performance of anaerobic thermophilic fluidized bed in the treatment of cutting-oil wastewater

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Abstract

This paper examines the effect of organic loading rate on the removal efficiency of COD and TOC anaerobic thermophilic fluidized bed reactor (AFBR) in the treatment of cutting-oil wastewater at different hydraulic retention time (HRT) conditions. The essays are development at laboratory scale using a porous support medium.

The AFBR reactor was subjected to a programme of steady-state operation over a range of hydraulic retention times, HRTs, in the range 12–2 h and organic loading rates, OLRs, between 11.9 and 51.3 kg COD/m^3 d. The highest efficiency was 95.9% for an OLR of 13 kg COD/m^3 d and HRT of 11 h. Over an operating period of 92 days, an OLR of 51.3 kg COD/m^3 d was achieved with 67.1% COD removal efficiency (71.3% TOC) in the experimental AFBR reactor.

Although the level of biogas generation was not high, the anaerobic fluidized bed technology provided significant advantages over the conventional physico-chemical treatment applied in the factory. The effluent had a better quality (lower organic loading) and it was possible to reuse it in different applications in the factory (e.g., irrigation of gardens). The biological treatment did not lead to the generation of oily sludge, which is considered as hazardous waste by legislation. Furthermore, a continuous stream is produced and this reduced the impact of large flows discharged 4–5 times per week to the urban collector and MWWTP (municipal wastewater treatment plant).

Keywords: Thermophilic anaerobic digestion; Fluidized bed; Cutting-oil wastewaters

1. Introduction

The anaerobic treatment of industrial wastewater has become a viable technology in recent years due to the rapid development of high-rate reactors, such as the anaerobic filter and upflow anaerobic sludge blanket (UASB) (Fang et al., 1996; Lettinga, 1996; Dinsdale et al., 1997), both upflow and downflow stationary packed beds (Nebot et al., 1995; Perez et al., 1998, 2001; Romero et al., 2001), and fluidized or expanded beds (Garcia-Morales, 1997; Perez et al., 1997, 1998; Rodríguez-Cano, 2003). These developments are due to the fact that the methods combine a number of significant advantages – including low energy consumption, low excess sludge production, enclosure of odours and aerosols – over conventional aerobic methods with different activated sludge types for wastewater treatment (Ahring et al., 2002).

Interest in AFBR (anaerobic fluidized bed reactor) has grown as it combines the recovery of usable energy with good process efficiency and stability. Potential AFBR applications for the treatment of hazardous waste with inhibitory/recalcitrant compositions have also been reported (Seckler et al., 1996; Lin et al., 1998; Schreyer and Coughlin, 1999; Hansen et al., 1998; van Lier et al., 2001; Rodríguez-Cano, 2003).

Abbreviations: AFBR, anaerobic fluidized bed reactor; COD, chemical oxygen demand; COD_r, chemical oxygen demand removal; TOC, total organic carbon; TSS, total suspended solids; VSS, volatile suspended solids; HRT, hydraulic retention time; OLR_r, organic load rate removed; OLR_0, initial organic load rate.

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The treatment capacity of an anaerobic digestion system is primarily determined by the amount of active microbial biomass retained within the system, which in turn is influenced by wastewater composition, system configuration and operation of the anaerobic reactor. Unlike the conventional biofilm systems in which the growth support media are fixed in space either by gravity or by direct attachment to the reactor wall, the anaerobic fluidized bed system retains the growth support media in suspension by drag forces exerted by upflowing wastewater. Moreover, the distribution of biomass hold-up (in the form of a biofilm) is relatively uniform because of the completely mixed conditions maintained and the continuous biofilm sloughing process, which counterbalances the accumulation of biomass due to growth. Therefore, the anaerobic fluidized-bed system can be considered as a continuous-flow, completely mixed homogeneous microbial system (Tessele et al., 2002). The presence of growth support media in the reactor does not effect the interpretation of biomass hold-up in the anaerobic fluidized bed system. This is because the biomass hold-up can be directly measured in terms of attached volatile solids using the techniques developed by Shieh et al. (1985) and Mulcahy and Shieh (1987).

