

A review of the performance of aerobic bioreactors for treatment of food processing wastewater

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Abstract

Aerobic treatment is an alternative to the slower anaerobic treatment processes for concentrated industrial wastewater such as food processing wastewater. This paper reviews the performance of various aerobic treatment methods for the treatment of food processing wastewaters. It was noted that the total chemical oxygen demand (COD) removal efficiencies and process capacities were affected by the variations in organic loading rates. The review shows that most suspended growth bioreactors are effective at low organic loading rates for treating food processing wastewaters. All biofilm reactors have a similar level of COD removal, but the highest COD removal efficiency at a high organic loading rate was observed in flexible fibre biofilm reactor (FFBR). Attached growth processes exhibited better performance for treating high strength food processing wastewater effectively, compared with conventional suspended methods. The high specific surface area and low sludge production of flexible fibre biofilm reactors are other advantages, compared with other attached growth biofilm systems. A flexible fibre biofilm reactor is a sound alternative from a process and economic perspective.

Keywords: Suspended and attached growth; food processing wastewater; organic loading rate; aerobic bioreactors.

1. INTRODUCTION

Food processing industries produce vast quantities of wastewaters, which are characterised by a complex combination of organic matter in either a soluble or a volatile suspended form. Approximately 75% of the total organic matter is soluble. Hence, biological and chemical treatments are the most suitable approach to wastewater treatment [1]. Many biological treatment systems have been developed and used for the treatment of high strength wastewaters generated by food industries. Aerobic methods are considered to be the most effective with lower economic costs [2,3]. These processes allow the removal of large amounts of soluble biodegradable COD in the concentration ranges up to 4000 mg/L [4]. Alternative options to conventional methods are possible. In many wastewater treatment processes, the cells are aggregated either into floc or biofilm forms [3,5]. Therefore, there are two basic types of aerobic biological treatment systems; suspended growth processes, and attached growth (or biofilm) processes. There is greater interest in the application of biofilm reactors to remove organic substances and for nitrification than in suspended growth systems [7,8]. But to this day, studies comparing the performances of various bioreactors for treating food processing wastewaters have not been reported. The purpose of this paper is to review and assess the performance of the various processes involved in biological aerobic treatment processes (suspended and attached growth) for food processing wastewaters.

2. AN OVERVIEW OF CHARACTERISTICS OF FOOD PROCESSING WASTEWATER

Food processing industries typically consume large quantities of water. The average consumption of water expressed as water to product ratio is 10:1 [9,10]. The main reasons for the production of large quantities of food processing wastewater are the hygiene and quality control requirements. As an example, approximately 1.4 million m³ of wastewater are generated annually in the USA from 20,000 food processing industries [11]. The chemical and biological components of the wastewater streams of most concern to food processing industries are the high concentrations of carbon, nitrogen and phosphorus, as well as total suspended solids. Wastewater characterization is essential for designing of biological treatment systems. This is also important in the evaluation of existing facilities for optimizing performance and available treatment capacity [3]. The main characteristics of some food processing wastewater are summarized in Table 1.

Table 1. Characteristics of some food processing wastewater.

Sources of wastewater	Characteristic of wastewater (mg/L)					
	COD	BOD ₅	SS	TKN	TP	Oil and grease
Dairy	1155-9185	NA	340-1730	14-272	8-86	7-62
Meat processing	4976	NA	1348	372	NA	170
Sea food	6000	NA	280	540	8	NA
Potato processing	4800-9025	1200-3650	1300-5340	NA	NA	NA
Brewery	8240	NA	2901-3000	0.0196-0.0336	16.124	NA
Sugar	688-1612	555-1290	0.56-6.69	NA	NA	NA
Tomato canning	6953	3406	1380	151.4	47.5	NA
Coffee	35900-40000	NA	14100-18300	80-120	NA	NA

