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Advances in biological systems for the treatment of high-strength wastewater

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ABSTRACT

The elevated organic content of high-strength wastewater makes aerobic treatment systems uneconomical. High-strength wastewaters are preferably treated anaerobically, thus providing a potential for energy generation while producing low surplus sludge. This paper provides an overview of high rate anaerobic digesters developed during the second half of the last century, focusing on anaerobic filter (AF), anaerobic fluidized-bed reactor (AFBR), and upflow anaerobic sludge blanket (UASB), along with their applications in high-strength wastewater treatment. Despite the unique compact design of these systems that combines the treatment and clarification in one reactor, they fail to provide complete stabilization of high-strength wastewater. Further downstream treatment is usually required to meet effluent regulatory limits. Therefore, advanced hybrid systems such as membrane bioreactors (MBRs), combined and integrated anaerobic–aerobic bioreactors are discussed in this review for their potential as effective treatment alternatives. The factors affecting the performance of these hybrid systems have been highlighted. MBRs provide excellent effluent quality with reduced footprint, but their major drawback is membrane fouling which increases maintenance and operating costs. Combined anaerobic and aerobic systems have been developed to provide a cost effective and efficient treatment for high-strength wastewater. Integrated anaerobic–aerobic systems employing biogranulation can provide a promising high-strength wastewater treatment technology. However, the design and operation of the integrated granular bioreactors are still in the development phase with limited data in continuous flow regime and large-scale operation. Long-term granule stability and long start-up are other obstacles. Further research is needed to overcome these shortcomings.

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1. Introduction

Industrial wastewater is a major source of water pollution due to its elevated organic content. There are many types of industrial wastewaters based on different industries. Organic industrial wastewater is that produced from chemical industries that use organic substances for their main processes. Examples of these industries include pharmaceuticals, cosmetics, organic dyes, adhesives, synthetic detergents, pesticides, textile factories, paper manufacturing plants, oil refining industry, brewery and fermentation, and metal processing industries [1]. The effluents of these industries, typically referred to as high-strength wastewater, need to undergo pre-treatment followed by biological treatment to remove the organic matter. However, biological high-strength wastewater treatment is posing a challenge especially with the more stringent environmental regulations on wastewater discharge.

Although there is no clear definition of high-strength wastewater, it is generally described as any wastewater containing contaminants at concentrations greater than domestic wastewater [2]. The American National Standard Institute, by way of recommendation for aerobic treatment units, defines domestic wastewater as any wastewater with 5 day biochemical oxygen demand (BOD_5) of 100–300 mg/L and total suspended solids (TSS) of 100–350 mg/L [3]. Turkdogan-Aydinol et al. [4] identified low-strength wastewater as those with chemical oxygen demand (COD) concentrations <1000 mg/L. Unlike municipal wastewater, industrial wastewater is characterized by high organic strength ranging from 1 to 200 g COD/L [5]. However, the concentrations of contaminants in high-strength wastewater vary from one industry to another because of the different chemicals used during the main process; hence, a wide range of values have been identified in the literature. It has been described as wastewater having BOD_5 concentration in the range 100–3,685 mg/L, TSS from 142 to 4375 mg/L, and oil and grease (O & G) from 50 to 14,958 mg/L [6]. The organic strength (as mg COD/L) of some industrial wastewaters is as follows: pharmaceutical effluents 5000–15,000, breweries 1500–5000, tannery 200–4000, and pulp 800–10,000 [1,7].

The biodegradability of the wastewater plays a major role in biological treatment. Biodegradability is represented as BOD/COD ratio. Wastewater is considered readily biodegradable at a BOD/COD ratio ≥0.5 [8]. Therefore, readily biodegradable wastewaters such as dairy industry wastewaters with COD value of 2000 mg/L are deemed as low strength level [9], while petrochemical effluent of 1000 mg/L COD is considered high-strength [10,11]. With less than 30% biodegradable content in pharmaceutical effluent [1], biological treatment is deemed challenging. In general, Chan et al. [12] described high-strength wastewater as any wastewater containing COD concentration above 4000 mg/L. By means of classifying a suitable COD range for aerobic treatment, it was widely reported that high-strength wastewaters were identified as those of COD concentration greater than 4000 mg/L, where aerobic treatment is no longer feasible; whereas, an anaerobic treatment would provide a suitable treatment option that requires no oxygen, produces less excess sludge, and offers a potential energy source [13–15]. For the purpose of this review, high-strength wastewater is considered as that characterized by COD concentration greater than that of domestic level, where conventional municipal wastewater treatment plants are not capable of handling.

This paper provides an overview of the conventional biological high-strength wastewater treatment technologies alongside their limitations. Advanced biological technologies introduced during the last five decades for treating high-strength wastewater are reviewed with focus on high rate anaerobic digesters such as anaerobic filter (AF), anaerobic fluidized bed reactor (AFBR), and upflow anaerobic sludge blanket (UASB). In addition, emerging hybrid systems such as membrane bioreactors (MBRs), combined and integrated anaerobic–aerobic systems are discussed as potential treatment alternatives.

2. Conventional biological technologies

Biological wastewater treatment remains an attractive technology because of its economic advantages over other treatment processes in terms of capital and operating costs [16]. It also offers the opportunity to convert waste into renewable energy [17] and degrade industrial compounds without generating toxic by-products [18]. Despite these advantages, conventional biological treatment processes fail to degrade high-strength wastewater and produce high quality effluent. The most common conventional biological treatment systems are outlined below, namely: activated sludge, trickling filter, and lagoons.

2.1. Activated sludge

Aerobic treatment processes such as conventional activated sludge (CAS) are commonly used in the treatment of low-strength organic wastewaters (COD < 1000 mg/L). Thus, they are not suitable for the treatment of high-strength industrial wastewaters [13,19]. CAS can however, be used as a polishing step of anaerobically treated effluents.

A major drawback of CAS is the poor separation between biomass and the treated effluent due to the presence of active biomass in floccular form [20]. The solid–liquid separation is imperative to producing high-quality effluent. The secondary clarifiers serve the purpose of biomass separation from the treated effluent [21]. However, poor settling of activated sludge has been frequently reported [21–23], resulting in suspended solids being carried over the weirs with the effluent. The settling velocity of biomass determines the efficiency of the solid–liquid separation [24]. It has been

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