Cutting oils are emulsionable fluids that are widely used in metalworking processes (for lubrication and refrigeration during the machining of metallic pieces and, to a lesser extent, glass) (IHOBE, 1994). Cutting oils normally consist of oil, water and additives (fatty acids, surfactants, heavy metals, biocides, etc.) and generate toxic waste after prolonged use. Oily wastes derived from industrial processes are classified as Special Waste under current legislation. This means that there are restrictions on the movement, treatment and disposal of waste oil.

Opportunities for cleaner production mainly involve the reduction in the use of toxic materials, the prevention of the formation of large volumes of wastewater, hazardous waste or air emissions containing toxic pollutants and, finally, improvements in energy conservation. The breakthroughs outlined above should enable this manufacturing sector to improve environmental management and benefit from economies gained by speeding up the adoption of emerging technologies that will reduce waste and costs in terms of environmental compliance and energy expenditure (Tilche and Orhon, 2002).

Conventional approaches to recovering oil from spent cutting fluids do not lend themselves to oil recovery. Cracking stable emulsions and separating oil and water phases results in an oily sludge and large volumes of strongly acidic water, both of which require further treatment before they can be safely disposed of. New technological alternatives have been developed and different treatment combinations have been investigated (Cosmen, 1996; Ortíz de Zárate and Abia Aguila, 1997; Abdel-Gawad and Abdel-Shafy, 2002). Biological treatment has been used to remove metal-working fluids (i.e., to trap oil and solids from cutting fluids). However, these systems are prone to fouling by the free oils. In addition, the oil concentrate still needs to be disposed of and a large volume of water must be treated to separate a small (<5%) amount of oil. Generally, the oily wastes are too dilute to be incinerated.

The organic composition of the cutting-oil waste has led to numerous studies concerning the application of aerobic biological techniques to reduce the organic load in the cutting-oil waste. The applicability of anaerobic fluidized bed reactor has been demonstrated in the treatment of toxic and recalcitrant compounds, including cutting-oil waste (Schreyer and Coughlin, 1999). The anaerobic treatment of metal–cutting-oil fluid has been published by several authors (Kim et al., 1992; Sutton et al., 1994; Van der Gast et al., 2004). Nevertheless, the use of biological treatments requires further investigation.

The purpose of the study described here was to elucidate the treatment efficiency in a AFBR that decomposes cutting-oil wastewater. The experimental protocol was designed to examine the effect of organic loading rate on the efficiency of COD and TOC removal under different hydraulic retention times, HRT, conditions.

2. Methods

The study was conducted on a laboratory scale over a three-month period.

Description of anaerobic fluidized bed reactor (AFBR). The experimental system used in the lab-scale study consisted of a transparent Plexiglas column with a cross-section of 21.24 cm^2 and 135 cm in length. The bottom of the column was moulded into a conical shape in order to promote uniform fluidization of media and bioparticles (i.e., biofilm-coated media). Heated water was maintained at 55 °C and was pumped from a recirculation water bath through the constant temperature jacket surrounding the reactor.

The reactor was initially charged with 252.6 g of coated support medium (coated SIRAN), which had previously been colonized in semicontinuous anaerobic thermophilic fixed-bed reactor (Rodríguez-Cano, 2003). The support occupied an initial height of 35.5 cm in unexpanded mode. In expanded mode, the support occupied 400 mL (active volume).

The effluent from the AFBR was recycled through a variable speed centrifugal pump in order to provide upflow velocities for media and to maintain a bioparticle expansion level of 18–20%. Such upflow velocities also ensured that completely mixed conditions were maintained in the liquid phase (Rodríguez-Cano, 2003) and the active volume of the digester remained constant throughout the study. Recycle flow was drawn at a depth 7 cm below the free liquid surface in the enlarged section in order to avoid entrapment of gas accumulated in the headspace above. The recycle flow was then pumped into the bottom assembly. This stream was collected in a settler in order to separate the solid fraction from the liquid stream. The pumping rate was adjusted periodically to account for varying biomass to keep a constant fluidized bed level. Plugging