3. VARIOUS AEROBIC BIOREACTORS USED FOR FOOD PROCESSING WASTEWATER TREATMENT

Bioreactors contain open, mixed population microbial cultures which also acquire a diverse population of grazing organisms. In aerobic processes, organic substances are oxidized into carbon dioxide, water, and new biomass cells by employing a heterogeneous mixture of microorganisms with oxygen present. The aerobic bioreactors reviewed in this paper are divided into two categories. The suspended growth systems are completely mixed flocculant processes, including aerated lagoon (AL), aerobic jet loop reactor (AJLR), sequencing batch reactor (SBR), and the activated sludge process (ASP). Attached growth or biofilm systems, where bacteria are attached on a support medium can have many types of reactor configurations, including the trickling filter (TF), rotating biological contactor (RBC), fluidized bed reactor (FBR), fixed film bioreactor (FFBR), and flexible fibre biofilm reactors (FFBR) [12,13].

4. OPERATIONAL AND PERFORMANCE PARAMETERS OF VARIOUS BIOREACTORS

In suspended growth processes, several operational parameters may affect the process performance. Figure 1 presents the effect of the organic loading rates versus the COD removal efficiency for AJLR, ASP and SBR reactors. From the figure, for SBR it is clearly shown that the COD removal efficiency decreased as the organic loading rate increased. It can be seen from the figure that both ASP and SBR achieved a high COD removal efficiency at an OLR less than 4 kg COD /m³.d. The

same trend is observed for ASP. However, due to insufficient data points in the AJLR case, the trend is not as clear. It is important to note that the process efficiency is dependent on the other operational conditions and control parameters. In SBR at a low OLR of 0.4 kg COD/m³.d, the COD removal efficiency was about 99.5%. Similarly, in ASP, the removal efficiency was 98% at 0.354 kg COD/m³.d OLR. On the other hand, 70% of COD removal efficiency was obtained at 2.4 kg COD/m³.d. In general, SBR and ASP achieved similar performances. These processes are efficient and achieve a high COD removal efficiency at low organic loading rate. Most of the suspended growth systems have shown similar performances despite the variation in the process conditions such as the food: mass ratio (F/M), oxygen supplement, amount of sludge recycled and sludge age.

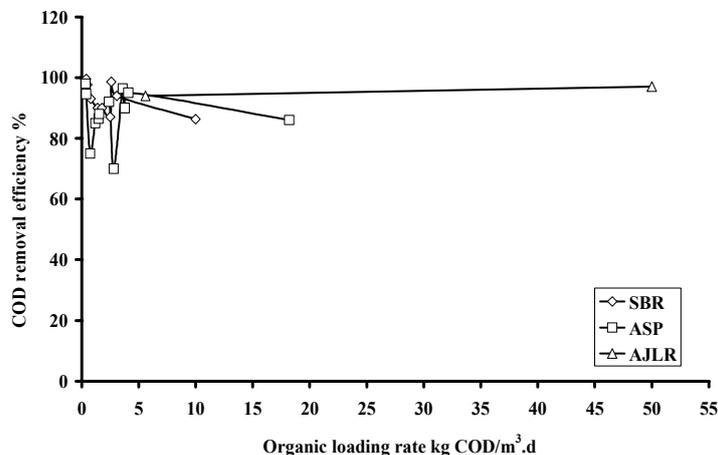


Figure 1. COD removal efficiency versus organic loading rate in suspended growth systems.

Figure 2 presents the influence of organic loading rate (OLR) on the COD removal efficiency of attached growth processes. In general, it can be seen from the figure that as OLR increases the COD removal efficiency decreases, showing an overall decreasing trend. It gives an indication that a reverse linear relationship exists between OLR and COD removal efficiency. Most of the attached growth systems in Figure 2 show more than 80% COD removal efficiency at an OLR less than 5 kg COD /m³.d. However, in RBC there is an exceptional point that does not present the real fact of the reactor performances. On the other hand, at high OLR between 10-30 kg COD/m³.d, especially in FBR and FBBR reactors, a low COD removal efficiency of less than 75% is observed. FFBR, in contrast, exhibited a different performance. Due to insufficient data FFBR still can show a better capacity for treating food processing wastewaters. As the figure shows the FFBR achieved higher COD removal efficiency, with corresponding OLR of 7.7 kg COD/m³.d which was not achieved by any other attached growth reactors. This could be because of some of the features of FFBR differed from the rest of the biofilm reactors. Meanwhile, FBR, FBBR and FFBR are the only reactors that have kept their efficiency at more than 70% in the range of 1-17 kgCOD/m³.d of OLR. Food processing wastewater is varied in COD concentration, and not all biofilm reactors could resist or treat a high COD concentration at high OLR. This is due to (1) high surface contact in unit of volume, (2) relatively uniform substrate distribution throughout the reactor provided by higher upward fluid movement; and (3) higher process stability resulting from microbial activities of most of the biofilm developed in the reactor [14].

