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High strength wastewater treatment in a jet loop membrane bioreactor: kinetics and performance evaluation

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Abstract

Treatment of wastewater containing high organic matter was investigated by means of a jet loop bioreactor combined with a membrane process. Volume of jet loop bioreactor and area of membrane filtration unit were 23 l and 155 cm^2 respectively. It was found that jet loop reactor had high mass transfer coefficient (K_La) varying from 58.8 to 486 h^{-1} depending on the water flow rate (i.e. power input) and air flow rate. Oxygen transfer efficiency and oxygenation capacity of the reactor varied from 12 to 22.5% and from 0.2 to 1.8 kg O_2 kW^{-1}, respectively. The efficiency of jet loop membrane bioreactor was found to be approximately 97% for a volumetric organic load of 2–97 kg COD/m^3 day over a period of 10 weeks. The reactor was not disturbed from the organic loads up to 68 kg COD/m^3 day, but the treatment efficiency decreased to about 60% at higher organic loads. This decrease was due to insufficient oxygen transfer rate. The relationship between the effluent substrate concentration and the specific oxygen uptake rate (SOUR) values was determined. Applied food/microorganism (*F/M*) ratio was varied between 2.5 and 17 day^{-1}. Critical sludge age of the system (Θ_c^m) was evaluated to be 7.2 h. Sludge with unsatisfactory settling characteristics formed at high *F/M* values under turbulent conditions. Therefore, membrane process was used for solid–liquid separation and effluent solid concentration was approximately zero. Specific cake resistances (α) changed with *F/M* ratio. It was found that permeate fluxes were significantly effected with *F/M* ratio much more than mixed liquor suspended solids (MLSS). Average flux was 2.50 m^3/m^2 day for 0.2 μm pore sized cellulose acetate membrane. It was concluded that the jet loop membrane bioreactor has distinctive advantages such as the ability to treat high strength wastewater, low area requirements and easy operation.

Keywords: Biological water treatment; Jet loop bioreactor; Membrane bioreactor; Membrane filtration; Process intensification; Wastewater treatment

1. Introduction

Conventional biological treatment processes have been used for many years in the treatment of industrial and domestic wastewaters. However, these processes have some disadvantages such as larger area requirement, necessity of the transportation of wastewater to the unpopulated areas due to odour and other emission problems. For this reason, some studies have been carried out to develop smaller and faster wastewater treatment systems. The use of loop and airlift reactors coupled with membrane filtration may be seen as examples of such an approach.

Among the different types of loop reactors, it was found that the reactors where the mixing and flow circulation are achieved through jet flows had improved performance characteristics (Padmavathi and Remananda Rao, 1993). This type of loop reactors, normally referred as jet loop reactors (JLRs), have become increasingly important in conducting chemical and biochemical reactions (Blenke, 1985; Wachsmann et al., 1985; Dutta and Raghavan, 1987; Jain et al., 1990; Remananda Rao and Padmavathi, 1991; Karamanev et al., 1992; Ma Xianliou et al., 1992; Prasad and Ramanujam, 1995a,b; Keskinler et al., 2004). A JLR is basically an assembly of two concentric cylinders of

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which the inner one is known as “draft tube” and the outer one as “reactor”. A two-fluid nozzle (liquid and gas), also usually with a structure of concentric cylinders, disperses the gas delivered in one of the tubes by means of the liquid jet delivered in the other tube (Dutta and Raghavan, 1987; Dirix and Wiele, 1990; Velan and Ramanujam, 1991, 1992a,b). If wished, the liquid and the gas from their respective reactor exits can be recirculated back to reactor through the two-fluid nozzle until the liquid is saturated with the gas. JLRs have found applications in wastewater treatment processes due to their high mass transfer rates (Yenkie et al., 1992; Lübbecke et al., 1995; Bloor et al., 1995), as well as their intrinsic high turbulence characteristics which also result in the disintegration of large biomass aggregates thus creating a very large surface area for greater microbial activity. Aeration efficiency of conventional activated sludge process is about 8% with the possibility of upgrading to 20% if pure oxygen is used (Eckenfelder and Mustreman, 1994). However, the aeration efficiency suffers at higher pollutant loads. JLRs can conveniently meet the high oxygen requirement at high biomass concentrations.