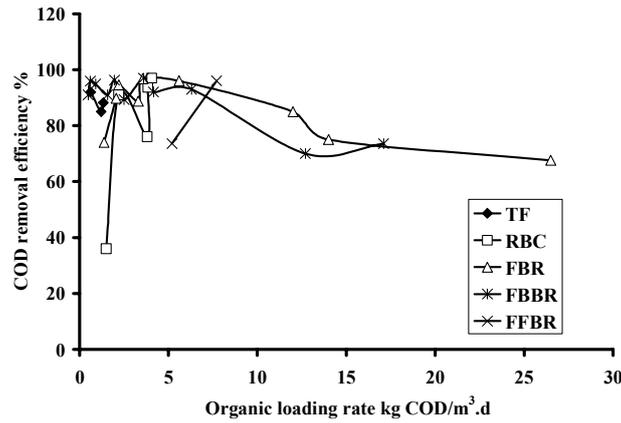


Figure 2. COD removal efficiency versus organic loading rate for attached growth systems.

5. PERFORMANCE COMPARISONS OF VARIOUS AEROBIC BIOREACTORS

Attached growth processes use a wide variety of support media. The characteristics of the support media are very important to the process efficiency. Among these features is the specific surface area where microorganisms develop and grow. Figure 3 shows the specific surface area for various biofilm reactors. The specific surface area varies considerably due to the different materials used. The flexible fibre packing media has the highest specific surface area, at more than 2000 m²/m³, compared with the media used in other biofilm reactors. On the other hand, the trickling filters have the lowest specific surface area, but are nevertheless somewhat comparable with a fluidized bed reactor and fixed bed reactors. Therefore, the flexible fibre might offer a better treatment potential and thus better quality effluent, because of the larger number of active microorganisms.

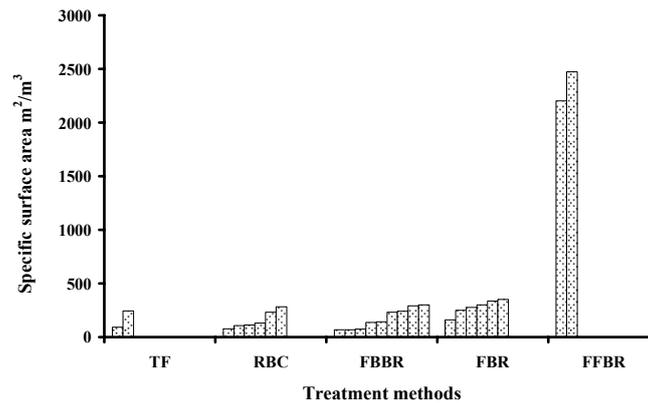


Figure 3. Surface areas of various biofilm reactors.

Figure 4 illustrates the removal efficiency with respect to the aerobic biological treatment processes. Generally, it can be seen that all methods removed high levels of COD effectively. In suspended growth systems, the sequencing batch reactor (SBR) attained a high average COD removal efficiency at approximately 93%. The aerobic jet loop reactor also achieved a slightly superior average of 95.5% of COD removal, but this requires caution as there are only two data points. The

activated sludge process shows slightly inferior average COD removal efficiency to other suspended growth process. However, in attached growth systems, none of the reviewed methods have any considerable difference, and all show the same pattern in COD removal efficiency in a wide average of 78.7% - 88.4%. The average of the removal efficiency in a rotating biological contactor (RBC) was lower in comparison with other biofilm reactors. This is due to an abnormal point that makes the average 78.4%. But if we exclude this point, the average would be 89.4%, which is similar to other methods.

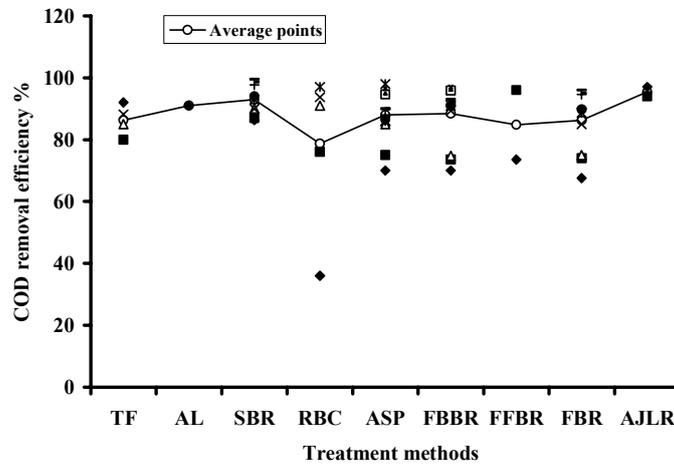


Figure 4. COD removal efficiencies of various methods.

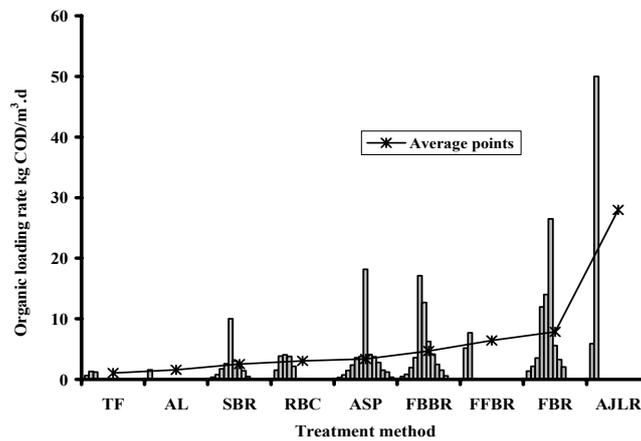


Figure 5. Organic loading rate versus aerobic bioreactors.

Figure 5 compares the organic loading rates as applied in a range of biological treatment reactors. It can be seen that there is a clear and significant trend in the average organic loading rate. The trickling filter has the lowest organic loading rate with an average of 1.05 kg COD/m³.d. On the other hand, aerobic jet loop reactors recorded the highest average organic loading rate, which is 27.95 kg COD/m³.d. This is considered an exceptional case because there are only two points and one is much higher than the other. Consequently the data for aerobic jet loop reactors may not provide a meaningful comparison. In FBR, the average organic loading rate is 7.84 kg COD/m³.d, a

little higher than those in flexible fibre biofilm reactors (6.4 kg COD/m³.d). However, this may be due to the point with an exceptional high OLR (26.5 kg COD/m³.d) but low COD removal efficiency (67%). Similarly, fixed bed reactors also could be operated at low organic loading rate with 4.71 kg COD/m³.d average. Furthermore, some other methods such as activated sludge reactors, rotating biological contactors, and sequence batch reactors also show a lower average organic loading rate. Therefore, it can be concluded that there is a significant difference between the OLR of suspended growth processes and attached growth processes.

6. CONCLUSIONS

The results from this review indicate that all aerobic bioreactors can be effective in the treatment of food processing wastewaters. However, the COD removal efficiency is generally lower when the organic loading rates are increased. In addition, suspended growth reactors are operated with lower organic loading rates, while attached growth reactors are operated at high organic loading rates, with the exception of the trickling filter and rotating biological contactor. Therefore, it can be concluded that attached growth bioreactors offer better performance, especially for cases with higher wastewater strengths. The high specific surface area and low sludge production of flexible fibre biofilm reactors are further advantages when compared with other attached growth biofilm systems. The analysis shows that a flexible fibre biofilm reactor is a sound alternative amongst all biofilm reactors from a process and economic perspective.

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