For the separation of activated sludge from the treated wastewater, sedimentation is the most economical separation process. As the reaction rate is directly proportional to biomass concentration, a high concentration is necessary in the reactor, and thus it requires a proportionally larger sedimentation tank. Membrane filtration of biomass is a suitable process to increase the concentration of biomass in the reactor. It is also more reliable in operation and needs less space than a conventional sedimentation tank. If a JLR and a sedimentation tank combination is used in wastewater treatment, a cloudy effluent is formed due to non-flocculating motile bacteria (Bloor et al., 1995). Therefore, for both increasing sludge concentration in a JLR and achieving good solid–liquid separation, membrane filtration can offer great advantages. The other advantages of the membrane separation system include: (1) the absence of solid waste and pathogenic microorganism in the effluent; (2) low production of excess sludge (Lübbecke et al., 1995); and (3) efficiency of separation due to partial elimination of membrane fouling (Akay et al., 2000). A bio-reactor integrated with a membrane module system is usually referred as membrane bioreactor (MBR). Therefore, the present system involves a JLR coupled to a membrane filtration unit for the separation of the biomass will be referred as jet loop membrane bioreactor (JL-MBR).

Both JLR and membrane separation/reaction systems are seen as ‘process intensification’ both in chemical and biotechnology (Akay, 2004, 2005; Akay et al., 2004; Erhan et al., 2004; and Keskinler et al., 2004). The combination of several intensified unit operations can further enhance the processes as drive towards an intensified technology gathers momentum (Akay and Tong, 2003; Akay, 2004). Therefore, the investigation of a process containing two intensified unit operations are also important in the matching of the processes and understanding the process dynamics.

In treatment systems where membrane filtration is used in place of final sedimentation tank, it is possible to obtain 90–99% chemical oxygen demand (COD) removal rate due to the highly increased microorganism concentration (Chaize and Huyard, 1991; Yamamoto and Win, 1991; Bailey et al., 1994a,b). Increase of biomass concentration in a bioreactor is limited by physical properties of the suspension. Increasing biomass concentration decreases the mass transfer depending on the type of wastewater. Reactors with a high mass transfer performance such as JLRs allow for much higher biomass concentrations than conventional mass transfer equipment. JL-MBRs are especially appropriate for highly loaded industrial wastewater in which the sludge concentration of 20–40 $\mathrm{g\,l^{-1}}$ can be achieved (Ahmadun, 1994; Lübbecke et al., 1995; Muller et al., 1995). In the case of domestic wastewater treatment with JL-MBRs, applied loads between 2–4 $\mathrm{kg\,COD\,m^3\,day^{-1}}$ have been reported (Chiemchaisri et al., 1993; Muller et al., 1995).

The aim of this study is to determine the overall volumetric mass transfer coefficient $(K_L a)$, oxygen transfer efficiency, bio-kinetic coefficients based on both Monod equation, and SOUR from a laboratory scale JL-MBR wastewater treatment system. The first two tasks, as will be explained later, were performed using tap water–air mixture. As the membrane filtration unit is an important part of the treatment process being investigated, the interactions between the steady-state (limiting) permeate flux (J_P^*), specific cake resistance, α, food-microorganisms ratio (*F/M*) and mixed liquor suspended solids (MLSS) concentration have also been evaluated. The results are expected to provide valuable information for the treatment of high strength wastewater.

2. Experimental

2.1. Equipment and operational procedure

The general schematic representation of the experimental system used in the investigation is shown in Fig. 1. The work presented in this paper consisted of two main stages. In the first stage we investigated mass transfer characteristics of the reactor using tap water–air mixture. In the second stage we concentrated on the biological wastewater treatment and its kinetics. Certain sections of the general test system were common for all the tests but some were stage specific. The heavy solid flow lines were in use for all the tests but the broken flow lines and the relevant apparatus were used only during the biological wastewater treatment stage. Thus, the data given in Figs. 2–4 have been obtained without the test section described by the broken flow lines and the rest of the data generated with both test dictions in operation.

The reactor (the outer tube) and the draft tube (the inner tube) were made of Perspex cylinders of 15 and 7 cm diameter and 4 and 3 mm thickness, respectively. The reactor was 141 cm in overall height with a bottom section of